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INDIA'S T&D MARKET

The Engine Driving the World's Largest Synchronous National Grid

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Registered Office – Mumbai
501, Kakad Chambers, 132, Dr A Besant Road,
Worli, Mumbai 400 018.
Phone: +91(0) 22 24930532 / 6528
Fax: +91(0) 22 2493 2705 • Email: mumbai@ieema.org

Corporate Office – New Delhi
Rishyamook Building, First floor,
85 A, Panchkuian Road, New Delhi 110001.
Phone: +91 (0) 11-23363013, 14, 16
Fax: +91 (0) 11-23363015 • Email: delhi@ieema.org

Branch Office – Bengaluru
K Seetharaman, *Assistant Director*
State Head – Karnataka, Kerala and Tamil Nadu
Regional Representative-Southern Region
Mobile: +91 99800 04982
Email: k.seetharaman@ieema.org

Branch Office – Kolkata
Sanjoy Mukherjee, *Regional Representative-Eastern Region*
Mobile: +91 98308 50757
Email: sanjoy.mukherjee@ieema.org

Website: www.ieema.org

STATE HEADS

Rajesh Parab
Senior Executive Officer & State Head-Maharashtra
Mobile: +91 97022 69598
Email: rajesh.parab@ieema.org

Anuj Kumar Chaturvedi
State Head-UP, Uttarakhand & MP
Mobile: +91 98396 03195 / 95191 38844
Email: anuj.chaturvedi@ieema.org

Ashish Vikram
State Head-UP
Mobile: +91 98733 05589
Email: ashish.vikram@ieema.org

Omkar Pradhan
State Head-Gujarat
Mobile: +91 98199 06433
Email: omkar.pradhan@ieema.org

Mohammad Irfan Parray
State Head-Jammu & Kashmir
Mobile: +91 98584 55509
Email: Irfan.parray@ieema.org

Nilankha Chaliha
State Head-North East
Mobile: +91 97063 89965
Email: nilankha.chaliha@ieema.org

Rajnish Kaushik
State Head-Haryana, Punjab, Himachal Pradesh & Chandigarh
Mobile: +91 99911 10246
Email: rajnish.kaushik@ieema.org

Sairam Rayepeddi
State Head-Hyderabad
Mobile: 9642345691
Email: sairam.rayepeddi@ieema.org

FROM THE PRESIDENT'S DESK

Dear Readers,

India is making significant strides in the electrical sector. The country has reportedly added the highest ever capacity in a single year with a combined generation of 52,537 MW this fiscal (up to January 31, 2026). Of this, 39,657 MW alone has been added from renewable energy sources, including solar and wind. India's total installed power generation capacity now stands at 520,510.95 MW comprising non-fossil fuel capacity of 271,969.33 MW as on January 31, 2026.

Recently, the Central Government issued the consultation draft Electricity (Amendment) Bill, 2025, proposing comprehensive reforms in the power sector. The draft bill seeks to take measures for financial sustainability, promote competition, strengthen regulatory accountability, and accelerate India's transition towards non-fossil fuel-based electricity generation, in alignment with the vision of Viksit Bharat @ 2047.

Budget 2026-27 too provides a strategic push for comprehensive economic reforms. We welcome the advancement on green energy with a Rs20,000 crore outlay over five years proposed to scale CCUS technologies across five key sectors, including power. At IEEMA, our members have been consistently building capacities to promote Make in India, cater to domestic demand, and tap global markets.

The recent meeting between the Ministry of Heavy Industries and Canadian delegation is another major step. It will help strengthen cooperation in critical minerals, clean mobility, advanced manufacturing, and sustainable industrial development. Development of a robust and secure battery manufacturing ecosystem and access to critical minerals essential for clean energy technologies is a welcome move.

With such an action-packed February, IEEMA hosted the twin shows of BuildELEC and CompELEC in Mumbai, under its 'West Konnect' initiative. These shows were a comprehensive showcase for the building and component segments of the electrical industry. We hosted unique buyer-seller meets for electrical components while presenting the future of intelligent, efficient building infrastructure. The Startup initiative – Electraverse – hosted a startup showcase featuring 12 budding ventures with unique ideas. Young@IEEMA also hosted a Leaders Unplugged session featuring prominent names in the business of electrical manufacturing. The initiative also launched its podcast series at the forum.

We have much exciting times ahead of us, and I invite all of you to take active part in India and IEEMA's growth story!

VIKRAM GANDOTRA

Dear Readers,

February has been a high-voltage month of strategic progression for the electrical and electronics manufacturing industry. We find ourselves at an important juncture where policy, international diplomacy, and industry are aligning to create unprecedented momentum for our sector.

The recently announced Union Budget gave a clear roadmap for sustained economic momentum, focusing on a robust increase in capital expenditure to Rs12.2 lakh crore. This investment-led growth is anchored by a commitment to fiscal consolidation, targetting a deficit reduction to 4.3 percent of GDP. By balancing strategic capital investment with fiscal stability, the government has created a favourable climate for the electrical and electronics sector to scale and succeed.

On the international front, we are witnessing a transformative period for India's trade relations. The reduction of US tariffs from 25 percent to 18 percent marks a significant step toward a long-term economic partnership. The announcement of the India-EU Free Trade Agreement is a welcome move that facilitates advanced market access, global value chain integration, and strategic collaboration in energy transition and sustainable manufacturing. IEEMA remains committed to guiding our members as we deepen these industrial ties.

Our sector's growth is also being strengthened by strategic dialogues regarding clean energy and regional cooperation. The recent India-Canada meetings focused on clean mobility and the development of a secure battery manufacturing ecosystem, specifically regarding access to critical minerals. The meeting between Union Minister of Power Shri Manohar Lal, Minister of State Shri Shripad Naik, and Bhutan's Minister of Energy Shri Lyonpo Gem Tshering reinforces our longstanding cooperation in the power sector. At IEEMA, we welcome these concrete projects and partnerships as essential pillars for a resilient energy future.

At IEEMA, we recently concluded a successful edition of BuildELEC and CompELEC. Organised under the 'West Konnect' initiative, these leading platforms featured 150 exhibitors and facilitated approximately 1,000 structured B2B meetings with over 100 buyers. Highlighting the sector's emerging talent, the event featured the IEEMA Startup Forum, where 12 finalists pitched their innovations to a distinguished panel of judges for a chance at cash prizes. The event also hosted an engaging session under the 'Young at IEEMA' initiative, featuring keynote presentations and an insightful fireside chat.

Looking ahead, we are gearing up for ELROMA, E3, and the State Power Conclaves as we build momentum toward the world's largest electrical show – ELECRAMA 2027. I encourage all of you to stay tuned and remain active participants in our many initiatives as we build a resilient power economy together.

CHARU MATHUR

COVER STORY

T&D INFRASTRUCTURE: THE BACKBONE OF THE NATIONAL GRID

India's transmission and distribution (T&D) sector is entering a phase of sustained structural growth – not only through grid infrastructure expansion, but a deeper transformation driven by renewable energy growth, rising peak demand, and a clear policy focus on modernising distribution. As the renewable penetration rises and demand becomes more dynamic, improving grid flexibility and resilience takes centre stage. This calls for faster deployment of storage, flexible transmission technologies, and advanced grid management systems, as this Cover Story explores…

India's power transmission and distribution (T&D) sector is undergoing a defining phase, driven not just by grid infrastructure expansion but by energy transition goals, rising electricity demand, digitalisation, and structural reforms.

A recent PIB release by the Ministry of Power (MoP) points to the national transmission network (220 kV and above) crossing 5 lakh circuit kilometres (ckm) as of early 2026, with total transformation capacity exceeding 1,407 gigavolt-ampere (GVA) – reflecting rapid expansion to accommodate load growth and renewable energy (RE) evacuation.

The country's HV architecture now spans 765 kV, 400 kV, 220 kV and HVDC corridors, supported by a dense network of substations nationwide. Furthermore, the National Electricity Plan (NEP) outlines an additional 191,474 ckm of transmission lines and about 1,274 GVA of transformation capacity by 2031-32. These investments will significantly enhance interstate transfer capability and reinforce RE integration through the scale up of ultra HVDC links and dedicated green energy corridors.

High-Growth for Transmission

The transmission segment is poised for high growth, with investments estimated at Rs9.1 lakh crore by 2032 to integrate 600 GW of RE, says **Dr Nilesh Kane, Chief Transmission Business & Mumbai Distribution, The Tata Power Company Limited.**


Dr Nilesh Kane

He adds that rapid urbanisation, RE integration, grid modernisation, and competitive frameworks such as tariff-based competitive bidding (TBCB) are strengthening private sector participation and cost efficiency. "The Draft NEP 2026 reinforces this trajectory by promoting dedicated green feeders, cross-border interconnections, advanced transmission technologies, and parity between renewable and conventional energy dispatch by 2030 – ensuring a resilient, future-ready transmission network."

Performance Improvements for Distribution

The distribution segment is showing significant improvements in financial and operational performance. "Market reforms and digitalisation have propelled profitability, with infrastructure investments, smart metering, and network expansion projected to grow at 7.7 percent CAGR from FY2026-33 and supporting a peak demand of 366 GW by 2030," shares Dr Kane.

A recent integrated report from the MoP shows that the Revamped Distribution Sector Scheme (RDSS) has improved aggregate technical and commercial (AT&C) losses from 21.91 percent in FY2021 to 15.04 percent in FY2025, billing efficiency from 86.99 percent to 87.59 percent, and collection efficiency from 96.6 percent to 97 percent, with 17 utilities achieving 100 percent collection efficiency.

"The Draft NEP 2026 strengthens this momentum, targetting single-digit AT&C losses, establishing distribution system operators (DSOs) for optimised network sharing, public-private partnership (PPP) model distribution, parallel licensing and promoting distributed energy resources, peer-to-peer trading, and underground cabling in urban areas," says Dr Kane. He adds that financial reforms, including indexed tariff adjustments and reduced cross-subsidies, further enhance sustainability of distribution companies (discoms).

Opportunities for Boosting the Value Chain

Gajanan Kale, Chief Odisha Distribution Business, Tata Power Company Limited, and CEO, TP Northern Odisha Distribution Limited (TPNODL), shares that the government's focus on operational efficiency in distribution, particularly through RDSS and accelerated smart metering, is beginning to improve network visibility and service quality across states. At the same time, decentralised initiatives such as PM Surya


Gajanan Kale


Image courtesy: GR Infraprojects Limited

Ghar have given strong momentum to rooftop solar, signalling a structural shift toward distributed generation.

In transmission, he says, the scale of expansion is equally significant. Growth in inter-regional transfer capacity, aligned with the 'One Nation, One Grid' vision, is steadily strengthening system integration and enabling renewable-rich regions to serve distant demand centres.

"For integrated utilities like ours, this creates an opportunity to strengthen the entire value chain, from bulk power evacuation to last-mile delivery, while building a more resilient and future-ready power system," he adds.

Sustaining Long-Term Profitability for EPC Players

The transmission and substation engineering, procurement, and construction (EPC) segment in India is entering one of its most dynamic growth phases. For EPC players such as Kalpataru Projects International Limited, this translates into strong and sustained order visibility.


Rajeev Dalela

At the same time, adds **Rajeev Dalela, President-T&D (India & SAARC), Kalpataru Projects International Limited (KPIL),** project expectations are evolving. "Utilities now require faster evacuation of renewable power, compressing execution cycles, and shifting the sector from traditional multi-year projects to quick-turnaround assignments. This demands rapid mobilisation, higher resource availability, and significantly greater planning agility."

The developer ecosystem is also transforming due to heightened competition and entry of new infrastructure players into the transmission space. "While this expands capacity and capability across the sector, competitive bidding has increased pricing pressure across the value chain." Dalela notes that in such an environment, execution excellence, cost discipline, and selective bidding become essential to sustaining long-term profitability.

Segments Gaining Most Traction

Power and distribution transformers continue to hold the largest share of India's T&D equipment market, remaining the backbone of grid expansion to meet rising electricity demand, RE integration, and replacement of ageing assets. "The transformer market in India is estimated at Rs55,000-65,000 crore annually," shares Dr Kane.

For **Venkat Muvvala, President & Chief Business Officer, Jakson Infra,** in India's fast expanding T&D sector, "the strongest traction is from extra high voltage (EHV) and ultra-high voltage (UHV) equipment, including transformers, reactors, high capacity circuit breakers (air-insulated switchgear [AIS] and gas-insulated switchgear [GIS]), current transformers (CTs), and capacitor voltage transformers (CVTs), as the country rapidly scales its 400 kV, 765 kV, and HVDC networks." He adds that the EHV substations ecosystem is also seeing accelerated demand as renewable integration and urban load growth require higher capacity, compact, and digitally enabled substation designs. "Demand is rising for critical grid stabilising technologies such as flexible AC transmission systems (FACTS) and static synchronous compensator (STATCOM) systems to manage intermittency and maintain grid stability." On the material side, Muvvala notes that transmission towers, high performance conductors, and HV cables, especially for urban and underground corridors, will significantly drive the T&D market going forward.

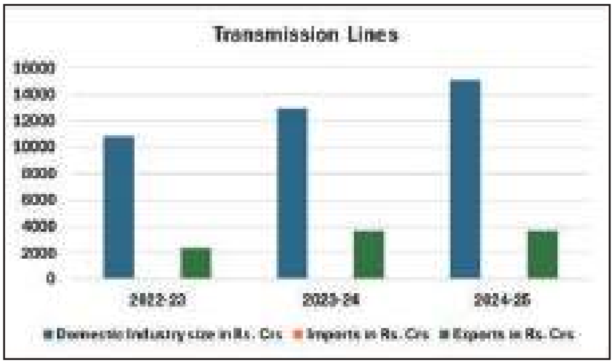

Venkat Muvvala

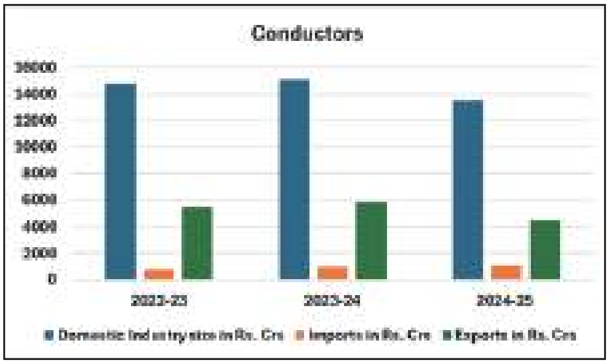
Strong growth momentum is also emerging in high-efficiency technologies such as high-temperature low-sag (HTLS) conductors, EHV underground cables, and HVDC systems. "HTLS conductors are growing at 15-18 percent CAGR, EHV underground cables at 14-16 percent CAGR, and individual HVDC projects can involve investments of Rs20,000-30,000 crore depending on length and voltage level," says Dr Kane. These advanced transmission solutions are critical for enhancing capacity, addressing right-of-way constraints, and enabling long-distance RE evacuation, supporting India's ambitious target of 500 GW of non-fossil energy capacity by 2030.

Digital substations and modern protection systems are also becoming mainstream as utilities seek faster response and better visibility of network conditions, observes Kale. In distribution, he shares that smart meters, SCADA platforms, automation equipment and communication infrastructure are seeing rapid adoption under RDSS. "Energy storage – both grid-scale batteries and pumped hydro – is emerging as a key enabler, helping manage renewable variability and improve system stability."

Equally important is the growing role of software, notes Kale. "Forecasting tools, data analytics and AI-driven asset management are starting to reshape

Indian Transmission Line Tower and Conductor Industries





Source: IEEMA

how networks are planned, operated, and maintained."

Saurabh Kaushik

While **Saurabh Kaushik, Business Unit Head, GR Infraprojects Limited,** agrees to HV equipment witnessing strong demand, at the same time, he shares, "We are facing supply-side constraints; sharp cost escalation in transformers, reactors, and circuit breakers; and rising raw material costs impacting insulators and other components." In this context, the Make in India initiative becomes critical. "We not only need assembly capacity but deeper manufacturing capability with global competitiveness. Strengthening domestic original equipment manufacturer (OEM) ecosystems will directly improve project timelines and cost stability," Kaushik adds.

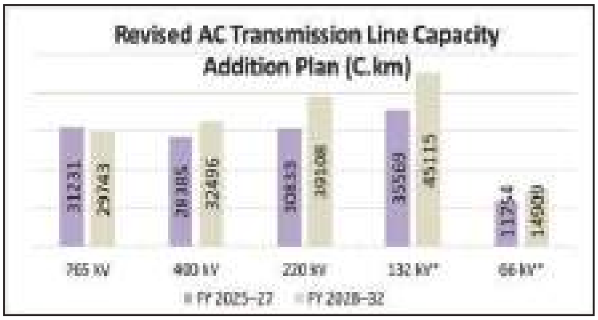
Strengthening Inter-State and Intra-State Transmission Investments

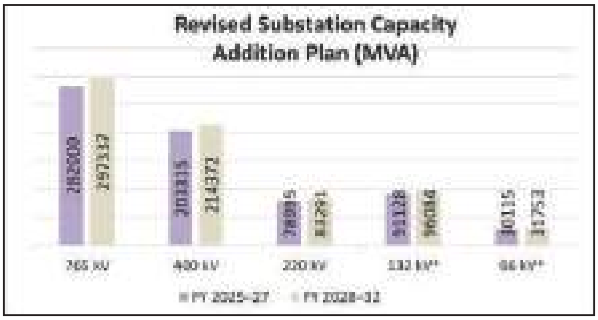
Inter-state transmission projects currently under implementation in the country are expected to add approximately 40,000 ckm of transmission lines and 399 GVA of transformation capacity, as per data released by MoP. Additionally, intra-state transmission projects under implementation are expected to add another 27,500 ckm of transmission lines and 134 GVA of transformation capacity. Transmission capacity additions will help evacuate the increasing non-fossil power generation, which is targetted at 500 GW by 2030.

"Progressive policies supporting green data centres, RE development, and green hydrogen have created strong structural drivers for T&D infrastructure growth, making the modernisation and expansion of both inter-state and intra-state networks a strategic necessity," says Dr Kane.

Notably, Tata Power is expanding its transmission footprint with over 7,800 ckm of operational and under-construction lines, targetting more than 10,000 ckm by 2029. "Strategic participation in TBCB projects – including recent completions under the National Rural Self-Support Scheme (NRSS), South East UP Power Transmission Company Limited (SEUPPTCL), and Jhajjar-Kotri Power Transmission Limited (JKPTL) – demonstrates our operational and executional capabilities," Dr Kane avers. Looking ahead, Tata Power has an investment pipeline of about Rs10,000 crore in the Mumbai Metropolitan Region (MMR) over the next five years and approximately Rs50,000 crore in TBCB projects by 2030, highlighting the scale of capital required to strengthen both inter-state and intra-state networks.

IEEMA Study on Demand Landscaping of Electrical Equipment by 2032





Developing India's T&D Infra with Technological Innovation & Digitalisation

Technological innovation will be central to the next phase of India's T&D development. The focus is shifting from conventional expansion to smarter optimisation of existing infrastructure, enabling faster, more resilient, and cost-effective grid development.

"One of the most effective solutions is reconductoring with HTLS conductors, which allows utilities to increase transmission capacity by 1.5-2x on existing lines without acquiring new land or building additional corridors. In urban areas with limited space, GIS substations are preferred for their compact footprint, reliability and scalability. The transition to SF -free switchgear further aligns grid expansion with sustainability objectives by reducing greenhouse gas emissions," notes **Dr Nilesh Kane, Chief Transmission Business & Mumbai Distribution, The Tata Power Company Limited.**

Wider deployment of HVDC corridors can move large volumes of renewable power over long distances with lower losses. "Energy storage, combining batteries with pumped hydro, will provide the flexibility required for a renewables-heavy grid," says **Gajanan Kale, Chief Odisha Distribution Business, Tata Power Company Limited,** and **CEO, TP Northern Odisha Distribution Limited.**

For **Rajeev Dalela, President-T&D (India & SAARC), Kalpataru Projects International Limited,** innovation will be the key differentiator in the years ahead. While complete mechanisation in tower erection and stringing may still be some distance away, incremental advancements – such as the adoption of tower cranes, drone-based stringing, and improved lifting technologies – are expected to be the next areas of focus for EPC players, he believes. Notably, KPIL was the first EPC company in India to deploy double-arm gin pole (DAGP) technology, advancing mechanised transmission tower erection with improved productivity and safety.

In the substation segment, GIS-based designs are enabling reduced land footprints and faster construction timelines, adds Dalela. "The use of factory-built assemblies and plug-and-play modules is also gaining wider acceptance, leading to improved standardisation and quality control. Over time, such innovations will help the sector overcome resource constraints, enhance safety, and achieve higher execution efficiency."

Emerging solutions also focus on flexible grid management. Here, Dr Kane shares that battery energy storage systems (BESS) help manage renewable variability, reduce curtailment, and improve peak load management, while electric vehicle (EV) infrastructure and vehicle-to-grid (V2G) integration allow managed charging and turning EVs into distributed grid assets.

On the distribution side, Kale adds that smart meters, advanced distribution management systems, and automated substations can sharply reduce losses and improve service quality. Artificial intelligence (AI)-based forecasting and predictive maintenance will help utilities move from reactive operations to proactive asset management. "Equally important is integrated planning across generation and T&D. Digital twins and system-level simulations can help anticipate congestion, optimise investments, and improve overall network efficiency."

"Technology must now move from optional to foundational," avers **Saurabh Kaushik, Business Unit Head, GR Infraprojects Limited.** He shares that key technology focus areas for the industry should include: The integration of supervisory control and data acquisition (SCADA) + energy management systems (EMS) at national and regional levels; AI-based load and renewable forecasting; Digitalisation in RoW management; and advanced grid monitoring systems. "The next phase of grid expansion must be digital-first, not only steel-and-conductor driven," he adds.

Transformation with Digitalisation

Digitalisation is central to modernising the grid, with automation technologies transforming both execution and operations.

Technologies such as SCADA, GIS, ADMS, and DERMS enable real-time monitoring, distributed energy resource management, predictive tripping analysis, and automated control helps in improving grid stability, optimising dispatch, and reducing balancing costs, says Dr Kane. "IoT-based asset management using digital twin allows continuous health monitoring of transformers, lines and substations, enabling predictive maintenance, extending asset life and reducing outages and breakdowns."

Furthermore, digitalisation is transforming discoms into data-driven energy service providers. "AI and machine learning (ML) enable predictive maintenance, real-time monitoring, advanced load forecasting, thus improving reliability, reducing outages, and extending asset life. Smart meters and data-driven discoms provide real-time consumption monitoring, improve billing accuracy, reduce electricity theft, and enhance operational transparency," Dr Kane shares.

"Real-time data, analytics, and automation are transforming grid operations by improving outage response, enhancing demand-supply balancing, and enabling greater participation of distributed resources such as rooftop solar and EVs," says Kale. From a consumer perspective, he shares that digital platforms are improving transparency, billing efficiency, and service responsiveness. This becomes even more important as consumers increasingly turn into prosumers, contributing energy back to the grid. "The future grid will be intelligent, adaptive and customer-centric, capable of integrating diverse energy sources while delivering reliable power at scale," he believes.

India's digital infrastructure – now supporting 1.03 billion internet users with 70 percent penetration – provides the backbone needed for nationwide rollout of digital grid systems, observes **Venkat Muvvala, President & Chief Business Officer, Jakson Infra.** To maximise existing corridors, he adds, "wider adoption of FACTS and STATCOM systems, series compensation, HTLS conductors and dynamic line rating can enhance transfer capacity without proportionate RoW expansion and use of extensive multi-circuit towers to reduce RoW constraints." He adds that to keep pace with renewable growth, grid planning must integrate UHVDC systems, smart substations, and enhanced protection and automation.

A future ready transmission network will ensure India remains not only the world's largest synchronous grid, but one of its most advanced and resilient grids.

"Capacity building and skilled manpower will be essential to sustain this transformation," says Muvvala. "Utilities must develop expertise in digital operations, HVDC systems, advanced protection, and AI enabled asset management, while field teams are trained in drone inspections, digital maintenance tools, and modern safety practices. Strengthened training academies, Centres of Excellence, and industry-academia partnerships will ensure a steady pipeline of professionals capable of operating a highly digital and renewable intensive grid."

Image courtesy: Kalpataru Projects International Limited

The scale of additions currently under implementation clearly reflects the magnitude of India's energy transition. The planned expansion of inter-state and intra-state networks, together adding well over 60,000 ckm of transmission lines and significant transformation capacity, is essential to support rising demand and large-scale renewable integration.

"However, this should be viewed as part of a longer investment cycle," adds Kale. "Over the next decade, T&D investments are expected to run into several lakh crore rupees as India builds evacuation infrastructure for renewable-rich regions, strengthens inter-regional connectivity, and upgrades intra-state networks to handle higher loads and decentralised generation."

What is equally important is timing. "Renewable capacity is coming up much faster than transmission assets, so grid development must be planned ahead of generation to avoid congestion and curtailment. Alongside interstate corridors, focused investments in sub-transmission and distribution infrastructure will be critical to ensure that bulk power actually reaches consumers reliably," observes Kale. He adds that PPPs, TBCB, and innovative financing mechanisms will thus play a central role in mobilising capital at scale, while integrated planning across generation and T&D will be key to maximising returns on these investments.

While the scale of expansion is unprecedented and necessary, RE growth from solar parks, hybrid wind-solar projects, and offshore wind requires matching transmission readiness. "Evacuation infrastructure cannot lag generation capacity," notes Kaushik. Beyond capital investment, he points to three areas that demand focus: 1) Strengthening intra-state networks for last-mile evacuation. 2) Standardisation of grid infrastructure across states. 3) Expansion of domestic manufacturing capacity. "Transmission investments must be strategically focused on resilience, redundancy, and digital readiness and not just physical expansion."

To facilitate greater private investment in intra-state transmission projects at the state level, Muvvala believes it is essential to strengthen overall project bankability and long-term revenue certainty from an investor's perspective. He says, "Several states have initiated intra-state transmission projects under the TBCB framework in alignment with the principles of the Electricity Act, 2003, and subsequent MoP guidelines. However, in most cases, the transmission service agreement (TSA) is executed with state discoms and other long-term transmission customers (LTTCs), rather than being directly backed by a regulatory revenue determination mechanism. This structure may raise concerns regarding long-term payment security, counterparty risk, and enforceability of cost recovery over the 25-35 years asset life."

Unlike the inter-state transmission framework regulated by the Central Electricity Regulatory Commission (CERC), where revenue recovery mechanisms are well defined and pooled through centralised payment security structures, intra-state projects depend significantly on the financial health and creditworthiness of state utilities. "This

directly influences investor confidence, financing terms, and cost of capital," says Muvvala.

Further, he adds, "Timely approvals, dispute resolution, and tariff adoption orders by the respective state electricity regulatory commissions (SERCs) are critical for ensuring financial closure and reducing regulatory risk. Expedited regulatory processes and stronger payment security frameworks will materially enhance investor participation and accelerate development of intra-state transmission infrastructure."

Addressing Developmental & Operational Challenges

Developing transmission infrastructure in India involves a wide spectrum of challenges, spanning technical, regulatory, environmental, and market-related dimensions.

Kaushik shares that persistent challenges remain: Land acquisition and right of way (RoW), environmental and forest clearances, and variability in state-level policies. "Lack of uniform RoW guidelines across states increases uncertainty and project timelines. Standardisation and faster statutory approvals are essential to prevent time and cost overruns," he notes.

In agreement, Muvvala suggests that both the Central and state governments must develop a uniform policy applicable for the whole country and obtain RoW rights by the respective governments and pass it on to transmission project developers, "so that developers are not at the mercy of local landowners and administration."

According to Kale, supply chain pressures, including volatility in metals and long equipment lead times, are affecting both costs and timelines. Apart from physical infrastructure challenges, he adds that coordination across multiple agencies, evolving regulatory requirements, and approval timelines often determine project outcomes. "As a sector, we need faster clearances, standardised processes, and wider use of digital project management tools to compress development cycles."

On the operational side, the sector currently faces a demand-supply imbalance in skilled manpower and vendor capacity. "Labour scarcity is emerging as a key issue across the construction sector. Tower erection and stringing activities, which still depend heavily on manual labour, offer limited opportunities for mechanisation in the short term. Over the past two years, erection rates have nearly tripled, exerting notable cost pressures on contractors and impacting overall project economics," says Dalela.

Strong technical pre qualification requirements, financial viability concerns, compounded with execution risks and limited private sector involvement result in elevated costs, delayed commissioning timelines, and threaten timely renewable integration, notes Muvvala. "Addressing equipment availability, enhancing mechanisation and project management capacity, easing overly stringent technical entry barriers for capable and financially strong EPC contractors with prior experience and project management track record in power generation and T&D will result in increased participation of capable EPC players. This will consequently reduce project cost and time."

The World's Largest Synchronous Grid: Advantage with Responsibility

India's achievement in operating the world's largest synchronous national grid is a matter of national pride. However, to propel the sector to its next phase of growth and global competitiveness, certain structural issues require urgent attention.

As renewable penetration rises and demand becomes more dynamic, the most urgent priority is improving grid flexibility and resilience. This calls for faster deployment of storage, flexible transmission technologies, and advanced grid management systems to manage intermittency while maintaining reliability.

Industry experts share more on areas that require urgent attention to further propel the sector...

Indigenisation/local manufacturing

Dr Kane: A primary concern is indigenisation and local manufacturing of critical T&D equipment, including transformers, switchgear, high-efficiency conductors, EHV cables, and HVDC components. Despite initiatives such as Make in India and the Production-Linked Incentive (PLI) scheme for electronics and advanced manufacturing announced in Budget 2026, India remains dependent on imports for key raw materials including 2.39 lakh tonne of refined copper and 1.5 lakh tonne of copper wire in FY2025 and specialised equipment with long lead times. Price volatility in copper and aluminium continues to significantly impact project costs, planning, and execution.

Kale: India has made good progress in downstream manufacturing, but gaps remain in high-voltage equipment, power electronics, and upstream renewable components. Bridging these gaps will require sustained policy support, technology partnerships, and scale. A stronger domestic manufacturing ecosystem is essential not only for energy security but also to reduce exposure to global supply chain disruptions.

Muvvala: Capacity expansion of local manufacturing ecosystems, expanding research and development (R&D) capabilities, and building scale in advanced equipment in EHV substations and HVDC systems, digital protection systems, and grid automation solutions will be critical. Policy stability and long-term visibility of orders can further incentivise capital investment in domestic capacity.

Kaushik: Restrictions on sourcing equipment from certain countries have created procurement challenges. This underlines the importance of building robust domestic manufacturing. A well-structured PLI scheme for transmission equipment can accelerate capacity creation and reduce dependency.

Exports

Kale: Exports offer meaningful potential, particularly as many emerging markets are embarking on similar grid modernisation journeys. However, Indian manufacturers face intense global competition and varying quality benchmarks. To succeed internationally, the focus must be on consistent quality, global certifications, and scale efficiencies.

Muvvala: India could emerge as a competitive global supplier of transmission equipment and EPC expertise, particularly to emerging markets in Asia, Africa, and the Middle East. However, improving global certifications, financing support mechanisms, export credit access, and supply chain efficiencies will be key to scaling exports. Building strong global brands, backed by quality and timely execution, will determine long-term success.

Kaushik: India has strong potential to become a global supplier of transmission equipment. With scale and quality compliance, we can serve emerging markets across Asia and Africa.

Tariff impact

Dr Kane: While global trade uncertainties and tariff volatility remain a concern, domestic policy measures are increasingly supportive to the sector. The Budget 2026 has introduced duty exemptions for capital goods used in T&D and renewable projects, while streamlining customs and regulatory processes help accelerate equipment deployment. Incentives under PLI and electronics manufacturing programmes strengthen local production of smart meters and grid automation equipment, which are essential for modernising the grid and enabling large-scale renewable integration.

Kale: Tariffs and non-tariff barriers imposed by other countries are becoming an important consideration, especially as clean energy equipment increasingly intersects with geopolitics and carbon policies. This reinforces the need for India to deepen domestic value chains, diversify export markets, and improve competitiveness rather than rely on any single geography.

Muvvala: Protectionist trade policies and tariffs imposed by importing countries can affect the competitiveness of Indian manufacturers. At the same time, global trade uncertainties may increase input costs for critical raw materials. Mitigating these risks requires diversified export markets, strategic sourcing strategies, and bilateral trade engagements that ensure fair market access.

Kaushik: Tariff increases by countries like the US have pushed up raw material costs, indirectly affecting Indian OEMs. Strategic sourcing and domestic value addition will be key to managing volatility.

Other critical considerations

***Kale*:** Project execution challenges such as RoW, equipment availability, manpower constraints, and cybersecurity also need attention. As grids become more digital, protecting critical infrastructure from cyber risks will be just as important as physical reliability.

Muvvala: Beyond manufacturing and trade, the sector must address grid flexibility, storage integration, cybersecurity risks, skilled workforce development, relax technical PQs and financial sustainability of utilities, and resolve RoW issues by respective governments. The next decade will demand not just infrastructure expansion, but digital intelligence, resilience, and sustainability embedded into grid planning.

Dalela: The government needs to consider rationalising customs duties on the import of advanced technologies such as specialised cranes and drones to accelerate mechanisation and improve productivity in infrastructure execution.

Kaushik: With rising renewable penetration, intermittency management becomes critical. Reactive compensation systems and advanced grid management tools must scale rapidly.

Addressing these issues together through coordinated policy, targetted fiscal incentives, tariff rationalisation and trade agreements along with technology adoption and capacity building will be key to unlocking the next phase of growth for a globally competitive T&D ecosystem.

The Road to 500 GW of Non-Fossil Fuel

Transmission infrastructure is the backbone of India's energy transition and increasing its capacity is key to achieving 500 GW of non-fossil fuel capacity by 2030. As renewable capacity scales up, strong transmission infrastructure will enable seamless renewable evacuation, maintain grid reliability, support regional power balancing, and strengthen national energy security.

That said, achieving India's 500 GW non-fossil target will depend as much on grid readiness as on generation capacity addition. The key challenge will lie in execution – effectively managing resource constraints, commodity volatility, and competitive pricing, while upholding safety, quality, and timely delivery, believes Dalela. "Companies that invest today in innovation, vendor capability, and people development are best positioned to lead the next decade of growth in this dynamic sector."

In agreement, Kale says that reaching 500 GW of non-fossil capacity is not just about adding renewable generation, it is about building a grid that can absorb, balance, and deliver this power reliably across the country. "Strong inter-regional links will allow surplus green energy to flow to demand centres, while resilient intra-state networks will ensure last-mile delivery. This will require a sustained expansion of transmission line length, transformation capacity, and inter-regional transfer capability over the remainder of the decade, supported by digital monitoring and storage integration."

In essence, transmission is not just a supporting infrastructure; it is a strategic enabler of India's energy transition. A stronger, smarter grid will ensure that the country's renewable ambitions translate into reliable, affordable, and sustainable power for long-term growth.

With sustained investment, policy continuity, and large-scale adoption of digital and storage technologies, India can build one of the world's most advanced and resilient power systems.

India's Power Transmission Network Crosses 5 Lakh CKM

Further addition to the transmission capacity will help evacuate the increasing non-fossil power generation, which is targetted at 500 GW by 2030.

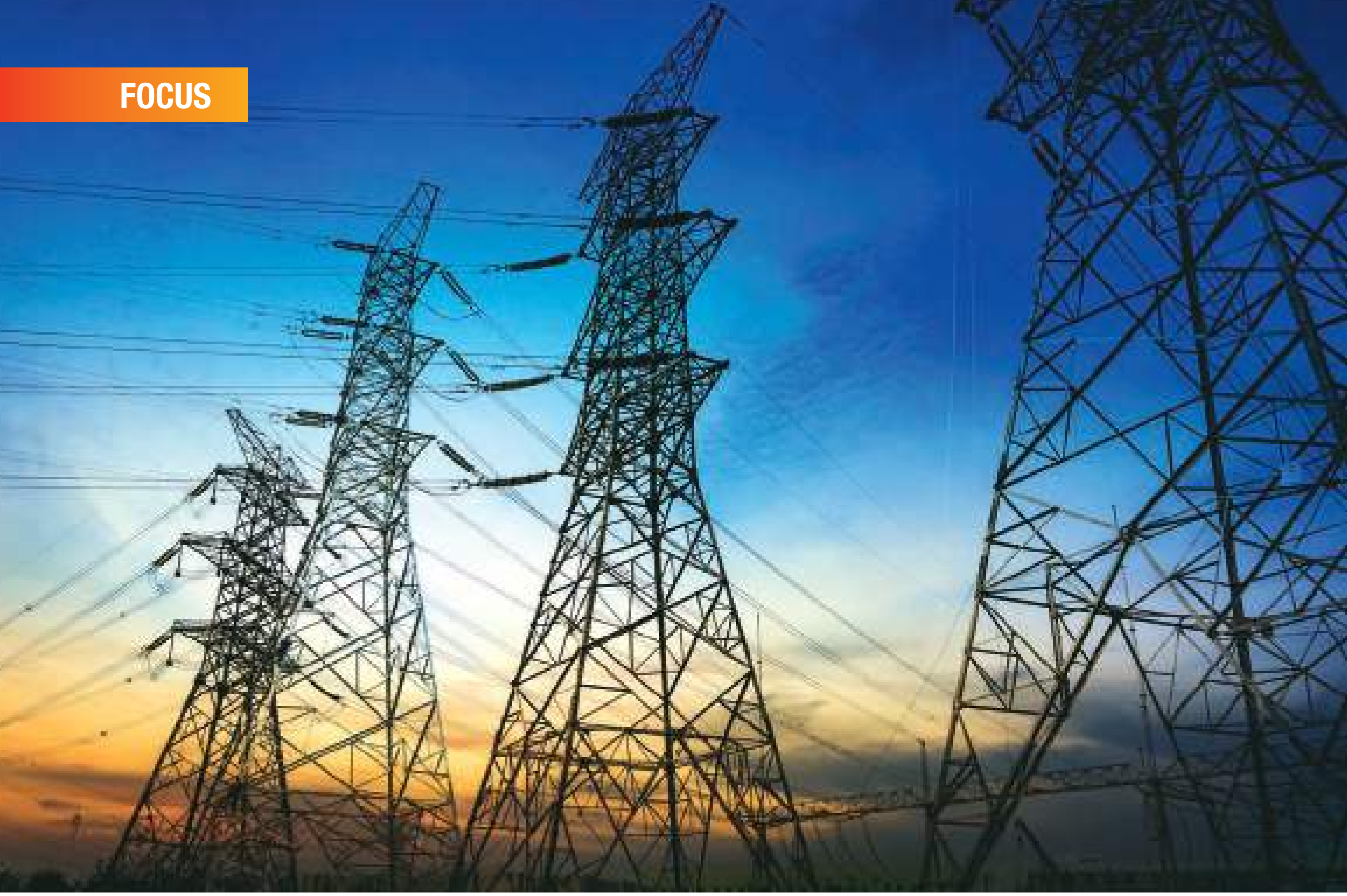
India's national power transmission network has achieved a significant milestone, crossing over 5 lakh circuit kilometres (ckm) of transmission lines (220 kV and above) along with 1,407 gigavolt-ampere (GVA) of transformation capacity (220 kV and above).

A PIB release by the Ministry of Power states that the world's largest synchronous national grid achieved this feat on January 14, 2026, with the commissioning of 628 ckm transmission line of 765 kV from Bhadla II to Sikar II substation for evacuation of renewable power (RE) power from Rajasthan Renewable Energy Zone. With commissioning of this transmission line, an additional 1,100 MW of power can be evacuated from the RE zone of Bhadla, Ramgarh and Fatehgarh Solar Power Complex.

Since April 2014, the country's transmission network has grown by 71.6 percent with the addition of 2.09 lakh ckm of transmission lines (220 kV and above), boosting transformation capacity (220 kV and above) by 876 GVA. The inter-regional power transfer capacity, which now stands at 120,340 MW, has enabled seamless transfer of electricity across regions, successfully realising the vision of 'One Nation – One Grid – One Frequency'.

The inter-state transmission projects currently under implementation will add approximately 40,000 ckm of transmission lines and 399 GVA of transformation capacity. In addition to these, the intra-state transmission projects under implementation are expected to add another 27,500 ckm of transmission lines and 134 GVA of transformation capacity, which will further enhance grid reliability and power evacuation capability.

Addition to the transmission capacity will help evacuate the increasing non-fossil power generation, which is targetted at 500 GW by 2030.



Strengthening Transmission Infrastructure for a Renewable Future

Strengthening transmission is not only about adding capacity but also about modernising the entire high-voltage ecosystem to ensure grid stability and operational resilience, writes **Keyur Shah, Chairman & Managing Director, Yash Highvoltage Limited.**

India's energy transition has moved from ambition to execution. Renewable capacity is scaling rapidly, with larger solar parks, wind corridors, and hybrid projects coming online across geographies. As this growth accelerates, the focus must shift from generation alone to an infrastructure that enables clean power to reach demand centres reliably and efficiently. That infrastructure is transmission.

Renewable resources are often located far from consumption hubs. This geographical mismatch makes a robust, high-capacity transmission network essential. Without adequate evacuation corridors and grid readiness, clean energy risks are being curtailed, undermining both project viability and national sustainability goals.

Transmission as the Enabler of Renewable Integration

Unlike conventional power, renewable generation is variable, decentralised and increasingly bidirectional. This introduces new technical challenges for the grid, including voltage fluctuations, dynamic load patterns, and higher switching frequencies. Legacy transmission systems were not designed for these operating conditions.

To support higher renewable penetration, India requires:

- Extra high voltage (HV) transmission corridors for bulk power transfer.
- Faster grid connectivity for renewable projects.
- Advanced substations capable of handling dynamic operating environments.
- Equipment designed for reliability under fluctuating loads.

Strengthening transmission is therefore not only about adding capacity but also about modernising the entire HV ecosystem to ensure grid stability and operational resilience.

HV Infrastructure and Grid Reliability

HV equipment forms the backbone of a dependable power system. Transformers, instrument transformers, switchgear, and insulation systems must perform consistently despite thermal stress, harmonics, and ramping associated with renewable energy (RE).

In renewable heavy networks, the margin for failure is significantly lower. Equipment must be engineered for long servicing life, minimal maintenance, and superior dielectric performance. Reliability at the component level directly influences system availability and reduces the risk of outages.

As India expands inter-regional transmission and green energy corridors, the demand for technologically advanced HV solutions will continue to grow. Local manufacturing capability, stringent testing protocols, and alignment with global standards will be critical to meeting this demand.

The Strategic Importance of Bushings

Within this HV ecosystem, bushings play a vital yet often understated role. They provide the insulated interface that allows current to pass safely between transformers, reactors, and the grid while maintaining electrical insulation to grounded structures.

With the shift towards higher voltage and more dynamic grid conditions, the performance expectation for bushings have evolved. They must deliver:

- High dielectric strength for extra high voltage (EHV) applications.
- Thermal stability under variable loading profiles.
- Partial discharge free and resistance to ageing.

Advanced bushing technologies enhance transformer reliability, extend asset life, and reduce or eliminate the probability of catastrophic failures. In a renewable grid where equipment is subjected to frequent load variations, their role becomes even more critical.

Building a Future- Ready Transmission Network

India's transmission expansion plans are aligned with its renewable targets, but infrastructure development must be accompanied by deeper technological capability. Indigenous manufacturing of HV components, lifecycle-based asset management, and digital condition monitoring will be key enablers.

A future ready grid will be characterised by:

- High capacity, low loss transmission systems.
- Smart substations with real-time diagnostics.
- Standardised, high-quality components.
- Strong domestic supply chains for critical equipment.

Such an approach not only strengthens grid resilience but also supports the broader goal of energy security.

Powering the Renewable Economy

Transmission is the silent force that converts renewable potential into delivered energy. Every unit of clean power that reaches industries, cities, and households depends on the strength and reliability of the HV network behind it.

By investing in modern transmission infrastructure and high-performance components such as bushings, India can ensure that its renewable expansion is matched by grid readiness. This will reduce curtailment, improve efficiency, and enable round-the-clock availability of green power.

A sustainable energy future will be built not only on megawatts of renewable capacity but on the robustness of the systems that carry that power across the country. Strengthening transmission today is essential to unlocking India's renewable energy grid for tomorrow.

ABOUT THE AUTHOR

Keyur Shah, Chairman and Managing Director, Yash Highvoltage Limited, is a first-generation entrepreneur who has built a strong reputation in India's power industry. With more than 25 years of experience, he has combined vision, conviction, and strategic foresight to transform the company into one of the fastest-emerging leaders in the highly specialised field of transformer bushings. His qualifications include a civil engineering diploma and a certification program in Strategy Execution from Harvard Business School.

India-US Interim Agreement:

Enabling Additional Market Access, Supporting More Resilient Supply Chains

The US and India have reached an Interim Agreement framework, demonstrating a common commitment to reciprocal and balanced trade based on mutual interests and concrete outcomes.

The United States of America (US) and India have made a statement of having reached a framework for an Interim Agreement regarding reciprocal and mutually beneficial trade (Interim Agreement), announced the **Ministry of Commerce & Industry (MCI)** in a PIB release.

As reported, the framework reaffirms the countries' commitment to the broader US-India Bilateral Trade Agreement (BTA) negotiations, launched by US President Donald J Trump and India Prime Minister Narendra Modi on February 13, 2025, which will include additional market access commitments and support more resilient supply chains. The Interim Agreement between the two countries will represent a historic milestone in both countries' partnership, demonstrating a common commitment to reciprocal and balanced trade based on mutual interests and concrete outcomes, said the release.

Some of the key terms of the Interim Agreement, as per the US-India joint statement in the MCIs' PIB release, will reportedly include:

- The US and India commit to provide each other preferential market access in sectors of respective interest on a sustained basis.
- The US and India will establish rules of origin that ensure that the benefits of the Agreement accrue predominately to the US and India.
- Both countries will address non-tariff barriers that affect bilateral trade.
- For the purposes of enhancing ease of compliance with applicable technical regulations, both countries intend to discuss their respective standards and conformity assessment procedures for mutually agreed sectors.
- In the event of any changes to the agreed upon tariffs of either country, the US and India have agreed that the other country may modify its commitments.
- Both countries will work towards further expanding market access opportunities through the negotiations of the BTA. The US has affirmed that it intends to take into consideration, during the negotiations of the BTA, India's request that the US continue to work to lower tariffs on Indian goods.
- The US and India have agreed to strengthen economic security alignment to enhance supply chain resilience and innovation through complementary actions to address non-market policies of third parties, as well as cooperation on inbound and outbound investment reviews and export controls.

- India intends to purchase USD 500 billion of US energy products, coking coal, among others, over five years. India and the US will significantly increase trade in technology products, including graphics processing units (GPUs) and other goods used in data centres, and expand joint technology cooperation.
- The US and India commit to address discriminatory or burdensome practices and other barriers to digital trade and to set a clear pathway to achieve robust, ambitious, and mutually beneficial digital trade rules as part of the BTA.

At IEEMA, we welcome the strategic trade agreement between India and the US, signalling a recalibration of trade relations between the two countries.

Commenting further, says **IEEMA President Vikram Gandotra,** "The immediate reduction of US tariffs to 18 percent from 25 percent, and withdrawal of additional 25 percent penalty reflects a significant diplomatic achievement and brings back opportunities to the Indian electrical equipment industry.

IEEMA congratulates Hon'ble Prime Minister Shri Narendra Modi for his leadership towards steering these negotiations. We look forward to working closely with the government and industry stakeholders to translate this momentum into stronger, long-term trade partnerships with the US, boosting growth and competitiveness for both nations."

IEEMA Director General Charu Mathur adds, "The reduction of US tariffs from 25 percent to 18 percent signals a significant step towards a long-term economic partnership between India and US.

We are thankful to the Hon'ble Union Minister of Commerce and Industry Shri Piyush Goyal for the forward-looking dialogue and finalising the trade agreement. We at IEEMA remain committed to working with the government and industry to build stronger trade partnerships with the US."

The PIB release states that the US and India will promptly implement this framework and work towards finalising the Interim Agreement with a view to concluding a mutually beneficial BTA consistent with the roadmap agreed in the Terms of Reference.

Redefining Transformer Asset Management

This paper by **Goutam Sinha, Chief Product Officer; Dr. Kallol Mallick, Chief Technology Officer** and **RK Tiwari, Chief Advisor of MindPower Analytics** along with industry expert **BN De Bhowmick,** presents a Software-as-a-Service (SaaS)-based framework that integrates offline diagnostics with real-time operational insights through an AI/ML-driven analytics layer.

Transformer fleet maintenance is at a turning point. Traditional methods depend on isolated offline diagnostics and field experience, while modern utilities are increasingly deploying real-time sensors. Yet, these data sources – offline and online – remain largely disconnected, resulting in inconsistent health assessments and reactive maintenance.

This paper presents a Software-as-a-Service (SaaS)–based framework that integrates offline diagnostics with real-time operational insights through an Artificial Intelligence (AI)/ Machine Learning (ML)-driven analytics layer. The platform unifies test data, sensor information, and maintenance history into a predictive health assessment model. By leveraging scalable, multi-tenant cloud architecture, it enables utilities to extend transformer life, reduce operational costs, and adapt to a changing workforce landscape.

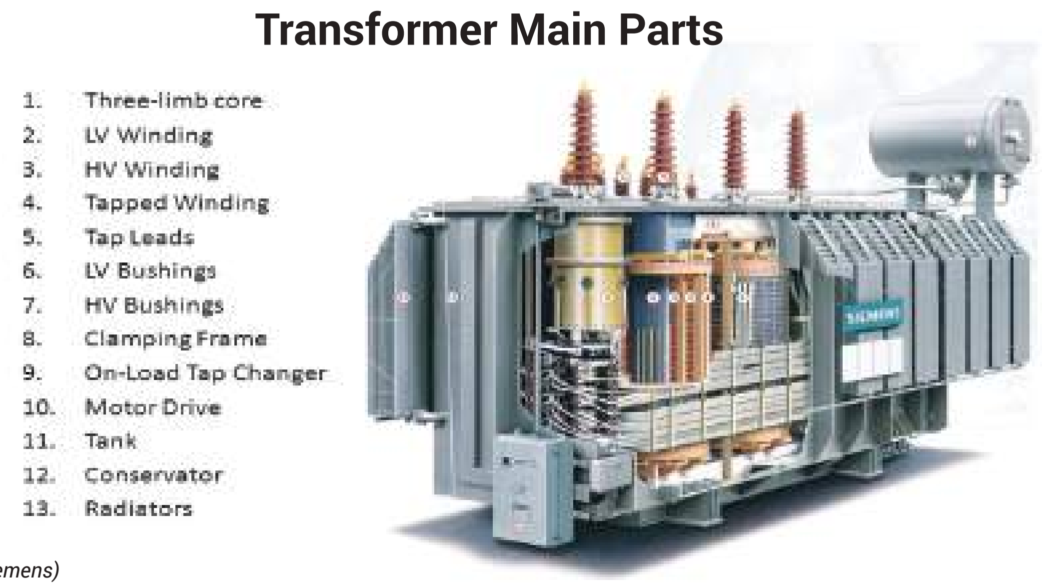
An additional field insight challenges industry convention: older transformers, some operating for more than 40 years, often demonstrate better health than newer units. This observation opens an important conversation on evolving designs, standards, and long-term asset resilience.

Introduction

Power transformers are long-life, capital-intensive assets critical to reliable grid operation. Their failure can trigger significant power interruptions, revenue loss, and public scrutiny. Historically, utilities have relied on time-based or condition-based maintenance guided by test results such as oil parameters, furan, and insulation resistance. However, with the rise of digital substations and sensor networks, new opportunities for predictive maintenance have emerged.

The challenge is that offline diagnostics (historical IT data) and online monitoring (real-

Figure 1: Transformer Component Schematic



(Courtesy: Siemens)

time OT data) exist in silos. Without integration, organisations lose the ability to identify early deterioration trends or quantify risk consistently.

This paper outlines a SaaS and AI/ML framework that bridges this gap. By combining data from multiple sources – laboratory tests, field sensors, and maintenance logs – into a unified platform, it delivers actionable insights and enables predictive, data-driven decisions across transformer fleets.

Industry Challenges

Utilities and industrial operators face several interrelated challenges in transformer fleet management:

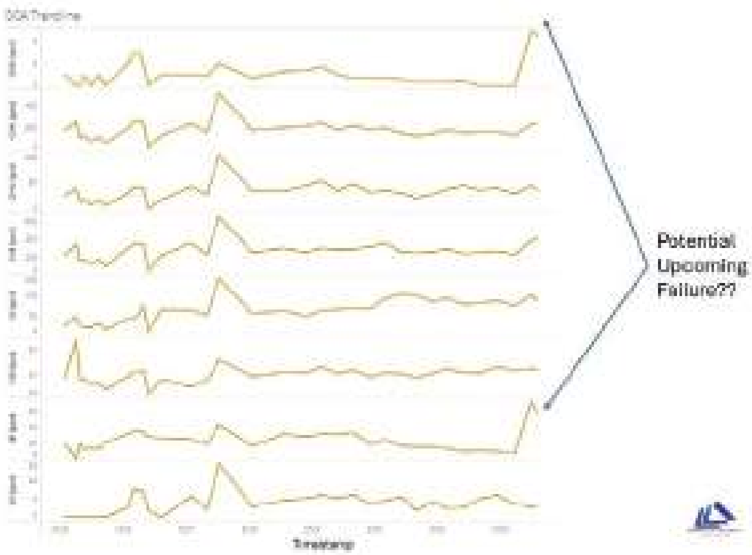
- Fragmented data ecosystems – Offline test data, design records, and operational sensor readings are stored in separate systems, making cross-analysis difficult.
- Reactive maintenance practices – Maintenance schedules are often predetermined or triggered by alarms rather than risk of failure.
- Evolving standards – Modern standards such as IEC 60599 and IEEE C57.104 d prioritise diagnostic interpretation but focus probably on newer transformer designs, sometimes undervaluing older units with proven reliability.
- Workforce transition – A generation of transformer experts is retiring, and fewer new engineers are entering the field with deep legacy knowledge. Organisations must capture and digitise institutional expertise.
- Pressure to optimise cost and reliability – Stakeholders expect improved uptime and asset longevity without proportional increases in maintenance expenditure.

The SaaS Framework for Transformer Fleet Management

A cloud-native, multi-tenant SaaS platform provides the foundation for integrating offline and online datasets at scale. The proposed framework unifies the following four components:

- Offline diagnostics repository – Consolidates transformer test data such as oil parameters

Figure 2: Transformer Asset Long Term Trend



and DGA data[1],[2],[4], furan, and bushing tests into a centralised knowledge base.

- Online sensor integration layer – Streams real-time parameters (temperature, moisture, few DGA parameters, partial discharge, vibration, etc) for continuous condition monitoring[3].
- Data reliability and weighting engine – Assesses the age, frequency, and completeness of test and sensor data to ensure that health indices reflect trustworthy and up-to-date information.
- AI/ML analytics and insights engine – Applies statistical learning and predictive modeling to detect early degradation patterns, correlate multi-parameter changes, and recommend optimal maintenance actions[5].

Together, these components enable a holistic and standardised view of transformer health, regardless of vendor or data source.

Key benefits include:

- **Scalability:** Multi-tenant deployment supports transformer fleets across geographies and organisations.
- **Consistency:** Delivers uniform interpretation of health scores across heterogeneous transformers and data sources.
- **Timeliness:** New industry-driven features, analytics updates, and security enhancements are available immediately through the SaaS model.
- **Collaboration:** Role-based dashboards allow engineers, planners, and executives to view insights tailored to their specific responsibilities.
- **Adaptability:** The same architecture can extend seamlessly to other substation assets (eg, breakers, transmission links) with minimal reconfiguration or retraining needs.

AI/ML Analytics and Predictive Insights

AI and ML transform data from a historical record into a forward-looking intelligence system. Within this platform, algorithms continuously learn from aggregated transformer behavior across fleets to identify deviations that may precede failures.

Figure 3: Real-Time Online Sensor Data Trend

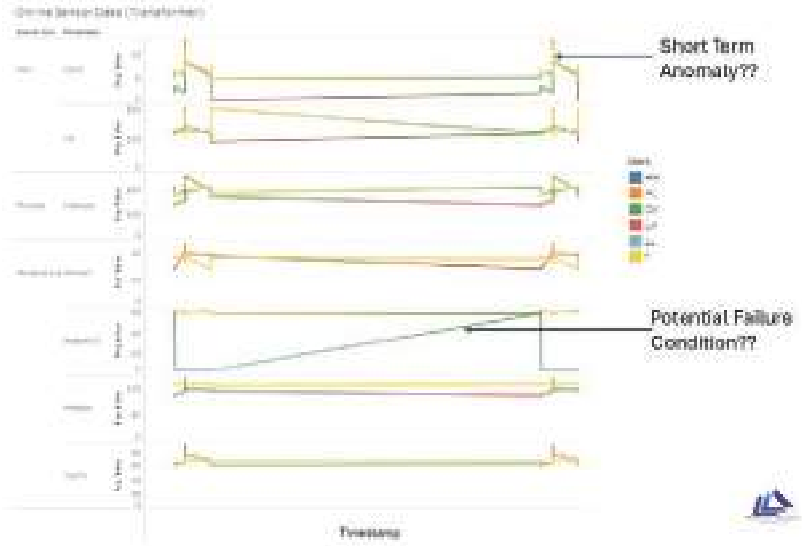
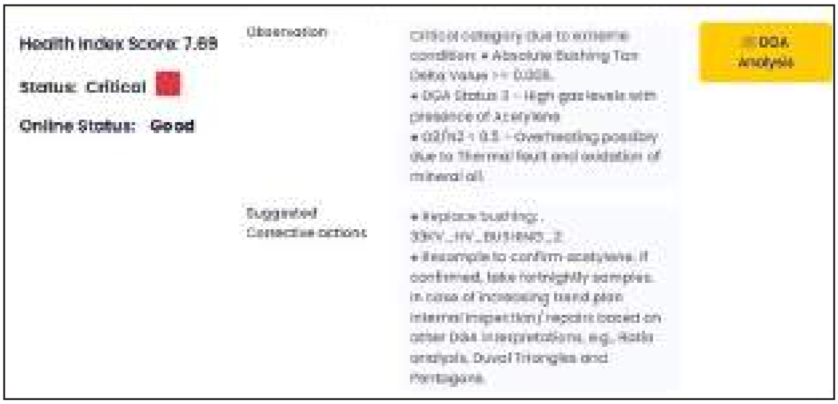


Figure 4: Sample Analytics Engine Output



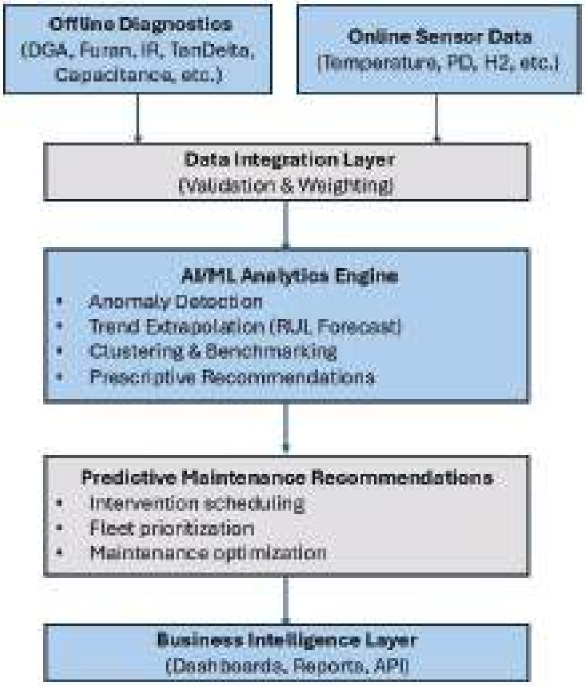
Key analytical functions include:

- **Anomaly detection:** Identifies parameter shifts such as rising gas concentrations or accelerating moisture levels.
- **Trend extrapolation:** Forecasts remaining useful life (RUL) based on multi-factor regression of chemical and electrical indicators.
- **Clustering and benchmarking:** Groups transformers with similar operational signatures, enabling peer comparison and prioritisation.
- **Automated recommendations:** Converts analytics output into prescriptive guidance (eg, “schedule oil sampling within <NNN> days” or “inspect cooling circuit”).

By combining AI/ML analysis with expert-defined thresholds, the platform provides both interpretability and accuracy – supporting the decision-making of seasoned engineers while helping newer staff navigate complex diagnostics.

Furthermore, when operators permit the

Figure 5: Workflow of AI/ML Analytics Engine for Predictive Maintenance



inclusion of anonymised fleet data, the resulting larger pool of transformer information enhances AI/ML learning models for the entire industry. This collaborative approach allows the framework to evolve continuously, improving diagnostic precision while maintaining data security and regulatory compliance.

Field Observations and Learnings

Deployments across diverse transformer fleets have revealed an intriguing and somewhat controversial trend: older transformers, including units aged 35-50 years, frequently display better health indices than newer ones.

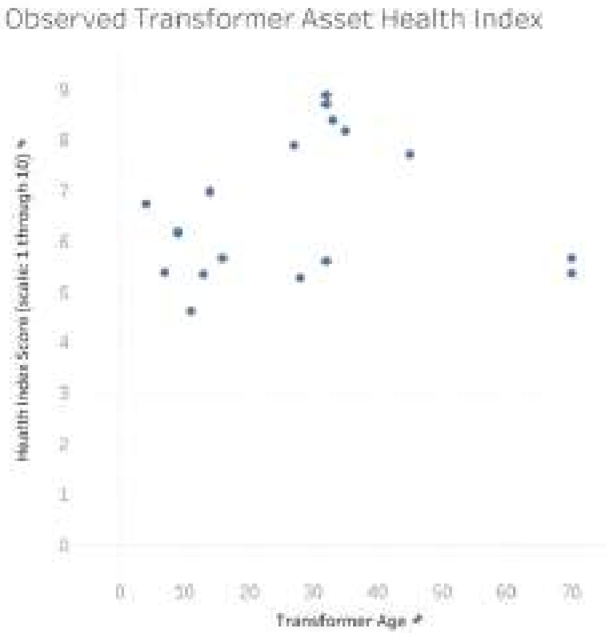
Observed transformer types include:

Rating
220/132/33
132/33
66/11
33/11
33/6

Possible explanations include:

- Design robustness: Legacy transformers were often over-engineered for safety margins, making them inherently more resilient.
- Material quality: Historical insulation materials and core construction may age more predictably.

Figure 6: Transformer Age vs. Health Index Observations



- Operational stress: Newer units operate closer to rated limits under higher load variability.
- Testing frequency bias: Older assets are monitored more diligently, leading to richer historical data.

These insights raise key questions for industry bodies and manufacturers:

- Should maintenance priority always correlate with asset age?
- How can standards evolve to balance modern efficiency with long-term durability?
- Could legacy design principles inform future manufacturing and procurement practices?

Rather than conclusions, these questions are presented as opportunities for industry dialogue supported by data.

Business and Operational Impact

The SaaS-based predictive framework delivers measurable business value alongside technical innovation:

- **Reduced maintenance cost:** Targeted interventions replace unnecessary periodic servicing, optimising budgets.
- **Minimised downtime:** Early detection of anomalies reduces unplanned outages and revenue loss.
- **Extended asset life:** Predictive insights support asset refurbishment strategies rather than premature replacement.
- **Scalable deployment:** Multi-tenant cloud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architecture simplifies rollout across utilities or subsidiaries.

- **Knowledge continuity:** Embedded analytics and data histories capture the expertise of retiring engineers while supporting new personnel with guided diagnostics.
- **Sustainability alignment:** Longer asset lifespans and optimised oil usage contribute to lower environmental impact.

Conclusion

The convergence of offline diagnostics and real-time sensor intelligence within a SaaS and AI/ML environment marks a new phase in transformer asset management. By integrating historical and live data, utilities can transition from reactive to predictive operations – achieving higher reliability, extended asset life, and measurable cost savings.

Beyond technology, this framework also addresses human and organisational dimensions. As the expert workforce evolves, digital platforms must preserve accumulated knowledge while enabling the next generation to make data-driven decisions confidently.

The concepts outlined in this paper are exemplified by the SmartPower Solution Suite[6] from MindPower Analytics, which implements this holistic SaaS and AI/ML framework for transformer fleet management. Designed as a multi-tenant, standards-compliant platform, SmartPower integrates offline diagnostics, real-time sensor data, and predictive analytics into a unified system – demonstrating how utilities can achieve fleet-wide visibility, cost optimisation, and workforce adaptation through scalable, collaborative architecture.

This paper establishes a reference framework for objective transformer health indexing and predictive asset management. The approach provides a scalable pathway for utilities to evolve from reactive maintenance toward continuous, data-driven reliability management. Future work will expand these methods to other substation assets and integrate deeper AI/ML models for real-time optimisation and cross-fleet benchmarking.

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ABOUT THE AUTHORS

Goutam Sinha, Founder and Chief Product Officer, MindPower Analytics, has more than 40 years of experience delivering large-scale, real-time, mission-critical platforms. His current work focuses on analytics and AI-driven systems for asset-intensive environments, supporting global deployments to improve reliability, operational efficiency, and lifecycle decision-making.

Dr. Kallol Mallick, PhD & B.Tech(CS) (IIT Kharagpur), PGDCA (Santa Clara University), is a technologist-researcher-entrepreneur with three decades of experience in embedded systems, real-time analytics, and AI, bridging industry and academia.

RK Tiwari is a distinguished power transmission sector leader and former executive director, BHEL, with more than 40 years of experience. He is an IISc alumnus, NABL Lead Assessor, National Vishwakarma and BHEL Excel Award recipient, currently advising POWERGRID and leading electrical organisations.

Barin De, a senior power systems professional, is retd executive director of POWERGRID with more than 35 years of experience in transmission asset management, large power transformer diagnostics, and digital substations, with deep expertise in IEC 61850, condition monitoring, and CIGRE-aligned practices supporting reliability and lifecycle performance of utility-scale electrical assets.


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Unlocking Europe for India's Electrical & Electronics Sector

Through this article, **TS Vishwanath, Founder & Executive Chairman, VeK,** highlights where European demand is emerging, which products offer the strongest opportunities, and how MSMEs can leverage the India-EFTA, India-UK and India-EU trade frameworks to build a sustainable export presence.

Indian exports of electrical and electronic products to Europe have grown steadily at a 24.8-percent CAGR from 2020-2024, according to the ITC Trade Map. Despite this growth, India's share in the European markets (approximately 0.79 percent) remains relatively marginal compared to European imports. This gap between rising demand in Europe and low penetration of Indian products represents a clear opportunity, particularly for micro, small and medium enterprises (MSMEs), which form the backbone of India's electrical and electronics manufacturing ecosystem.

India has recently concluded a trade and economic partnership agreement (TEPA) with the European Free Trade Association (EFTA), signed a comprehensive free trade agreement (FTA) with the United Kingdom (UK), and concluded an FTA with the European Union (EU). Together, these three frameworks may reshape market access conditions for Indian exporters.

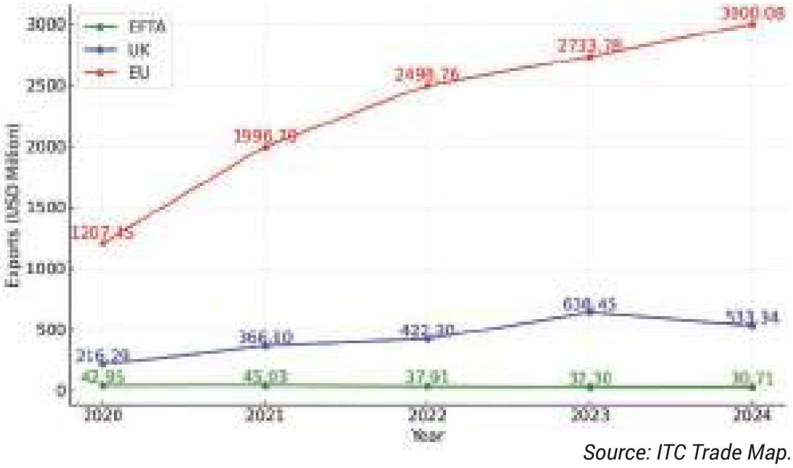
This article draws on trade data and product-level analysis to explain where European demand is emerging, which products offer the strongest opportunities, and how MSMEs can leverage the three European FTAs to build a sustainable export presence.

Demand Drivers in Europe

Europe's rising demand for electrical and electronics products is being driven by three interlinked structural trends.

1. **Grid modernisation and expansion** have become a priority across the continent. Much of Europe's transmission and distribution (T&D) networks were designed decades ago for centralised power generation. Today, grids must

IEEMA's Exports in EFTA, UK and EU Markets (2020-2024)



Source: ITC Trade Map.

accommodate decentralised renewable energy (RE), cross-border electricity trade, and digital monitoring systems. This has led to sustained investment in transformers, substations, switchgear, conductors, and grid automation equipment. Countries such as Germany, France, the UK, Spain, and the Nordic states are committing significant investments to reinforce and upgrade their electricity networks.

2. **RE integration** is reshaping power systems. Europe's climate commitments require the rapid deployment of wind, solar, offshore energy, and energy storage. Every renewable project requires extensive electrical balance-of-plant equipment – cables, switchgear, transformers, power electronics, and control systems. As renewable penetration increases, so does demand for grid-stabilising equipment – an area where Indian manufacturers already have strong capabilities.
3. **Industrial electrification and automation** are accelerating. European industries are electrifying production processes to reduce emissions and energy costs, while simultaneously investing in automation and digital control systems. This is driving demand for rotating machines, motors, drives, power electronics, and industrial control equipment.

Demand Hubs: Priority European Markets for Indian Electrical Exports

Europe's demand is concentrated in specific national markets that function as import and investment hubs. For Indian exporters, prioritising these hubs is critical.

- **Germany** remains the largest and most important anchor market for electrical equipment in Europe. It combines the highest import volumes with a sophisticated industrial base and large-scale grid and energy investments. Indian exports to Germany have grown steadily, yet India's overall share in German imports remains limited, indicating significant long-term potential.
- **The UK** has emerged as India's fastest-growing European destination, supported by grid modernisation, offshore wind, electric vehicle (EV) charging infrastructure, and energy transition investments. India's share of UK imports remains modest, leaving ample room for expansion.
- **France and the Netherlands** form a second tier of large and stable import markets. France's focus on grid resilience and electrification, combined with the Netherlands' role as a logistics and energy hub, supports consistent demand across transformers, cables, switchgear, and power electronics.
- **Spain and Greece** are smaller in absolute size but have shown high growth rates in recent years. RE expansion and EU-supported infrastructure investments are driving rising imports of electrical equipment, making these markets attractive entry points for Indian SMEs seeking to scale up faster.
- **The Nordic region (Norway, Sweden, Finland)** represents high-value, technologically advanced markets. Import volumes reflect demand for advanced electrical systems used in renewables, industry, and smart grids. These markets are standards-driven but offer strong commercial potential under preferential trade frameworks.

Product Opportunities for Indian Exporters

India's export performance over recent years highlights clear product strengths that align well with European demand.

Core product segments with established export strength

- Low-voltage (LV) switchgear and controlgear
- Transformers (distribution and power)
- Winding wires and cables
- Rotating machines and generator components
- Power electronics and associated equipment.

These products are central to grid expansion, renewable integration, and industrial electrification – making them well-positioned for sustained demand.

Emerging and niche opportunities

- High-voltage switchgear
- Conductors and insulators
- Capacitors and specialised electrical components

- Equipment linked to RE, energy storage, EV charging, and grid automation.

For many MSMEs, the opportunity lies not in developing entirely new products, but in adapting existing portfolios to Europe's specifications and positioning them for infrastructure-led demand.

FTAs as Strategic Enablers for Market Access

India-EFTA: Investment-led market access and technology partnerships

The India-EFTA, signed in March 2024 and in force since October 2025, is a comprehensive agreement between India and the EFTA countries – Switzerland, Norway, Iceland, and Liechtenstein. The agreement modernises trade rules, enhances regulatory cooperation, and strengthens long-term engagement across high-value sectors.

Europe's rising demand for electricals is being driven by grid modernisation and expansion, RE integration, and industrial electrification and automation.

A defining feature of the TEPA is its Investment Chapter, which anchors long-term, high-quality capital flows into India. Under this chapter, EFTA countries have committed to increasing foreign direct investment (FDI) into India by USD 50 billion over the first 10 years, followed by an additional USD 50 billion over the subsequent five years. This investment is explicitly linked to job creation, skill development, manufacturing expansion, and advanced technology collaboration. The TEPA also promotes cooperation in digital technologies, clean technologies, biotechnology, advanced materials, and sustainable metallurgy.

For Indian electrical manufacturers, including MSMEs, the opportunity lies towards industrial partnerships. The agreement enables firms to combine manufacturing scale with technology absorption, R&D capability, testing infrastructure, and services to become embedded suppliers to European value chains.

Recommendations

1. **Identify EFTA firms seeking India manufacturing bases:** Proactively map firms diversifying supply chains and position as long-term manufacturing or component partners integrated into Europe-bound value chains.
2. **Attract strategic investment into technology and capacity expansion:** Engage EFTA firms with structured joint venture (JV) proposals, positioning India as an environmental, social and governance (ESG)-aligned, cost-efficient manufacturing base for Europe. Anchor discussions around technology transfer, export-dedicated capacity, and long-term supply commitments.
3. **Build design and engineering services capability:** Offer customisation, compliance documentation, and lifecycle engineering support to match the expectations of advanced European markets.

India-UK FTA: Immediate commercial gains and market expansion

The India-UK FTA, signed on July 27, 2025, aims to significantly expand trade and investment between India and the UK. While final ratification is awaited, the agreement provides clarity on tariff schedules, compliance pathways, and procurement access, allowing firms to prepare ahead of implementation.

A defining feature of the FTA is the combination of streamlined compliance and immediate tariff elimination. Self-certification under rules of origin reduces transaction costs and administrative friction. Zero-duty access for key electrical products, including switchgear, controlgear, and cables, enhances India's price competitiveness relative to non-preferential suppliers. The calibrated opening of UK public procurement further complements these gains, providing structured access to long-term channels and stable demand.

The FTA can benefit MSMEs by securing UK-recognised certifications, offering value-added services and exploring public procurement opportunities. Protecting intellectual property and investing in innovation will further strengthen market positioning.

Recommendations:

1. **Institutionalise access to UK public procurement:** Register on procurement portals and pursue grid, EV infrastructure, and electrification tenders that offer predictable, long-term demand.
2. **Secure UK-recognised certifications:** Ensure full compliance with applicable standards to avoid technical barriers and reduce buyer hesitation during vendor qualification.
3. **Establish a local commercial footprint:** Develop distributor, warehousing, or service partnerships to meet delivery and after-sales expectations.

India-EU FTA: From Market Access to Value-Chain Realignment

The India-EU FTA, concluded on January 27, 2026, represents a structural reset of India's trade relationship with Europe, extending well beyond tariff reduction. With legal finalisation and ratification expected by 2027, the agreement positions the EU as a strategic extension of India's manufacturing and value chain partner in the electrical and electronics sector.

Key provisions:

1. **Tariff elimination and export competitiveness**
   - **EU commitment:** Elimination of tariffs on electrical and electronics products, reducing current duties of up to ~10 percent to 0 percent, subject to agreed staging periods, with final schedules to be confirmed at formal signing.
   - **India commitment:** Phased reduction of tariffs on machinery and electrical equipment from levels of up to 44 percent to 0 percent over 5-10 years, increasing competitive pressure in the domestic market.

For many MSMEs, the opportunity lies in adapting existing portfolios to Europe's specifications and positioning them for infrastructure-led demand.

2. **Regulatory alignment and market integration**
   - Mutual recognition of conformity assessment, certification procedures, and documentation requirements, including streamlined rules of origin.
   - Lower compliance costs and faster market entry for Indian exporters.
   - Establishment of a dedicated working group on conformity assessment to reduce duplicative testing and improve predictability for exporters.
3. **Intellectual Property Rights (IPR)**
   - High standards of IP protection and enforcement aligned with WTO TRIPS obligations.
   - Framework to support technology collaboration, licensing, and JVs between Indian and EU firms.
4. **Dedicated SME Chapter**
   - Creation of a publicly accessible digital platform providing consolidated information on market access, regulatory requirements, and customs procedures.
   - Establishment of SME contact points on both sides to facilitate business entry and operational understanding.
5. **Sustainability and CBAM-related provisions**
   - CBAM remains applicable, but implementation frictions are reduced through recognition of Indian carbon-verification mechanisms.
   - Access to EU-supported green transition financing enables investments in cleaner production, RE sourcing, and carbon-tracking systems.
   - Positions compliant Indian firms as preferred suppliers in ESG-driven European procurement markets.

For Indian exporters, the strategic implication is clear. The India-EU FTA rewards firms that treat regulatory compliance, sustainability, and technology upgrading not as costs, but as competitive assets.

Recommendations:

1. **Secure CE/EN certification:** Given long compliance timelines, early certification is essential to avoid losing first-mover advantage post-ratification.
2. **Institutionalise ESG and carbon tracking:** Invest in measurement and reporting systems to align with CBAM-linked requirements and ESG-driven procurement frameworks.
3. **Upgrade capability in higher-value segments:** Invest in technology depth across grid automation, high-voltage equipment, and digitally integrated systems, where long-term margins are stronger.
4. **Integrate into European supply ecosystems:** Build partnerships with engineering, procurement, and construction (EPC) contractors, original equipment manufacturers (OEMs), and system integrators in key markets to secure inclusion in approved vendor networks.

Conclusion

Europe's energy transition and grid modernisation are long-term, policy-driven investments. For Indian electrical and electronics manufacturers, the issue is no longer demand, but market positioning.

The India-EFTA, India-UK and India-EU trade agreements together mark a decisive shift in market access. Tariffs are being eliminated, regulatory pathways are clearer, and MSME-specific facilitation is now built into the trade architecture. However, these agreements reward prepared exporters.

In Europe, competitiveness is determined by standards compliance, certification, sustainability credentials, delivery reliability, and after-sales capability. Indian firms that treat these as strategic investments, rather than costs, will gain durable access to European supply chains.

The opportunity is therefore not simply to export more, but to embed into Europe's electrical and electronics ecosystem as long-term, trusted suppliers. The policy window is open; execution will determine outcomes.

ABOUT THE AUTHOR

TS Vishwanath, Founder & Executive Chairman, VeK – Policy Advisory and Research, has more than 35 years of expertise analysing multilateral and bilateral trade agreements, global economic policies, and regulatory frameworks. He has an in-depth understanding of competitiveness and policy dynamics across sectors.

DECODING BUDGET 2026 FOR INDIA'S POWER SECTOR

The recently announced Budget provides a forward-looking outlook for India's power sector, balancing decarbonisation, energy security and domestic capability building. It reinforces the country's position as a resilient global player in clean energy technologies and a low-carbon energy future.

The recently announced Union Budget 2026 presents a forward-looking outlook for the power sector. With emphasis on tariff rationalisation and infrastructure readiness, it focusses on clean energy scaling along with cost competitiveness and supply-chain resilience.

Furthermore, the reduction in basic customs duty on essential inputs like batteries, key minerals and power electronics is expected to augment renewables, energy storage, electric vehicle (EV) charging infrastructure and grid modernisation.

Prioritising investments in transmission capacity, storage, grid technologies and scalable clean power assets will be key to capitalise on opportunities the Budget presents.

Key Policies

Restructuring of financing corporations

The Budget presented an impactful financial reform with an aim to achieve scale and improve efficiency in the public sector NBFCs. As a first step, the restructuring of Power Finance Corporation (PFC) and Rural Electrification Corporation (REC) has been proposed. The announcement of the Infrastructure Risk Guarantee Fund is another highlight, which has the potential of promoting private capital across power generation, transmission, distribution, and storage.

Clean tech and industrial decarbonisation

A Rs20,000 crore carbon capture, utilisation, and storage (CCUS) roadmap has been announced over five years, covering power, steel, cement, refineries and chemicals.

Electricity and energy storage

Customs duty exemptions have been extended for battery energy storage manufacturing, key solar inputs and critical mineral processing.

EV and clean tech manufacturing

Duty exemptions for capital goods in lithium-ion battery manufacturing, solar glass production, nuclear power projects and critical mineral processing will continue to strengthen domestic manufacturing capabilities, reduce import dependence, and support India's clean energy transition.

Nuclear energy

The Budget has proposed to extend the existing basic customs duty exemption on imports of goods required for nuclear power projects till 2035 and expand it for all nuclear plants irrespective of their capacity.

Tariff Changes

Exemptions/concessional rates have been extended up to March 31, 2028, for the following:

- Electrical energy supplied to domestic tariff area (DTA) by power plants of 1,000 MW or above, and granted formal approval for setting up in SEZ prior to July 19, 2012.
- Electrical energy supplied to DTA from power plants of less than 1,000 MW, and granted formal approval for setting up in SEZ prior to July 19, 2012.
- Parts, components and accessories except lithium-ion cell and printed circuit board assembly (PCBA) for use in manufacturing lithium-ion battery and battery pack.
- Inputs, parts or sub-parts for use in the manufacturing of PCBA of lithium-ion battery and battery pack.
- Parts, sub-parts, inputs or raw material for use in the manufacturing of lithium-ion cells.
- Lithium-ion cell for use in the manufacturing of battery or battery pack other than for cellular phone or EV, ie, including BESS.
- All items of machinery, and auxiliary equipment required for initial setting up of a project for generation of power or generation of compressed biogas (bio-CNG) using non-conventional materials.

The reduction in basic customs duty on essential inputs like batteries, key minerals and power electronics is expected to augment renewables, energy storage, electric vehicle charging infrastructure and grid modernisation.

- All items of machinery, and auxiliary equipment for setting up of fuel cell-based system for generation of power or for demonstration purposes or balance of systems operating on biogas or bio-methane or by-product hydrogen.
- Specified goods for use in the manufacturing of sheets or backsheets, which are used for manufacturing of solar photovoltaic cells or modules.
- Copper wire or refined copper for manufacturing photovoltaic ribbon for solar photovoltaic cell or modules.
- Forged steel rings for the manufacture of special bearings for use in wind operated electricity generators.
- Goods for manufacture or the maintenance of wind operated electricity generator components.

Other tariff changes made effective from February 2, 2026:

- Exemption with respect to custom duty for capital goods imported with respect to lithium-ion cell for use in the manufacture of battery energy storage system (BESS). The same was earlier available only for capital goods used in manufacture of lithium-ion cells meant for mobility application.

- BCD rate on sodium antimonate, falling under tariff item 2841 90 00, for use in manufacture of solar glass is being decreased from 7.5 percent to Nil.
- Concessional BCD rate of nil is prescribed on specified goods for use in the manufacture of ethylene vinyl acetate (EVA) sheets or backsheets, which are used in the manufacture of solar photovoltaic cells or modules. The entry has been modified and exemption now applies to specified goods for use in the manufacture of sheets/ encapsulants of EVA, polyolefin elastomer (PoE) or combinations thereof or backsheets, which are used in the manufacture of solar photovoltaic cells or modules falling under CTH 2915, 2933, 3208, 3506, 3815, 3901 or 3920.
- The exemption for goods required for setting up a nuclear power project (under Chapter 9801) has been expanded by removing the earlier capacity threshold of 440 MW or above. Further, the validity of the exemption has been extended from September 30, 2027, to September 30, 2035.
- BCD rate on all goods falling under tariff item 8401 30 00 (fuel elements [cartridges], non-irradiated) for generation of nuclear power is being decreased from 7.5 percent to nil.
- BCD rate on control and protection absorber rods and burnable absorber rods falling under tariff item 8401 40 00 for generation of nuclear power is being decreased from 7.5 percent to nil.

Industry Reacts

IEEMA welcomes the Union Budget 2026 for providing a solid foundation for long-term industrial stability and competitiveness.

Says **Vikram Gandotra, President, IEEMA,** “The Budget offers a strategic push for comprehensive economic reforms that set the stage for sustainable growth by driving employment, productivity, and competitiveness.

IEEMA welcomes the emphasis on manufacturing and the strategic securing of self-reliance in critical minerals, including the proposal to provide basic customs duty exemption on the import of capital goods required for processing critical minerals in India. To advance green energy, a Rs20,000 crore outlay over five years is proposed to scale CCUS technologies across five key sectors, including power, aligning with the December 2025 roadmap. The strong push on infrastructure, including the establishment of new dedicated freight corridors, and the enhanced focus on Tier-II and Tier-III economies will provide a significant boost to the electrical equipment industry.

IEEMA and its members have been consistently building capacities to promote Make in India, cater to the domestic demand, and tap global markets. Recognising the need to enable critical infrastructure and boost investment in data centres, the proposed tax holiday till 2047 will further drive demand and strengthen India’s digital and industrial ecosystem.”

For **Siddharth Bhutoria, President-Elect, IEEMA,** “The Union Budget 2026 presents a forward-looking roadmap for India’s industrial and services growth. Building on semiconductor momentum, the government launched ISM 2.0 to advance semiconductor equipment manufacturing, Indian IP design, and supply chain resilience, nearly doubling the outlay to Rs40,000 crore to capitalise on sector growth. The establishment of hi-tech tool rooms and the Rs10,000 crore SME Growth Fund will strengthen domestic manufacturing, build Indian IP, and nurture MSMEs as future champions.

The focus on linking education with employment and enterprise will be critical in developing a skilled, technology-ready workforce and positioning India as a global leader in services and innovation.”

Adds **Hartek Singh, Vice President, IEEMA,** “We welcome the government’s support for new energy – the basic customs duty (BCD) exemption on capital goods used for manufacturing lithium-ion cells for battery energy storage systems, which will strengthen India’s energy storage ecosystem. The exemption of customs duty on sodium antimonate for solar glass manufacturing is a timely step that will support domestic solar manufacturing, lower costs, and reinforce India’s clean energy transition.”

Charu Mathur, Director General, IEEMA, says, “The Budget focuses on a robust increase in capital expenditure, raising the allocation to Rs12.2 lakh crore for FY27 to spur investment-led growth. This growth is anchored by a commitment to fiscal consolidation, targeting a deficit reduction to 4.3 percent of GDP. By prioritising high-impact capital outlay while simultaneously strengthening macroeconomic indicators, the Budget establishes a strategic framework for sustained economic momentum.”

Calling it support for electrical goods and EV manufacturing, says **R Anand, Head-Industrial Relations, Indirect Taxes and Admin, Larsen & Toubro Ltd** and **Power Transmission & Distribution, IC & Mentor, Economics & Taxation Sub-Committee, IEEMA Public Policy Committee,** “The Union Budget 2026 extends focused support to the electrical goods and electric vehicle (EV) manufacturing sectors, recognising their critical role in India’s clean energy transition and industrial growth.” He points to key measures that include: Customs duty exemptions and rationalisation on select power electronics, semiconductor inputs, and EV battery materials, reducing input costs and improving price competitiveness; and incentives aimed at increasing localisation of power electronics, motors, chargers,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and energy storage systems, which are essential for EVs, renewable energy, and smart grid applications. "These interventions are expected to benefit manufacturers across the value chain, including MSMEs, contract manufacturers, and export-oriented units," he believes.


R Anand

To further enhance supply-chain security, Anand adds that the Budget has announced the development of Rare Earth Corridors, particularly in states such as Tamil Nadu, which already have a strong electronics and electrical manufacturing base. "These corridors will ensure reliable access to critical raw materials required for power electronics, EV motors and batteries, and advanced electronic and semiconductor applications. Additionally, new initiatives for capital goods manufacturing, advanced tool rooms, and precision engineering facilities have been announced. These measures will improve manufacturing efficiency, reduce lead times, and lower dependence on imported tooling and machinery, especially for contract manufacturers."

Speaking on the projected economic and employment impact, Anand says that by the end of FY2026-27, ECMS alone is projected to generate Rs11,156 crore in fresh investments, Rs29,024 crore in incremental production, and 19,240 new direct jobs, alongside substantial indirect employment. "Taken together, the combined impact of ECMS, PLI schemes, infrastructure investments, and duty rationalisation is expected to significantly strengthen India's manufacturing ecosystem."

He concludes sharing that, "By addressing long-standing structural challenges such as component dependency, supply-chain vulnerability and high input costs, the Budget lays a solid foundation for achieving India's ambitious goal of a USD 500 billion electronics ecosystem by 2030-31. These measures are poised to drive sustained industrial growth, generate large-scale employment, enhance exports, and reinforce India's technological self-reliance in the years ahead."


Bharanidharan Pandyan

Bharanidharan Pandyan, Joint Managing & Whole-time Director, Quality Power Electrical Equipments Ltd, thinks the Budget sends an important long-term signal for the power sector. "Data centres and AI infrastructure – that are now fundamental to the digital economy – are extremely power-intensive. A single upcoming facility like the Google data centre in Vizag is close to 1 GW, and new developments in Texas are touching 11 GW, equivalent to powering an entire city such as Pune. With tax holidays and favourable policies for software and technology players, the resulting demand could far exceed current power infrastructure and capacity-addition trajectories. In that sense, the Budget indirectly but very powerfully incentivises the entire energy sector, creating a strategic opportunity for utilities and power developers to accelerate investment and build the backbone of India's digital future."

For **Keyur Girishchandra Shah, Managing Director, Yash Highvoltage Ltd,** "India's Union Budget 2026 reinforces the government's commitment to infrastructure-led growth and building resilient, future-ready power systems. The sustained focus on capital expenditure and modernising infrastructure, coupled with the increasing adoption of digital and technology-enabled solutions, provides a supportive backdrop for strengthening the nation's electrical ecosystem. With infrastructure projects and grid systems becoming more complex and data-driven, the emphasis on efficient project execution, operational performance, and advanced engineering solutions will support the evolution of power transmission and generation networks. This environment underscores the importance of quality, innovation, and reliability in power equipment."


Keyur Girishchandra Shah

He adds that the Budget's policy direction is well aligned with the company's strategic focus on engineering excellence, robust manufacturing, and technology-integrated solutions. "It instils confidence to continue investing in advanced capabilities, digitalisation, and skilled talent while contributing to India's secure, efficient, and sustainable power infrastructure."

To conclude, the Budget provides a forward-looking framework for India's power sector with decarbonisation, energy security and capability building as its focus areas. It furthers the country's position as a resilient global player in clean energy technologies and a low-carbon energy future.

Here's to building an even more globally competitive electrical and electronics manufacturing base!

Different LV Earthing Systems & Regulation 18 of CEA Safety Regulation 2023

This article by **Dr Rajesh Kumar Arora, Sr Manager (Technical) D&E, DTL, New Delhi,** discusses the five main earthing configurations and their structures, advantages, disadvantages, and associated safety protection systems.

Earthing (grounding) is to make an electric connection between a conductive part and a local earth. Earthing is a fundamental concept in electrical installations, providing a path for fault currents and helping ensure electrical safety. It prevents electric shock hazards, limits overvoltages, and ensures the proper operation of protective devices. There are several earthing systems in use worldwide, primarily classified as Terre-Neutral (TN), Terre-Terre (TT), and Isolated Terre (IT). This article discusses the five main earthing configurations – TN-S, TN-C, TN-C-S, TT, and IT – and their structures, advantages, disadvantages, and associated safety protection systems.

1. Introduction

Earthing is to make an electric connection between a conductive part and a local Earth. The connection to local Earth can be intentional or unintentional or accidental and can be permanent or temporary.

The *CEA Regulations* 2023 define earthing as connection of the exposed conductive and extraneous parts of an installation to the MET of that installation or connection of neutral of transformer or generator to general mass of earth or to earth bonding bar of that installation.

The IS 732 defines earthing as connection of the exposed conductive parts of an installation to the MET of that installation.

Here, the main earthing terminal (MET) is part of the earthing arrangement of an installation and enables the electric connection of a number of conductors used for earthing or bonding purposes. and earthing arrangement means all the electric connections and devices involved in the earthing of a system, an installation, or equipment.

1.1. Significance of earthing (grounding)

i) Safety from electric shock

- Prevents accidental electrocution by giving fault current a low-resistance path to the ground.
- If a live wire touches the metal body of an appliance, grounding ensures that electricity flows to the earth, not through a person who touches it.

ii) Protection against electrical fires

- Fault currents without grounding can lead to sparks, overheating, or fires.
- Earthing helps to quickly trip circuit breakers or fuses, preventing potential fire hazards.

iii) Equipment protection

- Sensitive electrical and electronic devices are shielded from surges (eg, lightning or switching surges).
- Prevents damage due to voltage fluctuations and ensures longevity of equipment.

iv) Voltage stabilisation

- Provides a common reference point for all voltages in the system.
- Helps maintain consistent voltage levels in multi-phase systems, reducing electrical noise and instability.

v) Legal and regulatory compliance

- Earthing is mandatory in most countries as per safety codes (eg, NEC, CEA).
- Ensures installations are certified safe and meet standards.

2. Concept of Earthing (Grounding)

When the neutral for a system is not connected with the earth, it is known as electrical system without earthing, as depicted in Figure 1.

Largely, galvanised iron is used for earthing. The earthing provides a simple path to the leakage current and fault current in the system. The short-circuit current of the equipment passes to the earth, which is assumed to have zero potential. Thus, it protects system equipment and personnel working with these equipment from damage as well as shock current, as shown in Figure 2.

The system earth resistance should be such that during any fault, earthing is designed to ensure protection, ie, the protective gear must operate to isolate the faulty section, eg, by circuit breaker or fuses.

2.1. Types of electrical earthing

The electrical equipment mainly consists of two non-current carrying parts. These parts are neutral of the system or frame/support structure of the electrical equipment. From the earthing of these two non-current carrying parts of the electrical system, earthing can be classified into two types:

1. Neutral (system) earthing
2. Equipment earthing.

Neutral (system) earthing

In neutral earthing, the neutral of the system

Figure 1: Electrical System Without Earthing

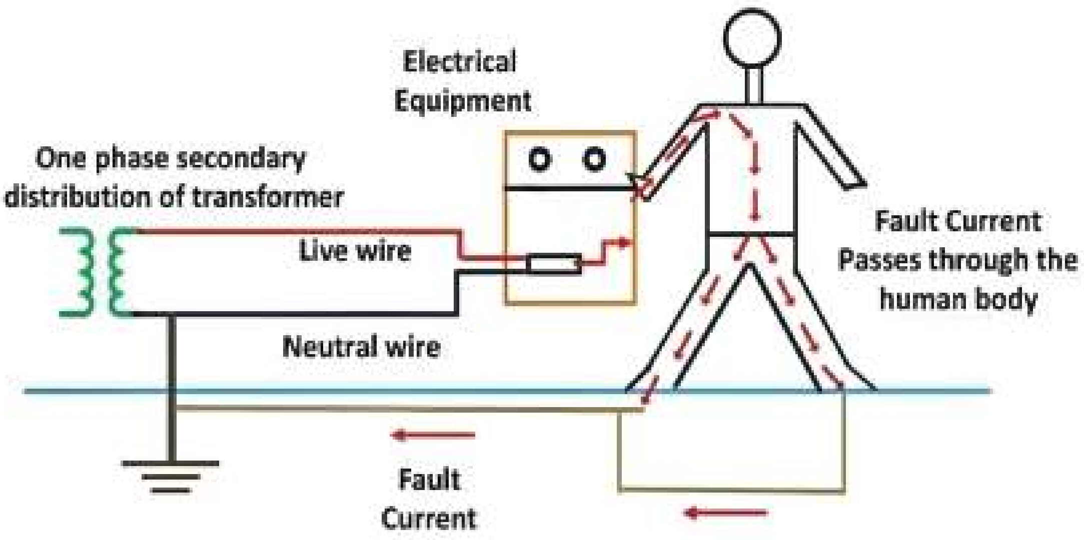


Figure 2: Electrical System with Earthing

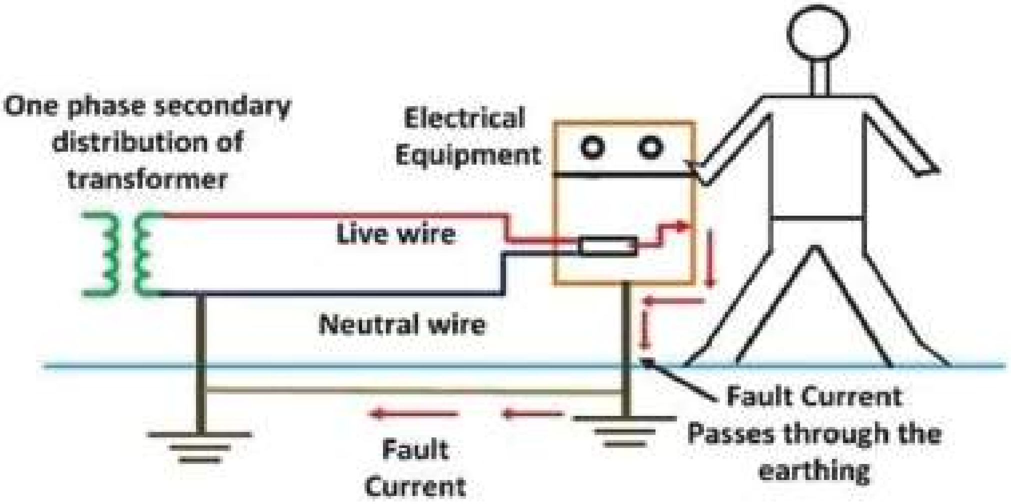
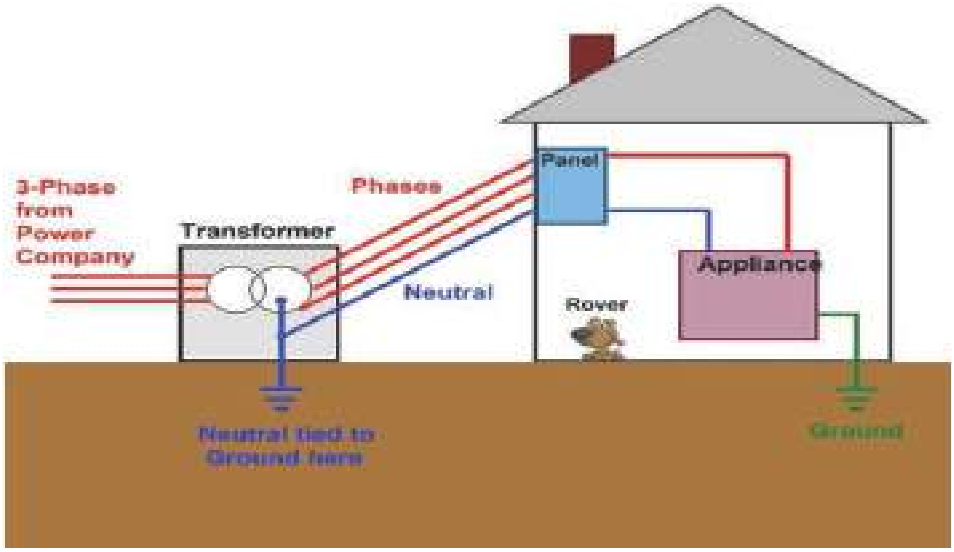


Figure 3: Neutral and Equipment Earthing



is directly connected to the earth with the help of some metallic conducting wire. Neutral earthing is also called system earthing. Such type of earthing is mostly provided to a system that has star winding. For example, neutral earthing is provided in generators, transformers, diesel generator (DG) sets, etc, as shown in Figure 3.

Equipment earthing

This type of earthing is provided to electrical equipment. The non-current carrying part of the equipment such as its metallic frame is connected to the Earth by the help of conducting wires, as shown in Figure 3. If a fault occurs in the apparatus, the short-circuit current will pass the Earth by the help of the wire, thus protecting the system from damage.

3. Classification of Earthing System

A low voltage (LV) distribution system may be identified according to its earthing system. These are defined using the five letters:

1. T (direct connection to Earth)
2. N (neutral)
3. C (combined)
4. S (separate) and
5. I (isolated from earth).

The first letter denotes how the transformer neutral (supply source) is earthed while the second letter denotes how the metal work of an installation (frame) is earthed. The third and fourth letters indicate the functions of neutral and protective conductors, respectively.

There are three possible configurations:

1) **TN:** Transformer neutral earthed, frame connected to neutral.
   The TN system includes three sub-systems: TN-C, TN-S and TN-C-S.
2) **TT:** Transformer neutral earthed and frame earthed.
3) **IT:** Unearthed transformer neutral, earthed frame.

3.1. TN earthing system

In a TN earthing system, the supply source (transformer neutral) is directly connected to Earth with one or more conductors, and all exposed conductive parts of an installation are connected to the neutral or protective earth conductor. The three sub-systems in TN earthing system are described below with their key characteristics.

3.1.1. TN-C earthing system

TN-C system has the following features:

1) Neutral and protective functions are combined in a single conductor throughout the system. (PEN – Protective Earthed Neutral).
2) The supply source is directly connected to Earth, and all exposed conductive parts of an installation are connected to the PEN conductor, as shown in Figure 4.

Advantages:

- Cost-effective: Only one conductor (PEN) is used instead of separate PE and N.
- Simplified wiring and reduced conductor size.
- Suitable for short-distance power distribution.

Disadvantages:

- Safety risk if PEN conductor breaks, as exposed conductive parts may become live.
- Electromagnetic interference due to shared current in PEN.
- Not compatible with RCDs, limiting personal protection.
- Not allowed in many modern installations due to safety standards.

Safety protection:

- Fuses or circuit breakers for overcurrent protection.
- Residual current devices (RCDs) are generally not effective without separate protective conductor (PE).

Applications:

- Often used in older or budget-limited distribution networks.

3.1.2. TN-S earthing system

TN-S system has the following features:

1) A TN-S system has separate neutral and protective conductors throughout the system.
2) The supply source is directly connected to Earth. All exposed conductive parts of an installation are connected to a PE via the main earthing terminal of the installation, as shown in Figure 5.

Advantages:

- High safety due to separate neutral and protective conductors.
- Low electromagnetic interference (EMI) makes it suitable for sensitive electronic equipment.
- Reliable fault disconnection due to low impedance path.
- No neutral current in the PE conductor, ensuring safer earthing.

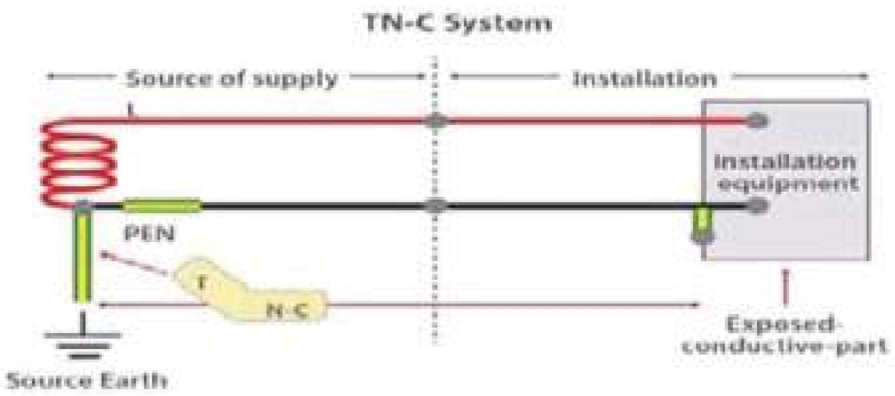
Disadvantages:

- More expensive due to the need for separate PE and N conductors.
- More complex wiring increases installation time.
- Susceptible to multiple earth fault scenarios requiring careful design.

Safety protection:

- RCDs or miniature circuit breakers (MCBs) detect faults between live and Earth.
- Overcurrent protection devices (OCPDs) trip if excess current flows.

Figure 4: TN-C Earthing System



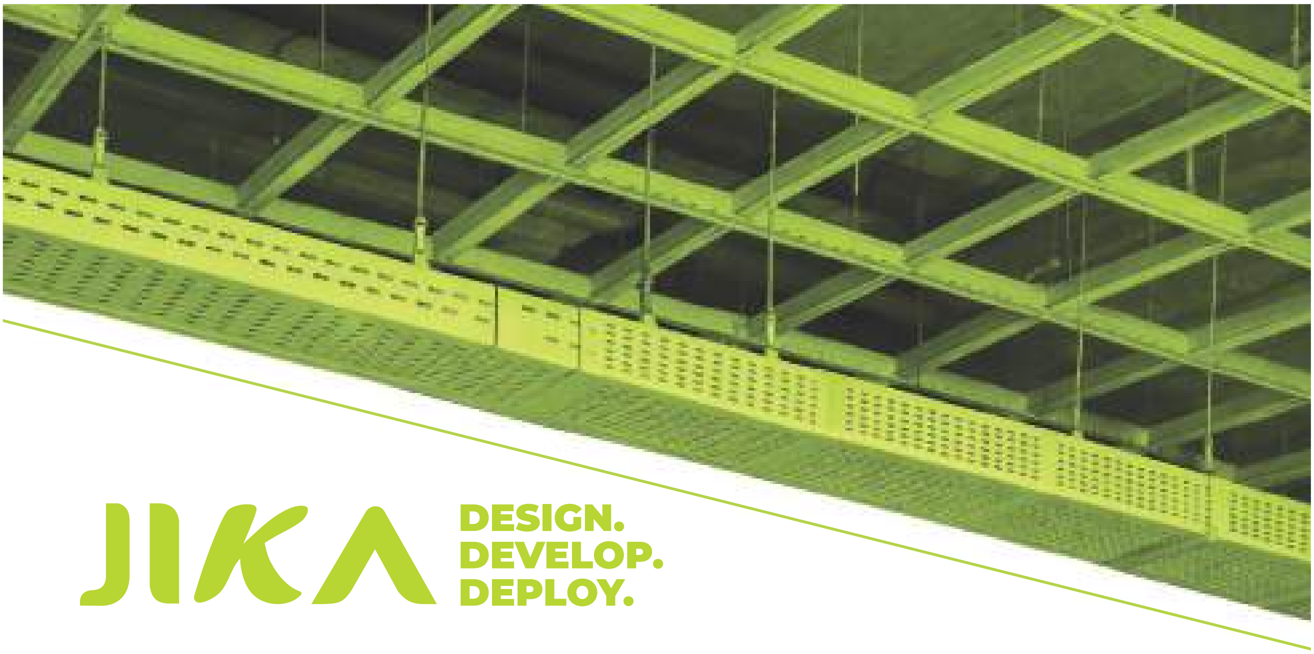
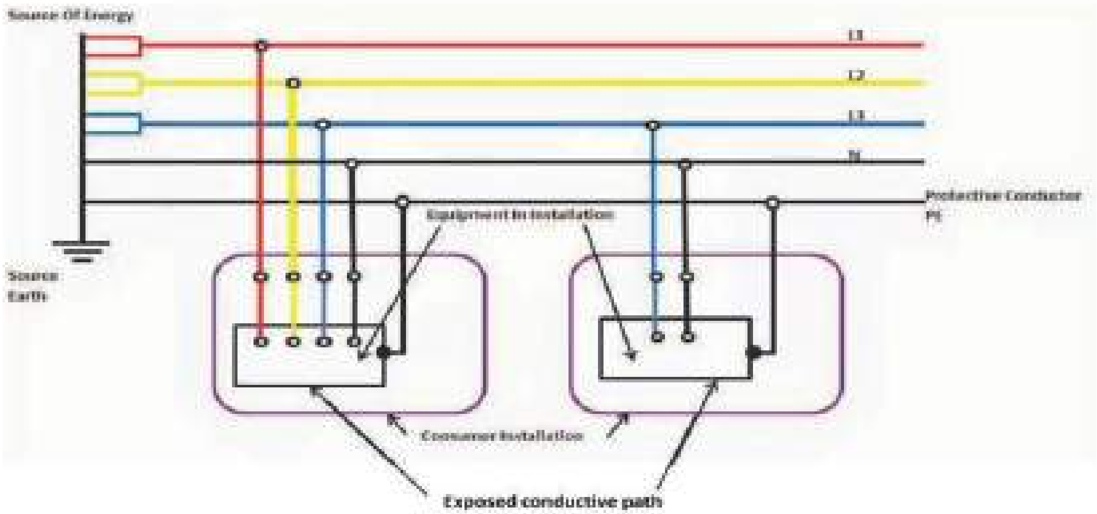


Figure 5: TN-S Earthing System



- Quick disconnection during Earth faults to prevent shock.

Applications:
- Commercial and industrial installations where electrical noise reduction is essential.

3.1.3. TN-C-S earthing system

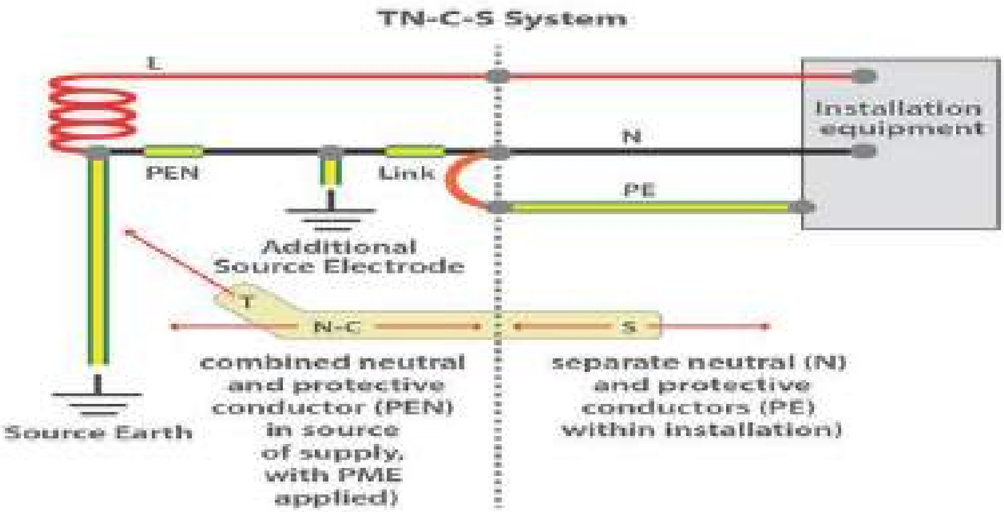
TN-C-S earthing system has the following features:
1) Neutral and protective functions are combined in a single conductor in a part of the TN-C-S system. The supply is TN-C and the arrangement in the installation is TN-S, as depicted in Figure 6.
2) Use of a TN-S downstream from a TN-C.
3) All exposed conductive parts of an installation are connected to the PEN conductor via the main earthing terminal and the neutral terminal; these terminals being linked together.

This type of distribution is known also as protective multiple earthing and the PEN conductor is referred to as the combined neutral and earth (CNE) conductor.

The supply system PEN conductor is earthed at several points, and an earth electrode may be necessary at or near a consumer's installation.

Advantages:
- Economical: Shared PEN up to a point, then separate PE and N.
- Improved safety compared to TN-C.
- Supports RCDs, enhancing fault and shock protection.
- Widely accepted in modern residential and commercial networks.

Figure 6: TN-C-S Earthing System



Disadvantages:
- Still dependent on PEN integrity – a broken PEN can be dangerous.
- Requires robust earthing and bonding at the consumer end (PME compliance).
- Voltage rise risk during Earth faults on the PEN conductor.

Safety protection:
- RCDs to detect leakage currents.
- Equipotential bonding to reduce touch voltages.
- Multiple earthing points to minimise rise in Earth potential.

Applications:
- Residential, commercial, and mixed-use installations.

3.2. TT earthing system

In this system, the supply source has a direct connection to earth. All exposed conductive parts of an installation also are connected to an earth electrode that is electrically independent of the source earth, as shown in Figure 7.

The fault loop impedance is higher, unless the electrode impedance is very low indeed.

Advantages:
- Independent local earthing enhances safety, especially in remote areas.
- Not reliant on utility earthing, making it ideal where reliable utility earth is unavailable.
- Excellent shock protection with RCDs.

Disadvantages:
- Higher earth fault loop impedance, so disconnection requires RCDs.
- Sensitive to ground conditions; requires low-resistance earth electrodes.
- Regular testing and maintenance of the earth electrode are needed.
- Slower fault clearance without proper RCDs.

Safety protection:
- RCDs are mandatory, typically 30 mA for personal protection.
- Earth electrodes must have low resistance to ensure proper fault current flow.
- Earth loop impedance testing is crucial during installation.

Applications:
- Rural or remote areas.
- Small buildings with no PME availability.

3.3. IT earthing system

In this system, the supply source is either connected to Earth through deliberately introduced high earthing impedance (impedance earthed IT system) or is isolated from Earth. All exposed conductive parts of an installation are connected to an earth electrode, as shown in Figure 9.

The conductive parts including metal body of the installations are connected to earthed through one or more local earth electrodes. These local electrodes do not have any direct connection to the source.

It is pertinent to mention here that single phase IT system shown in Figure 8 is not used in India (except special location).

Advantages:
- High continuity of supply: First fault does not interrupt operation.
- Excellent for critical systems like hospitals, ships, and data centres.

Figure 7: TT Earthing System

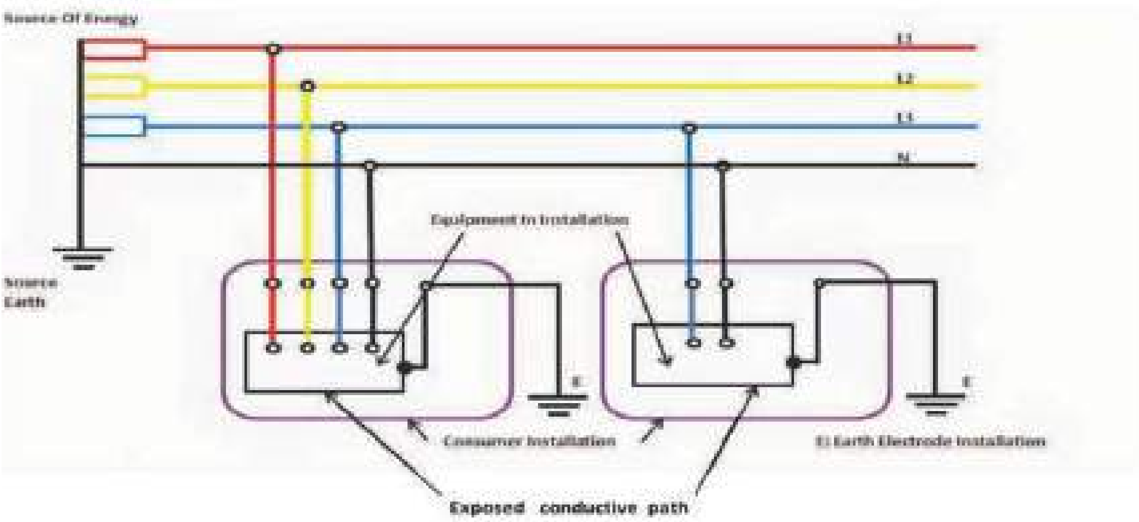
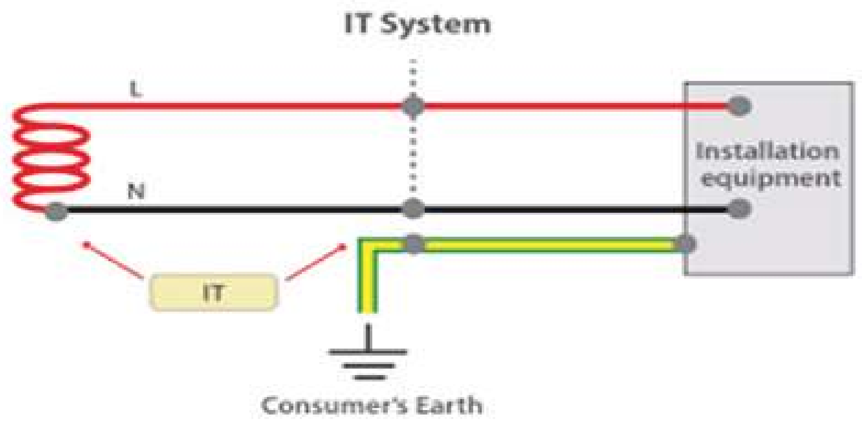


Figure 8: IT Earthing System



- Low touch voltage under fault conditions.
- Reduces risk of fire from ground faults.

Disadvantages:
- Complex and expensive to design and maintain.
- Requires insulation monitoring devices (IMDs) for early fault detection.
- Specialised training required for operation and maintenance.
- Faults must be located and repaired quickly before a second fault occurs.

Safety protection:
- Insulation monitoring devices (IMDs) detect the first fault without shutting down the system.
- Alarms or indicators alert personnel of insulation failures.
- RCDs and MCBs may be used for secondary fault protection.

Applications:
- Hospitals (operating theatres).
- Mines, military, ships.
- Data centres.

4. Comparison of All Earthing Systems

Comparison of all earthing systems basis earth fault loop impedance, RCD preferred, need earth electrode at site, PE conductor cost, etc, has been carried out as follows:

5. Earthing And Bonding Difference and Significance

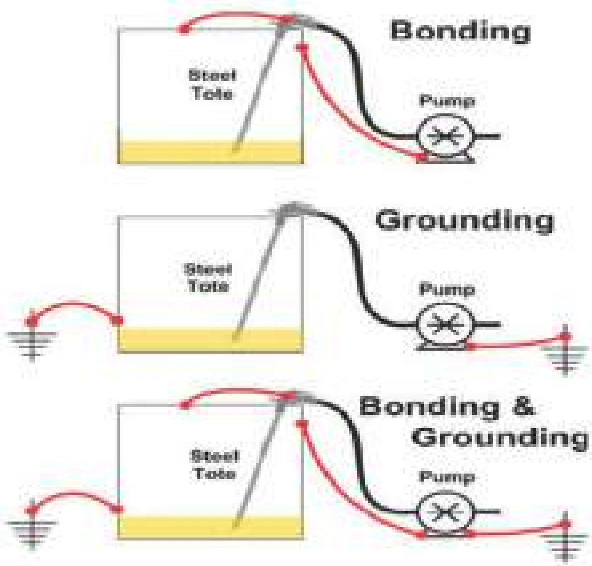
Earthing and bonding are both vital safety measures in electrical systems but serve different purposes. Earthing connects electrical equipment or systems directly to the Earth to safely dissipate fault currents, preventing electric shock and equipment damage. It provides a reference point of zero potential and ensures protective devices operate correctly during faults (as already discussed in detail). Bonding, on the other hand, involves connecting all exposed and extraneous conductive parts together to maintain equal potential and eliminate voltage differences between metal parts. While earthing directs fault current to the ground, bonding prevents electric shock by ensuring all

Table 1: Comparison of Different LV Earthing (Grounding) Systems

Earthing System Conditions	TN-C	TN-S	TN-C-S	TT	IT
Earth fault loop impedance (EFLI)	Low	Low	Low	High	Highest
RCD preference	No	Optional	Optional	Yes	NA
Need of earth electrode at site	No	No	Optional	Yes	Yes
PE conductor cost	Least	Highest	High	Low	Low
Risk of broken neutral	Highest	Highest	High	No	No
Safety	Least Safe	Safest	Safe	Safe	Less safe
Electromagnetic interference	High	Low	Low	Least	Least
Safety risks	Broken neutral	Broken neutral	Broken neutral	High loop impedance (step voltages)	Undetected second fault

accessible conductive surfaces remain at the same potential (Refer to Figure 9).

Figure 9: Bonding and Earthing Concept



Equipotential bonding in an electrical system is the practice of electrically connecting all exposed and extraneous conductive parts to maintain the same potential and minimise voltage differences. This connection ensures that, in the event of a fault, no dangerous potential exists between metallic parts that a person might touch simultaneously. Let's understand the terms exposed and extraneous conductive parts (Refer to Figure 10).

A. **Exposed conductive parts:** Conductive parts of electrical equipment that are not normally live but can become energised during a fault and can be touched.
   Examples: Metal casings of appliances, metal switchgear frames, exposed metal conduits, and cableways.
   Protection: Must be permanently connected to the protective earthing conductor and the main earthing terminal.
B. **Extraneous conductive parts:** Conductive parts that are not part of the electrical installation but can introduce a potential, often earth potential, and may become energised during a fault.
   Examples: Metal water and gas pipes, structural steel, metal reinforcement in concrete, radiators, and metallic building elements.
   Protection: Must be connected to the main earthing terminal via equipotential bonding to ensure they are at the same potential as exposed parts, preventing dangerous touch voltages.

Equipotential bonding is achieved through main and supplementary bonding conductors. Its primary purpose is to enhance safety by reducing the risk of electric shock, providing a low-resistance fault path,

Figure 10: Touch Voltage Between an Exposed-Conductive-Part and an Extraneous-Conductive-Part

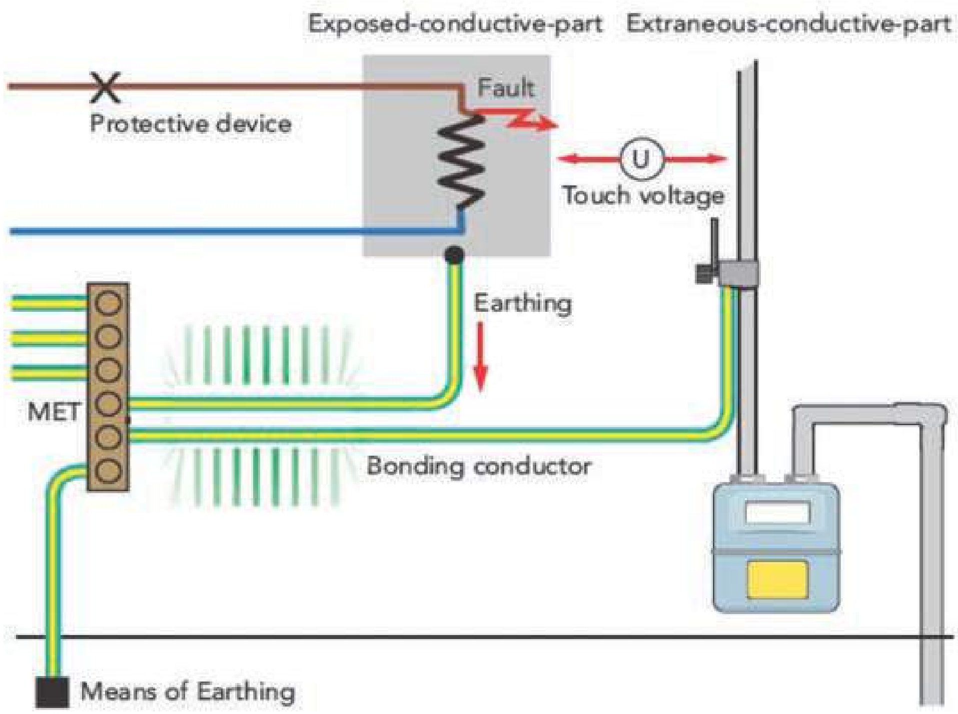
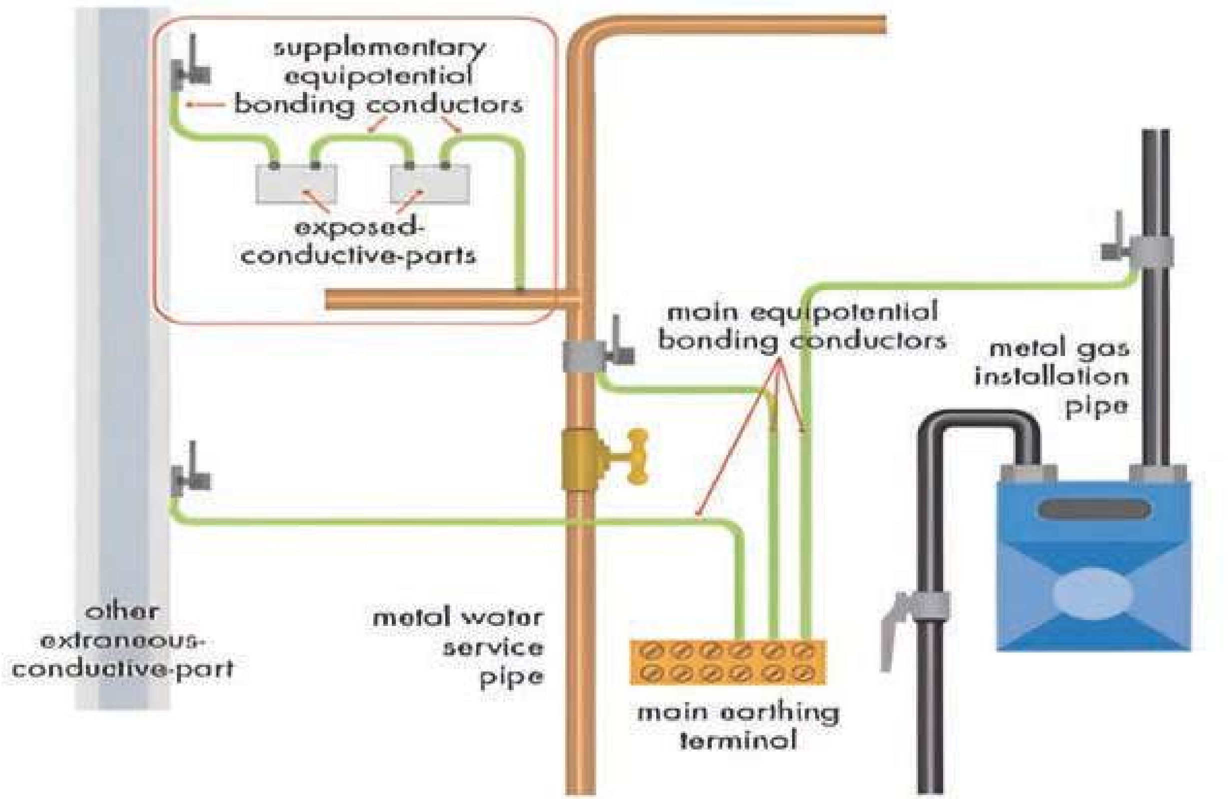


Figure 11: Main and Supplementary Bonding Concept



and enabling protective devices to disconnect faulty circuits promptly.

Main bonding and supplementary bonding are essential safety measures in electrical installations designed to prevent electric shock and ensure proper operation of protective devices. Main bonding involves connecting the main protective conductor to the main metallic parts of a building, such as gas, water, or structural steel pipes. This creates a common reference point for all metallic parts, ensuring that, in the event of a fault, no dangerous voltage difference exists between them. It also allows protective devices like circuit breakers or fuses to operate quickly by providing a low-resistance fault path.

Supplementary bonding, on the other hand, is the additional connection between exposed conductive parts and nearby extraneous conductive parts in locations where the risk of electric shock is higher, such as bathrooms or kitchens. It equalises potential differences within a localised area, reducing the risk of current passing through a person who simultaneously touches two metal surfaces at different potentials (Refer to Figure 11).

The significance of both forms of bonding lies in enhancing electrical safety, minimising shock hazards, and maintaining system integrity. Together, main and supplementary bonding ensure that any fault current is safely directed to Earth, thereby protecting people, property, and equipment from electrical dangers.

6. Regulation 18 – Earthed Terminal on Consumer Premises

What it requires:

1) The electricity supplier must provide and maintain a proper earthed terminal on the consumer's premises.
   For installations with voltage exceeding 250 V, the consumer must provide their own earthing system (an independent electrode), which must be inter-linked with the supplier's earthed terminal via a suitable link.
2) The consumer must take all reasonable precautions to prevent mechanical damage to the earthing terminal and its lead belonging to the supplier.

Why it matters:

- Proper earthing is critical for protecting persons and equipment from fault currents and electric shocks (Refer to Figure 12).

Figure 12: Explanation of Reg.18 of CEA Safety Regulation

- Ensures that the supplier's and consumer's earthing systems are coordinated, reducing risk from improper or missing earth connections.

Key points to remember:

- Applies to every consumer's installation where supplier provides supply.
- If voltage >250 V, consumer's own electrode is mandatory and must link with supplier's earth.
- Both supplier's and consumer's earth arrangements must be maintained and protected from damage.

7. Conclusion

Choosing the right earthing system is essential for ensuring electrical safety, reliability, and compliance with regulations. Each system has its unique structure, benefits, and associated protection mechanisms.

- TN systems offer reliable protection when combined with circuit breakers and RCDs.
- TT systems are ideal for areas with no connection to utility earth, relying heavily on RCDs.
- IT systems prioritise continuity of service with insulation monitoring for early fault detection.

Proper design, installation, and maintenance of earthing and protection systems are crucial for minimising electrical hazards, ensuring user safety.

Earthing and bonding are two different ways of providing safety to electrical systems from sudden and unexpected leakage or discharge of current due to various reasons. Although earthing is a more common term we come across, bonding is also equally important in all electrical systems. At the same time, the electrical bond alone does not ensure complete protection, but along with grounding, it helps discharge the extra current to the ground, thus making the system safe.

As per regulation 18 of CEA Safety Regulation, it must be ensured that the supplier's and consumer's earthing systems are coordinated, reducing risk from improper or missing earth connections.

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ABOUT THE AUTHOR

Dr. Rajesh Kumar Arora obtained the B. Tech. & Master of Engineering (ME) degrees in Electrical Engineering from Delhi College of Engineering, University of Delhi, in 1999 and 2003, respectively. He completed his PhD in grounding system design from UPES, Dehradun. He is a certified energy manager and auditor and has worked in 400 kV and 220 kV substations for more than 14 years in Delhi Transco Limited (DTL). He has also worked as Deputy Director (Transmission and Distribution) in Delhi Electricity Regulatory Commission (DERC), contributed to the OS department of DTL, and rendered services in the SLDC of Delhi Transco Limited (DTL). He currently works in the Design and Engineering (D&E) department of DTL. His research interests include high voltage technology, grounding system, protection system, computer application, and power distribution automation.

FOCUS

Ensuring Fire-Resistant Safety in Chemical Processing Facilities: A Comprehensive Electrical System Design Approach

Designing electrical systems for chemical facilities – be it a fragrance blending plant or a large chemical processing unit – demands adherence to NFPA standards and a proactive safety culture. Critical components include explosion-proof enclosures, fire-resistant wiring, advanced gas detection and redundant safety power supplies, writes **Vijaykumar Potdukhe, Managing Director, Privij Consultants Engineering Pvt Ltd.**

In recent years, the chemical manufacturing industry has grappled with rising fire incidents in India, many stemming from electrical short circuits and system failures. Ensuring safety in environments laden with flammable chemicals is not just a regulatory requirement but a moral imperative. A meticulously designed electrical infrastructure adhering to National Fire Protection Association (NFPA) standards is vital to prevent fires, safeguard personnel, and protect assets.

The Importance of Hazard Classification and Zone Segregation

Chemical plants often handle volatile substances, creating potential explosive atmospheres. Therefore, precise hazard classification is pivotal. Based on NFPA 70 (NEC) and International Electrotechnical Commission (IEC) standards, areas are classified into zones and divisions:

Zone 0: Continuous presence of flammable vapours
Zone 1: Occasional presence under normal operation
Zone 2: Rare or temporary presence
Division 1: Hazards are present during normal operations
Division 2: Hazards only occur in abnormal conditions.

For example, in a fragrance blending plant, zones containing aromatic alcohols, solvents and volatile compounds are marked as Zone 1, necessitating explosion-proof enclosures, intrinsically safe instrumentation and fire-resistant cabling.

Advanced Equipment and Protective Measures

Explosion-proof enclosures and wiring: Utilisation of Ex d explosion-proof enclosures with flame paths and sealing features, compliant with IEC 60079-0 standards, contain internal arcs and prevent surface ignition. Wiring in hazardous zones is replaced with mineral-insulated copper cables rated for 1,000°C for two to three hours, ensuring circuit integrity during high temperature fires.

Intrinsically safe control systems: Embedding intrinsically safe barriers safeguards sensors, level gauges and asset monitoring devices from igniting vapours. Control panels feature fail-safe logic to enact automatic shutdowns upon detecting faults or leaks.

Fire and gas detection and suppression: Deploying gas sensors with PLC interfaces enables early leak detection, triggering alarms and emergency shutdown procedures. Foam-based suppression systems activate within milliseconds of vapour detection, preventing fire escalation.

Lighting and power resilience: Inspection-grade explosion-proof LED lighting enhances visibility without ignition risk. Fire-resistant cables power critical safety systems, emergency lighting and communication networks, maintaining operations in the event of a fire.

Emergency Power & Safety Protocols

Reliable power backup: In accordance with NFPA 110, UPS systems and diesel generators ensure critical safety systems – fire alarms, emergency shutdowns and communication – remaining functional during power outages or fires.

Egress and signage: Illumination and signage meet NFPA 101 standards, facilitating safe evacuation under fire or emergency conditions.

Grounding and lightning protection: A meshed grounding grid and lightning rods reduce static buildup and supply transient suppression, significantly lowering ignition hazards due to static charges or lightning strikes.

Case Study: Fragrance Chemical Blending Plant

A leading manufacturer of fragrances faced significant safety challenges due to an outdated electrical infrastructure, with non-explosion-proof enclosures and insufficient fire-resistant protection.

Approach and implementation

Classified blending and storage zones as Zone 1, installing Ex d explosion-proof enclosures.

Replaced all wiring with mineral-insulated copper cables rated for 1,000°C, ensuring circuit integrity during fires.

Incorporated intrinsically safe barriers for sensor and control circuits, coupled with PLC-based leak detection.

Installed foam-based fire suppression systems activated automatically upon vapour detection.

Upgraded power backup with UPS and standby diesel generators.

Ensured all safety signage, emergency lighting and grounding were compliant with NFPA 70, NFPA 110 and NFPA 101.

Results and benefits

The plant's upgraded system maintained continuous operation under fire scenarios, effectively contained vapour leaks, and reduced ignition risks. It achieved full NFPA compliance, enhancing safety standards and operational robustness while ensuring personnel safety.

Final Thoughts: A Holistic Safety Approach

Designing electrical systems for chemical facilities – be it a fragrance blending plant or a large chemical processing unit – demands adherence to NFPA standards and a proactive safety culture. Critical components include explosion-proof enclosures, fire-resistant wiring, advanced gas detection and redundant safety power supplies.

This comprehensive strategy not only minimises fire and explosion risks but also ensures compliance, operational continuity, and most importantly, the safety of personnel and the environment. In a world where safety cannot be compromised, integrating rigorous electrical safety measures is essential for sustainable industrial growth.

ABOUT THE AUTHOR

Vijaykumar Potdukhe, Managing Director, Privij Consultants Engineering Pvt Ltd, is a highly accomplished professional with a Bachelor's degree in Mechanical Engineering, a Master's degree in Industrial Engineering, and a Post Graduate Diploma in Piping Design. As a Chartered Engineer and an Indian Green Building Council Accredited Professional, he brings a distinguished level of expertise with 21 years of experience in the construction industry. He has previously worked with companies such as Blue Star Ltd, Tata Consultancy Engineering Ltd and Videocon Industries Ltd.

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Power System Adequacy: Enhancing Transformer Performance

This paper by **Pravinchandra Mehta (Member CIGRE India), CEO, Persotech Solutions, Vadodara (ex GETCO),** describes various points of power system network components that may cause the failure of power transformers based on his experience. The paper is a great learning for designers of transformers and substations.

Power transformers are key equipment in the switchyard of power installation. Considering it is an expensive equipment in the power system network, owners of power transformers expect the equipment to have good health and a long operational life. Transformer outage in a switchyard or sub-station can cause major disturbance in the power network. Failure of power transformers not only causes longer power outage but also huge economic losses due to their capital or repair cost.

This paper discusses the healthy running of power transformers and root cause analysis of its failure, particularly from the viewpoint of power system network configuration/installation/protection adopted, etc. It describes various points of power system network components that may cause the failure of power transformers based on experiences of the author. By application of engineering knowledge and references, the obstacles can be well tackled.

The paper aims to bring awareness among stakeholders and not disregard any installation practices. Most of the analysis is carried out through state-of-the-art software. The outcome of such a study can be great learning to transformer and substation designers and may also be useful for research and development (R&D).

1. Introduction

Electrical power is the backbone of national development, and reliable operations of substations is the demand of the day. Transformers play a key role in catering power supply to customers. In a switchyard of any station requiring a huge amount of power transfer, power transformers are the main equipment and maintaining its life is crucial given its high cost and functional role. Thus, to ensure reliability of power supply to customers, the safe running of transformers is a must. Several measures are being taken at the operation and maintenance level. Even at the design stage, due care is taken on this subject. This paper sheds light on engineering ideas while tackling issues of designing transformers and substations/power system networks. It also refers to general fault analysis and explores ideas on future designs.

The objective of designing good equipment is to have longer life with trouble-free operations. During operations, a fault in sub-station or other installation causes revenue loss as well as power shutdown, causing distress to customers. Every operator aims to have the least fault with its installation. Analysis of outage/failure helps power system operators improve the system. Such analysis is shared here.

2. Causes of Power Transformer Failure

Reasons for power transformer failure may be considered due to:

- Manufacturing defect.
- Improper installation and commissioning.
- Lacunae in maintenance.
- System inadequacy.

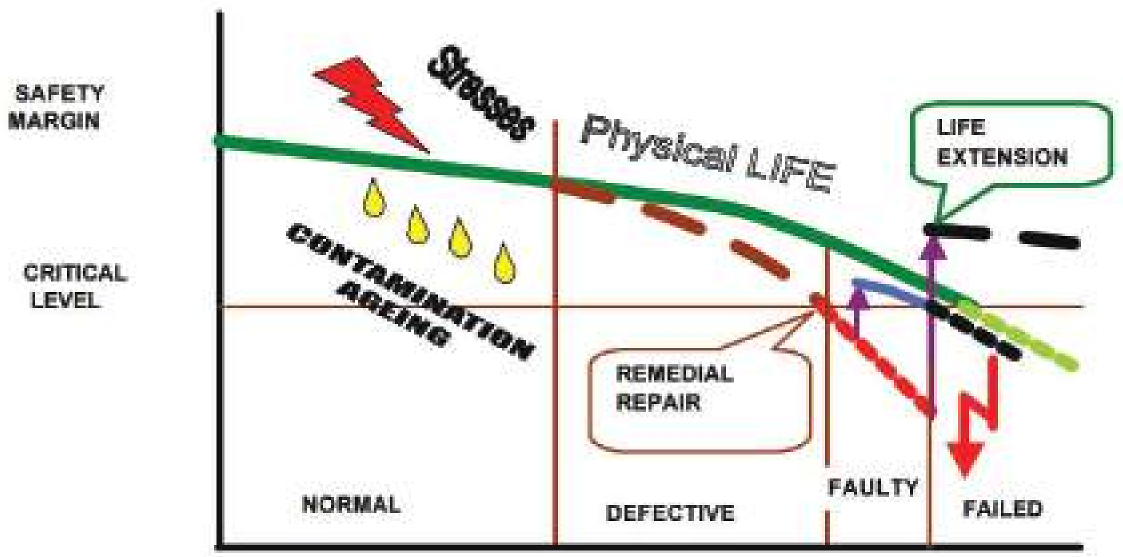
Several documents are available worldwide on the analysis or study of power transformers failure. The International Council on Large Electric Systems (CIGRE) has published several useful documents. As per CIGRE document 225-2003, the transformer condition during its life cycle is given in Figure 1, wherein its physical normal life cycle is described against the routine challenges. A condition-based monitoring system can provide an assessment of the transformer's health. In modern complex power systems, several factors are to be considered while maintaining transformer health. These factors are discussed in this paper.

Incidences of immature failure or life reduction have been noticed in recent power systems, which are a matter of concern for manufacturers as well as users. With this in view, of the general causes of failure mentioned above, system inadequacy is considered in this paper. Adequate power systems will help increase the life of power transformers.

System inadequacy may comprise of:

- Non-operation of main relay (differential relay).
- Improper settings of differential relay.
- Non-operation of restricted earth fault section.
- Non-operation or late operation of back-up relay (overcurrent and earth fault). This will affect while encountering fault current and the transformer is supposed to back up the load feeder relay during fault in downstream section(s).
- Improper relay coordination in the entire switchyard.
- Inadequate earthing system.
- Improper protection against surges (direct stroke of lightning and travelling surges).

Figure 1: Transformer Condition During its Life Cycle



Courtesy: CIGRE Doc 225-6-2003.

- Saturation of CT protection core (primary side or secondary side).
- Improper selection of CT parameters (knee point voltage, magnetising current).
- Sluggish operation of circuit breaker.
- Improper insulation coordination of the switchyard.
- Resonance due to system configuration.
- Transient over voltage (TOV) conditions and harmonic current flow due to improper controlling or managing the power electronics devices and renewable energy (RE) integration.

3. Understanding the Role of Inadequacy of Power System Components

3.1. Issues with protection relay(s)

Delayed operations of protection relay cause thermal stress on winding conductor and insulation, thus reducing the life of transformers. Non-operation of relay may cause even transformers to fail. The types of incidents noticed are:

- Non-operations of main protection relay.
- Non-operation of REF element of the main protection relay.
- Non-operations of back-up protection relay (phase overcurrent and earth over current relays).
- Delay in operations of back-up protection relay.
- Improper configuration or settings of main protection relays for incoming EHV line(s).
- Causes of maloperation of protection systems and consequences thereof.
  a) Fault in the control and protection circuit.
  b) Improper settings and configuration of relays.

Findings of case study incidences as below:

- Coordination of transformer relays with respect to downstream relays found improper. Every now and then downstream feeder fault is cleared by transformer relay and with delayed timing. Feeder relay may not have functioned properly, causing faults reflected in transformer winding for longer periods.
- In a 220/33kV transformer, improper configuration or settings in the differential relay – second and fifth harmonic current blocking was found improper, which caused delay in tripping of differential relay (as the fault current also had the second or fifth harmonic component settings, causing the blocking of relay operations for a longer time).
- In a 220/33kV transformer installed in a switchyard to evacuate RE power, the over flux element of differential relay was disregarded. Repetitive over-voltage incidences were recorded in event recorder during transformer operations for more than one year. Tripping of over flux relay was disabled, which caused stress on the winding insulation and in a moment, one system surge transformer failed. However, this was not the only reason for failure, but this part supported the deterioration of winding insulation. All the events of set voltage should have been passed on to the maintenance concerned in charge so that corrective actions could be taken to restrict the over voltage incidences.
- In a switchyard, to evacuate RE power, two 400/33kV transformers were running parallel. The 33-kV side was connected to RE power. There were two incoming/outgoing 400 kV lines. During the LG (single line to ground) fault on one of the 400 kV lines, the transformer fed the fault and auto reclosure operation of the line caused higher magnitude of temporary over voltage. The auto reclosure feature of the relays of EHV line should be selected/configured with due care.

3.2. Issues with associated equipment

The problem with associated equipment of a transformer bay may create serious issues with the health of power transformers.

- In a 400/33-kV transformer, the increasing trend of H2 gas was observed. It is evident that H2 gas can be due to partial discharge. Detailed investigation revealed that the HV side bushing CT was shifted from its centre position of turret of bushing, which caused partial discharge, and hence, H2 gas. Fixing the CT with tie arrangement at turret resolved the issue.
- A review of the disturbance recorder (DR) file for a failed 220/132kV transformer at a grid substation showed that the U phase pole of the LV side circuit breaker operated sluggishly, resulting in sustained fault current in that phase winding.
- In investigations carried out for EHV class power transformer cases, it was found that protection core of the CT could not provide the knee point voltage requirements as per protection relay demand, which caused the relay to be non-operational, thus inviting transformer failure.
- In some cases, the CT was found saturated due to one or other reasons, which caused trouble with the protection circuit.

4. System Configuration/Selection of Power System Components

- Power system resonance or transformer ferro resonance may cause excessive over voltage in the system, which may damage the transformer winding insulation.
- A study with the help of advanced software can reveal the situation and optimum system parameters can be achieved through selection of proper components (eg, instead of long length of power cables on LV side of the transformer, a bus

duct would be more suitable).

- An inadequate earthing system can cause excessive ground potential rise (GPR), which may lead to repeated over voltage conditions faced by transformer windings. In certain instances, this resulted in the failure of the 11-kV cable termination installed within the cable box on the secondary side of a 66/11-kV transformer at a grid substation, thereby affecting transformer parts like bushings, studs, etc.
- Inadequate earthing systems also cause poor performance of power system protection, leading to equipment failure.
- Inadequate surge protection systems can cause excessive residual voltage during surge suppression, which can cause winding insulation failure. A proper insulation coordination study is required for the entire switchyard and associated systems such as overhead lines and cables connected to it.
- A proper earthing system plays a key role in insulation coordination and selection of surge protective devices.
- In one of the studies carried out, it was found that inadequate selection of surge arresters of transformer bay of a 400/33-kV power transformer installed at a switchyard to evacuate RE power caused excessive residual voltage appearing at HV winding, resulting in transformer failure.
- In the case of gas insulated switchgear (GIS) substations, very fast transient over voltage (VFTO) plays a vital role in over voltage, which can affect transformer winding. A comprehensive study utilising advanced software and expert guidance can be conducted to accurately assess the extent of the issue, after which appropriate remedial measures can be implemented.

5. Lacunae on Maintenance

Many a times, poor erection commissioning and lacunae on maintenance can cause power transformers to have a reduced life.

- Erection, testing and commissioning should be carried out as per the quality plan.
- Improper tightness of the joints, oil seals part may cause moisture ingress into the transformer, and over time, cause deterioration of insulation property of the paper.
- Silica gel in the breather changes colour when affected by heavy atmosphere moisture and sustained with the same material, it will cause the moisture to enter the body of the transformer, resulting in damage to oil and paper insulation. Regular reconditioning or replacement of silica gel should be the practice to safeguard against this danger.
- Oil should be regularly tested for electrical breakdown strength and water content. When necessary, filteration or other remedial measures must be taken.
- Other regular tests should be carried out as per the filed quality plan (FQP).
- A condition monitoring system may largely help in health assessment, for eg, temperature distribution measurement may give an abnormal rise of top oil temperature, which indicates poor oil circulation that may be due to low location of outlet pipe (production defect). A decrease found in inlet outlet temperature may indicate a reduction of cooling capacity due to contamination. An increase in no-load loss and load loss may indicate that the problem is associated with main flux and stray flux, respectively. The dissolve gas analysis (DGA) will provide several findings on development of abnormalities within the transformers. Timely actions on the finding may increase life expectancy, reduce abrupt outage, or even prevent premature failure.

6. Recommendations and Conclusions

- For manufacturing transformers, good quality material should be used to meet the design parameters.
- For example, the use of continuously transposed conductor with epoxy bonding (CTCE) may be implemented looking at the system requirements.
- Transformers should be commissioned under the supervision of experienced personnels of the manufacturers.
- A well-documented operation and maintenance manual should be given to the customer by the manufacturer, wherein proper guidelines to follow maintenance schedules should be mentioned.
- All equipment should be selected with proper system study.
- All protective relays should be coordinated with downstream relays and be properly configured with the required parameters and settings.
- At the time of transformer commissioning, an insulation coordination study should be ensured. Accordingly, spacing of surge arresters from transformer bushings, its jumper length, risers to the earthing systems, should be maintained.
- Study of VFTO should also be part of the quality plan at the time of erection in case of GIS.
- Operation of all relays and its grading with respect to current and time should be thoroughly checked on a regular basis. Checking of control circuitry should also be part of this maintenance schedule.
- Initial signature documents like sweep frequency resonance analysis (SFRA), DGA and all site acceptance tests should be preserved at the office of maintenance in charge and service

department of the transformer manufacturer.
- At regular intervals, low voltage (LV) (routine) tests, routine oil tests, DGA, tan delta of winding and bushing should be carried out and studied for variation noticed of any outside tolerable limits, and accordingly, remedial measures should be taken.
- Dynamic contact resistance measurement (DCRM) test of on load tap changer (OLTC) should be carried out in consultation with the manufacturer of the OLTC.
- At regular intervals, DCRM test of the EHV circuit breaker should be performed in consultation with the manufacturer of the CB.
- Adequacy of earthing and surge protection systems should be checked at regular intervals (at least once in five years of switchyard operation).
- Increase in short circuit level of the power system network, TOV due to various system components and complexity, and harmonics due to large scale RE power dumping into the system, among other points should be specifically checked during the adequacy study.
- Effects of operation of auto reclosure(s), various TOV, resonance effects, among others, due to changes in power systems should be reviewed, especially where large power transformers are installed.
- Condition-based monitoring system may be adopted wherever found suitable and beneficial.
- Regular analysis of the findings of studies/tests/monitoring should be conducted, and remedial measures should be taken to enhance the life of transformers.

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ABOUT THE AUTHOR

Pravinchandra Mehta, CEO, Persotech Solutions, Vadodara, has a total experience of more than 38 years and has previously worked with power utility GETCO. He is a member of CIGRE-NSCC4 and RAC of ERDA. Mehta's areas of interest include design of s/s training equipment failure analysis, power system study analysis, and protection coordination. He has presented several papers on electrical system design and study related subjects at the international and national level.

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Setting New Benchmarks

V-MARC India Limited stands among India's most trusted and fastest growing wire and cable manufacturing companies. With a strong presence across 24+ states, the company has established a robust distribution network that brings world-class electrical solutions to households, industries, and infrastructure projects across the country.

In 2006, under Vikas Garg's visionary leadership, the company established its factory at SIDCUL, Haridwar. By 2009, the product range had expanded to include LT PVC and XLPE cables, further solidifying the company's market position. April 2021 marked a significant milestone with the company's IPO launch.

V-MARC is among the few in India to adopt electron beam (eBeam) technology – a cutting-edge process that enhances the strength, durability, and heat-resistance of cables.

Backed by visionary leadership and a culture of innovation, the company continues to set new benchmarks in India's electrical industry while expanding its footprint in India and global markets.

Shaping the Future of Global Green Energy

This article by **Alok Mishra, Market Area Manager-Power Grid, DNV,** explores the emerging trends, challenges, and innovations defining the future of energy. It offers insights into evolving global trade dynamics, the strategic role of energy security, and the rapid digitalisation of power systems.

The global energy landscape is undergoing a profound transformation, driven by the twin imperatives of sustainability and security. As the world navigates this transition, the interplay of trade, digitalisation, and geopolitical stability has become more critical than ever. The need for resilient supply chains, accelerated renewable energy adoption, and smarter grid infrastructure is shaping policies and investments worldwide.

This article explores the emerging trends, challenges, and innovations defining the future of energy. It offers insights into evolving global trade dynamics, the strategic role of energy security, and the rapid digitalisation of power systems. From reshoring supply chains to leveraging artificial intelligence (AI) in grid operations, the energy transition is not just about technology – it is about foresight and collaboration.

Global Trade, Energy Security, and the Future of Supply Chains

Historical context

Since World War II, global trade has expanded nearly fourfold as a share of GDP, enabled by technological advancements and relative geopolitical stability. The past three decades of trade liberalisation, particularly after the Cold War and China's integration into the global economy, propelled international commerce. Industries optimised value chains to maximise efficiency, resulting in lower consumer prices and improved living standards, particularly in Asia and Latin America.

However, this era of seamless globalisation is fragmenting. Since the 2008 financial crisis, trade growth has slowed. The COVID-19 pandemic exposed vulnerabilities in global supply chains, while the Russia-Ukraine war underscored the geopolitical risks of overreliance on a few suppliers. Nations are now rebalancing from efficiency-driven models to resilience-focused strategies.

Key trends in energy security

1. **Energy as a national security priority**
   Reliable, affordable energy access has become central to economic security. Nations are prioritising local energy production and reducing reliance on volatile international markets.
2. **Volatile prices and market instability**
   The Ukraine conflict triggered unprecedented price spikes. Wealthier nations outbid others for liquified natural gas (LNG), while some developing economies reverted to coal to maintain energy security.
3. **Strategic infrastructure investments**
   Governments are investing in renewable energy (RE), storage, and smart grids, while simultaneously expanding fossil fuel infrastructure to address immediate supply gaps.
4. **Reshaping global supply chains**
   Rare earth metals, lithium, semiconductors, and steel disruptions are leading to reshoring (domestic manufacturing) and friendshoring (supply from allied nations).
5. **Securing green energy supply chains**
   Nations are seeking local production of lithium, cobalt, and rare earths essential for renewable technologies, although this raises costs in the short term.
6. **Nuclear energy resurgence**
   Nuclear power is regaining traction as a stable option, with some nations extending plant lifespans and others pursuing new projects despite safety, cost, and waste concerns.
7. **Social and economic pushback**
   Inflationary pressures have caused public dissatisfaction in some regions, leading governments to balance affordability against decarbonisation targets.

Geopolitical Risks and Energy Security

1. **Supply chain vulnerabilities: Lessons from COVID-19**
   Overdependence on concentrated suppliers, logistical bottlenecks, and raw material shortages inflated RE costs. Governments now pursue localised production and stockpiling.
2. **Energy weaponisation: Russia and Europe**
   Russia's use of gas exports as leverage transformed Europe's energy strategy, accelerating LNG imports, renewable projects, and nuclear reconsideration.
3. **US-China rivalry**
   Trade restrictions on semiconductors, solar panels, and rare earths are reshaping supply chains. This rivalry is pushing diversification into India, Vietnam, and other Asian markets.
4. **Reshoring and manufacturing**
   Major economies are funding domestic solar, battery, and semiconductor industries to mitigate geopolitical risks, although short-term costs remain high.

The Economics of Reshoring Energy Manufacturing

The economics of reshoring energy manufacturing highlight a trade-off between short-term costs and long-term resilience. While reshoring reduces dependency on foreign suppliers, it initially raises expenses as Western nations contend with higher wages, stricter regulations, and significant capital requirements. Governments are responding with subsidies and tax incentives to ease the transition. Between 2024 and 2030, costs are expected to rise by up to 10 percent due to capital expenditure surges and supply chain inefficiencies. From 2030 to 2045, costs should stabilise as economies of scale are realised and supply chains mature. Beyond 2045, reshored industries are projected to achieve global competitiveness through technological breakthroughs and advanced manufacturing. Ultimately, this shift will strengthen energy security, create jobs, and reduce vulnerability to geopolitical shocks, laying the foundation for a more resilient and independent energy future.

> **The global energy transition demands a careful balance between security, affordability, and sustainability, while adapting to ongoing geopolitical, economic, and technological disruptions.**

Solving the Energy Trilemma: Security, Affordability, and Sustainability

The "energy trilemma" reflects the challenge of achieving a delicate balance between three interdependent priorities: security, which ensures uninterrupted and reliable energy supply;

affordability, which guarantees cost-effective access for households and businesses; and sustainability, which drives the transition toward low-carbon, environmentally friendly solutions. Trade-offs are inevitable – reliance on fossil fuels may strengthen short-term security but undermine long-term climate goals, while subsidies can ease affordability pressures yet delay much-needed investment in clean technologies. Addressing the trilemma requires a multi-pronged strategy: diversifying energy sources, strengthening storage systems, and deploying microgrids to enhance security; promoting efficiency, transparent markets, and well-targeted subsidies to maintain affordability; and accelerating renewable energy deployment, introducing carbon pricing, and advancing circular economy practices to ensure sustainability.

Grid Charges and the Future Cost of Electricity

Rising grid investments

By 2050, grid expenditures are projected to account for more than a quarter of total energy spending, driven by the dual need to expand access, integrate large-scale renewables, and modernise ageing infrastructure. The regional impacts will vary significantly: Sub-Saharan Africa and Latin America are expected to face higher grid charges due to extensive new infrastructure requirements, while Europe and much of Asia may benefit from economies of scale, resulting in stable or even declining costs. For India, the outlook is mixed – rapid renewable integration and last-mile connectivity efforts are likely to raise costs, even as efficiency improvements create offsetting gains. Beyond infrastructure, electricity prices will also be shaped by taxation and subsidies, volatility in fuel prices (with coal still a major factor for India), cross-subsidies and state-level regulatory frameworks, as well as persistent transmission and distribution (T&D) losses and theft. Navigating these pressures will require India to prioritise smart grids, foster regional coordination, strengthen financing mechanisms, and implement tariff reforms that balance affordability with sustainability.

Offshore Wind in India: Potential and Challenges

With its 7,600 km coastline, India holds immense potential for offshore wind energy, supported by policies such as the National Offshore Wind Energy Policy (2015), the Lease Rules (2023), and the Viability Gap Funding (VGF) scheme, which together provide a regulatory and financial framework for development. Offshore wind offers multiple benefits: it can reduce dependence on fuel imports, help India achieve its nationally determined contributions (NDCs) and renewable energy targets, create jobs and stimulate ancillary industries, drive indigenous technology development, and provide a strong basis for green hydrogen production. However, the sector faces several challenges, including high capital costs and financing hurdles, deep-sea installation complexities, inadequate port and vessel infrastructure, intermittency and grid integration issues, environmental sensitivities in marine ecosystems, limited domestic expertise, and regulatory uncertainties. Addressing these hurdles will require international partnerships for knowledge transfer, focused research and development (R&D) and skill-building programmes, significant port infrastructure development, streamlined regulatory processes, and well-designed financial incentives and risk mitigation frameworks to attract private investment and ensure long-term sustainability.

Digitalisation and Artificial Intelligence (AI): Revolutionising the Power Sector

Digitalisation and AI are revolutionising the power sector, with technologies like AI, Internet of Things (IoT), and Big Data enabling real-time monitoring, predictive maintenance, and optimised asset management. A key distinction lies between Generative AI, which enhances productivity, customer service, and design optimisation but suffers from reliability issues, and Discriminative AI, which is already widely deployed for forecasting, predictive maintenance, and anomaly detection, offering greater reliability and explainability. Across the sector, AI is being applied in grid forecasting and flexibility management, predictive transformer maintenance, demand-response optimisation, and smart metering with peer-to-peer trading. Best practices for digital interventions include the use of Digital Twins to create real-time virtual replicas of assets, Augmented Reality (AR) for technician support and training, Virtual Reality (VR) for immersive training and scenario planning, and drones for asset inspection and monitoring. Together, these digital tools are enabling a more efficient, resilient, and intelligent power system.

Conclusion: A Strategic Path Forward

The global energy transition demands a careful balance between security, affordability, and sustainability, while adapting to ongoing geopolitical, economic, and technological disruptions. Energy security is now closely linked to local production, diversified supply chains, and stronger resilience strategies. Although reshoring increases costs in the short term, it ultimately strengthens independence and long-term competitiveness. Grid modernisation will be essential to unlock the full potential of RE, particularly in India, while offshore wind could become a game-changer for the nation's climate and energy security ambitions if infrastructure and financing challenges are effectively addressed. At the same time, digitalisation and AI are set to transform power systems, enhancing efficiency, resilience, and innovation. By 2045, decentralised, resilient, and geopolitically secure energy systems are expected to dominate, positioning the world on a pathway to a sustainable and inclusive future.

ABOUT THE AUTHOR

Alok Mishra, Market Area Manager-Power Grid, DNV, is a clean energy and e-mobility professional with extensive experience in RE integration, offshore wind, green hydrogen, and power sector resilience. He has led multiple high-impact projects in India and internationally, including India's first offshore wind project (FOWIND) and the country's first green hydrogen production from offshore wind. He has contributed to policy development, energy transition roadmaps, and digital transformation in emerging markets such as India, Southeast Asia, Middle East, Africa, and Europe.

The Complex Chemistry and Engineering Behind EV Batteries

In an EV, the battery is the major and central power source that drives the traction motors responsible for vehicle movement. This technical paper, with its contents organised into four distinct parts, provides a detailed exploration of EV batteries. In Part-1, **SV Varadarajan, Retired Technical Director, M. N. Dastur and Company (Pvt) Ltd, Chennai,** focuses on aspects such as environmental benefits of EV batteries, challenges caused to the environment, difference between Li-ion batteries in EV and grid supporting applications, reasons for adoption of Li-ion batteries over lead-acid batteries in EV, general features of a Li-ion battery, the proliferation of Li-ion batteries and basic type of battery cells.

Electric vehicles (EV) powered by Lithium-ion (Li-ion) batteries have emerged as a matchless alternative to conventional vehicles with internal combustion engine (IC) technology, promising to transform the automotive markets. This has been made possible by a single product, namely, the Li-ion EV battery. In fact, new advances have made the Li-ion batteries a huge 'disruptor' (gamechanger, innovator, and catalyst for positive change) of technology in the transportation sector as well as in the power grids as battery energy storage systems (BESS). The development and integration of advanced EV battery technologies have become central and most crucial in unshackling the true potential of EV, overcoming various formidable obstacles and addressing the complex issues related to range, performance, and ecological consequences.

The chemistry and engineering behind an EV battery is complex. In an EV, the battery is the major and central power source that drives the traction motors responsible for vehicle movement. It is the nucleus of EV, storing and delivering the electrical energy needed for starting, accelerating, and braking or decelerating. The battery's energy density and capacity determine vital parameters such as range, acceleration, and customer's confidence, resulting in enhanced driving experience. For EV, the electrical battery is equivalent to the ICE in a traditional vehicle. Both are principal energy providers for vehicle dynamics. Both are the most expensive parts of a vehicle and both are the heaviest single piece of equipment in their respective vehicles.

Government incentives for EV batteries in India include the following:

- The Faster Adoption and Manufacturing of Hybrid and Electric Vehicles (FAME) scheme, which provides subsidies per kilowatt hour (kWh) for vehicles like electric cars and buses by the Union Government, apart from subsidies given at the state level.
- The Union Government offers customs duty exemptions on critical battery inputs, such as Li-ion waste and nickel compounds.
- Production-linked incentives (PLI) for advanced chemistry cell (ACC) battery storage manufacturers.

Perhaps this is the appropriate time for new entrepreneurs to enter this rapidly growing manufacturing field. A few established automobile manufacturing companies in the country have already initiated actions to manufacture EV batteries. In course of time, more manufacturers are expected to join this group to start manufacturing plants either on their own or as joint ventures (JVs) with promising start-ups.

This paper provides a detailed exploration of EV batteries, with its contents organised into four distinct parts. In Part-1, the focus is on aspects such as environmental benefits of EV battery, challenges caused to the environment, difference between Li-ion batteries in EV and grid supporting applications, reasons for adoption of Li-ion batteries over lead-acid batteries in EV, general features of a Li-ion battery, the proliferation of Li-ion batteries and basic type of battery cells (part).

Parts-2, 3 and 4 of this paper (to follow in the coming editions) will explore basic types of battery cells, international battery day, discovery of Lithium in the early 19th century, importance of electrolyte in Li-ion battery, and popular types of Li-ion batteries used in today's EV, comparison of the main types of batteries, key minerals in a typical Li-ion battery, manufacturers of Lithium-ion batteries in India, sodium-ion batteries, solid-state batteries, various conformity battery standards*, Automotive Industry Standards Committee, testing, certification* and standardisation of batteries, The International Centre for Automotive Technology, Automotive Industry Standards, the role of interconnects in EV battery pack, the importance of adhesives in battery assembly, significance of thermal interface materials, battery management system and commercially available software for EV battery designs.

The development and integration of advanced EV battery technologies have become central and most crucial in unshackling the true potential of EV, overcoming various formidable obstacles and addressing the complex issues related to range, performance, and ecological consequences.

**There are separate conformity standards and separate rigorous testing standards for EV batteries, considering their complex chemistry and construction besides paramount importance to passenger safety.*

1. Placement of the Battery in EVs

In most passenger EVs, the large and heavy Li-ion battery pack (assembled out of many small battery cells) is located at the bottom of the vehicle floor pan, forming a wide, flat structure that lowers the vehicle's center of gravity for better stability and also maximises interior space. This is generally termed as floor-mounted battery architecture. This placement contributes to a more stable and balanced ride, as well as providing structural reinforcement to the vehicle's chassis. In some cases, the battery

Image 1: Li-ion Battery Pack Placed at the Vehicle's Floor

Image courtesy: Reference 1.

Image 2: Li-ion Battery Pack Placed in the Boot Area

Image courtesy: Reference 2.

packs are kept below the boot too. In larger vehicles like buses or commercial trucks, multiple battery packs may be distributed throughout the chassis, including the front, rear, sides, or even roof. Refer to Image 1 and Image 2.

There is also another concept known as structural battery, where the battery itself is designed to serve a dual purpose, acting as both an energy storage device and as a load-bearing structural component. The battery pack is designed to not only store energy but also to contribute to the overall strength and stiffness of the vehicle's frame, often using materials like carbon fiber.

Weight comparison: An EV (as of now) is generally heavier than a comparable ICE vehicle because of the large and heavy battery pack. For example, a small EV is typically about 15-25 percent heavier than a small ICE car, and a larger EV can weigh several hundred kilograms more than its gasoline-powered equivalent. The weight of the battery makes EV heavier. In small cars, the weight difference is substantial and this difference reduces when the model becomes large.

2. EV Predated the Advent of Internal Combustion-Based Vehicles

History says the EV was invented before traditional vehicles with ICE technology. The earliest patents related to EVs predate the German designer Karl Benz's work on gasoline engine-based vehicles by many years. Scottish inventor Robert Anderson reportedly invented an electric carriage in the 1830s, and American inventor Thomas Davenport patented a battery-powered car in 1837. Benz applied for a patent for 'Benz - Patent - Motorwagen' only in the year 1886. This three-wheeled vehicle is widely considered the world's first practical automobile, and it ran on gasoline.

Over the next decade, electric cars started to operate in Germany and then in the US, where the 'Electrobat' was used as a New York Taxi, with a top speed of 20 mph and a range of 25 miles. In 1899, the rocket shaped 'La Jamais Contente', with speed more than 100 kph was built and driven by Belgian electrical engineer Camille Jenatzy. However, the discovery of vast amounts of oil at the turn of the century sparked the transition to ICEs. In addition to this surge, Henry Ford pioneered the mass production of cars on assembly lines and developed the affordable Model T, which practically shut the advancement in EV. This trend continued until the 60s and 70s. Later, a series of oil crises occurred.

Gradually, battery technology improved along with growing environmental consciousness, which enabled the market for EVs to flourish[3]. The 'Lovebird', manufactured by Eddy Current Controls in 1993, is considered as India's first electric car, although it did not achieve commercial success. It was followed by 'Reva' in 2001, a famous two-seater. Rechargeable batteries for storing electricity for EVs were made possible in 1859, with the invention of the lead-acid battery by French physicist Gaston Planté. In 1881, French scientist Camille Alphonse Faure contributed to the large improvement in its designs, which led to an increase in the capacity and enabled profitable production on a large scale[3].

3. Environmental Benefits of EV Batteries

EV batteries play a pivotal role in achieving sustainable and eco-friendly emission-free transportation, which is the call of the day in reducing environmental degradation. In this context, EV batteries offer several benefits, as discussed below:

3.1. Reduction in greenhouse gas (GHG) emission

The use of fossil fuels in power plants and in various transportation systems, including aviation, agriculture activities and various industrial processes, are some of the factors that generate

greenhouse gases. Traditional transport, which employ ICEs, contribute substantially to air pollution through their tail pipe emissions. On the other hand, the battery powered EVs produce zero tail pipe emission* during its operation, leading to a cleaner atmosphere[1].

**Emissions generated during the process of manufacturing batteries as well as during manufacturing of EVs with its sub-systems have not been considered here.*

3.2. Conservation of fossil fuels

Fossil fuel reserves are finite and need to be conserved for future exigencies. In this context, EV batteries will reduce the consumption of diesel and petrol derived from crude oil, reduce dependence on the finite fossil fuel resources, and save them for future emergencies.

3.3. Potential for grid charging

Vehicle-to-grid (V2G) technologies make it possible for EVs to upload electricity to the power grid. This helps the grid in times of peak load as well in balancing the outflows vs inflows of energy. Due to the increasing number of EVs, the grid gets distributed energy sources, which will enable grid stability. The energy from EVs can be used to feed other consumers or to charge grid support batteries at various geographical locations.

3.4. Reduction in noise pollution

EVs are driven by electric motors, which are a lot quieter than ICEs. Noise is reduced. Also, there is less emission of heat in an EV when compared with an ICE. While EV batteries do emit heat, they are absorbed by large cooling plates and cooling fans.

3.5. Integration of more renewable power into utility grids

There has been a long-standing view that although EV batteries reduce air pollution locally at the vehicle level, they cannot reduce pollution caused by fossil fuel-driven power plants, which ultimately produce the energy required for charging EV batteries. To address this anomaly and also to reap the full benefits of emission-free EVs, the utility power grid must be transformed into a green grid, increasing the share of renewable sources while at the same time phasing out fossil fuel-based sources. Thus, the spread of EV necessitates the integration of more renewable power into the grid infrastructure.

3.6. Higher energy efficiency

In an EV, major components include a battery, an inverter, and traction motors. All these components are known for their higher energy efficiency. This increased efficiency level reduces energy wastage and guarantees energy optimisation – an important green environment requirement.

4. Environment Challenges

Manufacturing EV batteries is complex and demanding, as many environmental issues exist. An EV battery is like a coin having two faces – on the 'head' side, its operation creates clean energy but on the 'tail' side, its manufacture creates environmental deterioration. These are discussed briefly[1]:

4.1. Raw material extraction

Lithium (Li), Cobalt (Co), and Nickel (Ni) are some major critical earth minerals* required for manufacturing Li-ion batteries. Their extraction and processing involve environmentally detrimental practices. These include but are not limited to loss and degradation of habitat, endangering resident species, land downgrading, deforestation, use of scarce water sources, application of heavy acids, poor or absent treatment of effluents.

**Li, Co, and Ni are not rare earth minerals, which specifically refers to the 15 elements in the lanthanide series, with addition of Scandium and yttrium, which are vital in defense and industrial applications.*

4.2. Energy-intensive manufacturing

The estimated gate-to-gate energy use, GHG emissions, water consumption, and N-methyl-2-pyrrolidone (NMP) consumption (used as solvent in battery manufacture) were found in a study conducted in factories manufacturing EV batteries and the same are given here: (i) Around 30-35 kWh energy was consumed per kilowatt hour (kWh) of battery capacity. (ii) GHG emissions were around 10 kgCO2 eq per kWh of cell production. (iii) Water consumption varied considerably among factories, from 28 litre per kWh to 67 litre per kWh. (iv) The specific consumption of NMP was found around 0.51-0.56 kg per kWh of cell production5. It may be observed that the above findings cast a shadow on the environmental benefits gained during the operation of batteries in EVs.

4.3. Battery recycling efforts

- Recycling EV batteries is critical to reducing environmental impact and recovering valuable materials. Traditional recycling methods involve shredding batteries and using chemical processes to separate the components. However, innovative approaches are improving efficiency and sustainability. Modern methods concentrate on recovering a higher percentage of valuable and scarce materials, including Li, Co, Ni, and Manganese. These advanced methods not only reduce the environmental footprint of battery production but also lower costs by reintroducing recycled materials into the supply chain. Engineering companies are also exploring 'direct recycling', which aims to recover battery materials in a form that can be directly reused in new batteries, further enhancing the sustainability of the EV battery industry[6,7].

- Recycling helps in recovering materials from used EV batteries to be reused in new batteries or other applications. This process is crucial for sustainability, reducing environmental impact, and conserving valuable resources. Recycling methods include mechanical, hydro-metallurgical, and pyro-metallurgical processes, with the potential to recover over 95 percent of materials like Li, Co, and Ni. EV batteries are also re-purposed to be used in applications such as fork-lifts and in clean energy systems or as grid supporting batteries. EV batteries are very hard to recycle, but some of their components, especially Ni and Co, are valuable – which pays back investments.
- One important challenge is to avoid fires when batteries are in the process of dismantling. To avoid this, batteries are to be cautiously discharged before starting any work. Old or broken Li-ion batteries can catch fire, which adds to the danger of stockpiling them for disposal. This calls for proper storage with ventilation.
- In many instances, it is easier to reuse the batteries, instead of recycling. An older EV battery may no longer be useful for long-distance driving but could still have enough storage capacity to find a second life in an electric sub-station.
- Prevention is better than cure - charging methods become the cue: The life of batteries can be prolonged with careful usage. This prevents their early degradation. Direct current (DC) fast charging, which can replenish an EV battery much quicker than standard alternating current (AC) charging, is definitely convenient for the EV owner but at the same time it affects battery health. Frequent fast charging can generate more heat and stress battery cells, potentially accelerating degradation, leading to replacement of batteries. AC charging is slower, gentler on the battery, more cost-effective, and ideal for home and workplace use over extended periods.
- Mitigating damage: To minimise the impact of fast charging, many EV use advanced thermal management systems and adaptive charging algorithms. These technologies help maintain optimal temperatures and adjust charging rates based on the battery's condition and usage patterns.
- Smart charging practices prolong the life: EV owners can also adopt smart charging habits, such as using fast charging primarily for long trips or emergencies and relying on slower, regular charging for daily use. Limiting fast charging sessions to about 80 percent capacity can further reduce stress on battery cells and extend their lifespan. AC charging must be prioritised for routine charging to minimise stress on batteries. EV batteries are designed to undergo DC fast charging safely, due to integrated thermal management systems (provided in the battery management system [BMS], discussed in the later part of this paper), which regulate heat by controlling the charging current.

4.4. Second-life applications for EV batteries

When an EV battery's capacity drops below 70-80 percent, it may no longer be suitable for vehicle use but can still be valuable in other settings. These used batteries can be repurposed for energy storage systems, extending their usefulness and minimising waste7.

- Residential and commercial energy storage: Second-life EV batteries can store energy from renewable sources such as solar or wind, making it available during peak demand periods. This application helps smooth out energy supply and demand, supporting a more stable and sustainable grid.
- Grid storage projects: Automotive companies and tech startups are exploring the integration of second-life EV batteries into larger grid storage systems. These batteries can store excess energy generated during off-peak times and release it when needed, enhancing grid reliability and facilitating the broader adoption of renewable energy (RE). *(A few years back, Nissan Motor Corporation experimented with this idea by using new and old batteries from their Leaf EV model to power a soccer stadium. But the prior [and most critical] condition for such applications is the knowledge about the state of the batteries' health.)*

5. Difference Between Li-ion Batteries in EV and in Grid Supporting Applications[8.1 to 8.4]

Li-ion batteries are the lifeline of EVs and an increasingly vital component of modern power grids. Electrical battery storage plays an outstanding pivotal role in the stability of the grid, driven by renewable sources. In fact, in India, every tender for supply and installation of photovoltaic (PV) solar power plants also includes proportionally rated battery systems for grid support. EV batteries and grid supporting batteries, both use Li-ion technology, but they have different performance requirements and applications. EV batteries prioritise high energy density for range and acceleration while grid batteries focus on cost, longevity, and power delivery for grid stability and RE integration. Grid supporting batteries are needed for storing excess energy from renewable sources, providing backup power, and supporting grid stability through frequency regulation, peak shaving, and black starting.

6. Characteristics of EV Batteries and Grid-Connected Batteries

6.1. Characteristics of EV batteries

6.1.1. Goal: Maximising energy density for longer driving ranges and performances.

6.1.2. Distinguishing features: High power output, fast charging capabilities, and compact size.

6.1.3. Chemistry: Often use Nickel Manganese Cobalt (NMC) or Nickel Cobalt Aluminum (NCA) chemistry due to their high energy density.

6.1.4. Thermal runaway: Oxygen bond in an NMC battery is much looser than in an lithium iron phosphate (LFP; $LiFePO_4$) battery (used in grid systems). Due to this, thermal runaway can occur easily, and in some cases when the environmental temperature goes high, there lies a possibility for explosion.

6.1.5. Operating voltage: In an EV battery, it is generally 3.7 volts (V) per cell. Pack voltages vary from vehicle to vehicle, but nowadays many vehicles operate at around 400 V. This increased voltage (at 3.7 V) accelerates the interaction between the electrolyte and the cathode, resulting in the delivery of higher power. However, this strong reaction also tends to shorten the battery life.

6.1.6. Design constraints: EV battery requires sophisticated BMS to handle dynamic conditions and ensure safety under various operating scenarios. It also needs robust thermal management systems due to high power demands and space constraints. When designing EV battery modules, it is necessary to consider the space and weight of the battery compartment and to adapt to the safety requirements under dynamic operating conditions while pursuing power acceleration and extending the driving range. In addition, EV battery modules need to be designed with care considering collision or road accidents.

6.1.7. Costs: They generally have a higher cost due to stringent performance, safety requirements, and material demands.

6.2. Characteristics of grid-connected batteries

6.2.1. Goal: Cost-effectiveness, long cycle life, and the ability to provide grid services.

6.2.2. Distinguishing features: Emphasis on cost per kWh, long lifespan, and the ability to handle frequent charge and discharge cycles.

6.2.3. Chemistry: Nowadays increasingly apply LFP chemistry to reduce costs and ensure longer lifespan compared to NMC or NCA.

6.2.4. Thermal runaway: Oxygen bond in an LFP battery is much stronger than in an NMC battery (used in EV). Due to this, thermal runaway occurrences are limited.

6.2.5. Operating voltage: In a grid supporting battery, it is generally 3.2 V per cell. This voltage matches with lead-acid batteries, resulting in applications, which operate at 12/24/48 volts.

6.2.6. Design constraints: Grid-connected batteries (also called as energy storage system [ESS] batteries) also rely on BMS, but the emphasis shifts to long-term reliability and grid integration features. Thermal management can be designed for static environments. When designing ESS battery modules, it is necessary to consider the location environment (both physical and geographical), thermal management, long cycle life and cost efficiency and suitability for static applications. ESS battery modules focus on instantaneous response (through its own electronic front ends) and are fireproof and offer all-time fail-safe support to the grid, as the occurrence of blackouts cannot be predicted.

6.2.7. Costs: Costs are generally lower compared to EV batteries.

6.3. Summary

EV batteries are designed keeping in mind mobility and performance requirements. Grid support batteries are designed to deliver cost effectiveness, long life, and fail-safe support, which is crucial for smooth grid operation.

NMC batteries: Known for their high energy density, NMC batteries are commonly used in passenger EVs. They offer longer driving ranges, which is a key selling point for consumers.

LFP batteries: These batteries are prized for their thermal stability and longer life cycle, making them ideal for commercial applications like electric buses and delivery vehicles. They are also considered safer due to their lower risk of thermal runaway. Also, these batteries are used in grid support applications.

7. Reasons for Adoption of Li-ion Batteries over Lead-acid Batteries in EVs[9,10]:

'Reva' (Indian JV EV), which was successful in India and abroad, initially used (in the first model from 2001 to 2007) lead-acid batteries. Later, 'Reva' changed over to Li-ion batteries due to its many advantages. Li-ion batteries are made with Lithium in combination with other reactive metals like Cobalt, Manganese, Iron, or more, while lead-acid batteries are made with Lead and Sulfuric acid. The primary differences between these two types of batteries lie in their chemistry, energy density, efficiency, depth of charge, lifespan, and cost.

7.1. Difference in materials

- **Lithium-ion:** Uses lithium salt in the electrolyte and carbon or lithium compounds for the electrodes.
- **Lead-acid:** Uses sulfuric acid as the electrolyte and lead and lead oxide for the electrodes.
- **Safety of Li-ion vs lead acid:** Lithium-ion batteries

are safer than lead acid batteries as they do not contain corrosive acid and are less prone to leakage, overheating, or explosion.

7.2. Difference in energy density

- **Li-ion:** Packs more energy per unit weight and volume, meaning they are lighter and smaller for the same capacity, and hence, extensively used in phones, laptops, and EVs.
- **Lead-acid:** Bulkier and heavier for the same capacity but used in vehicles, starting batteries, and off-grid systems.
- **Capacity differences in Li-ion vs lead acid:** A battery's capacity is a measure of how much energy can be stored (and eventually discharged) by the battery. Although capacity figures can differ based on battery models and brands, Li-ion battery technology has been extensively tested and shown to possess a considerably higher energy density than lead-acid batteries.
- **Energy efficiency:** Li-ion batteries are more efficient, losing less energy during charge or discharge cycles. Li-ion batteries have an efficiency rate of 95 percent or more while lead acid batteries have a rate closer to 80-85 percent. High-efficiency batteries charge faster and have a higher effective battery capacity, similar to the depth of discharge.
- **Discharge rate and shelf life:** Li-ion batteries have a longer overall lifespan and better storage life than lead-acid batteries due to their slower self-discharge rates and greater energy density. While lead-acid batteries may have a good shelf life before charging, their cycle life is shorter and they lose more energy when idle compared to the more advanced, albeit more expensive, Li-ion technology. Li-ion batteries have a higher discharge capacity, can be deeply discharged (up to 80 percent or more) without significant damage, and maintain high discharge efficiency, whereas lead-acid batteries should only be discharged to 50 percent to prolong their short lifespan. Li-ion batteries can also discharge at a faster rate and are more efficient, losing less energy during the process, compared to lead-acid batteries.

7.3. Lifespan and durability

- **Li-ion:** High cycle life, lasting for thousands of charge/discharge cycles before needing replacement.
- **Lead-acid:** When compared to a Li-ion battery, a lead acid battery has a lower cycle life, typically needing replacement after 300-500 cycles. Deep discharge can significantly shorten lifespan.
- **Durability and life:** Discharging a battery to power a home or appliances and then recharging it with solar energy or the grid counts as one 'cycle'. The longevity of Li-ion batteries far surpasses that of lead acid batteries, owing to their superior capacity to endure multiple cycles. This attribute results in an extended effective lifespan of Li-ion products, which makes them an optimal choice over their lead acid counterparts.

7.4. Environmental impact

Li-ion batteries have a higher environmental impact during production, but their longer lifespan and higher efficiency can minimise it over their lifetime. Overall, Li-ion batteries are somewhat more environmentally friendly than lead acid batteries, as they do not contain toxic lead and sulfuric acid and

can be recycled with greater efficacy. However, it is to be noted that recovering precious metals from Li-ion batteries is a complex work and needs special chemicals and tools. These aspects are covered subsequently in this paper.

7.5. Re-usability

Li-ion cell modules like those found in EV batteries can be repurposed to make Second life energy storage solutions, capable of augmenting and powering green infrastructure in urban and rural areas alike. Lead-acid batteries are typically ineligible for any kind of re-purposing or reuse and must be recycled upon reaching the end of life.

7.6. Upfront cost per kilowatt hour

- **Lead-acid:** While lead acid vs Li-ion offers a lower cost per kilowatt hour initially, this advantage diminishes over time due to its shorter lifespan and need for replacements.
- **Li-ion:** Although the upfront cost per kilowatt hour of Li-ion vs lead acid is higher, their longer lifespan and higher efficiency translate to a lower total cost of ownership in the long run.

7.7. The charging aspects of batteries

7.7.1. The case of the lead acid battery

The charging efficiency of this type of battery is low at 75 percent. A lead-acid battery needs more energy for recharging than it delivers. The excess energy is used for gassing and for mixing the acid internally. Gassing is the electrolytic breakdown of water into Hydrogen and Oxygen gases during charging. This process, also known as water electrolysis, releases Hydrogen at the negative plate and Oxygen at the positive plate, creating a potentially explosive mixture. While gassing is a normal part of charging, excessive gassing can reduce battery capacity by consuming water and can be dangerous due to the flammability of Hydrogen gas. This process warms up the battery and evaporates the water inside, which results in the need to top up the battery with pure water. Lead-acid recharging has several limitations, some of which are described below:

- Fast or partial charges ruin a lead-acid battery. Poor maintenance will also reduce battery life.
- Long charging time of usually six to eight hours; unsuitable for today's fast moving world.
- The charger is usually old-fashioned and cannot collect full information on the battery. There are neither sensors in the battery nor any reading and controlling system in the charger. The charger can only check the voltage – this parameter alone is insufficient. Changes in temperature affect the recharge profile; so if the temperature is not measured, the battery will never charge completely in winter and emit large amounts of gases in summer. An incorrect charger or setting reduces battery life.

7.7.2. The case of Li-ion battery

Li-ion batteries can be fast charged to 100 percent of capacity. A Li-ion battery saves on energy consumed, and hence, provides a leaner electricity bill as it is up to 96 percent efficient and accepts both partial and rapid charging. A Li-ion battery can be charged to 50 percent capacity in only 25 minutes. This results in lower installed battery capacity than the capacity required with lead acid batteries, because Li-ion batteries can be recharged repeatedly over a short time. Electronic systems inside the battery control the charger effectively, so it can deliver the exact current that is consistent with internal parameters (voltage, temperature, charge level). The battery will not respond and rejects an unsuitable charger, and thus, protects itself.

7.8. Approximate battery weights

- Lead acid battery: 30 kg for kWh.
- Li-ion battery: 6 kg for kWh.

On average, Li-ion batteries weigh 5x lesser than standard lead acid batteries.

7.9. Maintenance criteria

7.9.1. The case of the lead acid battery

High maintenance and system costs occur. Regular maintenance is a must, and this happens to be high considering rising labour costs. Regular topping up water, maintaining the filling system, and removing oxide from the elements and terminals are must-do functions. There are other issues, as lead acid batteries release gas while they are charging, and therefore, require special enclosures or rooms with corrosion resistant exhaust fans, acid proof ducting, and acid proof tiling,

7.9.2. The case of the Li-ion battery

There are no special requirements such as dedicated space, ventilation systems, acid proof tiling, etc, as needed for lead-acid batteries.

8. General Features of a Li-ion battery11-13

Li-ion battery is, in fact, a generic term involving many different types of chemical combinations. Li-ion cells can be manufactured to optimise energy density or power density. Handheld electronics mostly use lithium polymer batteries (with a polymer gel as an electrolyte), a lithium cobalt oxide ($LiCoO_2$) cathode material, and a graphite anode, which together offer high energy density. Lithium iron phosphate ($LiFePO_4$), lithium manganese oxide ($LiMn_2O_4$ spinel), or Li_2MnO_3-based lithium-rich layered materials, lithium manganese-rich nickel manganese cobalt oxide (LMR-NMC) and lithium nickel manganese cobalt oxide ($LiNiMnCoO_2$ or

NMC) offer longer life and a higher discharge rate, due to which they are widely used in EVs. More information on the various features are described below.

- Graphite is the typical negative electrode of a conventional Li-ion battery while metal oxide or phosphate forms the positive electrode. The electrolyte is a solute consisting of a lithium salt dissolved in an organic solvent. The electrodes are prevented from touching each other (prevention of short circuit) by a separator. Current collectors connect the electrodes to the power circuit where the battery has to function11.
- Note on designation of positive and negative electrodes: Negative electrode is the anode when the cell is discharging and positive electrode is the cathode when discharging is prevented from shorting by a separator. The negative and positive electrodes interchange their roles, ie, negative electrode becomes positive and positive electrode becomes negative, when the battery is under charging. In the case of rechargeable batteries, it is customary to call the anode as a negative electrode and a cathode as a positive electrode.
- During charging, Li-ions from the cathode move through the electrolyte and insert themselves into spaces between the graphite's carbon layers – a process called 'lithiation'. At the same time, electrons are added to the graphite's conduction band, which helps stabilise the inserted Li-ions. The lithiation process is not immediate but occurs in several stages, where the Li-ions are not completely ordered or secured within the layers. These phases are referred to as stages, with the final, fully lithiated state being stage-1, or LiC6. This process results in a graphite anode with a maximum theoretical capacity of 372 mAh/g.
- The cathode (positive electrode) is chosen from one of three materials: (i) layered oxide (such as lithium cobalt oxide), (ii) a polyanion (such as lithium iron phosphate for Li-ion batteries*), or (iii) spinel (such as lithium manganese oxide).
- Polycations and polyanions form polyelectrolytes, which are polymers whose repeating units bear an electrolyte group.

  These groups dissociate in aqueous solutions, making the polymers charged. Their properties are thus similar to both electrolytes (salts) and polymers. Their (salt) solutions are electrically conductive. Like polymers, their solutions are often viscous[12].

  **Polyanions are different for Li-ion batteries and for Sodium-ion (Na-ion) batteries: In the case of Li-ion battery technology, polyanionic compounds such as iron phosphates or manganese phosphates are employed due to their high thermal stability, enhanced safety due to robust covalent bonds, and high operating voltages. In the case of Na-ion batteries (discussed in the later part of this paper), polyanion-type electrode materials are* $Na_3V_2(PO_4)_3$ *and* $NaTi_2(PO_4)_3$ *for Na-based cathode and anode materials, respectively. Both these materials have superior electro-chemical properties suitable for their application in Na-ion batteries[13].*
- Use of sealed container: Lithium reacts vigorously with water to form lithium hydroxide (LiOH) and hydrogen gas. Therefore, a non-water-based electrolyte is typically used, and a sealed container rigidly excludes moisture from the battery pack.
- Electrolyte: In general, a mixture of organic carbonates such as ethylene carbonate, and propylene carbonate containing complexes of Li-ions is used as electrolyte. Electrolytes are further discussed in detail in the later part of this paper.

9. The Proliferation of Li-ion batteries – The Time Line[10]

Li-ion batteries had traversed a long journey of about 55 years as chronicled below. It was not a single, instant switch from lead-acid batteries. In the 1990s, the pace of transition picked up, and the tempo continues to this day. These aspects are discussed in detail in a later section of this paper.

- 1970s: The first commercial lithium batteries appeared, mainly non-rechargeable types like those used in watches.
- 1985: Akira Yoshino, Fellow of Asahi Kasei Corporation and a professor at Meijo University in Nagoya, developed the prototype of the modern Li-ion battery with a safer Li-ion intercalation compound anode. He created the first safe, production-viable Li-ion battery, which became widely used in cellular phones and notebook computers.
- 1991: The Japanese multifunctional companies of Sony and Asahi Kasei commercialised the first rechargeable Li-ion batteries. This was based on the pioneering research work of M Stanley Whittingham (British-American Chemist) and John Goodenough (American solid-state physicist) that need a special mention here.
- 1990s and early 2000s: The early adoption of portable electronics like laptops and mobile phones due to their superior energy density, lighter weight, and longer lifespan.
- 1996: The first laptop computer powered by a Li-ion battery is released.
- Mid-2000s onwards: Expansion into power tools, digital cameras, medical devices, and EVs.
- Present day: Li-ion batteries continue to displace lead-acid batteries in various applications but lead acid batteries continue to be dominant in areas where cost and affordability are critical, like automotive starters and in micro-grid storage

applications. In fact, lead acid battery also finds a place in EV with Li-ion battery for providing the essential 12 V power needed to run accessories like headlights, wipers, power windows, and the onboard computer systems that control the vehicle's functions and for safety during black out of the main Li-ion battery.

- Li-ion dominance: Experts predict that Li-ion will continue to dominate the market in coming years, potentially reaching 75 percent share by 2030. Lead acid batteries will continue to exist in special application markets.

10. Basic Types of Battery Cells[14]

EV batteries consist of several small and compact cells, which are the fundamental building blocks. These cells are manufactured in three basic forms or shapes: (i) cylindrical, (ii) prismatic, and (iii) pouch battery cells, well known types used in various battery assemblies. Each type has its own set of advantages and disadvantages, and the choice of form type depends on the specific requirements of the battery application. In general, EV manufacturers place orders for the required type of cells from the cell manufacturers for their EV depending upon the EV's range per battery charge and EV's pay load (power) requirement, location and space availability for mounting the assembled battery inside the EV. The individual cells are assembled in the EV factory itself, factoring in the voltage and ampere hour (AH) capacity of individual cells, which will determine the total numbers required in the final battery assembly and the electrical interconnection combinations thereof.

10.1. Cylindrical cells

A cylindrical Li-ion battery consists of a cylindrical metal casing that houses the internal components, including the positive and negative electrodes, separator, and electrolyte. For example, a common type of cylindrical Li-ion battery is the 18650 cell, named for its dimensions: 18 millimeters in diameter and 65 millimeters in length. While the 18650 cell is the most well-known, there are other cylindrical cell form factors, such as 26650 and 2170 cells, each with different dimensions and specifications. These are popular and have been in use for a long time and are known for reliability and safety. With mass production possible, it will lower manufacturing costs. Cylindrical Li-ion battery cells have many applications used extensively in EV, apart from in various electronics actuated gadgets. Refer to Image 3 for a representative depiction of a cylindrical cell.

Cylindrical cell manufacturing process[16,17]:

The EV battery cylindrical cell manufacturing process involves three main phases namely, electrode manufacturing, cell assembly, and cell finishing. This process is highly precision driven and carried out in automated production lines with stringent quality control. The various aspects of the process are briefly described below:

Image 3: A Typical Cylindrical Cell

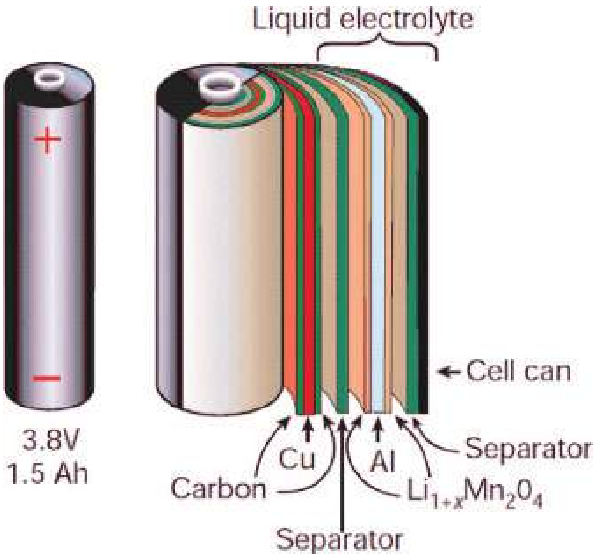

Image courtesy: Reference 15.

Manufacturing anodes and cathodes is the first step.

- Slurry formation: Raw material compounds such as NCM or LFP are mixed with a binder, conductive additives and solvent for the cathode. The anode slurry is created with graphite/silicon-graphite, carbon black, and a suitable binder. As the slurry is wet and fluid, it needs to be converted in a solid form through coating and drying process.
- Coating and drying: The cathode slurry is sprayed or coated onto a long strip of aluminum foil, and the anode slurry is sprayed onto a long strip of copper foil. The coated foil is then passed through a drying oven to evaporate the solvent.
- Calendering: It is a mechanical compression step where coated electrode sheets are passed between rollers to increase density, improve electrical contact between particles, and ensure consistent, reduced thickness. This process increases the battery's volumetric energy density, enhances electrical and ionic conductivity, and provides a controlled porous structure for efficient ion and electron transport, ultimately improving the overall cell performance.
- Slitting: The large rolls of coated foil are cut into long, narrow strips with specialised cutting machines or lasers.

Next comes the preparation of cell assembly.

- Cell assembly: Jelly roll winding is the process in cylindrical Li-ion battery manufacturing, where the anode, cathode, and separator are


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wound together in a spiral, jelly or 'Swiss roll' fashion, to form a compact and efficient internal structure. This wound unit, called the jelly roll, is then inserted into a cylindrical cell casing (often a nickel-plated steel can), and electrical connections called tabs are attached to the electrodes to create a functional, sealed battery cell. This winding process is faster than the stacking methods employed in the manufacture of prismatic and pouch cells. Metal tabs (eg, copper for the cathode and aluminum for the anode) are welded to the electrode strips to serve as electrical contacts. The positive cathode tab connects to the top of the can while the negative anode tab connects to the bottom of the can. This is carried out through ultrasonic or laser welding to achieve precision. After the jelly roll and tabs are in place, the can is sealed via crimping or beading to secure the jelly roll which is inside and create space for mounting safety monitoring components.

This is followed by the filling of the electrolyte in the can.

- Electrolyte filling and final sealing: Now an electrolyte tank injects into the can, the liquid electrolyte solution under vacuum condition, which ensures that the liquid fully penetrates the jelly roll. Thereafter, the cell is permanently sealed to prevent leakage and contamination.
- Charging, testing and ageing: In the assembly line, cylindrical battery cells are finished by first being sorted, cleaned, and grouped into modules. Then, they are electrically connected using bus bars and secured into a module case, often with an adhesive and a cooling plate for thermal management.

Finally, the modules are sealed, and the entire pack undergoes rigorous testing for electrical performance and safety before being integrated into the vehicle. This process is further described up to the packing stage below:

- Formation of SEI: The newly filled cell undergoes its first controlled charge and discharge cycles. This critical step creates a stable solid electrolyte interphase (SEI) layer on the anode, which is essential for the battery's longevity and performance.
- Degassing, if needed: For larger, higher-energy cells, gas generated during formation is released in a vacuum chamber before the final seal is applied.
- Ageing through storing and observing: The cells are stored at a controlled temperature for a period to allow the SEI layer to stabilise completely. This also helps in detecting any cells with defects by monitoring the open-circuit voltage.
- Testing and grading: Each cell is tested for its key electrical properties, such as capacity, voltage, and internal resistance. High-speed automation and computer vision are used to inspect physical defects. Cells with similar performance characteristics are then grouped together.

10.2. Prismatic cells

A prismatic cell is a type of lithium polymer cell that has a rectangular or square shape, although called as a 'prismatic' cell. Unlike cylindrical cells, which are tubular, prismatic cells have a flat design. Ease of stacking is ensured. In general, the electrode materials are kept in layers, and the cell itself is enclosed in a sturdy metal casing. These cells are often used in applications where space efficiency is crucial, as their flat shape helps better and compact packaging. Prismatic cells ensure space-efficient design. These are ideal for applications where space is at a premium. High energy density is achieved through stacking. Also, there is improvement in heat dissipation with improved thermal performance. A typical view of a prismatic cell may be seen in Image 4.

Image 4: A Typical Prismatic Cell: LiFePO4 Prismatic Cell Structure

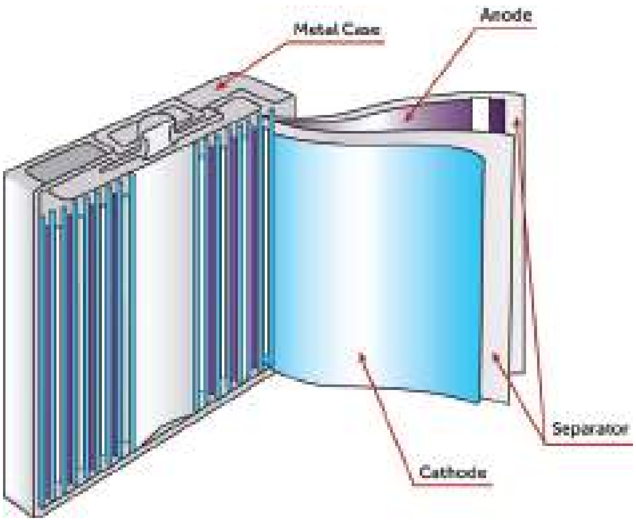

Image courtesy: Reference 18.

11. Conclusion

Part-1 is concluded here with a typical picture of a prismatic cell. The prismatic cell assembly line will be discussed in Part-2 of this paper.

Acknowledgement: The author wishes to record his gratitude to the various information sources which were consulted on the internet. A list of these references with respect to this part are given below for the readers' ready reference and further study and research in this rapidly growing field.

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Dedication

This paper is dedicated with sincere gratitude and respect to Padma Bhushan Dr. RM Alagappa Chettiar, the great Indian philanthropist, entrepreneur and eminent educationalist (1909-1957) and founder of the author's alma mater, Dr. Alagappa Chettiar College of Engineering and Technology at Karaikudi, Tamil Nadu, besides a host of educational institutions.

ABOUT THE AUTHOR

SV Varadarajan is an EE Graduate from Dr. Alagappa Chettiar College of Engineering and Technology, Karaikudi, Tamil Nadu 1971 batch and a PG Diploma in Business Management from AIMA, New Delhi. He has nearly 41 years of work experience in consultancy, erection, testing and commissioning, and maintenance of electrical, instrumentation and automation works in various integrated iron and steel projects and in thermal power plants in India and abroad. He has served as a member of BIS' Rotating Machinery Sectional Committee (ETD-15) and presented several papers and delivered lectures for students and faculty members in engineering colleges.

Capacity addition crosses 50,000 MW in FY2025-26

In FY2025-26 (up to January 31, 2026), a record 52,537 MW of generation capacity (from all sources) has been added, as per a PIB release. Of this, 39,657 MW has been added from renewable energy sources, which includes 34,955 MW of solar power, 4,613 MW of wind power, as per the release.

This marks the highest ever capacity addition in a single year, surpassing the previous record of 34,054 MW achieved in FY2024-25.

As on January 31, 2026, India's total installed power generation capacity stands at 520,510.95 MW, comprising:

- Fossil fuel-based capacity: 248,541.62 MW
- Non-fossil fuel capacity: 271,969.33 MW – Nuclear: 8,780 MW; renewable energy sources: 263,189.33 MW.

India-Canada meet to discuss clean mobility and critical minerals

Union Minister for Heavy Industries and Steel, Shri HD Kumaraswamy, recently held a high-level bilateral meeting with the Canadian delegation led by *H.E. Mr. Tim Hodgson, Minister of Natural Resources, Canada*, to strengthen cooperation in critical minerals, clean mobility, advanced manufacturing, and sustainable industrial development.

As reported, a major focus of the discussions was the development of a robust and secure battery manufacturing ecosystem and access to critical minerals essential for clean energy technologies.

The meeting reportedly witnessed detailed deliberations on joint coordination frameworks and collaboration opportunities in battery cell and component manufacturing, research and development on next-generation batteries, critical mineral supply chains, testing and certification infrastructure, clean mobility solutions, and sustainable manufacturing processes.

Summing up the discussions, Shri HD Kumaraswamy reportedly reaffirmed India's commitment to strengthening cooperation with Canada in clean energy, natural resources, and advanced manufacturing.

As per a PIB release, the meeting concluded on a positive note, with both sides expressing satisfaction over the constructive and outcome-oriented dialogue. It was reportedly agreed that structured follow-up mechanisms, technical consultations, and industry-level engagements would continue in the coming months to translate the discussions into concrete projects and partnerships.

India, GCC sign Terms of Reference for FTA

India and the Gulf Cooperation Council have signed the Terms of Reference (ToR) for the India-GCC Free Trade Agreement (FTA). The ToRs – which will guide the negotiations for the GCC-India FTA by defining its scope and modalities – were signed between Shri Ajay Bhadoo, Additional Secretary and Chief Negotiator, Department of Commerce and Dr Raja Al Marzouqi, Chief Negotiator, Secretariat General of the Gulf Cooperation Council.

The India-GCC FTA holds significant potential to unlock and expand trade with an important region, with which India has longstanding historical ties in trade and commerce. India's trade with GCC stood at USD 178.56 billion (exports: USD 56.87 billion; imports: USD 121.68 billion) in FY2024-25, accounting for 15.42 percent of India's global trade. In the last five years, India's trade with the GCC has expanded steadily, registering an annual average growth rate of 15.3 percent.

Collectively, the GCC countries represent a market of 61.5 million people (2024) and USD 2.3 trillion in terms of GDP at current prices, ranking 9th globally in this category. The GCC region is also a significant source of FDI for India, with cumulative investments exceeding USD 31.14 billion as on September 2025.

NTPC plans setting up of nuclear power projects

NTPC Ltd, a CPSE under the administrative control of Ministry of Power, Government of India (GoI), is planning for 30 GW nuclear capacity by 2047 through the following two routes, as per a PIB release:

i) Anu Shakti Vidyut Nigam Limited (ASHVINI), a JV of NTPC Ltd and Nuclear Power Corporation of India Limited (NPCIL), is in the process of establishing a 4 x 700 MW nuclear power project in the Banswara district of Rajasthan, called Mahi Banswara Rajasthan Atomic Power Project (MBRAPP).

ii) NTPC Ltd has formed a wholly owned nuclear

subsidiary, NTPC Parmanu Urja Nigam Limited (NPUNL), incorporated on 07.01.2025 under the Companies Act after getting requisite clearances.

The above target of 30 GW is a part of the government's decision of having 100 GW nuclear capacity by 2047.

To explore various options and possible collaborations with international partners, NTPC Ltd has issued an expression of interest (EoI).

Furthermore, NTPC Ltd, through its JV ASHVINI, is reportedly in the process of establishing a 4 x 700 MW nuclear power project in the Banswara district of Rajasthan, called Mahi Banswara Rajasthan Atomic Power Project (MBRAPP). The current projections envisage initial testing of MBRAPP's first 700 MW unit by FY2032-33.

Government issues draft Electricity (Amendment) Bill, 2025

The Central Government has issued the draft Electricity (Amendment) Bill, 2025, proposing comprehensive reforms in the power sector. The draft Bill seeks to take measures for financial sustainability, promote competition, strengthen regulatory accountability, and accelerate India's transition towards non-fossil fuel-based electricity generation, in alignment with the vision of Viksit Bharat @ 2047. The key reforms proposed are:

i) Financial viability: The proposed amendments mandate cost-reflective tariffs, empower commissions to determine tariffs suo motu from April 1st each year.
ii) Economic competitiveness: The proposed reforms aim to rationalise tariffs, unlock demand, reduce costs, and enhance India's economic productivity and global competitiveness.
iii) Energy transition: To achieve 500 GW of non-fossil capacity by 2030, the amendments propose empowering CERC to introduce market-based instruments to attract investment and accelerate renewable capacity addition. Enforceable non-fossil energy obligations are also proposed to align the Electricity Act with the Energy Conservation Act.
iv) Ease of living and ease of doing business: The amendments propose uniform national standards of service to improve supply quality and accountability. Consumer-friendly measures include capping assessment for unauthorised use to one year and reducing appeal pre-deposit requirements.
v) Regulatory strengthening: To enhance accountability and efficiency, it is proposed that governments may refer complaints against CERC and SERC members, with expanded grounds for removal. A 120-day timeline is proposed for adjudicatory decisions, and the strength of APTEL is proposed to be increased to address pendency.
vi) Other reforms: Powers for installation and maintenance of electric lines are proposed to be transitioned from the repealed Telegraph Act, 1885 into the Electricity Act, 2003, with states framing compensation framework. To reduce network duplication and costs, distribution licensees are proposed be permitted to supply electricity through shared networks, subject to regulatory approval and charges.

Upon enactment, the provisions of the Electricity (Amendment) Bill, 2025 will apply uniformly across all states.

The bill is reportedly currently in consultation stage and extensive consultation with different categories of stakeholders is in process.

India and Bhutan to strengthen cooperation in power sector

Minister of Energy and Natural Resources of Bhutan, Shri Lyonpo Gem Tshering, recently met with the Union Minister of Power and Housing & Urban Affairs, Shri Manohar Lal, and the Minister of State for Power and New and Renewable Energy, Shri Shripad Naik with an aim to strengthen the longstanding cooperation between the two countries in the power sector.

Indo-Bhutan hydropower cooperation began in 1961, followed by an agreement on hydroelectric power cooperation in 2006.

During the discussions, both sides reportedly deliberated on the commercial optimisation of power output from the Punatsangchhu-II Hydroelectric Project (1,020 MW). Emphasis was also placed on the early commissioning of the Punatsangchhu-I Hydroelectric Project (1,200 MW).

The discussion also covered the way forward for the Sankosh Hydropower Project. In addition, the cross-border transmission links till 2040 were reportedly assessed. It also covered the need to streamline approval for scheduling of power, particularly during lean months in Bhutan.

India-UK Offshore Wind Taskforce launched

Union Minister of New and Renewable Energy Shri Pralhad Joshi recently launched the India-UK Offshore Wind Taskforce in the presence of the Rt Hon Deputy Prime Minister of the UK David Lammy and British High Commissioner to India Lindy Cameron.

Calling the taskforce a 'trustforce', Shri Joshi said it reflects the confidence that India and the UK can work together to address real execution challenges. He urged that the platform deliver time-bound workstreams, measurable milestones and visible progress, converting global lessons into solutions tailored to Indian conditions.

Describing the India-UK Offshore Wind Taskforce as a working mechanism rather than a symbolic platform, the minister reportedly said that it has been constituted under Vision 2035 and the Fourth Energy Dialogue to provide strategic leadership and coordination for India's offshore wind ecosystem. He observed that while the UK has demonstrated global leadership in scaling offshore wind and developing mature supply chains, India brings scale, long-term demand and a rapidly expanding clean energy ecosystem.

Shri Piyush Goyal calls for India-Brazil trade surge beyond USD 15 billion, deeper ties in renewables, emerging tech

Union Minister of Commerce and Industry Shri Piyush Goyal addressed the Plenary Session of the India-Brazil Business Forum in New Delhi, highlighting the expanding cooperation between India and Brazil across sectors. Referring to the growth in bilateral trade by 25 percent in the past year to reach USD 15 billion, he described the current level as suboptimal and called for greater ambition in further strengthening economic engagement between the two countries.

Highlighting the India-Brazil partnership, the Minister described the two countries as natural partners, bound by democracy, diversity and shared aspirations for development. He observed that the relationship has evolved into a strong and multifaceted strategic partnership driven by people-to-people ties and expanding cooperation across sectors. Brazil is India's largest trading partner in the Latin America and Caribbean region, with bilateral engagement deepening in defence, energy, agriculture and agrochemicals.

Describing Brazil's strengths, Shri Goyal stated that India and Brazil together have the potential to reshape global value chains through resources, innovation and a forward-looking vision, and invited Brazilian companies to partner with India in co-creating jobs, adding value and leveraging technology.

The minister reaffirmed the shared commitment of both countries to safeguarding national interests and promoting equitable access within global intellectual property frameworks, particularly in protecting indigenous technologies.

MNRE holds stakeholder consultation on Draft Floating Solar Potential Assessment and Draft Policy Framework

The Union Ministry of New and Renewable Energy (MNRE) recently organised a stakeholder consultation workshop to discuss the draft Floating Solar Photovoltaic (FSPV) Potential Assessment Report and the draft Floating Solar Policy prepared by National Institute of Solar Energy (NISE) and IIT Roorkee, respectively.

Considering the prevailing land constraints faced in renewable energy (RE) projects, FSPV has emerged as an alternate avenue. However, only about 700 MW of FSPV projects have been commissioned in India so far. This is mainly due to lack of data on the potential sites and clear framework for project execution. To overcome this bottleneck, MNRE – in association with NISE and IITR – has prepared these documents.

Discussions at the workshop focused on providing innovative solutions like plug and pay models, allotment of water bodies with all necessary approvals, etc, for derisking the developers and investors. Based on the potential and policy, states/UTs may also identify and prioritise sites for the development of FSPV projects.

PLI Scheme with Rs1.91 lakh crore outlay drives strong industry participation across 14 strategic sectors

The Production Linked Incentive (PLI) scheme, with an incentive outlay of Rs1.91 lakh crore, represents a strategic reform initiative aimed at strengthening India's manufacturing base. With 836 applications approved across 14 strategic sectors, the scheme reflects strong industry confidence and robust adoption. Since its launch, the PLI scheme has demonstrated sustained uptake by industry and consistent expansion of manufacturing capacity.

As on December 31, 2025, the cumulative performance under the scheme, as per a PIB release, is as follows:

- **Approved applications:** 836 applications across 14 sectors
- **Investment:** Cumulative investment exceeding Rs2.16 lakh crore.
- **Production / Sales:** Cumulative sales exceeding Rs20.41 lakh crore.
- **Exports:** Cumulative exports exceeding Rs8.3 lakh crore.
- **Employment:** More than 14.39 lakh direct and indirect jobs generated.
- **Incentive disbursement:** Rs28,748 crore disbursed as on December 31, 2025.

These outcomes indicate sustained momentum in investment inflows, production expansion, export growth, and employment generation across targetted sectors.

Shri Piyush Goyal launches Export Promotion Mission to boost MSME exports, strengthen global competitiveness

The Union Minister of Commerce and Industry, Shri Piyush Goyal, recently launched seven additional interventions under the Export Promotion Mission (EPM), a flagship initiative of the Department of Commerce aimed at empowering micro, small and medium enterprises (MSMEs) for global markets. These interventions are designed to address key challenges faced by Indian exporters, promote broad-based and inclusive export growth, and strengthen India's position as a globally competitive export powerhouse.

Shri Goyal said the Export Promotion Mission is aimed at promoting new products, services and exporters, while enabling Indian businesses to access new markets. He noted that India has recorded double-digit growth in merchandise exports in the first half of February, reflecting strong market confidence and proactive industry participation.

He stated that the mission seeks to simplify processes for MSMEs, strengthen access to credit, enhance quality standards, support compliance with international regulations and expand logistics and warehousing infrastructure globally. Initiatives such as overseas warehousing, including Bharat Mart in Dubai, are intended to provide Indian exporters with strategic access to markets across the GCC, Africa, Central Asia and Europe.

The newly launched interventions aim to address structural constraints faced by MSMEs, including high cost of capital, limited access to diversified trade finance instruments, compliance burdens in international markets, logistics disadvantages, and barriers to market entry.

NATIONAL

CEA issues roadmap to 100 GW of hydro PSPs by 2035-36

The Central Electricity Authority (CEA) has issued a report – 'Roadmap to 100 GW of Hydro Pumped Storage Projects by 2035-36' – outlining policy, regulatory, institutional, and infrastructure measures required for enabling the development of 100 GW of pumped storage capacity over 10 years. According to the report, the total installed capacity of PSPs is expected to reach about 87 GW by 2033-34. The average capacity addition per year will be 9 GW per year. As per the report, India's pumped storage potential is estimated at about 267 GW, comprising about 58 GW of on-stream PSPs and 209 GW of off-stream projects. As of December 31, 2025, 10 PSPs with a combined installed capacity of 7 GW are in operation, while another 10 projects totalling 12 GW are under construction. Projects of about 9.6 GW with detailed project reports (DPRs) are concurred by the CEA but are yet to commence. The report also identifies 54 PSPs totalling 75 GW in the survey and investigation stage, including 52 closed-loop projects designed primarily for storage. It also notes that assessed PSP storage potential has sharply risen in recent years, increasing from 97,565.6 MW as of December 31, 2022, to 266,845.6 MW as of December 31, 2025.

Rajasthan Electricity Regulatory Commission notifies revised procedure for intra state grid connectivity

The Rajasthan Electricity Regulatory Commission (RERC) has notified the 'Procedure for Grant of Connectivity to the Intra State Transmission System'. It will apply to connectivity applications at 33 kV and above, covering state and central generating companies, independent power producers, renewable energy projects, and energy storage systems. The designated nodal agency – Rajasthan Rajya Vidyut Prasaran Nigam Limited – will process applications and grant connectivity. Under the framework, applicants will pay non-refundable processing fees ranging from Rs1-9 lakh depending on capacity and category. For renewable energy projects, grid connectivity charges are fixed at Rs250,000 per MW. Non-renewable applicants will pay the actual cost of the transmission bay developed for connectivity.

SJVN commissions 70 MW Dhubri solar project in Assam

SJVN Limited, through its wholly owned subsidiary, SJVN Green Energy Limited, has commissioned its 70 MW Dhubri solar power project in Assam. The project has been developed on 330 acre of lease-based land at Khudigaon Pt II village in the Dhubri district at Rs3.67 billion. It is expected to generate 141.13 million units in the first year and about 3,230 million units over 25 years. Power from the project will be supplied to Assam Power Distribution Company Limited.

MoP revises ash utilisation guidelines for coal and lignite-based thermal power plants

The Ministry of Power has revised the guidelines for disposing current and legacy ash by coal and lignite-based thermal power plants. The revised framework mandates 100 percent ash utilisation while limiting the tariff burden on electricity consumers. Thermal power plants will also be required to declare the quantity of "issuable ash" – fly-ash, bottom-ash and pond-ash – available for distribution after meeting existing commitments and technical constraints, before initiating disposal. A portion of issuable fly-ash is also mandated for supply at concessional rates to micro and small enterprises and local users within a 100-km radius of the plant.

NLC India, NALCO sign MoU for thermal and RE collaboration

NLC India Limited and National Aluminium Company Limited (NALCO) have signed an MoU for collaborating on the development of thermal and renewable energy projects. The agreement provides a framework for cooperation in a proposed 1,200-MW thermal captive power project and renewable energy development to meet NALCO's captive and long-term power requirements. The collaboration will also explore long-term power tie-ups, including captive and group captive arrangements, coal supply arrangements, and potential joint project development, including the formation of a JV company.

REC and PFC boards provide in approval for merger

The Boards of Directors of REC Limited (REC) and Power Finance Corporation Limited (PFC) have provided in principle approvals for proceeding with a proposed merger of the two public sector non-banking financial companies (NBFCs). As reported, the proposed restructuring will involve formulating a detailed merger scheme according to applicable laws and regulatory requirements, which will be placed before relevant authorities for approvals. PFC currently holds a 52.63 percent stake in REC, following the acquisition of the Government of India's shareholding in REC in 2019.

MNRE issues fourth revised ALMM II for solar cells

The Ministry of New and Renewable Energy (MNRE) has issued the fourth revised approved list of models and manufacturers (ALMM) for solar cells. As per the updated list, Evervolt Solar Technology India Private Limited has for the first time entered the ALMM II list with an enlisted annual capacity of 1,074 MW. Evervolt will manufacture mono passivated emitter rear contact solar cells sized 182.2 mm by 182.2 mm with 10 busbars, with efficiencies ranging from 22-23.5 percent. The revision also includes new model additions by existing manufacturers.

INTERNATIONAL

India, Bhutan to cooperate on hydropower projects and transmission planning

India and Bhutan have reportedly held discussions for strengthening cooperation in the power sector focused on hydropower development and long-term transmission planning. As reported, both countries have held discussions on commercial optimisation of power generation from the 1,020 MW Punatsangchhu II hydropower project and underlined early commissioning of the 1,200 MW Punatsangchhu I project to support Bhutan's power exports and regional energy security. Discussions were also reported on the future roadmap for the Sankosh hydropower project and transmission infrastructure planning up to 2040.

Bondada Engineering, Bryanston Renewables sign MoU for green-powered data centres

Bondada Engineering Limited (BEL) has signed an MoU with Bryanston Renewables FZCO, Dubai, UAE, to jointly develop green-powered data center packages in India and select international markets. The partnership aims at addressing the rapidly growing demand for sustainable digital infrastructure while supporting the expansion of energy-efficient and renewable-powered data ecosystems. The MoU establishes a collaborative framework between the two companies to develop/deploy data centre project packages powered by green energy. These solutions will cater to domestic and international investors as well as data centre operators, aligning with India's accelerating digital infrastructure growth and increasing focus on environmentally responsible data storage capacity.

World Bank approves USD 1.02 billion programme to enable regional electricity market in Central Asia

The World Bank has approved the regional electricity market interconnectivity and trade programme, a 10-year regional initiative to strengthen electricity cooperation, cross border power trade, and renewable energy integration across Central Asia. To be implemented in three phases, the programme is designed to establish the region's first regional electricity market. Phase-I will cover Kyrgyzstan, Tajikistan, and Uzbekistan along with the Central Asian countries' coordinating dispatch centre, CDC Energia. Under this phase, participating entities will receive USD 143.2 million in grants and concessional financing, including USD 140 million from the International Development Association and USD 3.2 million from the Central Asia Water and Energy Program.

India and Iceland to explore CCUS and geothermal projects

India and Iceland are reportedly exploring cooperation for developing geothermal projects and carbon capture, utilisation and storage (CCUS) projects with public sector undertakings (PSUs), Icelandic technology firms and research institutions. As reported, discussions between the two countries covered opportunities linked to India's estimated 10.6 GW geothermal potential, including ONGC's Puga Valley project with potential capacity of up to 100 MW.

Radiance Renewables raises USD 100 million to expand RE portfolio in India

With an aim to support the next phase of its green energy expansion in India, Radiance Renewables has secured about USD 100 million in equity funding. Impact Fund Denmark and the Dutch entrepreneurial development bank have each reportedly committed investments of about USD 50 million. Radiance Renewables – backed by Eversource Capital – plans to deploy the capital across greenfield solar projects, hybrid wind solar assets, and behind the meter installations for its core commercial and industrial customers. As reported, the company plans to expand into battery energy storage solutions and invest in inter-state transmission projects.

Adani Energy Solutions secures long-term financing from Japanese banks for ±800 kV HVDC project

Adani Energy Solutions Limited (AESL) has reportedly secured long-term financing from a consortium of Japanese banks for a high-voltage direct (HVDC) current transmission project to strengthen renewable energy evacuation across northern India. The project involves development of a ±800 kV HVDC transmission network with an evacuation capacity of 6,000 MW over a 950 km corridor connecting Bhadla in Rajasthan to Fatehpur in Uttar Pradesh. The project is expected to be commissioned by 2029.

CORPORATE

Torrent Power to acquire Nabha Power from L&T for Rs68.89 billion

Torrent Power Limited has entered into a definitive agreement with L&T Power Development Limited, a wholly owned subsidiary of Larsen & Toubro, to acquire 100 percent equity stake and convertible instruments in Nabha Power Limited for Rs68.89 billion. Nabha Power is a fully contracted thermal power asset with a reported revenue of Rs48.66 billion in 2024-25. Post acquisition, Torrent Power's operational capacity is expected to increase from about 5 GW to 6.4 GW.

Hartek secures substation orders worth Rs7.35 billion

Hartek Group's power systems business unit has secured cumulative orders across the utility, independent power producer, and industrial segments for substation and transmission infrastructure ranging from 66 kV to 765 kV. The orders are valued at Rs7.35 billion. The projects are reportedly spread across nine stated, including Jammu, Punjab, Haryana, Gujarat, Rajasthan, Madhya Pradesh, Maharashtra, Karnataka, and Andhra Pradesh. The projects awarded aim at strengthening regional and inter-state transmission networks and supporting power evacuation and grid reliability.

Tata Power commissions 765 kV transmission lines in Uttar Pradesh

Tata Power Company Limited has commissioned two 765 kV extra high voltage (EHV) transmission corridors in Uttar Pradesh totalling to 574 circuit kilometres (ckm) – the Mainpuri to Bara line spanning 380 ckm and the Mainpuri to Unnao line spanning 194 ckm. The corridors – developed under the South East UP Power Transmission Company Limited (SEUPPTCL) project – are expected to strengthen the Northern Grid while enabling large scale power evacuation across the state. Once operational, the lines are likely to facilitate evacuation of more than 3,000 MW of thermal power generated within Uttar Pradesh. The project executed involved over 42,000 metric tonne of tower steel, 6,900 km of conductor stringing and completion of more than 100 major crossings, including railways, rivers and existing transmission corridors.

Genus Power deploys 10 million smart meters under RDSS

Genus Power, as an advanced metering infrastructure service provider (AMISP), has reportedly deployed 10 million smart meters under the revamped distribution sector scheme (RDSS) across distribution companies in nine states. To strengthen production capability, the company has also commissioned an integrated manufacturing facility at Kotputli, in addition to its existing facilities at Jaipur, Haridwar, and Guwahati.

Bajel Projects secures ultra mega order for 765 kV inter-regional transmission corridor

Bajel Projects Limited has secured an ultra-mega domestic engineering, procurement and construction (EPC) order of about Rs4 billion for developing high-capacity transmission infrastructure. The contract – designated as transmission line package TL02 – involves construction of the 765-kV Vindhyachal Pool-Prayagraj double-circuit line part II under the inter-regional North Region–West Region transmission system strengthening initiative. The line aims to relieve loading on the existing 765-kV Vindhyachal-Varanasi double-circuit line and support more balanced power exchange between the northern and western grids.

KEC International secures USD 1.02 billion orders across several businesses

KEC International Limited has secured new orders worth Rs1.02 billion across its civil, transportation, transmission and distribution, and cables and conductors businesses. In T&D, the company has won 220 kV and 132 kV cabling works from a steel producer in eastern India and supply orders for towers, hardware and poles in the US. In cables and conductors, it has secured supply orders for various types of cables and conductors in India and overseas markets.

Powering India's Next Phase of Growth

With a legacy of more than five decades, KEI Industries Limited has built its reputation on the foundations of engineering excellence, uncompromising quality, and continuous innovation, and remains a committed partner in India's growth story.

As India advances toward becoming a globally competitive, infrastructure-led economy, the demand for safe, efficient, and future-ready electrical systems continues to grow at an unprecedented pace. At the heart of this transformation stands KEI Industries Limited (KEI), playing a vital role in connecting national ambition with reliable, high-performance solutions.

KEI is not just a manufacturer of wires and cables – it is a strategic enabler of India's development journey. From large industrial corridors and smart cities to high-rise residential developments and

landmark infrastructure projects, KEI's products form the essential backbone that supports progress, safety, and connectivity across the nation.

A Journey Defined by Quality and Innovation

With a legacy of more than five decades, KEI has built its reputation on the foundations of engineering excellence, uncompromising quality, and continuous innovation. As India's energy and infrastructure sectors evolve toward smarter and greener solutions, KEI remains committed to adopting advanced technologies and sustainable manufacturing practices that align with both global standards and national priorities.

One of the most significant milestones in this journey is the development of ConFlame Green+, a next-generation, environmentally responsible wiring solution. Designed with superior flame-retardant properties, low smoke emission, and reduced toxicity, ConFlame Green+ responds to the growing need for enhanced safety and sustainability in modern construction and industrial applications.

Driving Safety with Sustainability

ConFlame Green+ represents KEI's forward-looking approach to the future of electrical infrastructure.

As safety norms and environmental, social, and governance (ESG) expectations become increasingly rigorous, this innovation enables customers and partners to meet compliance requirements while maintaining high standards of performance and reliability.

For developers, engineering, procurement and construction (EPC) contractors, architects, and project consultants, ConFlame Green+ offers a dependable, future-ready solution – one that balances protection, environmental responsibility, long-term value and high performance.

Extending Impact Beyond Projects

KEI's presence is not limited to infrastructure and industrial sites alone. Through strategic brand initiatives and national-level engagements, KEI continues to build meaningful connections with households, professionals, and communities across India.

By aligning platforms that reflect values of performance, teamwork, and trust, KEI reinforces its promise of delivering products that stand for safety and reliability – whether powering large-scale icons projects like the world's tallest Statue of Unity, stadium, Parliament building, Ram Mandir, or everyday living spaces.

Strengthening the Framework of a Viksit Bharat

From power generation to transmission to distribution transport networks and power distribution systems to green buildings and expanding industrial zones, KEI remains a steadfast partner in India's growth story.

KEI's comprehensive portfolio includes house wires (ConFlame Green+, ConFlame FR, ConFlame FRLS, ConFlame HFFR), low tension (LT) power cables, high tension (HT) power cables, extra high voltage (EHV) cables, control and instrumentation cables, solar cables, flexible cables, stainless steel wires, and specialty cables – each engineered to deliver safety, durability, and performance across diverse applications.

Guided by innovation, sustainability, and a people-centric vision, KEI is not merely laying wires and cables – it is helping shape the foundation of a safer, smarter, and truly *Viksit Bharat*.

As the nation moves confidently toward a future defined by progress and resilience, KEI will continue to lead with integrity, responsibility, and lasting impact.

Digital Insulation Tester

Meco Instruments Pvt Ltd's model **DIT 918+** is a 2.5 kV-200 GΩ **digital insulation tester** that measures insulation resistance up to 200 GΩ, voltage up to 600 V AC and 1,000 V DC. It also has a special function of measuring polarisation index (PI) and dielectric absorption ratio (DAR).

The DIT 918+ digital insulation tester's features include: Large LCD display of 128 x 64 dot-matrix; high accuracy for insulation measurement for AC/DC voltage; range selection and single person push button operation; data holding function; auto range (insulation test); red LED indicator and red backlight for high voltage (HV); battery operated; IS 10656-1983-compliant; as per Safety Standard IEC/EN 61010-1 and 61010-31; Over Voltage CAT II, 600 V; and as per EMC Standard IEC 61326-Class B.

This is the best tool for testing insulation resistance and voltage of transformers, switches, HV systems, wires, cables, appliances and motors, among others.

Smart Water Meter

HPL Electric & Power Ltd (HPL) has launched **'Neeram Pulse'** – its **smart water metering solution** engineered for accurate measurement and seamless integration with automatic meter reading (AMR)/advanced meter infrastructure (AMI) systems, aimed at supporting utilities and smart city programmes as water networks transition to data-led operations.

Neeram Pulse has been designed for deployment environments where robustness, long life and tamper resilience are as critical as metering accuracy.

Its features include:

- Built to international and Indian standards: IS:779:1994 and ISO 4064.
- High-accuracy, long-life metering platform with dry dial multi-jet register and shielded magnetic coupling.
- Tamper and magnetic interference detection, supporting stronger revenue assurance.
- IP68 fully sealed water body, designed for challenging field conditions.
- AMR-ready with communication options including LoRa RF.
- Up to 10 years battery life (subject to configuration and operating conditions).

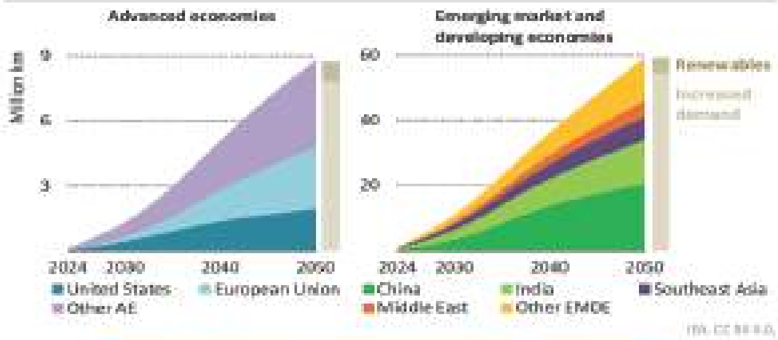
Select highlights of the advanced AMR module capabilities include:

- Reverse flow detection and recording, with alarm generation.
- Leakage detection and alarms through HES, supporting faster identification of losses.
- Event alarms including module removal, magnetic fraud attempt, backward flow and battery low.
- LoRa RF interface with frequency band 865–868 MHz and stated LOS reading distance (as per catalogue).

Global Scenario

Global Electricity Networks

Expansion of grid lines by driver in selected region/country in the CPS, 2024-2050

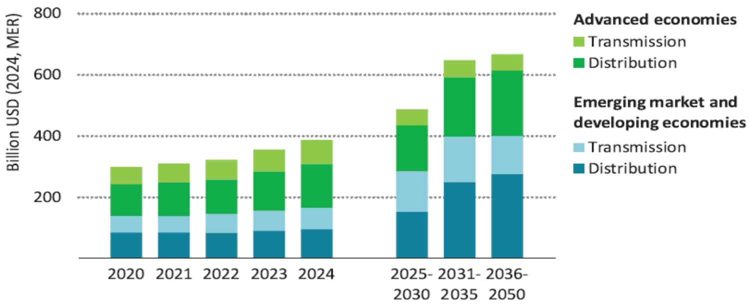


IEA. CC BY 4.0.

Most new lines are installed to meet increased demand; nearly 90% of all new lines are in emerging market and developing economies

Note: AE = advanced economies; EMDE = emerging market and developing economies.

Average annual grid investment by economic grouping in the CPS to 2035



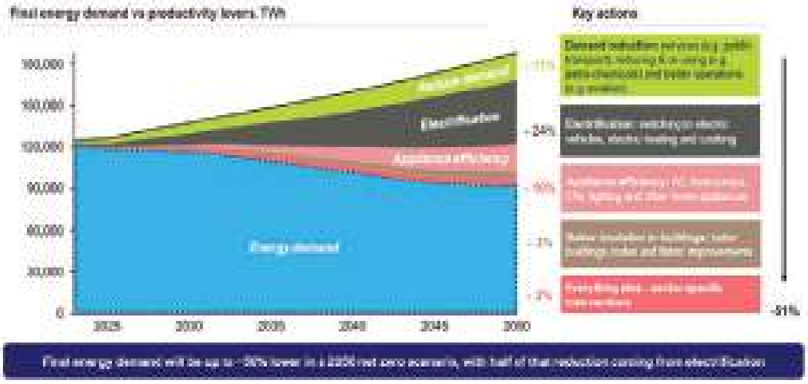
IEA. CC BY 4.0.

Grid investment rises in nearly all regions to modernise and expand transmission and distribution to meet rising electricity demand and to connect new sources of generation

Note: MER = market exchange rate.

ELECTRIFIED ENERGY SYSTEMS ARE MORE EFFICIENT, AS ELECTRIFICATION CAN REDUCE FINAL ENERGY DEMAND BY ~25% BY 2050

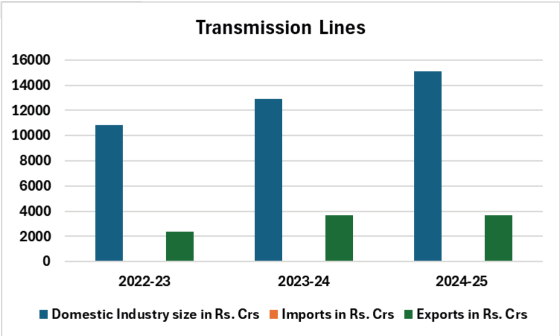
Grid build-out is a necessity for developing an electrified energy system, which is more efficient and often lower cost

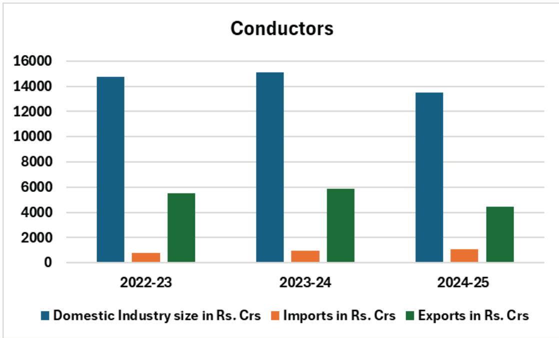


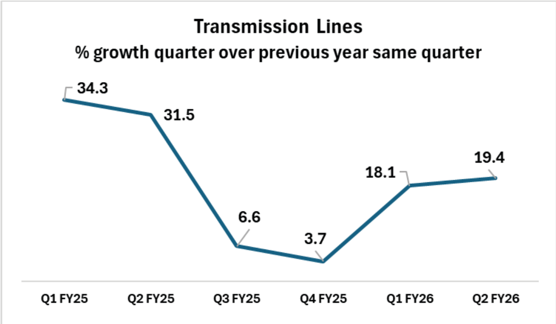
Source: WEO 2025, SYSTEMIQ

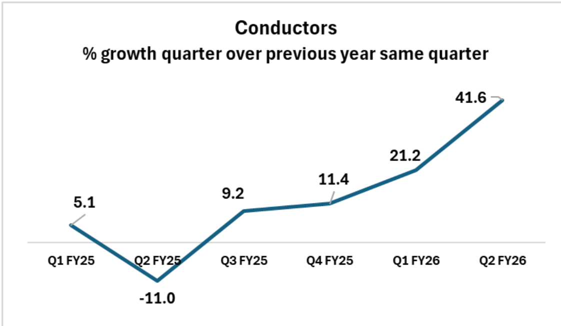
Indian Scenario

Indian Transmission Line and Distribution Sector

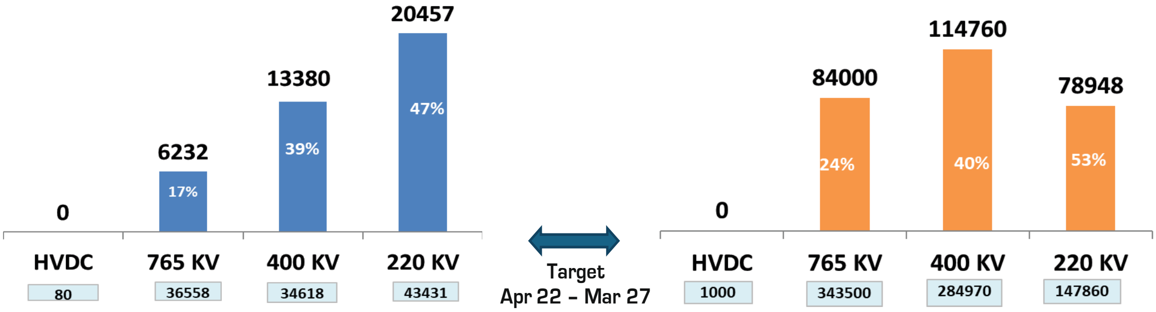




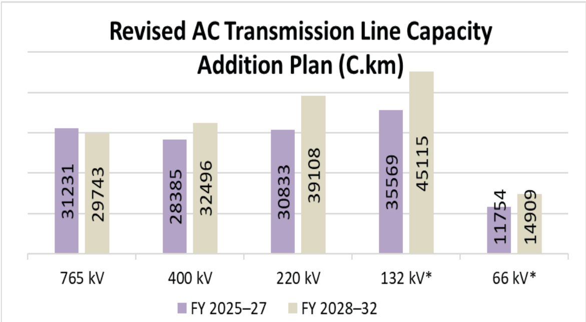


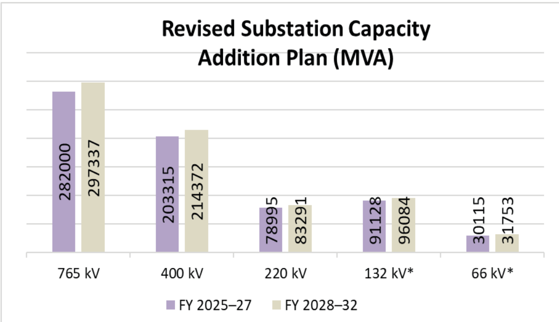


Target of 5 years FY23 – FY27 vs Achievement till Sep 25 (Apr 22 to Sep 25)



As per IEEMA study on demand landscaping of electrical equipment by 2032



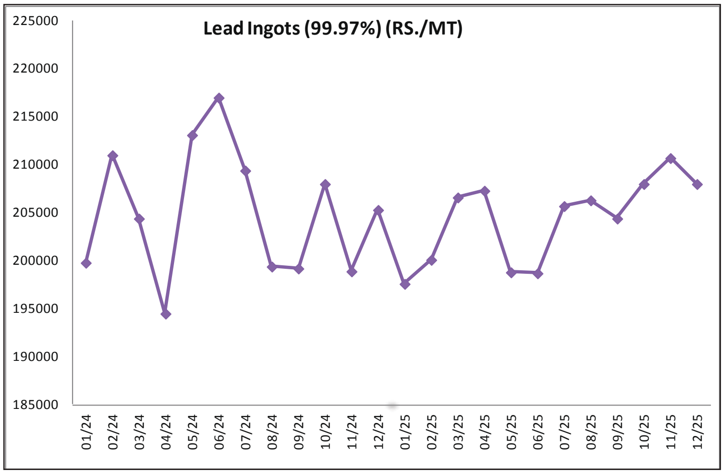


Source: IEEMA, CEA

Basic Prices and Indices

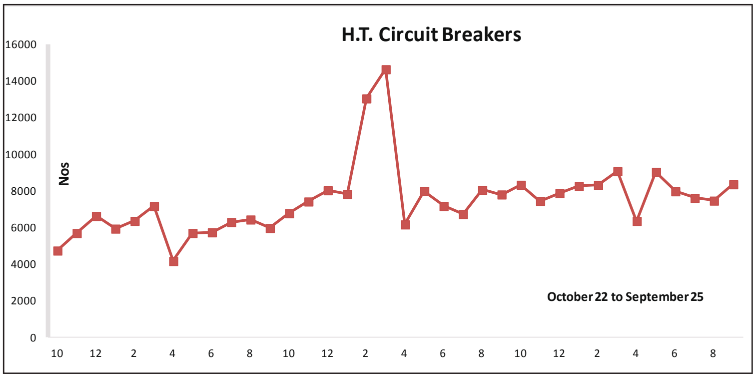
	as on December 1, 2025
IRON, STEEL & STEEL PRODUCTS	
BLOOMS (SBLR) 150mmX150mm	42214.00
BILLETS (SBIR) 100MM	44710.00
CRNGO Electrical Steel Sheets M-45,C-6 (Ex-Rsp)	117.45
CRGO Electrical Steel Lamination	567918.00
NON-FERROUS METALS	
Electrolytic High Grade Zinc	324500.00
Lead (99.97%)	208000.00
Copper Wire Bars	1119649.00
Copper Wire Rods	1144212.00
Aluminium Ingots - EC Grade (IS 4026-1987)	312808.00
Aluminuium Properzi Rods - EC Grade (IS5484 1978)	317892.00
Aluminium Busbar (IS 5082 1998)	386000.00
OTHER RAW MATERIALS	
Epoxy Resin CT - 5900	766.00

Phenolic Moulding Powder	115.10
PVC Compound - Grade CW- 22	151825.00
PVC Compound Grade HR - 11	152825.00
Transformer Oil Base Stock (TOBS)	99771.00
OTHER IEEMA INDEX NUMBERS	
(IN-BUSDUCTS) (BASE August 2000=100) FOR THE MONTH October 2025	408.45
(IN - WT) (BASE JUNE 2000=100)	422.50
(IN-INSLR) Wholesale price index number for 'Insulators' (Base 2011-12 = 100) for the month October 2025	135.20
(FE) Wholesale price index number for 'Manufacture of Basic Metals (Base 2011-12 = 100) for the month October 2025	137.10
(FP) Wholesale price index number for' Fuel & Power (Base 2011-12 = 100) for the month October 2025	145.20
(W) ALL INDIA AVERAGE CONSUMER PRICE INDEX NUMBER FOR INDUSTRIAL WORKERS (BASE 2016=100) October 2025	147.70
# Estimated, NA: Not available	



Source: IEEMA

Production Statistics



Name of Product	ACC Unit	Production		Highest Annual Production
		For the Month Sept.-25	From Oct. 24 to Sept. 25	
Electric Motors				
AC Motors - LT	000' KW	1,823.00	20,087.00	20,043.00
AC Motors - HT	000' KW	495.00	5,675.00	5,724.00
DC Motors	000' KW	32.00	405.00	618.00
Switchgears *				
Contactors	000' Nos.	1,526.00	18,030.00	17,639.00
Motor Starters	000' Nos.	146.00	2,322.00	2,519.00
SDF	000' Nos.	59.00	673.00	752.00
Circuit Breakers DIN Rail Mounted	000' Poles	22,144.00	264,723.00	251,710.00
Circuit Breakers - LT	Nos.	653,169.00	7,009,039.00	6,257,425.00
Circuit Breakers - HT	Nos.	8,362.00	96,067.00	119,282.00
Custom Built Product	Rs. Lakhs	57,329.00	405,136.00	452,536.00
HRC Fuses & Overload Relays	000' Nos.	1,577.00	21,532.00	21,910.00
Power Cables *	KM	111,730.00	1,103,100.00	1,104,504.00
Power Capacitors - LT & HT	000' KVAR	7,496.00	67,859.00	65,385.00
Transformers *				
Distribution Transformers	000' KVA	7,391.00	32,416.00	74,025.00
Power Transformers	000' KVA	76,271.00	266,567.00	244,163.00
Instrument Transformers				
Current Transformers	000' Nos.	157.00	6,659.00	7,800.00
Voltage Transformers	Nos.	17,664.00	226,538.00	217,752.00
Energy Meters	000' Nos.	5,087.00	47,954.00	38,545.00
Transmission Line Towers *	000' MT	110.00	1,249.00	1,166.00

Weighted Production

Source: IEEMA

INDEX TO ADVERTISERS

SHOCKS and SPARKS

CORPORATE COUPS

BY: **RG Keswani**

It was nearly 3 pm and the irate Sales Manager complained to his secretary. “This new salesman is so forgetful. I wonder whether he will be able to do justice to his job. I told him to bring a sandwich for me after his lunch.” Just then the door flew open and in bounced the salesman.

“Sir, you’ll never be able to guess it, I got an order of over a lakh of rupees. While I was having lunch, I met the manager of a large store. We got talking and he gave me this order” said the salesman looking at the sales manager for an appreciation.

“See” sighed the sales manager to his secretary “I told you. He’d forget the sandwich.”

Attendance at the council meetings of an Association was extremely poor and the last meeting was attended by only the president and one of the vice presidents.

New president wrote to each member informing him that he was the ‘Guest of Honour’ at the next meeting enclosing a badge with such inscription. All 25 members attended the meeting with badge on their lapels and arrived on the dot.

Form IV (See Rule 3)

Statement about ownership and other particulars about Newspaper

IEEMA Journal

1.	Place of publication	:	Mumbai
2.	Periodicity of its publication	:	Monthly
3.	Printer’s Name	:	Ms Charu Mathur
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6.	Names and addresses of individuals who own the newspapers and partners or shareholders holding more than one per cent of the total capital	:	Indian Electrical & Electronics Manufacturers’ Association 501, Kakad Chambers, 132, Dr A Besant Road, Worli, Mumbai 400 018.

I, Ms. Charu Mathur, hereby declare that the particulars given above are true to the best of my knowledge and belief.

(Ms Charu Mathur)
Signature of Publisher

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