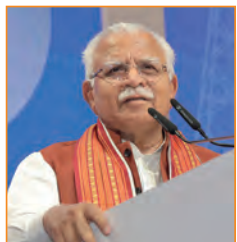


Towards a Resilient Grid

The three-day exhibition and conference, GRIDCON 2025, organised by Power Grid Corporation of India Limited (POWERGRID), in association with CIGRE-India, commenced on March 9, 2025, with a grand opening ceremony held at the India International Convention & Expo Centre, Yashobhoomi, Dwarka, Delhi.

Mr Manohar Lal, Union Minister of Power, Government of India, delivered the keynote address. The inaugural also saw special addresses by Mr Shripad Yesso Naik, Minister of State for Power and New and Renewable Energy; Mr Ghanshyam Prasad, Chairman, Central Electricity Authority (CEA); Dr Ajay Mathur, Director General, International Solar Alliance; along with a theme address by Mr R.K. Tyagi, Chairman and Managing Director (CMD), POWERGRID. There was also a keynote address by Dr Konstantin O. Papailiou, President, CIGRE, followed by a vote of thanks by Mr Naveen Srivastava, Director, Operations, POWERGRID.

Mr Manohar Lal, Minister of Power, Housing and Urban Affairs



Mr Manohar Lal highlighted the remarkable progress of India's power sector, reflecting on its journey from humble beginnings to its current prominence on the global stage. He recalled that in 1967, when he was in Class 7, villages like his first experienced the glow of an electric bulb. This marked a huge transition from studying under clay lamps to modern electricity. Despite initial scepticism about the limited impact of such small steps, the minister emphasised the importance of igniting even a single lamp in darkness, symbolising progress.

Mr Manohar Lal acknowledged the collective efforts that have contributed to the power sector's growth. He credited national leadership for effective policymaking, along with the dedicated involvement of various stakeholders, businesses and the general public. He highlighted the pivotal role of the power sector in economic growth, facilitating industrial expansion and driving national development.

Discussing future goals, Mr Manohar Lal emphasised that to achieve India's vision of becoming a developed nation by 2047, the power sector must expand significantly. He stresses the need for coordinated efforts between power generation companies, trans-



mission companies and discoms to ensure seamless energy delivery.

He drew a powerful analogy, comparing transmission lines to arteries in the human body, essential for delivering power where it is needed. He called for a faster development of transmission infrastructure to match the rapid growth in power generation, and stressed the need for cooperation between public and private sector participants.

On international cooperation, Mr Manohar Lal revealed ambitious plans such as the proposed undersea transmission line to Sri Lanka and a joint project with the UAE, which will involve setting up a transmission project with a significant investment of Rs 400 billion. He referenced India's "One Sun, One World, One Grid" initiative, which aims to unify and strengthen power connectivity across regions.

Addressing infrastructure challenges, Mr Manohar Lal stressed the need for new technology, improved land acquisition policies and public support to accelerate transmission line expansion. He noted that land acquisition must be achieved through consensus rather than compulsion, ensuring satisfaction among stakeholders. Additionally, he advocated for promoting domestic manufacturing to reduce dependency on imported transmission equipment such as transformers, HVDC components and insulators, reinforcing the "Make in India" vision.

He highlighted India's impressive economic growth, noting its rise from the 10th largest global economy a decade ago to the 5th position today, with aspirations to soon become the third largest. He credited the power sector as a key driver in this economic surge and emphasised the need to enhance power capacity to sustain this momentum.

Focusing on sustainable energy, Mr Manohar Lal stressed the importance of diversifying energy sources. He highlighted the shift from traditional thermal power to solar, wind, and nuclear energy as part of India's

commitment to achieving net-zero carbon emissions by 2070. He praised India's proactive steps in meeting climate targets, making it one of the fastest achievers among G20 countries. He also reiterated the country's ambitious goal of achieving 500 GW of renewable energy capacity by 2030.

The minister concluded by celebrating India's expanding transmission network, which has grown from 296,000 ckt km in 2014 to an estimated 475,000 ckt km in 2025. He encouraged continued investment to meet the projected Rs 9.16 trillion required for the power transmission sector by 2032. Commending the collective efforts driving these achievements, he urged stakeholders to persist in ad-

vancing India's energy infrastructure for sustained economic growth and environmental sustainability.

Mr Shripad Yesso Naik, Minister of State, for Power and New & Renewable Energy



Mr Shripad Yesso Naik expressed his gratitude to POWERGRID for organising GRIDCON 2025, which

serves as a crucial platform for discussing sustainability and adaptability. At a time when the world is witnessing an unprecedented energy transition, he emphasised that India is leading with a vision for a sustainable and resilient power sector.

Under the visionary leadership of Prime Minister Narendra Modi, India has set ambitious and necessary targets for its energy future, including achieving 500 GW of non-fossil fuel capacity by 2030 and net zero emissions by 2070. Over the past decade, India's energy landscape has undergone a remarkable transformation, with solar capacity increasing from a modest 2.8 GW in 2014 to surpassing 100 GW last month. The installed re-

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renewable energy capacity has grown by nearly 200 per cent, from 75.5 GW in 2014 to 220 GW today. Additionally, the transmission network has expanded significantly, growing from 2.97 lakh circuit kilometres in 2014 to 4.91 lakh circuit kilometres in 2025.

India is not only enhancing its energy security but also setting an example for the world in clean energy adoption. The country has already achieved 47 per cent of its 500 GW target and is well on track to meet its goals. With an even more ambitious target of 1,800 GW of renewable energy by 2047, India reaffirms its leadership in the global clean energy movement.

The transmission sector must evolve in tandem with energy generation to support the growing renewable energy capacity and ensure a stable, resilient power grid. As the integration of renewable energy sources increases, the role of a robust transmission infrastructure becomes even more critical. Since solar and wind energy are inherently variable, their integration requires grid modernisation and large-scale energy storage solutions.

To address this challenge, the government is actively promoting pumped hydro storage projects and battery storage as integral components of a stable power supply. India's current energy storage capacity of 4.86 GW needs to be scaled up to 74 GW by 2032, including 27 GW from pumped storage projects (PSPs) and 47 GW from battery energy storage systems (BESSs).

The National Electricity Plan (NEP) 2023-2032 has been finalised to cater to an anticipated peak demand of 458 GW by 2032. Correspondingly, India's transmission network is set to expand from 4.91 lakh circuit kilometres in 2024 to 6.48 lakh circuit kilometres by 2032. In line with this, extensive transmission systems have been planned for major renewable energy zones.

He also remarked that the power transmission sector across the world is facing supply chain constraints due to the increase in demand for transmission equipment as renewable energy deployment speeds up, and India is no exception. The rising demand for transformers, conductors and substation equipment puts pressure on the supply chain, and localisation of production is the need of the hour to address supply chain constraints. Renewable energy projects in India typically have a gestation period of one and a half years while the transmission network takes three to four years to come up. This time gets stretched further by right-of-way issues. Obtaining land for transmission corridors remains a significant challenge. While policies and guidelines have been put in place and approvals are being expedited, technological solutions like underground cable and advanced tower designs are the need of the hour to overcome this battle.

Mr Naik reiterated the commitment to growth by highlighting the outlined ambitious plan to spend Rs 9.15 trillion by 2032 to enhance power transmission. This investment will support the development of new transmission lines and substations, and increase India's presence in the global power equipment market. This initiative will drive innovation, create jobs and boost the economy.

Mr Naik also spoke about the need to leverage technology in smart grid visualisation solutions, AI, IoT and predictive analytics to improve real-time monitoring. The concept of grid resilience also extends to the development of transnational grid interconnections. Initiatives like One Sun, One World, One Grid aim to harness the diversity of solar power availability across different regions. The Ministry of Power along with the Ministry of New and Renewable Energy is working to iron out the bottlenecks in the renewables sector by engaging with stakeholders including manufacturers, technology providers, service providers, think tanks, researchers and academics.

Finally, Mr Naik spoke about the key role of POWERGRID and called it the backbone of the power transmission ecosystem in India. Currently, it carries about 45 per cent of the total power generated in India through its transmission network consisting of 400 kV and 765 kV AC and 800 kV and 500 kV HVDC system. Today, POWERGRID's interregional transfer capacity stands at 100 GW, which is 84 per cent of the national interregional transmission capacity. It has consistently maintained an outstanding track record of system availability at 99.8 per cent and has a formed a cross-border link between India and neighbouring countries, including Bangladesh, Nepal and Bhutan, with a transmission capacity of up to 4,745 MW.

Mr Naik noted that POWERGRID is doing very well in the competitive bidding era, winning more than 70 transmission projects by beating its competitors. The company has grown by leaps and bounds in the last 35 years. It has shown strong performance and has a leading position in the sector today. He stated that everyone gathered at GRIDCON 2025 should reaffirm their collective commitment to building a green and future-ready power transmission system. He noted that the deliberations on new technologies such as UHVAC, battery energy storage systems, renewable energy integration, green hydrogen plants, undersea cables, and e-mobility would be thought-provoking and insightful. He emphasised the importance of working together to drive India's power transmission sector towards a cleaner and more sustainable future.

Mr Ghanshyam Prasad, Chairperson, Central Electricity Authority



Mr Ghanshyam Prasad noted that all of us are aware of the energy transition taking place globally, including in India. The world is observing India for its initiatives, particularly in the power sector, which have accelerated the energy transition.

The country has successfully surpassed 200 GW of renewable energy capacity and is now targeting around 500 GW of renewable energy by 2030, 600 GW by 2032 and potentially around 2,000 GW by 2047 or 2050. This will be driven by a combination of various technologies, including solar, wind, storage, hydropower and nuclear.

With this expansion of generation capacity, there is a huge requirement of transmission infrastructure in India. Earlier, transmission service providers were concerned about low demand for transmission infrastructure. However, with the energy transition and the setting up of large renewable energy capacities, the transmission infrastructure pipeline has expanded significantly. The commissioning of transmission infrastructure is within the timeline and delays are being avoided. With this, the country is ensuring timely integration of renewable energy capacities, avoiding curtailment of generation and minimising generator losses.

Mr Prasad shared that the country plans to integrate 500 GW of non-fossil fuels by 2030 and the exclusive transmission plan for this has already been declared by the CEA. Further, 600 GW has been targeted for 2032 and around 2,000 GW by 2047. The aim is to ensure that the timeframes for transmission line development match the commissioning timelines of renewable energy projects.

The energy transition presents another key challenge as the country plans to increase the nuclear energy capacity from 8 GW to roughly 100 GW by 2047. In addition, there will be 100-150 GW of hydro power capacity by 2047. These projects will come up in difficult terrain, where setting up transmission infrastructure will be an arduous task. A huge network of transmission system will be developed to achieve these ambitious targets. Going forward, a large portion of the transmission network will get older, requiring replacement, upgradation and reconstruction.

Mr Prasad assured investors in the transmission space, particularly manufacturers, that there is a huge opportunity in the sector. All stakeholders need to collaborate to tap this potential.

He added that while a huge transmission network is being set up across the country, many villagers still question why they are not receiving 24 hours of power supply. Thus, going forward, the government's aim should be to ensure regular supply of power in rural areas.

Several meetings have been held with manufacturers and all stakeholders must now prepare for the setting up of higher voltage transmission lines. The sector has transitioned from 220 kV to 400 kV and 800 kV lines. The time has come to take another big leap and set up 1,200 kV lines, the highest voltage level in the world.

Another priority area for the transmission sector should be the promotion of domestic manufacturing and the Make in India initiative. The aim should be to achieve 100 per cent domestic content in transmission infrastructure equipment in the next five to seven years to avoid supply chain issues.

Another key priority area is the shift towards underground and subsea cables in order to tap offshore wind. In addition, interconnectors are needed to connect the Indian grid with the global grid, especially in Southeast Asia and the Middle East. In fact, these innovative technologies are also needed for connect the Andaman and Nicobar Islands and the Lakshadweep Islands. Going forward,

there will be a huge requirement of subsea cables, creating a significant opportunity for manufacturers.

Another priority is ensuring that the equipment and infrastructure are disaster resilient. In the past, particularly in Odisha and other regions, multiple towers have failed and a lot of time is taken to restore the grid. The country cannot afford more such power outages in the future.

Going forward, the power sector will face a myriad of challenges. The foremost challenge will be integrating variable renewable energy into the grid while ensuring accurate demand forecasting of renewable energy generation. The grid currently operates on a 15-minute time block, but it will need to transition to a 5-minute time block for more accurate renewable generation predictions.

Going forward, the integration of BESS into the power grid will be key and its integration must be planned in line with transmission planning to optimise both and improve grid monitoring.

Cybersecurity is another key concern given India has the largest synchronous grid in the world and also trading power with neighbours.

Going forward, grid operators need to do resource adequacy planning for both generation and transmission, at intra and inter-state levels, for the next 10 years. This presents a Rs 10 trillion investment opportunity.

Mr R.K. Tyagi, Chairman and Managing Director, POWERGRID



Mr R.K. Tyagi, Chairman and Managing Director, Power Grid Corporation of India Limited (POWERGRID), delivered the inaugural address at GRIDCON 2025: International Conference-cum-Exhibition. He began the address by highlighting the global shift towards energy transition, which is only possible through grid resilience and by adopting strategies to enhance the reliability, sustainability and adaptability of the power transmission system.

He noted that collaboration is key, stating that we must work as a common force within the energy sector to drive the global energy transition. Under the One Sun, One World, One Grid (OSOWOG) initiative, it is time to envision global platforms where we think and deliberate as ambassadors of the energy transition – beyond national, sectoral or organisational boundaries – to work towards resolving the challenges that the energy transition faces today.

Mr Tyagi noted, "POWERGRID is honoured to organise this international conference-cum-exhibition under the patronage of the Ministry of Power in collaboration with CIGRE India. This event brings manufacturers, professionals, researchers and academia from the power system community across the globe to shape the future of resilience, asset management and digital transformation. It provides a platform to explore cutting-edge insights, enable exclusive networking, unlock collaborative opportunities and develop strategies to enhance the reliability, sustainability and adaptability of power transmission systems."

He observed that electricity demand is increasing due to the rapid electrification of transport, air conditioning and industrial processes. The widespread adoption of electric vehicles, heat pumps, data centres and artificial intelligence applications continues to drive electricity consumption higher each year. Moreover, renewable energy now accounts for around one-third of the global electricity supply, with solar PV investments surpassing all other energy sources combined.

However, Mr Tyagi noted that the existing infrastructure must keep pace with this growth. Recognising these challenges, investment in transmission infrastructure is growing worldwide. To align with net-zero pathways, annual investment in the transmission segment must reach \$250-\$300 billion by 2030.

Today, India stands proud with an installed capacity of 466 GW and one of the world's largest synchronised grids, thanks to the unwavering efforts of players in the power sector. However, the journey is far from over. Energy transition and energy security, with affordability at the core, are focus areas for the country's rapid development. To this end, the Indian government has set a target of achieving 500 GW of non-fossil fuel-based capacity by 2030.

Mr Tyagi also noted that the Indian government has undertaken several initiatives to establish a transnational grid interconnection under the OS-OWOG initiative, which is spread over Southeast Asia to the European Union via South Asia, the Middle East and the African grid. The total planned investment in the grid till 2032 exceeds Rs 9 trillion. POWERGRID is committed to this mission and will continue to ensure that not a single MW of renewable power is wasted due to transmission constraints.

POWERGRID has always ensured that the Indian electricity grid is technologically at par with best-in-class international utilities. We are driving innovation by developing and adopting modern technologies like multi-circuit towers, extra tall and narrow-based towers, efficient conductors, insulated cross arms and GIS (over AIS) in urban areas.

Other recent technological innovations include the replacement of synthetic oil with more environmentally friendly ester oil for transformers and reactors, and ongoing efforts to replace SF6 gas with eco-friendly alternatives to minimise environmental impact. Further, POWERGRID has successfully commissioned the 1,200 kV test station at Bina, as well as several key ± 800 kV HVDC power links such as the Northeast-Agra, Champa-Kurukshetra and Raigarh-Pugalur lines. POWERGRID has also commissioned India's first state-of-the-art technology VSC-based HVDC system that combines sustainability, stability and grid resilience.

In conclusion, Mr Tyagi noted that GRIDCON 2025 is a platform where visions turn into blueprints and blueprints turn into action. A resilient power grid requires a robust transmission system, strengthened by collaboration, leadership and commitments to sustainability. To power the future, protect the present and preserve the planet, the time for change is now – and together, we will make it happen.

Dr Ajay Mathur, Director General, International Solar Alliance



Dr Ajay Mathur addressed GRIDCON 2025 on the role of renewable energy, solar integration and global partnerships. He emphasised that solar energy is abundant, sustainable and increasingly cost-competitive, making it a key driver of the energy transition. In developed nations, electricity consumption is more or less constant. Hence, solar power can meet daytime energy needs. However, in developing countries, the challenge is different. They often have to choose between solar electricity, which is available only during the day, and coal-based electricity, which provides round-the-clock power.

He noted that over the past year, four different auctions have reduced the price of round-the-clock renewable electricity to Rs 4-Rs 5 per kWh, as compared to thermal power tariffs of Rs 5.11-Rs 6.31 per kWh. "This is the economic straw that has broken the camel's back," he remarked.

On transmission infrastructure, he stated that transmission development remains a key bottleneck, as it takes significantly longer to construct lines compared to setting up solar or battery storage capacity. He proposed that each state should designate dedicated land pockets for renewable energy projects, similar to solar parks such as Khavda in Gujarat, Bhadla in Rajasthan, and Pavagada in Karnataka. If round-the-clock renewable energy projects are developed within these designated zones, transmission infrastructure can be planned accordingly. This would enable the seamless transfer of power from generation sites to load centres or high-tension transmission lines. Establishing such planned renewable energy hubs will facilitate better grid integration and eliminate the inefficiencies of ad hoc project locations.

Dr Mathur displayed eagerness to implement this model in India and extend these learnings to our 153 member countries, demonstrating successful strategies for renewable energy integration. Grid integration of renewable energy remains a significant challenge. Two years ago, the West African Power Pool approached ISA with concerns about incorporating increasing volumes of renewable energy into their grid. To help them gain a better understanding, a visit to India was facilitated. They observed POWERGRID's operations and visited the Southern India Load Despatch Centre, gaining first-hand experience on enhancing renewable energy integration. He recommended the establishment of universities and training centres, where professionals from across India and worldwide can gain practical knowledge on integrating intermittent renewable energy. This is a key challenge that remains to be addressed.

He also stated that several ways have been explored on how to manage the growing share of variable renewable energy and highlighted challenges such as the duck curve or the camel curve for energy demand. However, India has already addressed these issues with innovative solutions. These lessons must be shared globally.

Finally, he reaffirmed the commitment to accelerating the clean energy transition, calling it the need of the hour. He noted that the Hon'ble Minister has highlighted both national and global priorities as well as the pathways to achieve them. By integrating solar energy into our grids through cutting-edge technologies and policies, he emphasised that global partnerships can be fostered to help build a sustainable, resilient and inclusive energy future.

Dr Konstantin O. Papailiou, President, CIGRE



Dr Konstantin O. Papailiou highlighted that CIGRE, with over 20,000 members worldwide, is a global community dedicated to advancing power system expertise. Its mission as a non-governmental, non-profit organisation is to raise its voice and point out the problem, attract and educate young people, utilise better human capital and support research initiatives related to energy transition.

Papailiou noted that approximately 20 per cent of the world's population still lacks access to electrical power. Global electricity demand is expected to rise between 6,000 TWh and over 7,000 TWh by 2030, which is equivalent to adding the current electricity demand of the US and the European Union. By 2050, global electricity demand is projected to be 150 per cent higher in a Net Zero Emissions (NZE) by 2050 Scenario. Electricity networks serve as the backbone of power systems and must expand and modernise to support the energy transition. The total length of the electricity grid is expected to more than double from 2021 to 2050. The annual investment in grid infrastructure is projected to rise from around \$300 billion in recent years to approximately \$600 billion by 2030, with an average of \$800 billion per year until 2050.

To fully electrify the planet, global electricity demand in the NZE scenario by 2050 is estimated to be between 25,000 GW and 40,000 GW. Further, he highlighted that the current installed capacity from all energy sources is about 10,700 GW, of which approximately 3,300 GW comes from renewable energy sources (RES) and 400 GW from nuclear, both of which are carbon-free. This means that an additional 20,000 GW to 35,000 GW of power generation capacity must be added, requiring the construction and running of more than 1,000 power plants of 1,000 MW capacity per year until 2050. The majority of these new power plants will be based on wind and solar energy with some nuclear power plants as widespread commercial fusion power is unlikely to become viable before mid-century due to complex engineering challenges and regulatory hurdles.

The global transmission grid, which is largely composed of overhead lines, is currently estimated to span approximately 8-10 million circuit km. The energy transition will require the addition of 1.5-2.5 million km of new transmission lines, mainly high-voltage (HV) lines, including around 300,000-500,000 km of high-voltage direct current (HVDC)

lines. About 40 per cent to 60 per cent of the existing lines, equivalent to roughly 3-6 million km, will need to be replaced or refurbished by 2050. This means that the total requirement for HV overhead transmission lines by 2050 is expected to be between 4.5 million km and 8.5 million km.

Papailiou highlighted that decarbonisation is imperative, as carbon emissions drive climate change and increase the frequency of natural disasters. The power sector must lead the transition to full electrification with zero emissions. Governments and industry leaders must communicate the urgency of grid expansion and renewable energy adoption, as the energy transition is not optional but essential. Attracting and educating young engineers is crucial to sustaining this transformation. Establishing specialised academic programmes will help train the next generation of energy professionals. Strengthening human capital and supporting research in clean energy technologies will be key to achieving a sustainable, electrified future.

Mr Naveen Srivastava, Director, Operations, POWERGRID



Mr Srivastava thanked Shri Manohar Lal, Union Minister of Power, for his thoughtful address and for providing a clear vision for the development of the power sector. This will be crucial in meeting the country's future demand economically and reliably, facilitating the country's economic growth. His address increased the confidence of enterprises and communities involved in systems and renewable energy integration, strengthening the country's commitment towards net zero.

He also thanked Mr Shripad Yeso Naik for addressing the gathering with his insightful remarks, and Mr Ghanshyam Prasad for the CEA's invaluable support to the event. He also thanked Mr Ajay Mathur for sharing his views and guidance on combating climate change through solar energy solutions, and Dr Konstantin O. Papailiou for sharing his views and perspectives. He also thanked Mr R.K. Tyagi for his instrumental role in organising GRIDCON 2025. Under his mentorship, the event has become a reality today and is being attended by over 2,000 members. He also thanked the regulators, private business leaders, technical experts, researchers, start-ups and other distinguished guests.

GRIDCON 2025 has attracted delegates from 32 plus countries. Around 458 papers were called for the event, of which 158 have been selected and will be presented over the next two days, showcasing innovations in the sector. Mr Srivastava also thanked press and media representatives present at the event.

GRIDCON 2025 will also have a special "Women in Energy" session and "Next Generation" session, along with stalls from startups and academia, presenting their innovative ideas at the event. GRIDCON 2025 provides a platform for the young generation to meet experienced delegates, offering enriching takeaways on the energy sector. ■

Green Energy Superhighways

GEC progress, challenges and the road ahead

New transmission lines are crucial for India's renewable energy expansion. One of the flagship projects driving transmission grid expansion is the green energy corridor (GEC) project. Structured under two phases, GECs have played a key role at the intra-state level, integrating wind and solar power into India's grid. Highlighting the progress under this initiative, the Economic Survey 2024-25 states that almost 9,136 ckt km of transmission lines and 21,413 MVA of substations have been built under GEC-I, while GEC-II is extending into seven more states. Due to their importance in the sector, GEC projects have received a significant fund allocation of Rs 6 billion under Union Budget 2025-26.

The GEC initiative is set to enter its next phase, with a third phase in the works now. The power ministry has reportedly set March 31, 2025 as the deadline for states to submit proposals for intra-state transmission projects under the scheme. A look at how these green energy superhighways are shaping up...

Overview and progress so far

Back in 2012, a study report by Power Grid Corporation of India Limited (POWERGRID) identified gaps in power evacuation and transmission infrastructure in the vicinity of potential renewable energy sites and highlighted the need for a dedicated transmission infrastructure for large-

scale solar and wind power plants. Based on the report, states submitted their transmission plans to the Central Electricity Authority (CEA) for appraisal. Implementation work subsequently started in 2015.

GEC-I aims to evacuate 24 GW of power across eight states – Andhra Pradesh, Gujarat, Himachal Pradesh, Karnataka, Madhya Pradesh, Maharashtra, Rajasthan and Tamil Nadu. Overall, this phase entails setting up 9,767 ckt km of transmission lines and 22,689 MVA of substations. So far, Phase I projects have been completed in the states of Madhya Pradesh, Rajasthan, Tamil Nadu and Karnataka. The remaining four states have requested further extension owing to right-of-way constraints and the Great Indian Bustard issue. Almost 9,136 ckt km of transmission lines and 21,413 MVA of substations have been built so far. Projects are being implemented with a central grant of 40 per cent of the project cost or award cost, whichever is lower.

Network expansion under Phase II for the evacuation of around 20 GW of renewable energy is now under way across seven states. These are Gujarat, Himachal Pradesh, Karnataka, Kerala, Rajasthan, Tamil Nadu and Uttar Pradesh. Under GEC-II, the target is to add 7,574 ckt km of transmission lines and 29,737 MVA of substation capacity.

For the intra-state portion of the GEC Phase II scheme, the total



estimated cost is Rs 120.31 billion, with a central financial assistance (CFA) of 33 per cent of the project cost, that is, Rs 39.7 billion. Some states had requested a revision of transmission schemes under GEC-II, which was approved by the Ministry of New and Renewable Energy (MNRE). However, the CFA was limited, as approved by the Cabinet Committee on Economic Affairs for that particular state.

State transmission utilities are currently in the process of tendering projects under the scheme, which is scheduled for completion by 2025-26. States are preparing the packages and issuing tenders for implementing the transmission schemes.

Mega green energy evacuation projects under planning

Apart from the various ongoing intra-state projects, an important project sanctioned in 2024 under GEC-II was the establishment of an interstate transmission system (ISTS) to support a 13 GW renewable energy project in Ladakh. Being implemented by POWERGRID, the project entails the construction of approximately 713 km of transmission lines, covering 1,268 ckt km, and the installation of two 5 GW high voltage direct current (HVDC) terminals in Ladakh (Pang) and Kaital (Haryana). The infrastructure will facilitate the transmission of electricity generated from the 13 GW renewable energy project, along with a 12 GWh battery energy storage system, in Ladakh. The cost of Phase II projects is about Rs 207.73 billion, and the CFA will cover 40 per cent of the project cost amounting to Rs 83.09 billion. POWERGRID will finance the remaining project costs through debt and equity. The project is scheduled for completion by 2029-30.

In a recent update from the MNRE, it was reported that as of December 2024, 300 acres of land has been acquired at Pang for the project. The HVDC tender has been published,

with awards expected by March 2025. The LiDAR survey for the transmission lines has also been initiated.

Meanwhile, projects for power evacuation from bulk consumers such as green hydrogen and ammonia plants of about 20 GW and others of about 18 GW are in the works. As per the Interim ISTS Rolling Plan 2029-30 by Central Transmission Utility of India Limited, almost 19,500 MW of ISTS for various green hydrogen and ammonia plants is planned by financial year 2030. Of these, five ISTS schemes, costing Rs 156.29 billion, will support green hydrogen projects in Gujarat, Tamil Nadu and Andhra Pradesh. Gujarat will benefit the most with 13,500 MW, while Andhra Pradesh and Tamil Nadu will receive 3,000 MW each. Three ISTS schemes (8,200 MW) for Gujarat and Tamil Nadu have been approved under tariff-based competitive bidding.

In addition, mega transmission schemes are being planned for offshore wind transmission projects. Around 10 GW of offshore wind energy evacuation has been envisaged, including 5 GW in Gujarat and 5 GW in Tamil Nadu.

Challenges

The transmission infrastructure expansion is expected to require a significant capex in the next few years. As per the National Electricity Plan for Transmission released by the CEA, the development of transmission networks during 2027-32 is expected to entail a massive investment of almost Rs 4.9 trillion (at the 220 kV and above voltage level), of which the intra-state portion is estimated at Rs 993 billion.

Various approaches are being explored to attract institutional investment to tap into the financial potential of intra-state projects. In a notable initiative in December 2024, the CEA collaborated with the National Investment and Infrastructure Fund, PGINVIT and PFC Consult-

Project grants under GEC-I till December 2024

State	Eligible central grant (Rs billion)	Released till December 2024 (Rs billion)
Andhra Pradesh	3.61	2.90
Gujarat	7.46	5.44
Himachal Pradesh	2.37	2.06
Karnataka	3.26	3.26
Madhya Pradesh	6.55	6.24
Maharashtra	0.67	0.46
Rajasthan	2.41	2.41
Tamil Nadu	5.29	5.24
Total	31.64	28.04

Source: MNRE

Renewables capacity to be integrated into intra-state networks under the GEC scheme

State	Renewables capacity added under GEC-I (balance) as of March 31, 2024 (GW)	Renewables capacity to be added under GEC-II (GW)	Total (GW)
Gujarat	1.01	5.10	6.11
Himachal Pradesh	0.5	0.32	0.82
Maharashtra	0.92	0	0.92
Karnataka	0.58	2.64	3.22
Kerala	0	0.45	0.45
Andhra Pradesh	1.25	0	1.25
Rajasthan	0	2.48	2.48
Tamil Nadu	0.43	4	4.43
Uttar Pradesh	0	4	4
Total	4.69	18.99	23.68

Source: Ministry of Power

ing Limited to organise a workshop with leading transmission industry players, financial institutions, legal experts and representatives from state transcos to discuss asset monetisation for the state transmission sector. Since states have a significant potential to monetise brownfield transmission assets, various strategies were discussed for mobilising the much-needed funds for new infrastructure investment. Two models for investment were discussed in the workshop, the InvIT model and the acquire-operate-maintain-transfer (AOMT) model. In 2022, the CEA, in consultation with a few states and the NITI Aayog, prepared the guiding principles for monetising transmission assets through the AOMT model. The AOMT model was recommended as a clear and practical approach that states could adapt to their specific needs and conditions.

Meanwhile, to fast-track the completion of their green energy projects, states have approached regulatory commissions to increase the threshold limits for investment. According to recent reports, Rajasthan Rajya Vidyut Prasaran Nigam Limited has proposed raising the threshold limit for intra-state transmission projects under the Regulated Tariff Mechanism to Rs 20 billion, from the previous limit of Rs 2.5 billion for GEC projects in Rajasthan. This proposal is currently under review by the Rajasthan Electricity Regulatory Commission.

Outlook

Matching renewable energy capacity and transmission infrastructure

has been an ongoing effort as India steadily ramps up installations to meet its 500 GW target by 2030. This month, India's solar capacity reached the 100 GW milestone. As per CRISIL estimates, the country is expected to add 175-180 GW of solar capacity between 2025 and 2030.

Bulk transmission capacity will be crucial for integrating this upcoming generating capacity. As per the National Electricity Plan (NEP), around 297 GW of renewables capacity is planned to be evacuated by the states by 2032. Of this, more than 160 GW of renewable energy capacity is proposed to be integrated in Rajasthan and Gujarat, particularly four districts in Rajasthan – Jaisalmer, Jodhpur, Barmer and Bikaner – and the Khavda region in Gujarat.

GECs are also expected to facilitate cross-border interconnection projects. During a recent ministerial visit to India, Singapore announced that it is actively exploring the possibility of setting up a renewable energy corridor between the two countries. India currently has interconnections with its neighbouring countries, including Bhutan, Nepal, Bangladesh and Myanmar. The proposed corridor is expected to be in line with the One Sun, One World, One Grid initiative.

In sum, these green energy corridors are among the most ambitious grid infrastructure projects globally. Given the scale of India's renewable energy capacity additions, supporting investments and the timely execution of transmission infrastructure will play a key role in ensuring energy supply security. ■

Perspective

Pankaj Agarwal

Secretary, Ministry of Power

India has seen rapid progress in terms of installed capacity and electricity access. Total installed capacity is about 466 GW, while peak demand has reached about 250 GW. The country has become one of the largest synchronous interconnected national grid in the world, with 4,92,871 ckt km of transmission lines and 13,02,580 MVA of transformation capacity (as of January, 2025).

Transmission is playing a catalyst role in the energy transition of our country as well as globally, by extending the grid to renewable-rich areas and facilitating the connection of renewable energy projects to the grid. This transition is not only necessary, but also an opportunity to redefine India's energy landscape, with a target of achieving 500 GW of non-fossil energy capacity by 2030.

Embracing advanced technologies such as smart grids, AI and IoT in the construction, operation and maintenance of the transmission system is crucial for enhancing grid resilience, and enabling real-time monitoring and predictive maintenance. The success of these initiatives will hinge on strong collaboration, regional coordination and synergy between stakeholders. ■



Ensuring Grid Resilience and Peace of Mind with the ACCC InfoCore® System

In conversation with Hitesh Mundhada, Vice President, South Asia, CTC Global



How does grid resilience fit into the evolving energy sector?

The energy sector is rapidly transforming due to electrification, renewable energy expansion, and sustainability goals. This shift places immense pressure on transmission networks, requiring them to be more reliable, efficient, and resilient. Utilities face challenges such as aging infrastructure, rising power demand, and climate-driven extreme weather. Improving grid resilience is essential to overcoming these challenges and ensuring a smooth transition to cleaner energy.

High-temperature low-sag (HTLS) conductors like ACCC® Conductor, play a crucial role in modernizing grid infrastructure. These conductors boost efficiency and capacity while reducing

transmission losses as well as helping utilities address right-of-way (ROW) challenges. For instance, in India ACCC® Conductors have preserved approximately 21,000 hectares of land going into ROW as of 2024, minimizing the need for new infrastructure and easing ROW constraints.

How does the ACCC InfoCore® System provide 'peace of mind' to utilities?

CTC Global's ACCC InfoCore® System is a breakthrough in transmission technology. By embedding optical fibers within ACCC® Conductors and using proprietary infrared light technology, it enables real-time integrity verification. This process assesses the ACCC® conductor's core integrity before, during, and after installation, reducing installation risks and supporting proactive maintenance strategies.

A key advantage of the system is its ability to store integrity data in a cloud-based database, providing full traceability from manufacturing to operation. This allows utilities to assess asset health, make informed decisions, and implement predictive maintenance. By improving verification processes and minimizing failure risks, the ACCC InfoCore® System enhances grid resilience, operational efficiency, and infrastructure reliability thus providing much needed peace of mind to utilities!

Can you share real-world examples of ACCC InfoCore® System proving 'peace of mind' to utilities?

Certainly. Several utilities have successfully de-

ACCC InfoCore® System

✓ Conductor Integrity from Factory to Field

- Reduces installation related risk
- Provides peace of mind in minutes
- Simple, safe, reliable



ployed the ACCC InfoCore® System to enhance grid reliability and streamline project execution.

In Belgium, Elia used the system during a 150 kV line reconductoring project supporting a major data center expansion. The system provided daily verification reports, ensuring smooth installation and long-term reliability.

In the Netherlands, TenneT TSO B.V. deployed the system for a critical 380 kV upgrade to handle increased renewable energy flows. Despite adverse weather, the system provided real-time verification for each reel installed, ensuring seamless execution.

CTC GLOBAL

Asset Management

Strategies for optimising transmission operations

Robust power transmission is crucial for sustaining the growth of the power sector. Asset management strategies are imperative to ensure operational efficiency, reliability and the overall smooth functioning of the power system. In recent years, the sector has witnessed a surge in innovative solutions and technological advancements aimed at extending an asset's useful life through condition assessment, refurbishment and maintenance management. Regular operations and maintenance (O&M), along with the upgradation and replacement of assets, also plays a key role in managing transmission assets.

A look at the key trends and best practices being adopted for asset management...

Reliability-centred maintenance

Reliability-centred maintenance (RCM) is a cornerstone of effective asset management and crucial for addressing network complexities, handling ageing infrastructure, and ensuring cost optimisation and reliability.

RCM tailors maintenance plans for each asset based on its criticality and significance to grid operations. It typically integrates the health model, degradation model and impact model to provide valuable insights. The health model computes the asset health index using current data on the asset, while the degradation model evaluates failure probabilities based on historical data on asset failures. The impact model further assesses the potential impact of failure on the grid, and combines this with failure probabilities to arrive at a risk index. This entire process enables real-time health indexing along with risk-impact mapping. As a result, it leads to numerous benefits, including extended equipment life, reduced preventive maintenance, lower maintenance costs, optimisation of inventory, improved resource planning and data-driven decision-making. Notably, RCM can facilitate a reduction in man-hour requirements, with transmission line patrolling decreasing by 23 per cent and substation maintenance by 35 per cent.

RCM is being rapidly transformed by advancements in technology, such as sensors and data analytics, along with rising stakeholder expectations for higher service levels and sustainability. Standardising resilience and business continuity plans can further enhance benefits. Leveraging digital tools and data analytics for disaster prevention, such as cyclone preparedness, can also enable more proactive responses to emergency situations.

Best practices

GPS-enabled apps and high-resolution ground cameras are extensively being utilised for the maintenance of transmission lines, along with aerial inspections using helicopters, drones and GIS mapping. Similarly,

substation maintenance encompasses asset management practices ranging from condition monitoring to asset health indexing for transformers and reactors.

Hotline maintenance utilises insulated buckets to ensure the safety and uninterrupted upkeep of the transmission system, including repairing damaged equipment. This method provides numerous benefits, such as reducing technical losses, preventing costly outages, facilitating operation without disruption, and ensuring safety while performing critical maintenance tasks on live transmission lines. This is further complemented by the emergency restoration system, which is used for the quick, safe and efficient restoration of power during interruptions caused by natural disasters, sabotage or vandalism.

Utilities are also investing in new technologies such as advanced tower designs, high-temperature low-sag conductors and transmission line arresters, enhancing system reliability. For substations, the adoption of resin-impregnated paper bushings in transformers provides improved insulation and reliability.

Notably, the implementation of ester-based transformer fluids offers superior fire safety characteristics and biodegradability compared to conventional mineral oil-based fluids. Being a vegetable seed-based fluid derived from agricultural seed crops, natural ester offers a safe and green solution for high equipment performance. Additionally, for early-stage detection of degradation in transformer insulation, innovations such as alcohol-based ageing markers provide many advantages. Compared to furans, these offer a higher recovery rate after degassing old units, as well as higher detectability at temperatures exceeding 100 °C. Further, internet of things-based automation of valve hall inspection using wireless thermovision scanning can be beneficial for safely monitoring critical equipment and high-risk assets.

Utility initiatives

As the world's largest transmission utility to achieve the ISO 55001 certificate, on June 6, 2024, Power Grid Corporation of India Limited is committed to the effective management of its transmission assets throughout their life cycle. POWERGRID's strategic asset management plan covers all aspects of POWERGRID's transmission asset management domain, including the technical management of assets such as towers, conductors, transformers, reactors and switchyard equipment. From digital transformation, re-engineering processes, technology upgradation and human capital deployment, POWERGRID is adopting various initiatives to enhance asset overview, foster innovation, optimise business performance and enable smarter operations.

It has digitalised processes by converting all analogue processes



into digital forms by utilising SAP technology for enterprise asset management and QR code-based data entry of test results.

Powergrid Digital Application for Routine Patrolling and Assessment of Network (PG-DARPAN) is being used for app-based defect detection in transmission lines. Further, it has established the National Transmission Asset Management Centre (NTAMC), which is a centralised facility for the remote operation and monitoring of all POWERGRID substations, as well as for the centralised real-time monitoring of relays and optimisation of human resources by eliminating shift operations at substations. As of December 2024, around 281 substations were under remote operation from the NTAMC.

POWERGRID is also leveraging digitalised tools to optimise work processes through technologies such as drone-based patrolling and predictive outage management. Additionally, its artificial intelligence-driven defect identification system, called Asset Management through Artificial Intelligence in Transmission (AMRIT), is an image-processing-based solution for identifying defects in transmission lines. The system can identify over 40 types of defects with a processing speed of 100 photographs per minute and an accuracy rate of more than 70 per cent. Further, real-time health assessment of assets using the Powergrid Asset Management System aids in risk-based severity indexing of transformers and reactors, and provides a dashboard for monitoring critical equipment.

Another asset management highlight is the use of dynamic line loading (DLL). DLL has the ability to adjust the capacity of an overhead line in real time, based on varying climatic conditions (temperature, radiation, wind speed and direction). DLL implementation is being carried out in the 400 kV D/C Madurai-Tuticorin line.

Another key initiative is the implementation of e-vegetation management across six transmission lines (high vegetation-prone) in the north-eastern region. This aims to

assist inspection and maintenance teams in mapping transmission lines.

Apart from this, the Unified Digital Assessment of Asset Network platform integrates all digital data sources and asset registers. It offers various benefits, such as a geospatial view of assets and facilitates the monitoring of key performance indicators, critical asset identification, inventory analytics, equipment health analysis and outage management tools.

Meanwhile, 3D printing is being utilised for the manufacture and repair of key components, resulting in substantial cost savings. POWERGRID has also successfully introduced the concept of digital workers through the incorporation of augmented reality-based digital headgear and tablet-based intelligent inspection to facilitate O&M. The headgear enables remote virtual supervision and assistance, thereby reducing chances of human error during maintenance tasks. Tablet-based intelligent inspection allows for end-to-end asset management with QR code-based asset tracking, ensuring the efficient, paperless execution of O&M tasks.

POWERGRID is also engaged in various capacity-building initiatives through skill enhancement of its employees. Best practices are documented on its e-learning platform, PRAGYAN, and learnings are shared at various national and international forums.

Conclusion

The power transmission sector is undergoing a transformative shift, driven by a surge in innovative asset management solutions. By leveraging advanced technologies, the sector is enhancing operational efficiency, optimising operations, minimising equipment failure, and ensuring high system availability and reduced tripping. Collectively, this not only factors into a more reliable and efficient grid, but also paves the way for renewable energy integration, which is essential for meeting the ever-growing demand for energy. ■

Building Capacity

Transmission developments in the Asia-Pacific region

The past year ended with several highs for the global power transmission sector. The focus was on decarbonisation; introducing competition and efficiency in the power transmission market; expanding grid investments to improve grid flexibility and resilience, and integrate renewable energy sources (RES), including offshore wind (OSW), and energy storage technologies, into the grid; meeting new demands posed by rapidly burgeoning data centres and increasing electrification, particularly in advanced countries; and enhancing regional integration.

Countries in the Asia-Pacific region continued to invest in transmission during the year to meet their decarbonisation goals. China released its action plan for accelerating the construction of a new power system (2024-27) to achieve the “dual carbon” goal (to peak carbon dioxide emissions by 2030 and achieve carbon neutrality before 2060). It would focus on building large-scale transmission to support the proposed large-scale RES and OSW bases. It also plans to increase energy equipment replacement investments, including networks, by 25 per cent by 2027. Among projects, China commissioned two 1,000 kV UHVAC projects, Zhangbei-Shengli and Wuhan-Nanchang, which strengthened the North China UHV grid and completed the Central China sun-shaped UHVAC double-ring network, respectively. Seven UHV projects in the advanced construction stage will be put into operation during 2025, including two 1,000 kV UHVAC projects – Sichuan-Chongqing and Datong-Tianjin South, and five ±800 kV UHVDC projects – Jinshang-Hubei, Longdong-Shandong, Ningxia-Hunan, Hami-Chongqing and Shaanxi-Anhui.

India finalised the National Electricity Plan (NEP) for Transmission 2023-32, involving an investment of Rs 9.15 trillion and transmission expansion of 163,000 circuit km and 1,091 GVA at 220 kV and above voltages up to 2032. Additionally, nine HVDC lines aggregating 33.25 GW will be added. Several proposed interstate transmission system projects would be awarded through tariff-based competitive bidding (TBCB). In 2024, the first two HVDC projects were awarded via TBCB to Power Grid Corporation of India (POWERGRID) and Adani Energy Solutions Limited (AESL). Tendering of the initial projects to supply power to proposed green hydrogen and ammonia plants was initiated with long-term plans to support 20 GW RES for such plants by 2029-30. The flagship Green Energy Corridor-II, which will integrate 20 GW RES capacity into the transmission systems of seven states by 2030, is also part of the NEP. To support OSW, a Rs 74.53 billion viability gap funding scheme was approved for the initial 1 GW projects to be chosen through competitive bidding, with POWERGRID being responsible for offshore and onshore evacuation infrastructure.

Pakistan approved the restructuring of the National Transmission Despatch Company and the establishment of an independent system and market operator as part of an International Monetary Fund-supported reform plan. Sri Lanka's new government scrapped privatisation plans of the Ceylon Electricity Board but confirmed that reforms will continue in the electricity sector. Nepal focused on accelerating construction on delayed transmission corridors to evacuate the upcoming hydropower generation and awarded contracts for the country's first three 400 kV substations. It secured a \$311 million Asian Development Bank loan to upgrade the transmission and distribution (T&D) infrastructure and support solar PV generation. It emerged as the net exporter of power to India. Nepal also started exporting 40 MW of hydroelectricity to Bangladesh via India's grid under a tripartite agreement among the three countries, even as Bangladesh owed \$1 billion to Indian power companies, including Adani Power, for power purchases.

In Southeast Asia, the Association of Southeast Asian Nations (ASEAN) expedited the finalisation of the ASEAN Power Grid enhanced MoU. To advance multilateral power trade in the region, the Lao PDR-Thailand-Malaysia-Singapore Power Integration Project (LTMS-PIP) entered Phase II, doubling electricity trade to 200 MW after an agreement between Singapore and Malaysia. However, the modalities of extending the first phase (involving trade between Laos and Singapore) were still under discussion due to disputes over power purchase quantities via the transit countries of Thailand and Malaysia.

As part of Singapore's broader strategy to import 4-6 GW of clean energy by 2035, the Energy Market Authority (EMA) conditionally approved proposals to import 3.4 GW of green power from the Riau Islands, Indonesia, via new 1,000 MW subsea cables. Further, Vietnam's Petrovietnam Technical Services Corporation and Singapore's Sembcorp Utilities agreed to conduct a technical survey for a 2.3 GW OSW project in Vietnam, to directly supply electricity to Singapore via new subsea cables from 2030. Other ongoing regional projects currently at various implementation stages include subsea cables between Sumatra in Indonesia and Peninsular Malaysia, an overland link between Kalimantan (Indonesia) and Sabah (Malaysia), and upgrades to interconnections between Thailand and Malaysia.

Vietnam passed the revised Electricity Law, which will replace the existing law of 2004, effective February 1, 2025, to unlock stalled RES projects and meet growing electricity demand efficiently. The state-owned Vietnam Electricity National Power Transmission Corporation commissioned the 519-km, 500 kV Quang Trach-Pho Noi project, also known as the 500 kV Circuit-3 project, in a record time of less than one year to ensure power supply



from central to northern regions.

The Philippines' private transmission concessionaire, National Grid Corporation of the Philippines (NGCP), completed key energy projects of national significance, including the ±350 kV HVDC Mindanao-Visayas Interconnection Project, the 500 kV Hermosa-San Jose, 230 kV Cebu-Negros-Panay 3 backbone project and the Cebu-Bohol Interconnection Project. However, NGCP faced a PHP15.8 million penalty from the energy regulator for failing to meet deadlines for over three dozen critical projects.

Japan's Ministry of Economy, Trade and Industry was considering revising the master plan for wide-area grid development formulated by the Organization for Cross-regional Coordination of Transmission Operators (OCCTO) in 2023 (involving up to JPY7.9 trillion in investments), to accommodate large-scale new demand such as data centres and semiconductor manufacturing, and ensure efficient grid development, including local grids. OCCTO advanced the tendering of two key cross-regional undersea HVDC projects in the eastern (Hokkaido-Honsho) and western (Chugoku-Kyushu) regions identified in the master plan. The two projects, with a combined worth of JPY1.9 trillion-JPY2.2 trillion, will be awarded in 2025 or beyond to ensure their completion before 2035.

South Korea is also reconsidering its energy plans as it is expected to face power shortages to meet the projected electricity demand from data centres and semiconductor manufacturing clusters. The impact of insufficient grid capacity and delays in network expansion is already evident in the rapid increase in the curtailment of nuclear and RES power during the year. In 2024, Korea Electric Power Corporation commissioned the 345 kV North Dangjin-Shintangjeong line, 22 years after it was first conceived. The 6 GW Ulsan offshore wind farm (OWF) cluster, the world's largest floating OSW park, made progress with Ulsan City signing a letter of intent with the participating companies of the four projects, involving an investment of KRW37.2 trillion.

New Zealand's national grid operator received approval for its Net Zero

Grid Pathways Phase I to strengthen the backbone of the country's grid by 2035. This includes replacing HVDC submarine cables linking New Zealand's North and South Islands, for which it reserved Prysmian's cable manufacturing capacity.

The Australian Energy Market Operator published the 2024 Integrated System Plan, calling for the addition of 5,000 km of lines in 10 years. Half of this length is under construction, while the remaining will be delivered by seven actionable transmission projects. The New South Wales (NSW) government granted the Critical State Significant Infrastructure status to transmission projects, including New England Renewable Energy Zone (REZ) and Victoria to NSW Interconnection West. NSW granted planning approval for the Central West Orana REZ transmission link and transmission license to the latter's appointed network operator under a 35-year PPP. OSW development advanced in Victoria, which sought expressions of interest from private players for the transmission system to connect proposed OWFs in Gippsland. The AUD19 billion Australia-Asia PowerLink (AAPowerLink) project, which aims to transport Australian solar power to Singapore through a subsea HVDC cable in the 2030s, received environmental approval from the Northern Territory (NT) and Australian governments as well as conditional approval for power import from Singapore's EMA. The Australian government provided AUD250 million to NT grids under the Rewiring the Nation initiative.

In central Asia, the CASA-1000 Project, which aims to facilitate 1.3 GW of electricity exchange among Tajikistan, Kyrgyzstan, Afghanistan and Pakistan, made progress with the World Bank resuming funding for Afghanistan's portion and completion of the construction of 456 km of lines in Kyrgyzstan. The latter aims to export around 1.7 TWh through the project from 2026 onwards. Afghanistan, Turkmenistan, Kyrgyzstan, Kazakhstan and Uzbekistan invested in strengthening their domestic grids and advanced plans to increase electricity trade in the region, including green power exports to Europe (mainly from Uzbekistan) from 2030. ■

Transforming Transmission

Trends shaping the cables and conductors market

Cables and conductors are critical components of the power transmission and distribution (T&D) network, forming its backbone and enabling the seamless flow of electricity. With the growing demand for reliable power supply driven by rapid urbanisation, industrialisation and the integration of renewable energy sources, the cables and conductors market has witnessed significant expansion. This expansion reflects technological advancements in technology, increasing investments in infrastructure and a focus on enhancing transmission efficiency while minimising energy losses.

The robust growth of India's T&D sector has led to significant asset creation, driving the demand for cables and conductors. As per the Central Electricity Authority's (CEA) latest data, the aggregate transmission line length at the 220 kV and above voltage levels stood at 490,306 ckt km as of October 2024. The overall line length increased from 291,336 ckt km during 2013-14 to 485,544 ckt km during 2023-24, recording a CAGR of 5.24 per cent. In terms of voltage, significant capacity and lines have been added at the extra high voltage (EHV) levels, with 400 kV and 220 kV lines accounting for 84.69 per cent of the aggregate transmission line length, followed by 765 kV lines, with a share of 11.36 per cent. High voltage direct current (HVDC) networks currently have a small share in the total line length (1.92 per cent, 1.97 per cent and 0.06 per cent at the \pm 500 kV, \pm 800 kV and \pm 320 kV HVDC levels respectively), but are expected to witness strong growth in the next few years.

Going forward, the government's focus on building new lines and renewable energy infrastructure to achieve the 500 GW renewable energy target by 2030, modernising the ageing infrastructure and revamping the distribution grid under the Revamped Distribution Sector Scheme (RDSS) bodes well for the cables and conductors industry. According to the latest National Electricity Plan (NEP) projections, India will invest approximately Rs 9.15 trillion (around \$110 billion) in power transmission infrastructure by 2032.

Market growth trends

The growth of the cables and conductors market is primarily driven by the expansion of the power and infrastructure sectors. This growth is underscored by strong performance in both exports and domestic demand. According to the Indian Electrical and Electronics Manufacturers' Association, the sector has maintained a favourable trade balance, particularly in conductor and cable exports. Indian players are tapping into growing markets in Asia, Africa and Latin America by offering reliable and competitively priced products tailored to local requirements.

During 2022-23, conductor imports were valued at Rs 7.97 billion,

while exports rose to Rs 55.04 billion. This trend continued into 2023-24, with conductor imports increasing to Rs 9.45 billion and exports rising to Rs 58.81 billion, reflecting steady international demand for Indian conductors.

A similar growth pattern was observed in the HV and low voltage (LV) cable segment. In 2022-23, HV and LV cable imports stood at Rs 17.34 billion, while exports were significantly higher at Rs 68.9 billion. This momentum strengthened in 2023-24, with imports increasing to Rs 21.58 billion and exports soaring to Rs 80.05 billion. These figures highlight the robust export capabilities of the Indian cables industry.

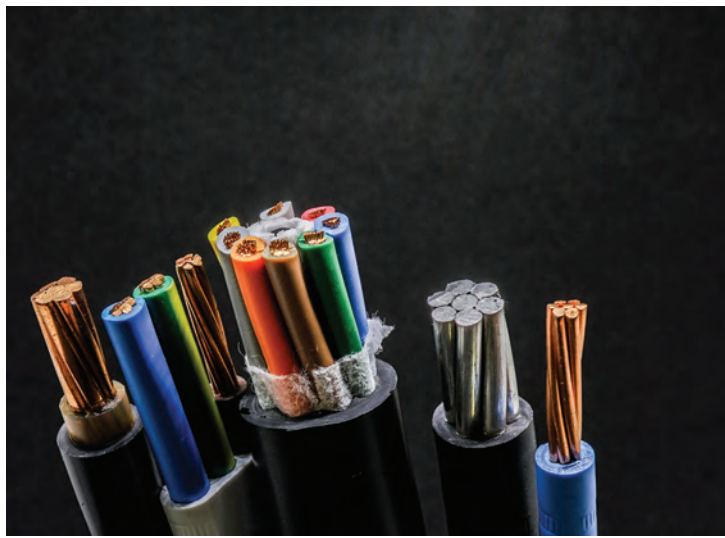
In the domestic market, the cables industry recorded a significant growth of 23.6 per cent in 2023-24 over the previous year. The conductor segment, although growing at a slower pace, recorded a modest growth of 2.1 per cent during the same period. These figures highlight the dynamic nature of the cables market and the steady performance of the conductors segment, driven by domestic infrastructure projects and export demand.

Opportunities and growth drivers

The government's latest notified NEP outlines substantial investments in renewable energy evacuation infrastructure over the next few years to evacuate more than 600 GW of renewable energy by 2032. Over the 10 year period from 2022-23 to 2031-32, the NEP aims to add more than 191,000 ckt km of transmission lines and 1,270 GVA of transformation capacity at the 220 kV and above voltage levels. The transmission network is projected to expand from 485,000 ckt km in 2024 to 648,000 ckt km by 2032. During this period, the transformation capacity is projected to grow from 1,251 GVA to 2,342 GVA.

The grid is expected to witness a significant capacity addition of 33 GW of HVDC bipole links, and an increase in interregional transmission capacity from the current 119 GW to 143 GW by 2027 and 168 GW by 2032. Furthermore, the transmission grid expansion plan entails cross-border connections to be set up with neighbouring countries like Nepal, Bhutan, Myanmar, Bangladesh and Sri Lanka. In addition, the plan envisages transmission interconnections with green hydrogen hubs and offshore wind energy plants in Gujarat and Tamil Nadu over the next 8-10 years. An investment of over Rs 9.15 trillion is expected in the transmission sector by 2032.

Meanwhile, RDSS, aimed at modernising and strengthening power distribution infrastructure, is gaining momentum. The scheme has an outlay of Rs 3,037.58 billion with a gross budgetary support of Rs 976.31



billion from the Government of India over a period of five years from 2021-22 to 2025-26. As of August 2024, projects worth Rs 2,620 billion have been sanctioned for distribution infrastructure works and smart metering works under the scheme. The huge capex being undertaken on the distribution side has provided a significant impetus to the domestic industry. The overall physical progress in loss reduction and smart metering under the RDSS is currently at 17.09 per cent and 3.28 per cent respectively (as per the RDSS dashboard accessed on November 22, 2024).

Meanwhile, the launch of the Pradhan Mantri Suryodaya Yojana in January 2024 for the installation of rooftop solar for 10 million homes has provided an incentive to cable makers. Also, the ongoing transition towards EVs is driving increased demand for charging stations, thereby increasing the uptake of cabling solutions.

Recent developments

On March 27, 2024, the CEA issued an advisory on implementing the Bureau of Indian Standards (BIS) standards and quality control orders for aluminium ingots, wire rods, and wires used in manufacturing conductors and cables. These include compliance with standards such as IS 5484 and IS 2067 for aluminium rods and wires, and IS 4026 for aluminium ingots.

The CEA also recommends the adoption of high-performance conductors (HPCs) made from diverse materials, including galvanised steel, zinc alloy and fibre-reinforced composites. While India lacks adequate test facilities for HPCs, leading to reliance on international testing centres and increased costs, these conductors provide cost efficiencies over time. Despite being two to three times more expensive than conventional conductors, HPCs reduce losses and associated operational expenses, making them an economically viable choice in the long term.

Additionally, on May 21, 2024 the CEA released guidelines for testing the carbon fibre composite (CFC) core of high-temperature low-sag conductors. The advisory emphasises including a mandatory "galvanic protection barrier layer thickness test" in power sector procurement tenders, aligned with the ASTM B987 stan-

dards. It further specifies that the salt spray test is unsuitable for determining the thickness of the galvanic protection barrier layer on CFC cores, as no correlation exists between the two tests.

Technology trends

XLPE (cross-linked polyethylene) cables are being increasingly adopted by utilities due to their superior performance characteristics. These cables exhibit higher resistance to thermal

deformation, attributed to their elevated thermal tolerance, which enhances their current-carrying capacity compared to conventional cables. Additionally, XLPE cables provide improved tensile strength, elongation and impact resistance, making them suitable for HV and EHV applications, supporting operations up to 132 kV.

In regions where acquiring right of way (RoW) is challenging, utilities are deploying underground cable systems. A notable example is the \pm 800 kV Raigarh-Pugalur HVDC link, commissioned during 2021-22 by Power Grid Corporation of India Limited (Powergrid). This project includes Bipole-II (Poles-III and IV of 1,500 MW each) and the \pm 320 kV, 2,000 MW Pugalur-Trichur voltage source converter-based HVDC system. A unique feature of this initiative is the integration of overhead lines with underground cables to address limited transmission corridor availability in Kerala.

New cable designs are emerging for specialised applications. Solar cables, for example, are engineered to evacuate solar energy from PV modules, and withstand high ultraviolet radiation, extreme temperatures and harsh weather conditions. Similarly, wind power cables are designed for the particular demands of wind energy systems.

E-beam cross-linked cables are gaining traction due to their enhanced durability, higher temperature resistance, increased current-carrying capacity, and reduced thickness. These cables find applications in steel mills, electric overhead cranes, ships and power stations. Emerging cable technologies also include warm dielectric and cryogenic dielectric cables.

On the conductor front, advancements such as HTLS, high surge impedance loading and gas-insulated line conductors are transforming transmission capabilities. These conductors have been utilised in projects like the recent 132 kV lines bid out by Odisha Power Transmission Corporation Limited, the 400 kV Meerut-Kaithal D/C line and the Nathpa-Jhakri hydro project. These conductors increase the transfer capability of transmission lines while reducing line losses. HTLS conductors can withstand high operating temperatures and operate at around 30 per cent more current-carrying capacity than con-

ventional conductors. They can help in achieving greater ampacity (ampacity) without significant modifications to existing towers.

A major application of HTLS conductors is in reconducting/uprating existing lines to increase their power transfer capacity. Currently, Powergrid is reconducting lines with high temperature endurance conductors to double the capacity of the transmission corridor. These lines include the Maithon-Maithon-RB 400 kV D/C line; the Siliguri-Bongaigaon 400 kV D/C line; the Kolhapur-Kolhapur (Maharashtra) 400 kV D/C line; the Pirana-Pirana (Torrent) 400 kV D/C line; the NP Kunta-Kolar 400 kV S/C line; the Alipurduar-Salakati 220 kV D/C line; the BTPS-Salakati 220 kV D/C line; the Dimapur-Imphal 132 kV S/C line; and the Loktak-Jiribam

132 kV S/C line.

High-temperature superconducting (HTS) power cables are capable of carrying 5-10 times the current of traditional conductors, but have yet to see commercial deployment in India. For now, aluminium conductor steel-reinforced and all-aluminium alloy conductors remain widely used for overhead power transmission in the country's T&D systems.

Challenges and the way forward

The cable and conductor industry, while positioned for substantial growth, faces several significant challenges that could hinder its progress. Volatile raw material prices, particularly for copper, strain profit margins and erode global competitiveness.

Rising fuel costs further compound this issue by escalating transportation expenses. In addition, the industry remains partially unorganised, with some manufacturers failing to comply with quality standards, resulting in inconsistent product offerings. Other challenges include the increasing cost of commodities and crude oil, and inflationary pressures, which collectively impact production costs. The sector also faces persistent RoW issues, which hinder the seamless execution of projects despite advancements aimed at minimising RoW requirements.

Looking ahead, the industry is expected to benefit from sustained demand, driven by the expansion of the T&D network and the integration of large-scale renewable energy projects. The rapid growth of the renewable energy sector has spurred demand for specialised cables that can handle the unique requirements of solar power plants and wind farms. These projects often involve long-distance transmission lines and complex grid connections, necessitating reliable and high-quality cable solutions. As India continues to expand its renewable energy capacity, the demand for cabling solutions is expected to surge.

Initiatives like Make in India, production-linked incentive (PLI) and Aatmanirbhar Bharat have been instrumental in reducing import dependency and boosting domestic manufacturing. By leveraging these opportunities and fostering innovation, the industry can address existing challenges and achieve long-term resilience and competitiveness. ■

Perspective

S.R. Narasimhan

CMD, Grid Controller of India Limited

India aims to achieve net zero by 2070. The sector will continue to witness a shift toward renewables and an increased focus on green hydrogen, green ammonia, emission-based despatch, flexible/virtual power purchase agreements, etc. The power sector has undergone a significant transformation in recent years, driven by the increasing integration of renewables, the emergence of new sources of clean energy such as rooftop solar and green hydrogen, and new loads such as space cooling, electric vehicles, data centres, electrolyzers and electric cooking.



Climate change-induced adverse weather conditions and an increase in high-impact, low-probability incidents highlight the urgency of enhancing system resilience. These events pose a significant threat to the reliability and security of the power system. The development of digital infrastructure, cybersecurity and scalable ways of working, supported by interoperable information and communications systems, is imperative. Several legal and regulatory reforms have been undertaken in the past decade. These have created a robust pathway for market development and optimal utilisation of the national grid. Additionally, the modernisation of control centres with AI tools and the maximisation of system performance will be crucial measures. Risk-based probabilistic transmission planning processes and criteria, along with non-wire alternatives, must evolve. Offshore wind and hybrid renewables (such as wind-solar and wind-solar-storage) should be seamlessly integrated into the grid. ■

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Key Statistics

Planned network additions

Planned interregional transmission capacity (MW)				
Inter-regional corridors	Addition planned during 2022-27	Estimated capacity at the end of 2026-27	Addition planned during 2027-32	Estimated capacity at the end of 2031-32
West-North	18,400	55,120	6,000	61,120
Northeast-North	-	3,000		3,000
East-North	-	22,530	6,000	28,530
East-West	1,600	22,790		22,790
East-South	-	7,830	4,200	12,030
West-South	10,000	28,120	8,400	36,520
East-Northeast	690	3,550		3,550
Total	30,690	142,940	24,600	167,540

Source: National Electricity Plan (Transmission)

Monthly capacity additions in 2023-24 and 2024-25 (MW)							
Month	Thermal	Nuclear	Hydro	Solar	Wind	Other renewables	Total
Jan-24	414	-	18	988	233	9	1,662
Feb-24	2,780	-	-	1,269	184	-	4,233
Mar-24	-	700	-	6,238	733	103	7,774
Apr-24	-	-	-	824	275	8	1,107
May-24	-	-	-	1,640	261	-	1,900
Jun-24	-	-	-	1,197	234	2	1,433
Jul-24	-	-	-	1,734	419	39	2,192
Aug-24	-	-	-	2,224	117	37	2,378
Sep-24	60	-	-	1,330	171	375	1,936
Oct-24	-	-	40	1,357	354	6	1,757
Nov-24	-	-	-	2,049	242	14	2,305
Dec-24	1,320	-	-	3,697	204	23	5,244
Jan-25	1,460	-	-	2,465	202	59	4,186

Source - Central Electricity Authority

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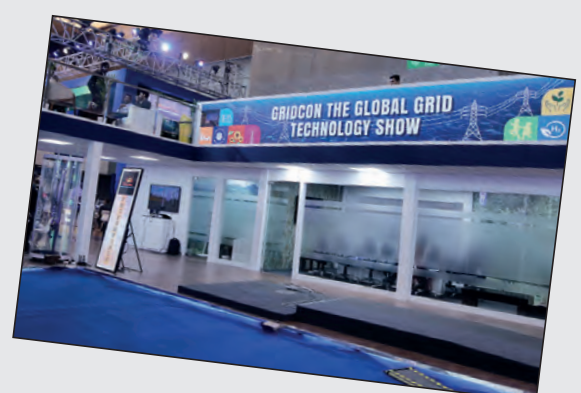
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Snapshots from Day 1



GRIDCON 2025

Agenda: Monday, March 10, 2025 (Day 2)

VENUE - EXHIBITION HALL 1 A AND 1 B

09:00 – 18:00 - Exhibition Area access for visitors

VENUE - PALASH HALL - C

Time	Agenda	Speaker
09:30 – 10:45	Offshore Transmission Network	Wessel Bakker, DNV, The Netherlands
10:45 - 12:00	Hybrid HVDC/MVDC/LVDC	Marcio Szechtman, CEPEL, Brazil
12:00 – 13:15	Virtual Protection, Automation C Control	Prithpal Khajuria, Intel, USA
14:00 – 15:15	Cybersecurity in Transmission System	Liu Chin Cheng, Viginia Tech, USA (Tentative)
15:15 – 16:30	Global Operational Experience of UHVAC Systems	Eiichi Zaima, CRIEPI, Japan; Yoshimitsu Umahashi, CRIEPI, Japan
16:30 – 17:15	Panel discussion 1: UHVAC Transmission System Implementation Roadmap Points for deliberation: <ul style="list-style-type: none"> • Equipment manufacturing • Testing • Upgradation of existing equipment reactive power management 	List of Panellists under finalization
17:15 - 18:00	Panel discussion 2: Global Trends in Energy Transition Points for deliberation: <ul style="list-style-type: none"> • Supply chain issues in generation and transmission • Maintenance of renewable energy enabling infrastructure • Issues in construction of transmission system for RE connectivity 	List of Panellists under finalization

Lunch – 12:30 to 15:00 - Exhibition Hall 1A for delegates/Juhi Café for VIPs

VENUE - PALASH HALL - B

Time	Agenda
10:00 – 12:00	Poster Presentations - PS 1 – 40 Papers
14:30 – 16:30	Poster Presentations - PS 1 C 2 – 40 Papers

VENUE – PALASH HALL – A

Time	Agenda	Remarks
10:30 – 13:00	CEO Meet (Leadership Circle)	CEO Meet in Hall A1
10:00 – 13:00	Technical Innovation Showcase	By different innovators/companies in Hall A2
14:30 – 16:00	TL Tutorial – Part 1	Tutorial session by Dr Konstantin O. Papailiou, President, CIGRE <ul style="list-style-type: none"> • History and actual issues of OHL • Electrical properties • Mechanical loads • Conductors including HTLS • Conductor vibrations • Fittings • Insulators • Construction and maintenance
16:15 – 17:45	TL Tutorial – Part 2	

Social Programme

19:00 – 22:00 – Gala dinner along with cultural programme

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