Report on Modernization of Transmission System and making Smart & Future Ready

Task Force on Modernization of Transmission

January 2023

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Executive Summary

Introduction

Transmission is an integral part of power supply system and key enabler for electricity generation and distribution. Indian transmission network is one of largest single national grid in the world spread over 4,60,358 ckm transmission line and about 11,26,287 MVA transformation capacity (Jun'22) operating at one frequency. The robust National grid, which is also interconnected with neighboring countries, viz., Bangladesh, Nepal, Bhutan, Myanmar, has facilitated development of vibrant power market enabling access to low-cost power supply in the South Asian region.

Indian power sector is under transition to address energy security and climate crisis. There is a continuous shift from fossil fuel to non-fossil fuel/renewable based generation (mainly solar & wind) to facilitate accelerated development of low carbon energy system. Towards this, India has set a target to attain 50% of its generation capacity through non-fossil sources by 2030 with great emphasis on capacity addition through wind and solar.

Major Challenges

Gestation period of renewable generation project is short in comparison with development of associated transmission infrastructure required for its evacuation and integration with National Grid. Increased focus on electrification of transportation through Electric vehicle also needs consideration. Further, there are many challenges in implementation of transmission system especially acquiring land for establishment of pooling stations/substations due to rapid urbanization, Right of Way issues, availability of skilled workforce for construction of new lines etc. In addition, transmission assets are getting older affecting the performance and reliability of the system. Besides, in recent past, frequency of natural disasters like thunderstorm, super cyclones, floods etc. has increased many folds making transmission infrastructure vulnerable. Due to increased number of transmission elements spread over geographically, its maintenance and upkeep to maintain high degree of system availability and reliability (reduction in forced outages/tripping) are also a challenge.

In view of the above, modernization of existing transmission infrastructure is required to improve its reliability, resilience, efficiency and to enhance transfer capacity using latest technology coupled with digitalization. Further, intermittency and variability of output from renewable generating stations are also to be addressed including provision of adequate balancing reserves, inertial support in maintaining grid security and stability. This calls for making transmission smart with minimal human intervention and self- correcting features.

Towards this, Ministry of Power, Govt. of India vide order dated 22.09.2021 has constituted a Task Force to formulate a plan for modernization of Transmission Sector and making it smart and future ready. The members of the Task Force have shared existing practices of their respective organizations and experiences. They also deliberated on various issues and stated their view points. A questionnaire/format was circulated to all state utilities including UTs to collect the base line data/information, technologies used, performance parameters and also plans for integration of new technologies including sensors, communication, automation, big data analytics, cyber security etc. Further, four sub-groups were formed drawing experts from various Utilities & Institutions to identify means / suggestion to address various issues.

The Task Force analysed the data provided by various transmission utilities as well as inputs of sub-groups. Based on the studies and deliberations, recommendations of the Task Force are presented in this report. Various technologies have already been adopted by transmission utilities, mainly at ISTS level, as listed below:

a) Transmission corridor addressing right of way and acquiring land for substation:

i) 765kV D/c lines, ±800kV 6000MW long distance multi terminal HVDC system
ii) ±320kV 2000MW VSC based HVDC system having overhead conductor and XLPE cable to facilitate reliable power supply to urban areas
iii) Multi-circuit towers, pole type towers, narrow based tower to reduce RoW issue
iv) Gas Insulated substation (GIS), hybrid substation i.e, combination of Gas Insulated switchgears and air-insulated bus bar, to reduce foot print for the substation land requirement substantially (about $1/4^{th}$ of conventional air-insulated substation)

b) Enhancing utilisation of existing capacity of Transmission corridor:

i) Reconductoring of existing lines with High Temperature Low Sag (HTLS) conductor to enhance power transfer capacity of transmission corridor
ii) Flexible AC Transmission System (FACTs): Series Capacitors, Thyristor Controlled Series Capacitors (TCSC) on important AC transmission lines to enhance power transfer capacity of the corridor with reliability**.**
State-of-the-Art STATCOMs and SVCs at strategically located substations, to maintain Voltages within permissible limits and ensure stability of the grid under various operating conditions while increasing power transfer
iii) Setting up of Multi-circuit tower by replacing existing conventional tower at strategic locations to avoid new right of way (RoW).
iv) Series reactor on bus bar/line to limit the fault current within design value and protect equipment from damages deferring construction of new facilities.

c) High System availability and reliability (avoiding forced outages/trippings)

i) Transmission Asset Management Centres for centralised remote monitoring and operation of geographically spread large number of substations for enhanced visualisation and operational efficiency with minimum human intervention.

ii) State-of-the-Art PMU based Wide Area Measurement Systems (WAMs) coupled with big data analytics for real-time monitoring of system parameters towards improved operational efficiency.

iii) Process Bus based digital substations towards digitalisation and automation efforts on protection & control system with ease on maintenance, remote testing and relay settings, reduction in down time as well as avoid mal-operation of protection system

iv) Advanced diagnostic tools like Frequency Response Analysis (FRA), Frequency Domain Spectroscopy (FDS), Dynamic Contact Resistance Measurement (DCRM), Third Harmonic Resistive Current (THRC) etc. for condition monitoring of critical equipment towards maintenance efficiency improvement

v) Use of Resin Impregnated Paper bushing for transformer/reactor, polymer long rod insulators in place of conventional ceramic insulator as per requirement.

vi) App based ground patrolling of transmission line, helicopter/drone based aerial patrolling of transmission tower top using Thermo-vision camera, corona camera, HD/Zoom camera etc.

vii) Transmission line arrester to reduce line tripping, controlled switching device to reduce transient stress on equipment, polymer insulator to avoid flashover etc.

viii) On-line condition monitoring of transformer and reactor, data-driven Transmission Asset health indexing

ix) Refurbishment of critical infrastructure like HVDC back-to-back station, long distance HVDC system etc. to enhance life span for providing power supply in a cost-effective manner.

x) Hot-line maintenance, aerial patrolling, to reduce line outage,

xi) Emergency Response System like ERS tower for quick restoration of damaged towers and extend power supply

xii) Well defined Crisis management plan

Analysis of data

Data from about 23 utilities with respect to transmission assets, network availability & reliability, average transmission losses, voltage profile, age of the transmission assets, technology adoption by the utilities were studied. Many utilities are yet to adopt various latest technology. It was observed that significantly large quantity of assets up to 220 kV are older than 20 years in various utilities. It was also observed that the annual availability of STU network is 98% or above. Transmission losses vary from 0.8% to 3.8% and there is a wide variation in network voltage profile.

Recommendations

Inter State Transmission Infrastructure is equipped with various modern technologies as well as latest O&M practices and smart features to meet the future requirements. However, there is opportunity to integrate latest technologies in the intra state transmission system. Based on review of existing practices adopted by various transmission utilities, challenges foreseen, future requirements and discussion with different stakeholders, recommendations covering ways / techniques required for modernization of existing transmission infrastructure especially at state level to cope with growing penetration of renewable capacity as part of energy transition and meeting demand with reliability and security, as well as making it smart & future ready are categorized as below:

- Modernization of Existing Transmission Infrastructure
- Use of advanced technology in construction
- Use of advanced technology in O&M
- Smart & Future Ready Transmission System
- Capacity Building and Up-skilling of workforce

Summary of recommended technological interventions is presented in table below:

Sl. No.	Technology	Application
1.	HTLS Conductors	Increasing the capacity of existing transmission corridors (1.8 -2 times)
2.	Refurbishment of old HVDC system	For life extension, high availability with better control and stability.
3.	Flexible AC Transmission devices (FACTs)	Enhancement of line loadability, improvement in stability, addressing the issue of uneven distribution of power flow on parallel corridors
4.	Dynamic Line Loading (DLL)	Dynamically enhancement of line loadability taken account of variation in atmospheric conditions
5.	Insulated Tower Cross Arm	Narrow ROW availability
6.	Energy Storage System	Higher utilization of Transmission, facilitate integration of Renewable generation, Ancillary service support
7.	Hybrid AC / HVDC system	Flexible transmission facility suitable for variable Renewable Integration, maintaining system parameters under various operating conditions.
8.	Conversion of AC line to HVDC Line	For enhancing the power transfer capacity of corridor by about 1.5 – 2.5 times.
9.	Photonic Coating on Conductor	Increasing the transmission capacity of 66 kV/132 kV lines by about 20-30%.

Sl. No.	Technology	Application
10.	Centralized Remote Monitoring, Operation of Substations including SCADA	Transmission Asset Management Center for remote monitoring and operation of all substations from single location, visualizing on Real time basis, outage / contingency planning.
11.	GIS/Hybrid Substation	Land optimization, Resilient infrastructure
12.	Process Bus Technology	Digital substations towards automation
13.	Fiberization of Transmission Lines	OPGW or phase conductor wrapped with fibers
14.	Wide Area Measurement System (WAMS)	Better Situational Awareness, Enhanced Visualization to system operators for reliable grid management, improve utilization of transmission infrastructure
15.	Drones	Survey, Stringing and Inspection of transmission assets
16.	Condition monitoring & Predictive maintenance using AI/ML algorithms	Data driven informed decision making for Maintenance, reduction in operation expenditure,
17.	Managing Age-old asset	Systematic identification, maintenance/ replacement of age-old asset
18.	Adaptive Protection System	Adaptive relay settings based on changing system configuration
19.	Helicopter in Line Construction	Material shifting in Wild Life & Forest area, Hilly terrain
20.	Robot	Minimize human intervention, minimize life risks/hazards, Time saving with accuracy during construction and maintenance
21.	Heavy duty Road Mat	Transport heavy equipment under adverse climatic conditions (rainy season, water logging)
22.	Augmented & Virtual Reality	Remote use of personal Skill, Capacity Building, Training
23.	Building Disaster Resilient Infrastructure	For less damage due to natural disasters
24.	Cyber Security	Prevention from Cyber threat and Information Security

Each of the above recommendations may be evaluated based on the system requirements, studies and techno-economic feasibility**,** implementation on case by case basis**.**

For effective utilization of modern infrastructure, utilities are required to make HR policies for capacity building of existing workforce along with addition of young professionals so that the personals involved in the planning, implementation, operation and maintenance can enhance their knowledge and managerial capability in association with the local technical/management institutes.

Salient features of Modern & Smart Transmission

The salient features of modern & smart transmission system are monitoring, analysing, control and communication capabilities to the electricity delivery system to maximize the throughput of the system while maintaining stability with reduce energy consumption, reliability and resiliency. In addition, enhancement of utilization of existing transmission capacity is another attribute of modern transmission system. Major interventions required are as under:

- Centralized Remote Monitoring, Operation of Substations including SCADA
- Flexible AC Transmission devices (FACTs) & DLL
- Fiberization of Transmission Lines through OPGW at 132 kV and above or phase conductor wrapped with fibres at 66 kV
- Wide Area Measurement System (WAMS) using PMUs and data analytics
- Hybrid AC / HVDC system
- Predictive maintenance using AI/ML algorithms
- HTLS Conductors
- Process Bus Technology
- GIS/Hybrid Substation
- Energy Storage System
- Drones & Robots in construction/inspection of transmission assets
- Cyber-Physical Security

Benefits of Transmission Modernization

Modernization of transmission network would facilitate reduction in forced outages, minimize human intervention, enhanced visualization, centralized data driven decision making etc. thereby improve system availability.

Making transmission smart and future ready would enable increased penetration of renewable energy resources as well as defer investment in transmission.

Way Forward

1. The Task Force has suggested various technological interventions required to make transmission system modern and future ready. Further, the interventions have been categorized as essential and optional considering the flexibility and security requirement as presented in subsequent para.
2. Implementation of a particular technological intervention would depend upon the specific circumstances of each utility.

3. System performance audit, prioritization of utility requirement, workforce skill/knowledge assessment are also to be carried out prior to taking up implementation of specific recommendation to make the system smart and future ready.
4. Cost-benefit analysis for individual utilities would need evaluation on a case-to-case basis. A detailed cost benefit analysis would also be required to establish the viability of the proposed intervention.
5. Since, Investment requirements for adoption of suitable technology and benefits are case specific, the same have not been assessed by this Task Force.
6. Suitable regulatory framework / enabling provisions may be ensured, wherever applicable, to promote investments for transition to smart and future ready grid.

Categorization of Recommendations:

Implementation of above recommendations can be prioritized to phase out the outlays. Accordingly, the recommendations have been categorized as essential to address flexibility and cyber security as well as optional that may be considered by the utilities on the basis of enhanced reliability standards requirements for specified areas in their system.

(a) Essential Level:

1. Centralized Remote Monitoring, Operation of Substations including SCADA: Transmission Asset Management Centre for remote monitoring and operation of all substations from single location, visualizing on Real time basis, outage / contingency planning.
2. Flexible AC Transmission devices (FACTs): Enhancement of line loadability, improvement in stability, addressing the issue of uneven distribution of power flow on parallel corridors, wherever feasible.
3. Increasing the capacity of existing transmission corridors through Reconductoring with HTLS conductors, wherever feasible
4. Fiberization of Transmission Lines through OPGW on EHV transmission lines or through phase conductor wrapped with fibres on lower voltage
5. Wide Area Measurement System (WAMS)
6. Integrated Cyber Security (Both IT & OT System)

(b) Optional Level:

Other recommendations are optional and may be considered by States on basis of reliability improvement requirement for specified areas.

Road map for making the transmission system modern and smart in Metropolis / cities and rural areas:

a) Metropolis / Cities

i) Short Term (1-2 years):

1. Adequate reactive compensation in the form of shunt devices (Mechanically Switched Capacitor/ Reactor) or VSC / Thyristor based devices (STATCOM, SVC, TCSC etc.) for maintaining system voltage for grid stability and security.
2. Increasing the capacity of existing transmission corridors through Reconductoring with HTLS conductors, wherever feasible
3. Drone based Survey, Stringing and Inspection of transmission assets
4. Integrated Cyber Security (Both IT & OT system)

ii) Medium Term (2-3 years):

1. Centralized Remote Monitoring, Operation of Substations including SCADA
2. Fiberization of Transmission Lines through OPGW at 132 kV and above or phase conductor wrapped with fibres at 66 kV
3. Wide Area Measurement System (WAMS)
4. Dynamic Line Loading (DLL) System
5. Augmented & Virtual Reality facilitating remote use of personal skill, capacity building and training of workforce as well as maintenance and inspection
6. Drones & Robots in construction/inspection of transmission assets
7. Building Disaster Resilient Infrastructure

iii) Long Term (3-5 years) :

1. All new lines at 220 kV and below may be considered as Underground cable for 220kV and below network in Metropolis / cities areas(Only for the section witnessing ROW issue). Wherever feasible, overhead lines at 220 kV & below in Metropolis / cities areas may be converted into underground cables progressively in 3-5 years.
2. All new Substations and expansion may be considered as GIS/Hybrid Substation for Land optimization and resilient infrastructure in Metropolis / cities areas.
3. Insulated Tower Cross Arm / pole-based towers for narrow ROW for new transmission lines
4. Some Energy Storage System as part of transmission service.

b) Rural areas

In rural areas, to ensure reliability in power supply emphasis may be given on strengthening / modernization of distribution infrastructure. Nevertheless, to maintain transmission system reliability, following modernization efforts may be taken up in phased manner

i) Short Term (1-3 years):

1. Adequate reactive compensation in the form of shunt devices (Mechanically Switched Capacitor/ Reactor) or VSC / Thyristor based devices (STATCOM, SVC, TCSC etc.) for maintaining system voltage for grid stability and security.
2. Drone based Survey, Stringing and Inspection of transmission assets
3. Integrated Cyber-Physical Security (Both IT & OT system)
4. Building Disaster Resilient Infrastructure

ii) Long Term (3-5 years):

1. Centralized Remote Monitoring, Operation of Substations including SCADA
2. Fiberization of Transmission Lines through OPGW at 132 kV and above or phase conductor wrapped with fibres at 66 kV
3. Augmented & Virtual Reality facilitating remote use of personal skill, capacity building and training of workforce as well as maintenance and inspection

Provisions to be considered in CEA regulations / guidelines

1. Optimization of ROW requirement for adoption of Insulated Tower Cross Arm especially in narrow corridors
2. Cyber-physical security especially at Operation Technology (OT) level
3. PMU based dynamic state monitoring of Transmission network
4. Building disaster resilient transmission infrastructure.

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Chapter-1: Introduction

1.1. Background

Transmission is an integral part of power supply system and key enabler for electricity generation and distribution. Indian transmission network is one of largest single national grids in the world operating at one frequency which is owned, operated and maintained by both Central & State utilities and Private licensees. Transmission network in the country is mainly classified as Inter State Transmission System (ISTS) and Intra-State Transmission System (In-STS). ISTS is the top layer of National Grid, mainly developed by POWERGRID and other private licensees, whereas In-STS is the bottom layer, developed by respective state utilities and private licensees. As of Jun'22, all India transmission network (220kV and above voltage level) includes about 4,60,000 ckm robust transmission lines with about 11,26,000 MVA transformation capacity facilitating seamless flow of power across the length and breadth of the country. The robust transmission grid also facilitated development of vibrant power market enabling access to low cost power supply. The cumulative inter-regional power transfer capacity of national grid is about 112GW. National Grid is also interconnected with transmission network of neighboring countries, viz, Bangladesh, Bhutan, Nepal and Myanmar with power transfer capacity of about 4200MW which shall be enhanced to about 8000MW by 2025 through cross-border lines. Further, reliable Indian grid is flexible enough to integrate more than 110 GW of variable renewable generation (about 27% of total Installed Capacity) facilitating energy transition towards increase in portfolio through non-fossil fuel-based generation.

1.2. Modernization of Transmission System

Indian power sector is under transition like in other countries to address energy security and climate crisis. There is a continuous shift from fossil fuel to non-fossil fuel/renewable (mainly solar & wind) based generation to facilitate accelerated development of low carbon energy system.

As per the updated Nationally Determined Contribution (NDC), India now stands committed to reduce Emissions Intensity of its GDP by 45 percent by 2030, from 2005 level and achieve about 50 percent cumulative electric power installed capacity from non-fossil fuel-based energy resources by 2030. This is a step towards achieving India's long-term goal of reaching net-zero by 2070. Towards this, it is envisaged that installed capacity through non-fossil fuel resources would be about 500 GW by 2030. Further, efforts are to increase electricity component in the total energy consumption and the share of renewable energy in the electricity mix to boost de-carbonization efforts. Expansion of E-mobility and E-cooking segments are also getting lot of impetus from policy makers.

Gestation period of renewable generation project is short in comparison with development of associated transmission infrastructure required for its evacuation and integration with National Grid. Increased focus on electrification of transportation through Electric vehicle also needs consideration. Further, there are many challenges in implementation of transmission system especially acquiring land for establishment of pooling stations/substations due to rapid urbanization, Right of Way issues, availability of skilled workforce for construction of new lines etc. In addition, transmission assets are getting older affecting the performance and reliability of the system. Besides, in recent past, frequency of natural disasters like thunderstorm, super cyclones, floods etc. has increased many folds making transmission infrastructure vulnerable. Due to increased number of transmission elements spread over geographically, its maintenance and upkeep to maintain high degree of system availability and reliability (reduction in forced outages/tripping) are also a challenge.

In view of the above, modernization of existing transmission infrastructure is required to improve its reliability, resilience, efficiency and to enhance transfer capacity using latest technology coupled with digitalization. Further, intermittency and variability of output from renewable generating stations are also to be addressed including provision of adequate balancing reserves, inertial support in maintaining grid security and stability. This calls for making transmission smart with minimal human intervention and self- correcting features.

1.3. Task-Force on Modernization of Transmission Sector

Ministry of Power, Govt. of India vide order dated 22.09.2021 has constituted a Task Force of the following officials to formulate a plan for modernization of Transmission and making it smart and future ready.

1. Shri K. Sreekant, CMD, POWERGRID –Chairman
2. Shri P. Guruprasad, MD, UPPTCL
3. Shri Dinesh Waghmare, CMD MSETCL
4. Dr. N. Manjula, MD, KPTCL
5. Shri Santanu Basu, MD, WBSETCL
6. Shri Debajyoti Das, MD, AEGCL
7. Shri Ishan Sharan, Chief Engineer (PSP&PA-I)- CEA
8. Prof. Ankush Sharma, IIT,Kanpur
9. Shri Nirmod Kumar, Director (IPHW Div.) MEIT
10. Shri Goutam Ghosh, Director (Transmission), MoP
11. Shri Vijay Chibber, DG/EPTA
12. Shri Atul Kumar Bali, Director NSGPMU
13. Shri P C Garg, COO, CTUIL- Member Convenor

Copy of Ministry of Power communication in this regard is enclosed at **Annexure-I.**

1.4. Terms of Reference of the Task Force

The Terms of Reference of the Task Force were following:

i. To suggest ways to make transmission system modern and future ready
ii. To suggest technological innovation and adoption of new technologies in transmission sector; and
iii. Any other issues deemed fit.

1.5. Deliberations during Meeting of the Task Force

The Task Force met twice through virtual mode to deliberate upon various aspects related with terms of reference. The first meeting of the Task Force was held on 14.12.2021 wherein various issues related to present status of transmission systems, technologies adopted, challenges being faced etc. were discussed. It was decided that a questionnaire/format for collection of base line data/information may be shared with all the stakeholders. It was also opined that few sub-groups would be formed in different identified areas to carry out in-depth analysis and give valuable suggestions, ways/ technological interventions for efficiency improvement and make transmission future ready.

The list of STUs from whom data/information sought and from whom data/information has been received is attached at **Annexure-II**. Data received from 23 STUs. Deliberations were held with the four sub-groups and identified list of tool/technologies for improvement in this regard.

The Task Force in its second meeting held on 01.07.2022 reviewed the findings of the data received from various transmission utilities, suggestions of sub-groups deliberated in the sub-group meeting (virtual mode) held on 16.03.2022. Observations, analysis and recommendations of the Task Force are presented in this report.

Chapter-2: Overview of Transmission System

2.1. Overview

India has uneven distribution of energy resources viz. coal, hydro, solar, wind etc. Coal is confined mostly in the eastern part viz. Jharkhand, Odisha, Chhattisgarh, M.P etc. Hydro potential is in North-eastern part viz. Arunachal Pradesh and upper part of Himachal Pradesh and J&K. Demand centers are mainly in western, northern and southern parts of the country. Considering economies of scale for setting up of large sized power plants like 2000-3000MW capacity as pit-head stations and power transfer to far-off located demand centers, necessitated building up of long-distance high capacity transmission corridors cutting across state boundaries as Inter State and Inter regional transmission system for smooth transfer of power from surplus to deficit areas. For onward absorption of power by the demand centers of individual state as well as facilitate evacuation power from Intra State generating stations, expansion and development of Intra State Transmission system took place.

In this way, National Grid was developed comprising Inter State and Inter regional transmission system integrated with Intra State Transmission System. Interstate and Inter regional transmission system development is under the purview of central utility/transmission licensees, while intra State transmission system by the respective State Transmission Utility/transmission licensees.

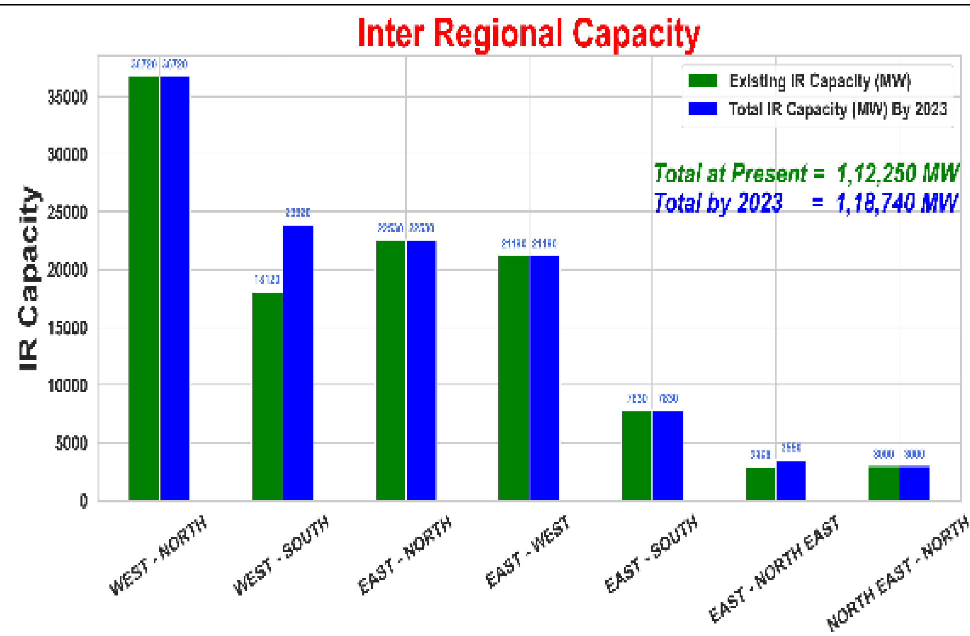


Figure 1: Link wise (Corridor wise) distribution of inter-regional transfer capacity

The National grid comprises high capacity EHVAC (765kV, 400kV & 220 kV) and HVDC links. The present cumulative Inter-regional power transfer capacity is about 1,12,750 MW, which is expected to grow upto 1,18,050 MW by the 2022-23. Corridor and voltage level wise distribution of inter-regional transfer capacity is shown in Figure 1 & 2.

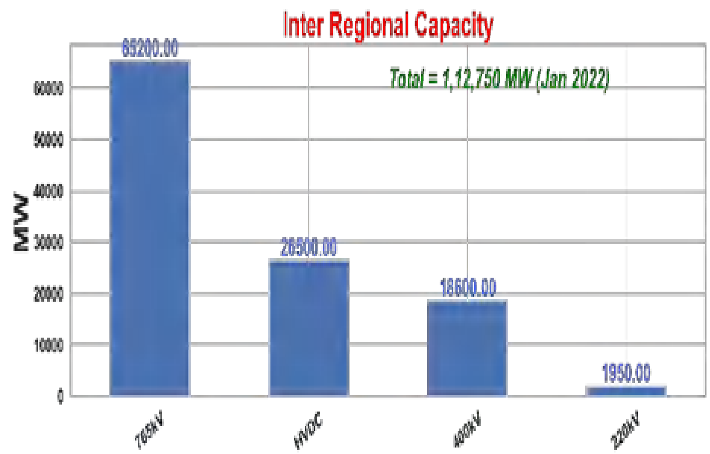


Figure 2: Voltage level wise distribution of inter-regional transfer capacity

The robust National grid is also interconnected with neighboring countries, viz., Bangladesh, Nepal, Bhutan, Myanmar, has facilitated development of vibrant power market enabling access to low-cost power supply in the South Asian region.

Recent emphasis is to increase share of renewable capacity mainly solar & wind in the overall installed capacity towards energy transition through non-fossil fuel resources. Major potential locations of solar and wind resources are in Tamil Nadu, Karnataka, Andhra Pradesh, Gujarat, Madhya Pradesh, Rajasthan, Ladakh. Solar and wind generation are mostly available during day time (other than peak scenario), while coal based generating stations are supplying base loads as well as cater to demand during night time. This calls for development of transmission infrastructure for interconnecting such resources with National Grid. In the process, Green Energy Corridors comprising Inter State and Intra State Transmission System including evacuation system for potential Renewable Energy Zones are being developed to facilitate renewable integration.

As mentioned earlier, total transmission line covers about 460,358 ckm and about 11,26,287 MVA transformation capacity. It includes 8 nos. long distance ±800kV/±500kV/±320kV HVDC system and 4 nos. HVDC Back-to-back stations. Sector wise summary of present transmission system (220 kV and above) is given in Table-1.

Table 1: Transmission System Overview in India as on Mar'22

	Central	State	Pvt/JV	Total
Trans. Line (ckm)	175791	249216	335351	460358
Transformation Capacity (MVA)	449736	630744	45807	1126287

Intra State Transmission System (In-STS) also includes 66kV network besides 132 kV, 220kV, 400 kV & 765 kV system. Voltage level wise distribution of lines and Transformation capacity in India is shown in Figure 3 & 4 respectively.

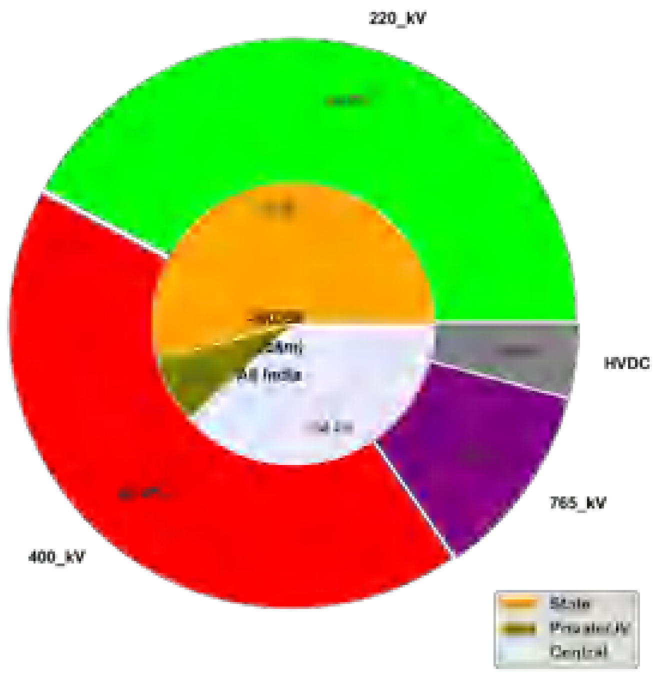


Figure 3:Voltage Level wise lines ckm (above 220 kV) in India, as on Mar'22

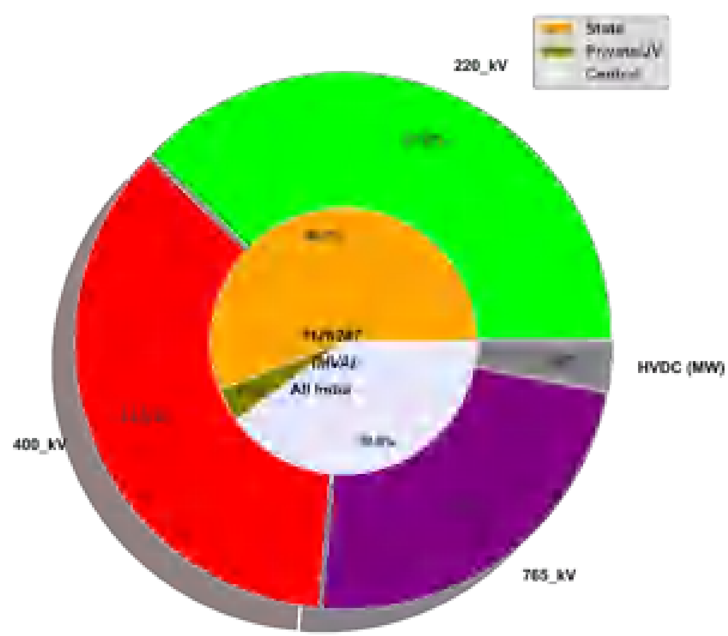


Figure 4:Voltage Level wise transformation capacity (above 220 kV) in India

2.2. Technology adopted

Following emerging technologies have been adopted in the transmission system mainly at ISTS level:

a) Transmission corridor addressing right of way and acquiring land for substation:

i) 765kV D/c lines, ±800kV 6000MW long distance multi terminal HVDC system
ii) ±320kV 2000MW VSC based HVDC system having overhead conductor and XLPE cable to facilitate reliable power supply to urban areas
iii) Multi-circuit towers, pole type towers, narrow based tower to reduce RoW issue.
iv) Gas Insulated substation (GIS), hybrid substation i.e., combination of Gas Insulated switchgears and air-insulated bus bar, to reduce foot print for the substation land requirement substantially (about 1/4th of conventional air-insulated substation)

b) Enhancement of existing transmission capacity:

i) Reconductoring of existing lines with High Temperature Low Sag (HTLS) conductor to enhance power transfer capacity of transmission corridor
ii) Flexible AC Transmission System (FACTs): Series Capacitors, Thyristor Controlled Series Capacitors (TCSC) on important AC transmission lines to enhance power transfer capacity of the corridor with reliability.
State-of-the-Art STATCOMs and SVCs at strategically located substations, to maintain grid parameter (Voltages) within permissible limits and ensure stability of the grid under various operating conditions while increasing power transfer
iii) Setting up of multi-circuit tower by replacing existing conventional tower at strategic locations to avoid new right of way (RoW).
iv) Series reactor on bus bar/line to limit the fault current within design value and protect equipment from damages deferring construction of new facilities.

c) High System availability and reliability (avoiding forced outages/trippings)

i) Transmission Asset Management Centers for centralised remote monitoring and operation of geographically spread large number of substations for enhanced visualisation and operational efficiency with minimum human intervention.
ii) State-of-the-Art PMU based Wide Area Measurement Systems (WAMs) coupled with big data analytics for real-time monitoring of system parameters towards improved operational efficiency.
iii) Process Bus based digital substations towards digitalisation and automation efforts on protection & control system with ease on maintenance, remote testing and relay settings, reduction in down time as well as avoid mal-operation of protection system.

iv) Advanced diagnostic tools like Frequency Response Analysis (FRA), Frequency Domain Spectroscopy (FDS), Dynamic Contact Resistance Measurement (DCRM), Third Harmonic Resistive Current (THRC) etc. for condition monitoring of critical equipment towards maintenance efficiency improvement.

v) Use of Resin Impregnated Paper bushing for transformer/reactor, polymer long rod insulators in place of conventional ceramic insulator as per requirement.

vi) App based ground patrolling of transmission line, helicopter/drone based aerial patrolling of transmission tower top using Thermo-vision camera, corona camera, HD/Zoom camera etc.

vii) Transmission line arrester to reduce line tripping, controlled switching device to reduce transient stress on equipment, polymer insulator to avoid flashover etc.

viii) On-line condition monitoring of transformer and reactor, data-driven Transmission Asset health indexing.

ix) Refurbishment of critical infrastructure like HVDC back-to-back station, long distance HVDC system etc. to enhance life span for providing power supply in a cost-effective manner.

x) Hot-line maintenance, aerial patrolling, to reduce line outage.

xi) Emergency Response System like ERS tower for quick restoration of damaged towers and extend power supply.

xii) PMU based Wide Area Measurement System (WAMS).

xiii) Well defined Crisis management plan.

Chapter-3: Challenges in Transmission

The present installed generation capacity is about 400 GW that was added since independence. It is expected to grow at a CAGR of about 9-10% to more than 800 GW by 2030, i.e., almost similar order of capacity is projected to be added in next 7-8 years which has been added in last 75 years. It also requires establishment of massive transmission infrastructure matching with capacity addition spread over the country. Further, majority of the capacity addition is envisaged through solar and wind generation projects having gestation period of about 15-18 months, whereas, commensurate transmission capacity development may take 24-30 months.

Therefore, ensuring adequacy of transmission infrastructure/capacity for evacuation of upcoming renewable capacity addition is a big challenge. In addition, existing transmission assets are aging and some of them are almost approaching/exceeded their life span, spread over geographically, many towers are in remote difficult locations, increased frequency of natural disaster, enormous data points related with condition monitoring of equipment etc., all these poses challenge in O&M of assets efficiently to ensure high system availability and reliability in a cost-effective manner as well as providing 24x7 quality power supply. Following section presents a brief description of various challenges with power transmission sector in India.

3.1. Challenges for Indian Transmission Sector

Major challenges in transmission sector are described as under:

3.1.1. Establishment of transmission infrastructure matching with upcoming generation projects

Growing addition of generation capacity mostly from solar and wind renewable resources have low gestation period, commensurate transmission system should be ready to evacuate and integrate the capacity as well as transfer power to the load centres in efficient, reliable and cost-effective manner. Rapid urbanisation, increasing awareness on environmental impact, acquiring land for new substation establishment, obtaining right of way for construction of transmission line became time consuming and posing challenges in timely availability of transmission infrastructure. Optimization of RoW and pushing more quantum of power per meter of RoW in the corridor, increase utilization of existing system are need of the hour.

3.1.2. Maintaining high availability & reliability of transmission system

Transmission systems are passing through varied topography and often subjected to harsh weather conditions, vagaries of climate change. On the other hand, almost 100% availability of transmission system is important for stable and efficient system operation as well as congestion free power transfer enable access to low cost power supply. In addition, maintaining high reliability level under various operating conditions is of paramount importance to ensure uninterrupted quality power supply. Transmission assets mainly consists of overhead transmission lines, transmission towers, underground cables, substation equipment i.e. Transformers, Reactors, Circuit Breakers, CT, CVT, Busbar, Lightning Arrestors, protection system etc. All the above components are to be maintained in healthy condition under different operating conditions to provide uninterrupted power supply to the end customers in safe and cost-effective manner.

3.1.3. Maintaining healthiness of vast aged assets

Transmission network comprises huge assets as part of transmission line, substation, control & protection, load dispatch facilities which were created over a period of several decades. Age old transmission infrastructure is also expected to achieve similar level of performance as compared to initial stage of their life. This age-old infrastructure reflects technology that was adopted decades ago which has to meet today’s growing and varied demands. Under such conditions, maintaining health of the age-old transmission infrastructure is a big challenge. To keep the existing infrastructure healthy, advanced diagnostic tools and condition monitoring system coupled with predictive maintenance technique with intelligent computation are needed.

3.1.4. Maintaining grid parameters and ensuring power quality

System voltage and line loadings are important parameter to ensure stable and secured grid operation. In addition, harmonics, voltage sag/swell, flicker, power factor etc. are other important power quality parameters that significantly impact the performance of power system. Maintaining these parameters within permissible limits across transmission network under various operating conditions is a challenge.

Besides, reduced inertia and fault level contribution by Solar and Wind generators coupled with variable and intermittent output resulted in frequent switching of line/reactor and increases electrical and thermal stress on the equipment affecting their performance and life.

Continuously varying diurnal and seasonal demand and generation profile and large-scale use of inverter based renewable generators, non-linear devices severely affect the grid parameters, system protection mechanism that often requires deployment of suitable compensating devices to maintain grid parameters within permissible limits.

3.1.5. Making transmission smart & future ready to deliver 24x7 quality power in a cost-effective manner

Conventional transmission system was designed to facilitate power transfer from large conventional generating stations to load centers in a unidirectional way. Proliferation of distributed energy resources at different voltage levels, large scale grid connected renewable generating stations, energy storage system, consumer became producer in some time of the day/month introduces complexity in managing the power flow over transmission infrastructure with reliability and security. It necessitates digitalisation, automation, intelligent computation with bi-directional (source to sink or vice-versa) facility of both electricity and information flow through transmission infrastructure. Towards this, smart grid, defined as a grid that brings together advanced monitoring technologies, intelligent computation, controls & self-healing features integrated with robust and reliable communications can enable efficient delivery of sustainable, economic and reliable 24x7 power supply.

3.1.6. Protecting the Transmission System against Cyber Threats

For advanced monitoring, control and automation of power system network, information and communication technology (ICT), IoT based sensors are widely being used. The power System applications and ICTs were developed in silos in the past. Therefore, adoption of ICT in power system is unstructured. Increasing use of digital applications, Internet of Things (IoT) for sensing, monitoring & control in the power transmission has made it vulnerable to cyber-attacks. This is causing greater challenges from Cyber-Security point of view. It is necessary to continuously monitor, assess cyber threat, risk, vulnerability, proper cyber security audit, testing mechanism / standards to be developed to address its challenges at device level, network level and application level to ensure cyber-physical secured transmission system.

3.1.7. Inadequate skilled workforce in Transmission Construction and O&M

Depletion of experts in the field of transmission line construction, testing and commissioning of new technology area is a challenge. In addition, there is shortage of indigenous experts/capability for O&M of new technologies like GIS, STATCOM, HVDC, digital substation etc. making dependence of services of OEM affecting restoration time, cost, which are a challenge.

Chapter-4: Technology Adoption in Transmission

To assess the current status of technology adoption in transmission utilities, a survey was conducted with State Transmission Utilities and POWERGRID.

4.1. Survey Methodology

A questionnaire was prepared to collect information on following aspects:

1. Voltage level wise no. of transmission lines, length, No. of tripping per year
2. Voltage level wise no. of Substations, Type (AIS/GIS) of Substations
3. Voltage level wise SCADA/Communications details
4. Voltage level wise age of transmission lines and Substations
5. Transmission Losses
6. Technology adopted in transmission line, substation, operation and maintenance, tractive power management, System operation at SLDC etc.
7. Maximum-Minimum voltage profile at different voltage level
8. Transmission network Availability (%) & Reliability (Tripping / Annum)
9. Substation wise workforce.

Copy of the questionnaire is enclosed at **Annexure-III.**

4.2. Analysis of Data Collected from Transmission Utilities

Data received from STUs/POWERGRID has been grouped in the following categories:

1. Transmission Assets
   a. Number of transmission lines and length of network
   b. Number of substations and Transformation Capacity
2. Transmission network Availability (%) & Reliability (Tripping / Annum)
3. Age of the Transmission Assets
4. Average Transmission losses (%)
5. Voltage profile
6. Technology adopted in transmission line, substation, operation and maintenance, tractive power management, System operation at SLDC etc.
7. Substation wise workforce.

Compilation of Data received from Utilities are attached at **Annexure-IV, V & VI**.

4.2.1. Transmission Assets

Summary of transmission network assets at 66 kV and above (STU-wise) viz, no. of transmission lines, total length of lines in ckm, No. of substations, total transformation capacity (MVA) is shown in Figure 5 and 6 below.

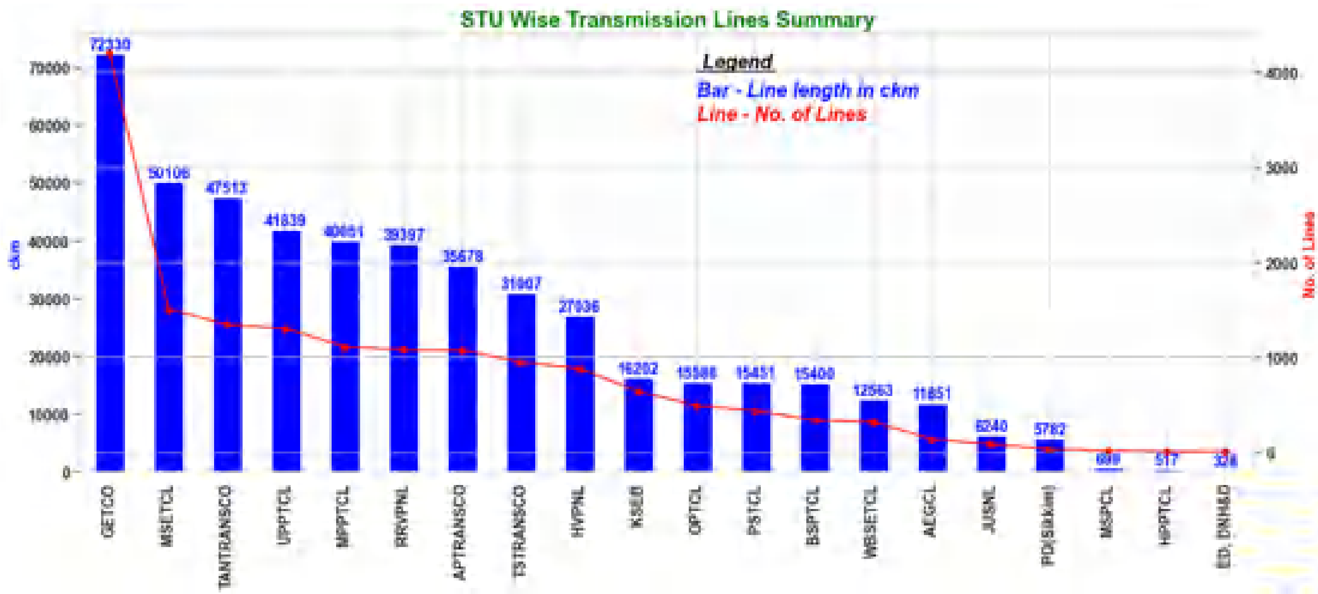


Figure 5: STU-wise no. of Transmission lines and total ckm

Note: Abbreviation of Utility name given at Annexure-II.

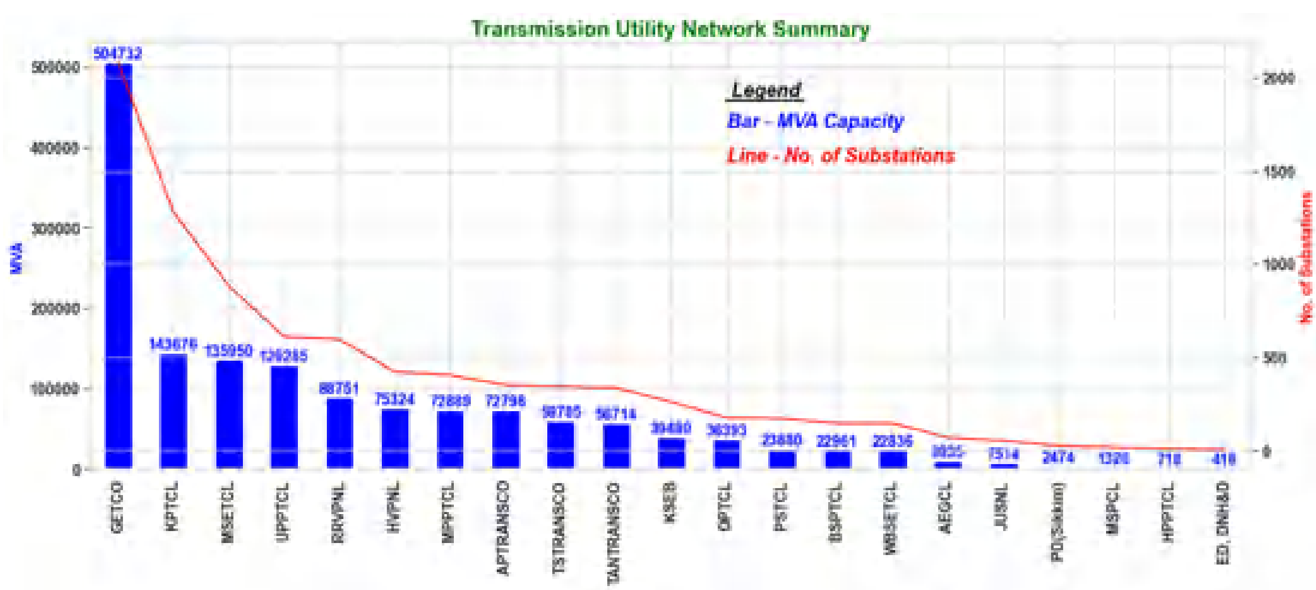


Figure 6: STU wise no. of Substations and total MVA

Transmission line assets under STU (mostly 220 kV Level) are in the range of 320-72000 ckm with no. of lines is in the range of 8-4200 nos. Transformation capacity is in the range of 418-

504732 MVA with no. of substations in the range of 6-2084 nos. The transmission assets under ISTS (POWERGRID) is 1,76,008 ckm and 4,46,940 MVA (mainly at 400 kV).

4.2.2. Transmission System availability and reliability

Summary of availability of STU transmission network is shown in Figure 7 below. It can be observed that annual availability is 98% or above. In case of OPTCL it is about 100%.

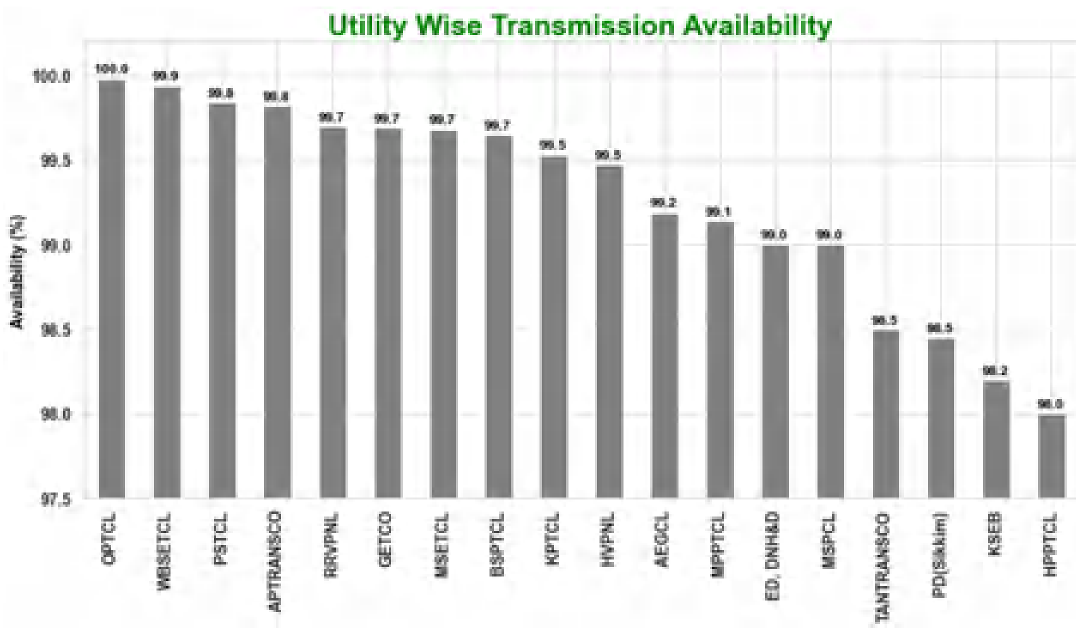


Figure 7: STUs wise Transmission Availability

The overall system availability in ISTS network (POWERGRID) is about 99.82%. Maintaining high availability of geographically spread transmission infrastructure is a challenge. Availability comparison of global Utilities for the year 2020-21 are as follows:

Table 2: Availability of Transmission System of Global Transmission Utilities

Sl. no.	Utilities	Transmission System Availability (%)
1	POWERGRID	99.83%
2	TNB, Malaysia	99.79%
3	NERC, USA	99.73%
4	ISA, Peru	99.48%
5	NGSa, Saudi Arabia	98.68%
6	REN, Portugal	98.66%
7	REE, Spain	98.50%
8	EirGrid, Ireland	95.71%
9	SPTL, Scotland	94.67%
10	NG, UK	94.38%

We may set a target of 99.75% availability for transmission system in India, as benchmark for all the utilities.

Utility wise Reliability of State transmission network, in terms of no. of trippings per line per year at different voltage levels are shown in Fig: 8-12 below:

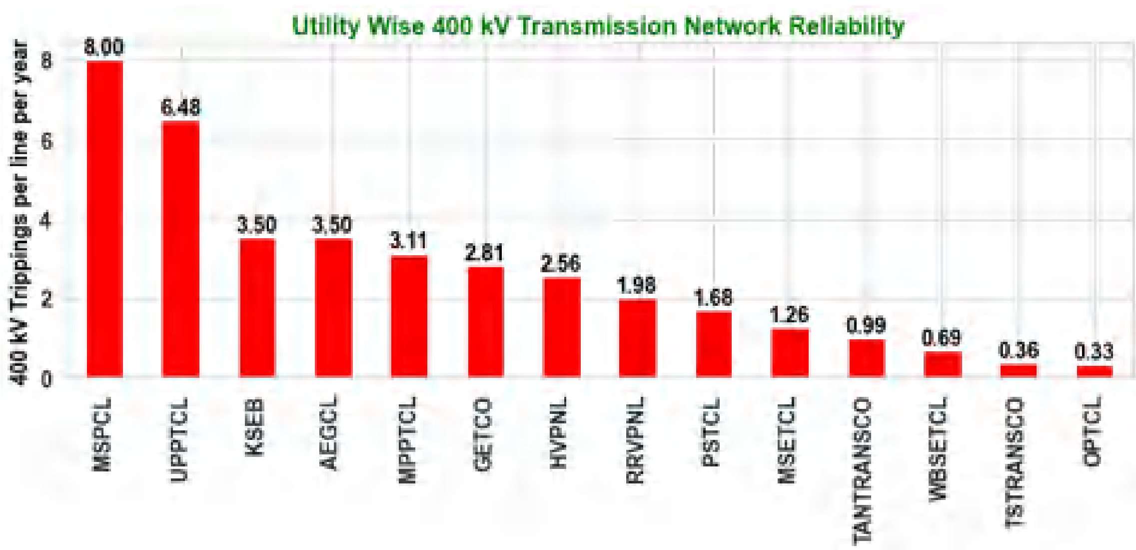


Figure 8: Utility wise 400kV Transmission Network Reliability Summary

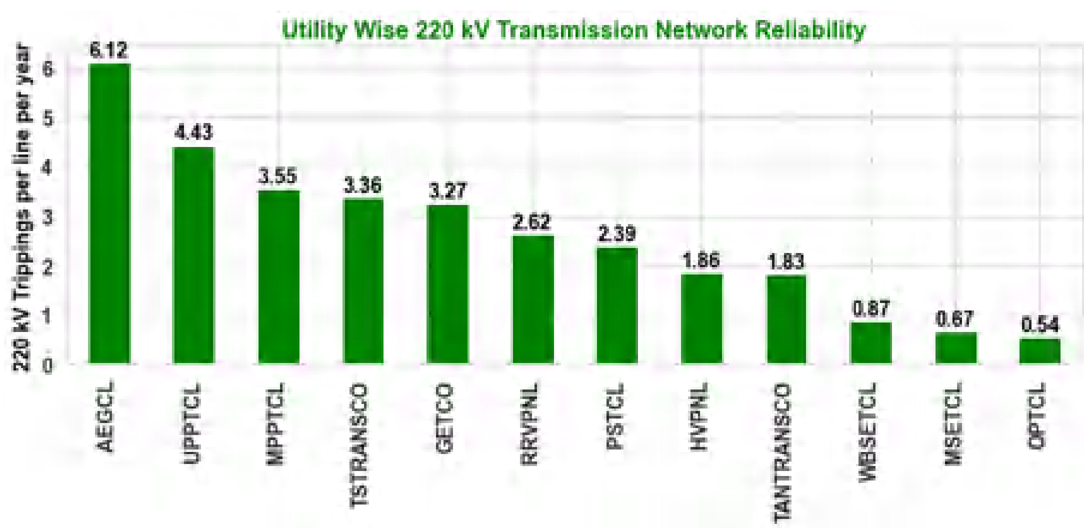


Figure 9: Utility wise 220kV Transmission Network Reliability Summary

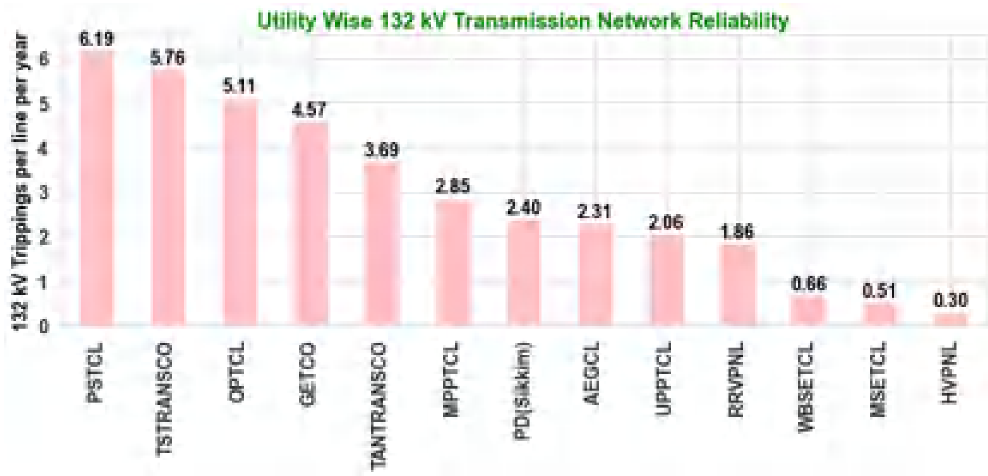


Figure 10: Utility wise 132kV Transmission Network Reliability Summary

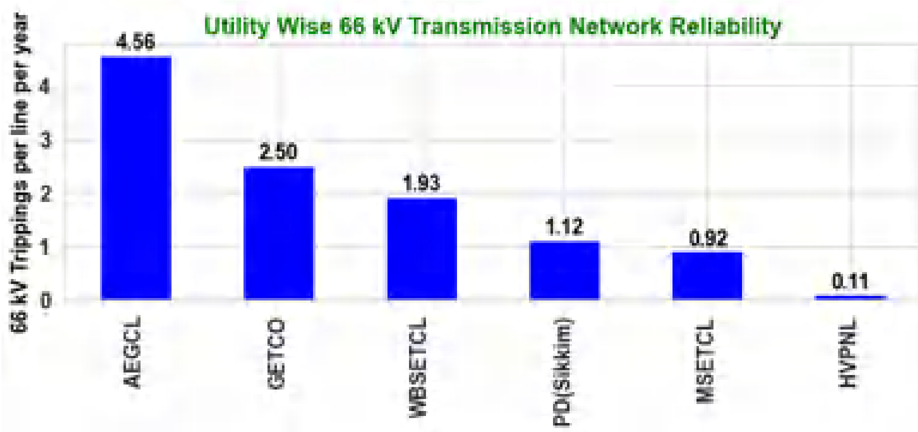


Figure 11: Utility wise 66kV Transmission Network Reliability Summary

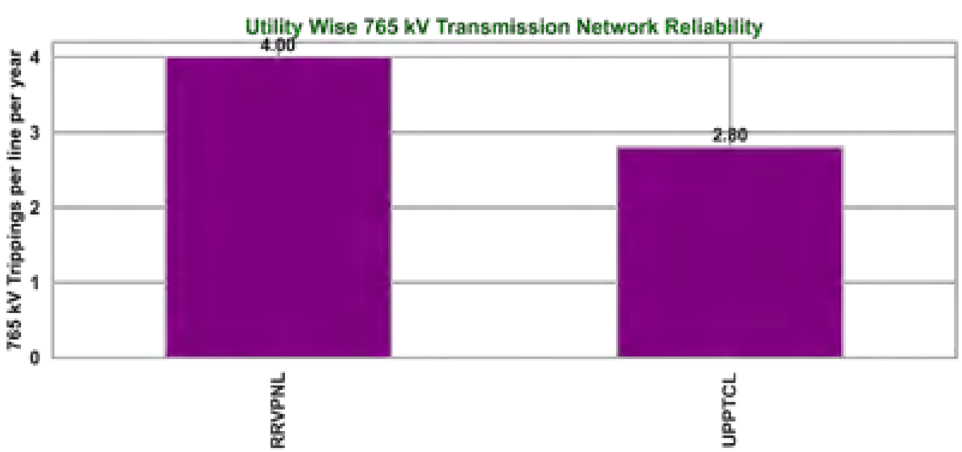


Figure 12: Utility wise 765kV Transmission Network Reliability Summary

In STU, average no. of trippings per line per year at 765 kV is in the range of 2.8 to 4, at 400 kV level it is in the range of 0.33 to 8, at 220 kV level it is 0.54 to 6.12, while at 132 kV level it is 0.3 to 6.2. In case of ISTS(POWERGRID), it is in the range of 0.36.

4.2.3. Age of Transmission System

Voltage and utility wise distribution of lines (ckm) and transformation capacity (MVA) are shown in Figure-13 and 14 below. It can be observed that significantly large assets upto 220 kV (1,60,919ckm & 1,40,844 MVA) are older than 20 years in various utilities.

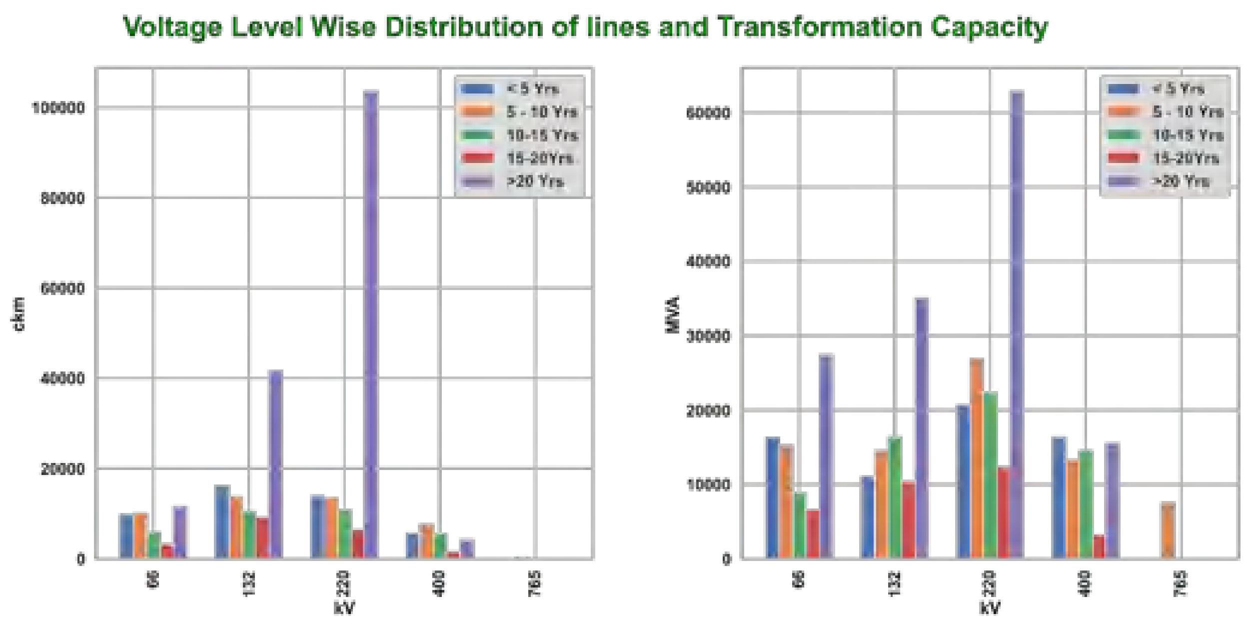


Figure 13: Voltage Level Wise Distribution of ckm and MVA

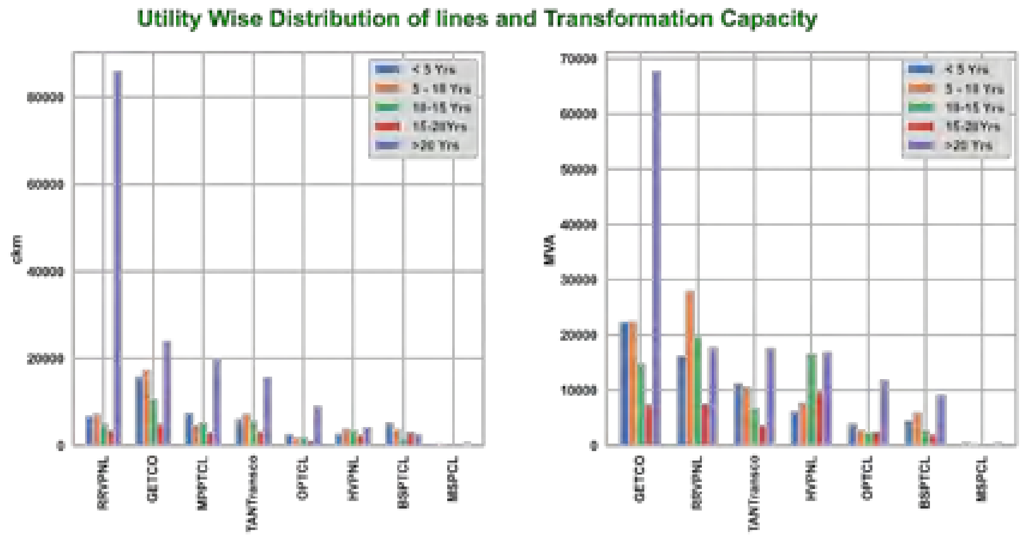


Figure 14:Utility Wise Distribution of ckm and MVA

4.2.4. Transmission System Losses

STU wise transmission losses are shown in Figure-15 below. It can be observed that it varies from 0.8 % to 3.8%. Average losses in ISTS network is in the rage of 2.5 - 3.5%

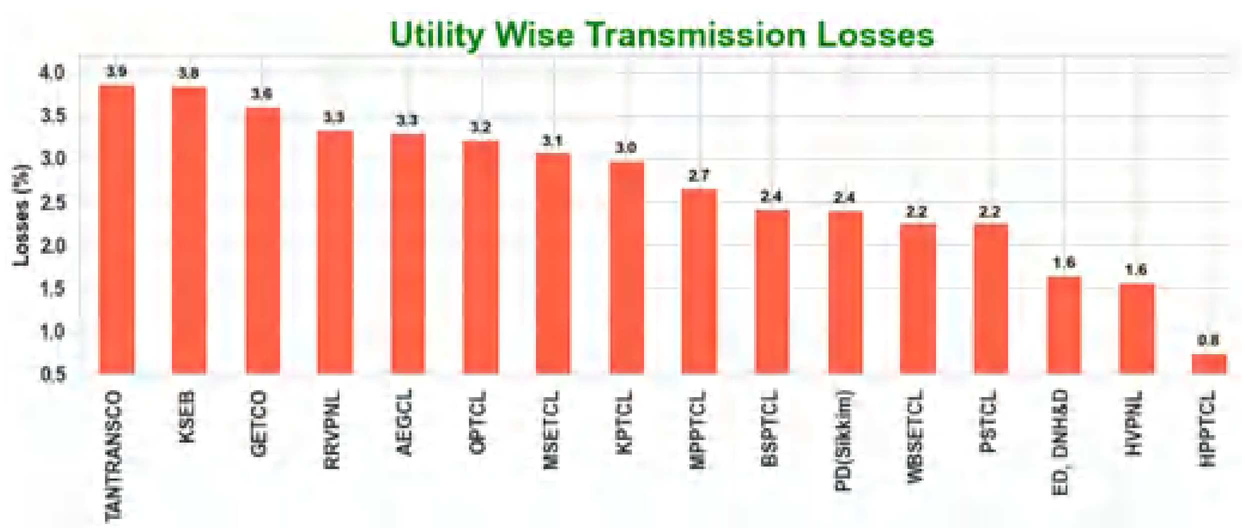


Figure 15: STUs wise Transmission Losses

4.2.5. Voltage Profile in STU network

There is wide variation in the voltage profile at various level. At 66 kV level, it is observed that voltages vary from 52 kV (-21.2%) to 74 kV (12.2%), at 132 kV it varies from 93 kV(-29.5%) to 143 kV(8.33%), at 220 kV level it varies from 191kV(-13.2%) to 245 kV(11.4%), and in the 400 kV level it varies from 390 kV (-2.5%) to 437 kV(9.25%).

In line with CEA Grid standards regulation, 2010 and CERC IEGC, we may set a target to achieve ± 5% voltage variation for 400 kV and above system, ±10% for 220kV, 132 kV and 110 kV system and ±9% for 66 kV and 33 kV system within a period of 2-3 years.

4.2.6. Technology adoption in the various STU network

Various technologies already adopted by utilities are presented through heatmap diagram. Green colored box indicates technology adopted by the utility and red colored box indicates absence of technology in the corresponding utility.

a) Transmission line:

Summary of information pertaining to utility wise use of various technology like High Temperature Low Sag (HTLS) conductor, Multi Circuit Tower/Narrow Based Lattice Tower (to reduce ROW requirement), Polymer Insulators, Insulated tower Cross - arm, Transmission Line Arrester and XLPE Underground Cable is represented below in Figure-16.

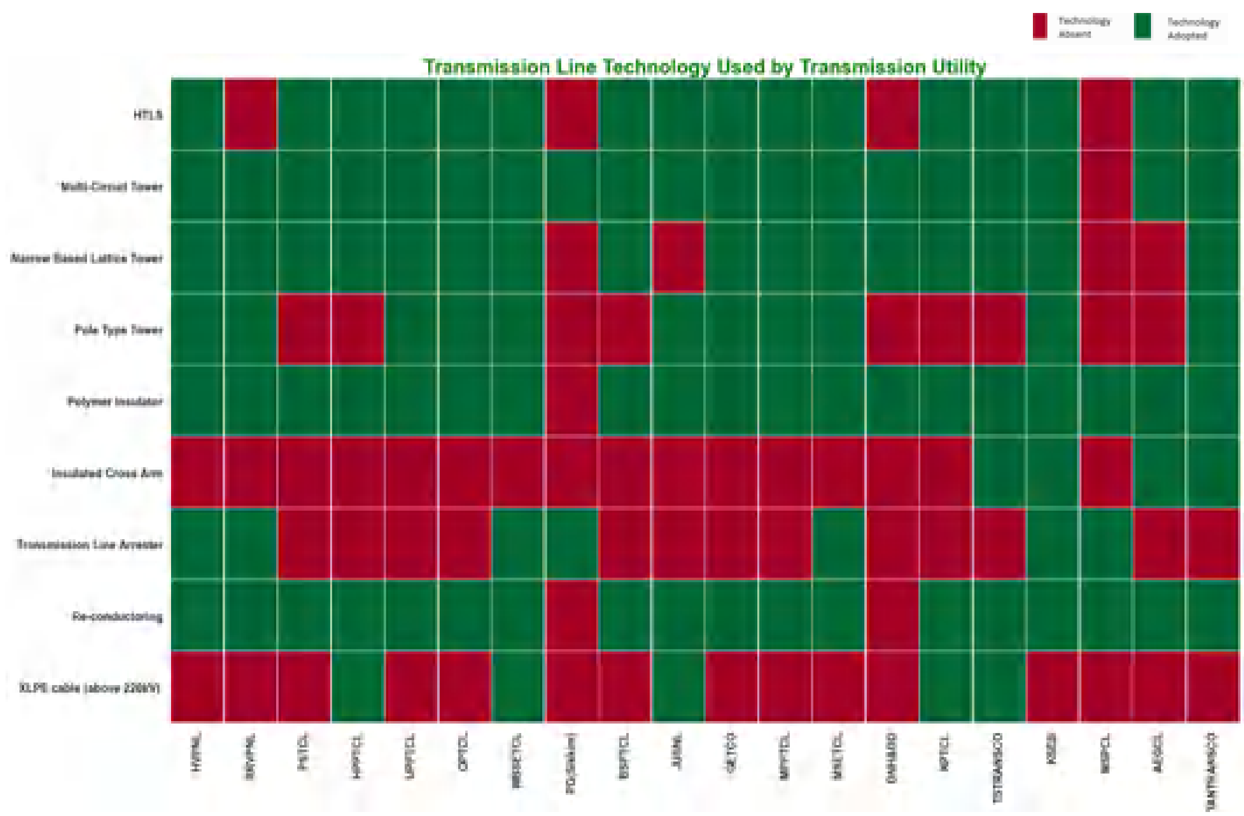


Figure 16: Technology Used by Utilities in the field of Transmission Lines

It is observed that very few utilities are using Transmission Line Arrester, Insulated tower Cross - arm and XLPE Underground Cable, on the other hand other transmission Technologies viz., HTLS, Multi Circuit Tower/Narrow Based Lattice Tower, Pole type Tower, Polymer Insulator, Reconductoring in their system are being used by most of the utilities.

b) Substation:

Summary of information pertaining to utility wise use of various technology viz., in implementation of substation like Air/Gas Insulated or hybrid substations (combination of GIS & AIS bus bar), Process Bus Technology, Mobile Substation, Reliable Bus Bar Arrangement, Substation SCADA, Remote operation and Control, Cyber Security, Use of Ester oil is represented below in Figure-17.

It is observed that very few utilities are using Mobile Substations, Process Bus Technology, reliable bus switching scheme at lower voltage, Substation remote operation and control, ester oil in Transformer, on the other hand other substation Technologies viz., GIS, Hybrid S/s, one and half breaker scheme at 400kV, Substation SCADA, Cyber Security are being used by most of the utilities.

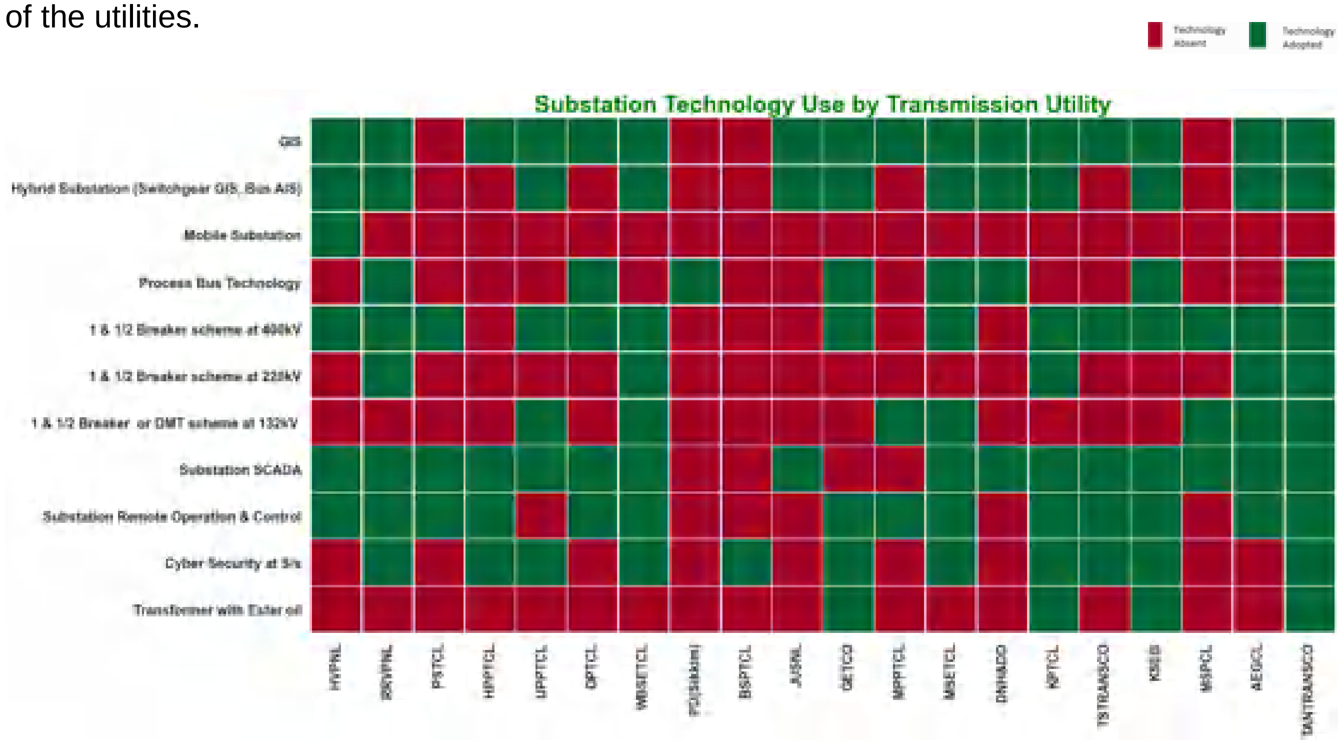


Figure 17:Technology Used by Utilities in the field of Substation

c) Reactive Power Management

Summary of information pertaining to utility wise use of various technology related with Reactive Power Management / Voltage Control like SVCs, STATCOM, Shunt Capacitor/ Reactor, Series Capacitor is represented below at Figure 18. It is observed that very few utilities are using Series Capacitor, STATCOM/SVC in their system, on the other hand other Reactive Power Management / Voltage Control Technologies like Shunt Capacitor/ Reactor are being used by most of the utilities.

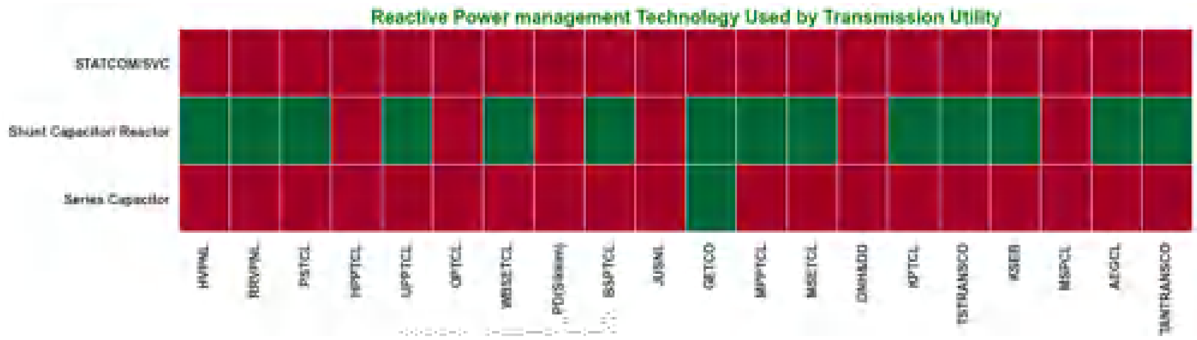


Figure 18: Technology Used by Utilities in reactive power management

All the above technologies are used at ISTS (POWERGRID) network also.

d) Operation and Maintenance

Summary of information pertaining to utility wise use of various technology in Operation & Maintenance like On-Line Condition Monitoring of Transformer and Reactor, Circuit Breaker, Lightning Arrestor, On Line Fault Locator, Thermal Imaging of equipment at S/s, Third Harmonic resistive measurement of lightening arrester, Live Line Maintenance, Aerial & Ground Tower Patrolling, Transmission Line Vegetation Management, Drone / Robot aided inspection of S/s & Line, Disaster Management Mechanism etc. is represented in Figure-19 below.

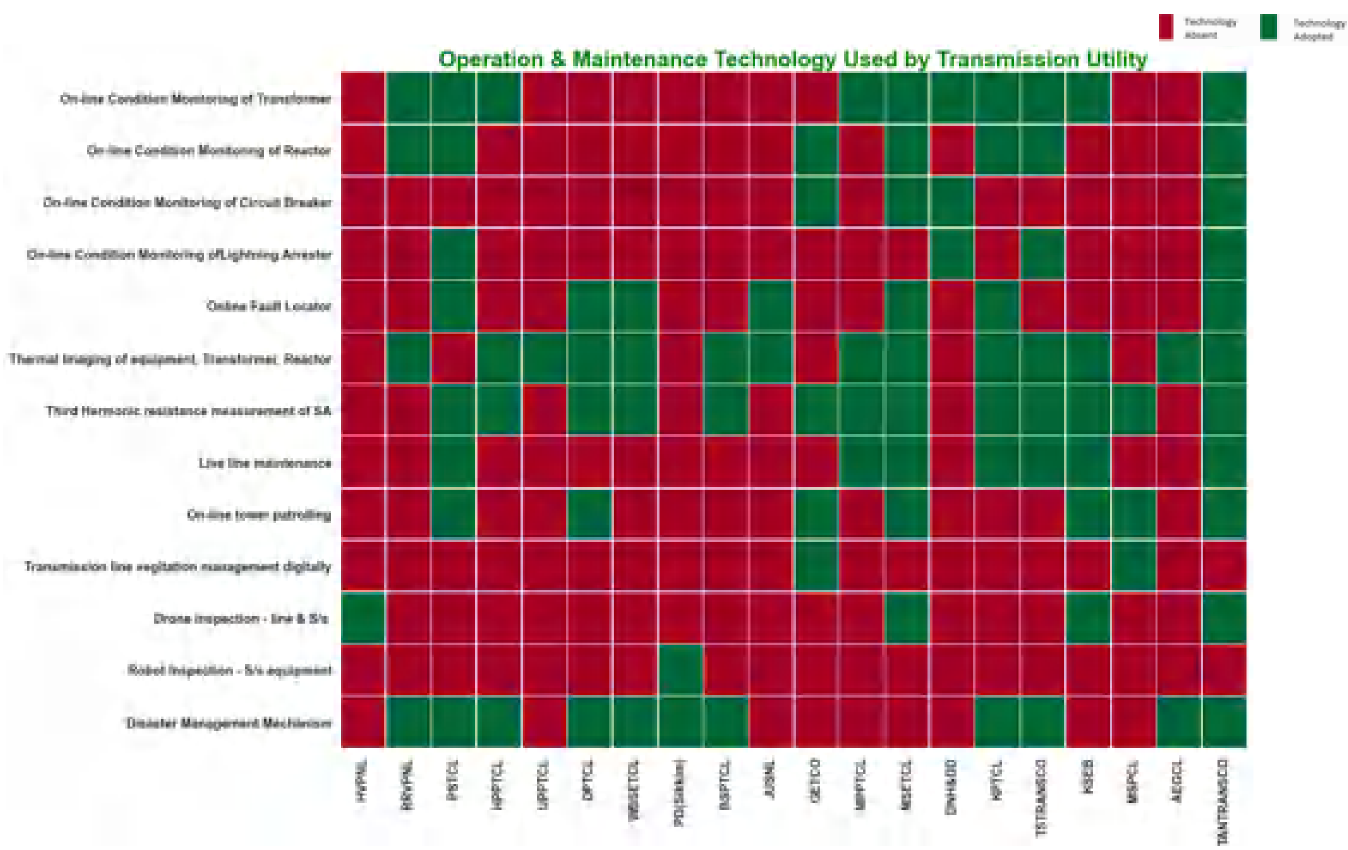


Figure 19:Technology Used by Utilities in Operation & Maintenance

It is observed that very few utilities are using On-Line Condition Monitoring of Transformer, Reactor, On Line Fault Locator, Live Line Maintenance, Aerial & Ground Tower Patrolling, Transmission Line Vegetation Management, Drone/Robot Inspection of S/s & Line, on the other hand other O & M Technologies like On-Line Condition Monitoring of Transformer, Thermal Imaging of equipments at S/s, Third Harmonic resistive current measurement of Lightening Arrester, Disaster Management Mechanism are being used by most of the utilities.

e) System Operation

Summary of utility wise use of various technology in System Operation like SCADA/EMS, EMS for Outage Planning, Back-up LDC, Cyber Security at SLDC is represented below at Figure-20.

It is observed that very few utilities are using SCADA/EMS, EMS for Outage Planning in their system, on the other hand, other System Operation Technologies like Cyber Security at SLDC, Back-up LDC are being used by most of the utilities.

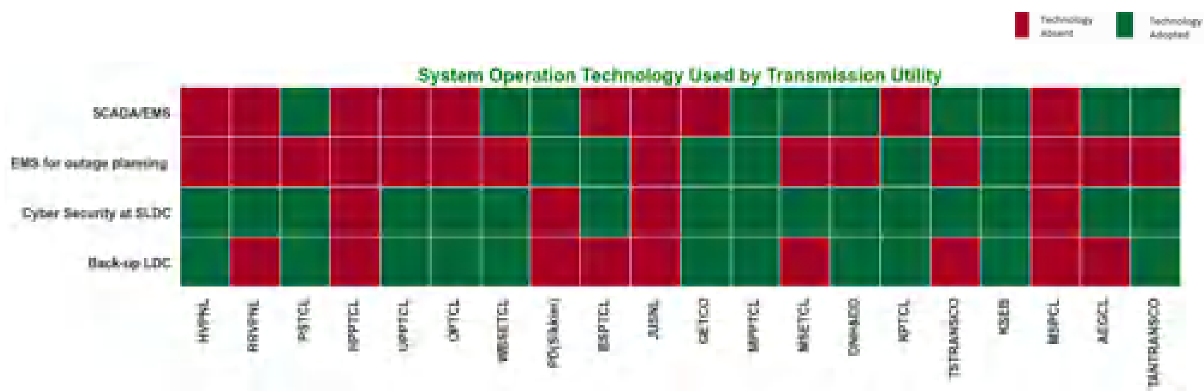


Figure 20:Technology Used by Utilities in System Operation

Chapter-5: Recommendations

Transmission utilities/licensees are adopting various technologies towards modernization of the infrastructure. Several advanced technologies are being used to improve and enhance the capacity of the transmission system, spanning both grid software and hardware. Sensor and software solutions coupled with robust communication system focus on improvements in visualization, control and protection systems, advanced sensing and metering tools, real-time contingency analysis tools, and artificial intelligence/ Machine Learning - assisted operator decision making processes. These technologies generally improve short-term outlook rather than a long-term horizon.

On the other hand, actuators and hardware solutions (e.g., FACT devices, HTLS conductors, cables, OPGW) focus on improvements in the physical assets and infrastructure responsible for carrying, converting or controlling electricity. Long-term system planning integrated with latest technology seeks to find an optimal transmission expansion plan with optimum aggregate benefits over the planning horizon. These technologies are generally more capital intensive than sensor and software solutions and improve the long-term reliability and resilience of the grid.

5.1. Salient features of Modern & Smart Transmission:

Modernization is not just about replacing lines and cables. It is also about digitizing and automating the grid. Thereby, avoiding outages by managing grids more intelligentially. In addition, it would also facilitate in providing better quality of services without investment in infrastructure.

The salient features of modern & smart transmission system are monitoring, analysing, control and communication capabilities to the electricity delivery system to maximize the throughput of the system while maintaining stability with reduce energy consumption, reliability and resiliency. In addition, enhancement of utilization of existing transmission capacity is another attribute of modern transmission system. Major interventions required are as under:

- Centralized Remote Monitoring, Operation of Substations including SCADA
- Flexible AC Transmission devices (FACTs) & DLL
- Fiberization of Transmission Lines through OPGW at 132 kV and above or phase conductor wrapped with fibres at 66 kV
- Wide Area Measurement System (WAMS) using PMUs and data analytics
- Hybrid AC / HVDC system
- Predictive maintenance using AI/ML algorithms
- HTLS Conductors

- Process Bus Technology
- GIS/Hybrid Substation
- Energy Storage System
- Drones & Robots in construction/inspection of transmission assets
- Cyber-Physical Security

Inter State Transmission (ISTS) Infrastructure is equipped with various modern technologies as well as latest O&M practices and also Smart to embrace future requirement. However, there is opportunity to integrate latest technologies/ways especially in the intra state transmission system. Based on review of existing practices of various utilities across the country and discussion with different stakeholders, recommendations covering solutions/techniques required for further modernization of existing transmission infrastructure to cope with growing penetration of renewable capacity and meeting demand with reliability and security, as well as making it smart & future ready are presented below.

5.2. Recommendation-1: Modernization of Existing Transmission Infrastructure

5.2.1. Re-powering of existing lines

(a) Through reconductoring

Repowering of existing transmission line using High Temperature Low Sag (HTLS) conductors, by replacing existing ACSR conductors using same tower would facilitate capacity enhancement of the line by almost 1.8 – 2 times using same corridor. Reconductoring is carried out on existing line and it does not call for additional ROW, thereby avoiding any related risk of execution delays.

In many cases with old lines, due to growth of habitation, available ground clearances below lines are no longer safe. Reduced sag achieved post reconductoring can help to improve these clearances, thereby improving safety near the line. Reconductoring of a line can be carried out much faster as compared to building a new line for increasing the capacity. The reconductoring process requires few hours of shutdown daily and line can be temporarily charged (with due precautions) during remaining hours till work resumes the next day. This solution helps decongest the transmission network in existing corridors, as well as defer investment in construction of new lines. Pictorial depiction of various HTLS conductors is shown in Figure-21 below.

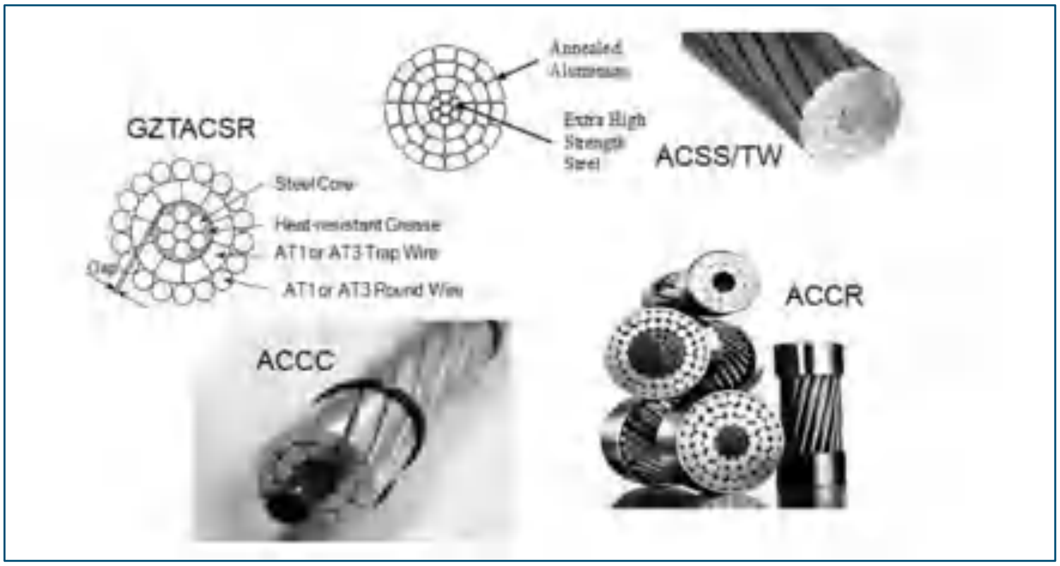


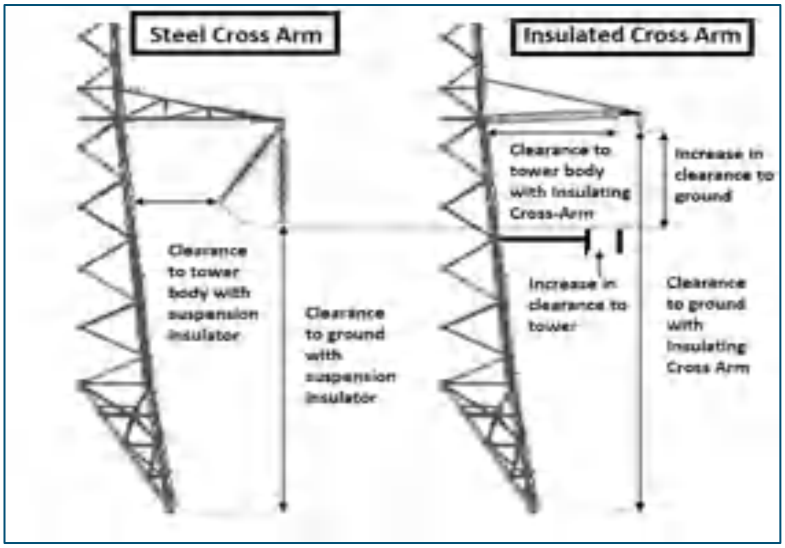
Figure 21: Examples of High -Temperature Conductor Designs

(b) Through Voltage Upgradation

Enhancement of existing transmission corridor capacity by use of insulated tower cross arm would help to upgrade the line voltage, while retaining the existing tower & foundation with few modifications and capacity enhancement by about 2.5 to 3 times in quick time. It would also defer investment in development of new transmission capacity.

Insulated tower cross arms replace existing steel cross-arms and suspended vertical insulator strings on traditional lattice towers, thereby enabling conductors to be attached directly to the cross-arm giving space and clearance margin to go for tower upgrade solutions. This combined with HTLS conductors would help to achieve voltage upgrade, thereby improving power transfer capacity while still not infringing ground clearances, as shown in Figure-22 below.

In addition, insulated tower cross arm can be used in the narrow corridor/congested areas, to address electrical clearances issue. However, reduced ROW requirement needs to be addressed by suitable provisions in the standards / regulations for wide scale adoption.



Tower with Insulated Cross Arm
(Introduced for the First Time by AEGCL)

Figure 22: Increase in ground clearance using insulated Cross Arm

5.2.2. Conversion of Existing AC lines to HVDC lines

The conversion of AC lines to HVDC bipolar system is an alternative for increasing the power transfer capability of existing corridor, reduction in losses, increase in power transfer capacity (about 1.5 – 2.5 times) and provide flexibility in operation.

The capacity of HVDC transmission line depends directly on the operating voltage and the ampacity of the line conductor. Higher DC voltages deliver higher capacity but account must be taken of conductor sagging and the effect of pollution level on the insulator creepage distance, which are one of the main determinants of the maximum DC voltage. Tower modification or use of composite insulators may enable an even higher DC voltage and enhance power transfer capacity of existing corridor. It covers changes in sub-conductor bundle configuration, insulator assemblies to maintain surface voltage gradient of the DC line. Based on the studies, techno-economic feasibility, suitable transmission lines may be identified for conversion of AC to HVDC to enhance power transfer capacity of existing corridor.

5.2.3. Refurbishment of old HVDC system

Refurbishment of old HVDC system may be carried out for life extension of the existing corridor and defer investment in development of new transmission line. Refurbishment of old HVDC system includes:

a) Replacement of obsolete control system with the new control system
b) Addition of new protection mechanism

c) Replacement of valves, switchgears etc.
d) Changes in harmonic filters

5.2.4. Dynamic Line Loadings (DLL)

Dynamic Line Loading (DLL) technology helps to determine the real-time or forecasted current-carrying capacity (or loading) of transmission line. This dynamic loading is achieved through calculations based on measurements of ambient conditions and the physical properties of the line, while ensuring reliability standards.

DLL systems provide the ability for operators to adjust line ratings ahead of time or in real-time conditions to help relieve transmission challenges. DLL sensors on line are becoming popular globally with the utilities for enhancing effective line capacity. DLL sensors once installed on the line conductor, provides real-time situational awareness of conductor temperature, sag, current, and weather conditions. Additionally, it provides predictive loading level to effectively enhance the line ampacity, under favorable weather conditions.

Figure 23: DLR Equipment with Weather Station

Depending upon weather, transmission line capacity can be enhanced by about 15-20%, reliability can be increased by using DLL device across the line without violating the operating temperature and sag limits. The DLL is a simple device which along with a weather station is easy & quick to install, voltage agnostic and is relocatable, as shown in Figure 23 above.

5.2.5. Use of FACTS devices

Existing transmission line loadability can be enhanced with the use of FACTS devices, series capacitor, Static Synchronous Series Capacitor (SSSC) by about 30%, depending upon the degree of line compensation. Besides, it also helps to control uneven loading in parallel corridors in meshed network. The technology solution is deployable mainly within substations.

5.2.6. Installation of Energy Storage System

Energy storage continues to emerge as one of ‘non-conventional alternative’ to mitigate the effects of renewable variability, optimize the utilisation of existing grid infrastructure and improve resiliency & reliability. Energy storage system is a flexible resource for grid operators that can deliver a range of grid services quickly and efficiently. It would facilitate in providing support on frequency regulation to address reduced system inertia due to increased penetration of inverter based renewable capacity.

Unfortunately, the cost of many of these services still exceeds to their values, compared to conventional solutions. As energy storage technology becomes more cost-effective, a wider range of its applications will become accessible including grid connected energy storage system. Implementation of energy storage system in the grid and its role is more complex than the simply inserting a battery in to a phone, it requires careful engineering design expertise.

Installation of Energy Storage System viz. Battery Storage, Pumped Hydro Storage, mechanical storage, thermal storage, electrical storage, chemical (Hydrogen) etc. would help in enhancement of capacity utilization of existing transmission line, thereby deferring the investment towards new transmission capacity addition. However, regulatory framework for deployment of large-scale energy storage system including tariff mechanism need to be addressed suitably.

5.2.7. Photonic Cooling on Conductor

Thermal rating of overhead conductors limits the transmission capacity especially at 66kV/132 kV /220 kV level. With photonic cooling technology i.e. putting photonic coating on the conductors, lowers the operating temperature of the line through increasing thermal radiation and minimise heat absorbed. In this way, the capacity of the line can be increased by 20 – 30%. Sufficient data/study shall be required before adoption of this technology. Further, this technology may be deployed in selected lines considering temperature zone and capacity enhancement requirement.

5.2.8. Upgradation of protection and control system to fully digital with Process Bus Technology

Retrofitting of conventional protection and control system with advanced IEC 61850 Process Bus based automation system would improve operational & maintenance efficiency and make it fully digital substation. Besides, it simplifies troubleshooting, reduce restoration time in case of any eventuality as well as reduces carbon footprint by replacing large amount of copper cables with minimal fibre optic cables. It would facilitate remote testing & fault diagnosis also.

5.2.9. Conversion of aged conventional substation to GIS/Hybrid substation

To cater the growing power transfer requirement at the existing old conventional substations especially at 132 kV and 220 kV level, may be converted with GIS or Hybrid substation, wherever required.

5.2.10. Managing age-old transmission asset

To facilitate in management of age-old transmission asset, advanced database/analytics-based system including ERP/SAP may be deployed for systematic identification, maintenance/ replacement of age-old asset. Such process would facilitate data/ information availability beforehand in respect of the age-old assets, so that timely availability of the required equipment/materials can be ensured. It would ensure uninterrupted supply of power without failure of the equipment due to ageing.

5.3. Recommendation-2: Use of advanced technology in construction

5.3.1. Use of Helicopter for material shifting in Wild Life & Forest area

Use of Heli erection / material shifting in hilly terrain, Wild Life & Forest area will reduce the impact on environment as no approach roads would be required to shift the material and T&P. It would also help in reduce the time for erection. An example of transmission line erection in hilly terrain is shown in Figure 24.

Figure 24: Using Helicopter for Tower Erection in Himalayan Valley in India

5.3.2. Use of Robot for erection work

Robot based erection work would help to minimize human intervention, accuracy of jobs, minimize life risks/hazards and time saving. This technology may be progressively adopted for selected jobs in view of high cost of investment at present, which may come down with more and more deployment of such technology.

5.3.3. Use of Heavy-Duty Road mat

To continue to work (i.e. carry heavy equipment) under adverse climatic conditions viz., rainy season, water logging situation on approach road, heavy-duty road mat may be used to avoid any delay in execution. This technology would be helpful in timely execution of project in remote locations where road condition is not good and there is limited time duration available to complete the job. However, cost-benefit analysis for its adoption would be required as adverse climatic condition may arise at certain places for shorter duration.

5.3.4. Use of Drones for Survey, Stringing and Inspection

Use of Drone or an unmanned aerial vehicle, is one of the innovative methods which can be deployed along with conventional methods to speed up execution process. It would improve the quality of survey and reduce stringing time with utmost safety and quality in hilly terrains, forests, river crossings, railway & power line crossings and agricultural fields. Drones would also facilitate use of LiDAR (Light Detection & Range) for reconnaissance and detail survey with profiling of line route, topographical mapping, 3D digital terrain modelling thus would save time, manpower and bring higher accuracy of line route and quick finalization of survey. LiDAR data is fully digital and highly adaptable for different uses, formats, transformation model and software. Typical terrain modelling using LiDAR is shown at Figure 25. It can also be used for stringing of conductor especially in difficult terrain.

Drones can also be used to accomplish other tasks such as power line and tower Inspection, HVDC valve stacks inspection, thermal scanning of equipment for identifying hot spots, defects etc. Drone equipped with ultraviolet camera can be used to analysis the corona effect.

For quicker adoption of this technology, standard technical specifications of drone, LiDAR camera etc. may be formulated.

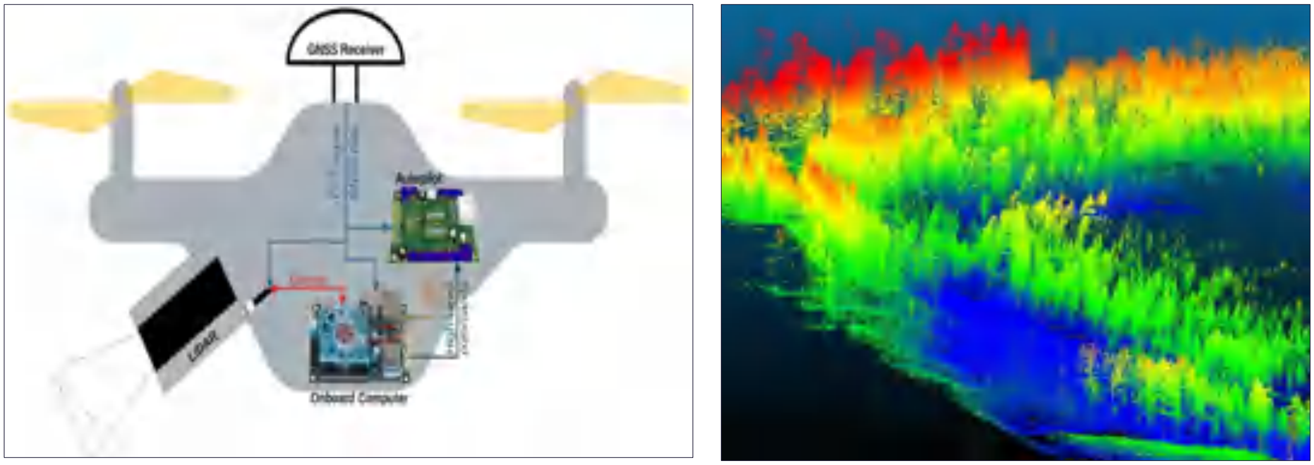


Figure 25: Using Drones for LiDAR

5.4. Recommendation-3: Use of advanced technology in O&M

5.4.1. Advanced diagnostic tools for Condition monitoring of substation equipment

It is important to detect defects in substation equipment at incipient stage using advanced diagnostic tools for equipment condition monitoring. It includes variable frequency capacitance and Tan delta measurement for Transformer/Reactor bushings, Current Transformer, Dynamic Contact Resistance Measurement for circuit breakers, Third Harmonic Resistive Current measurement for Surge Arrestors, Thermo-vision scanning of equipment etc. Preventive/Corrective actions can be taken in advance and major failures may be averted. In addition, periodic oil parameter checks, Dissolved Gas Analysis of Transformer/Reactor, particle counts, inhibitor content test are very useful for diagnosis of the problem and life enhancement of equipment.

5.4.2. Predictive maintenance using digitalization and AI/ML algorithms

Approaches to maintenance can be divided into four categories: reactive, proactive, preventive and predictive – in effect, a hierarchy of maintenance. The traditional, now outdated, reactive approach sits at the bottom of the pyramid, and has been largely superseded by more insightful methods. Different approaches adopted for maintenance of equipment represented in Figure-26.

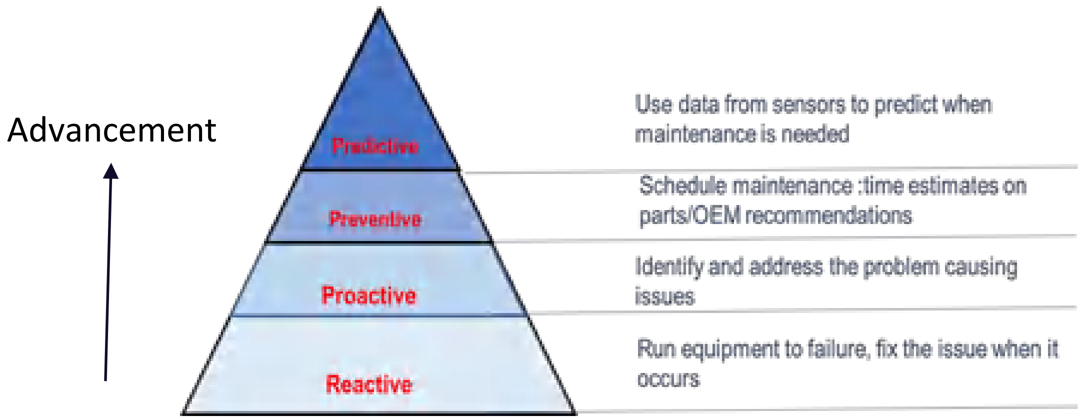


Figure 26: Different approach for maintenance

Predictive Maintenance is all about getting to the heart of the root cause of any potential issues, predicting time to failure and maximizing uptime. The clear advantage of predictive maintenance is that catastrophic failure can be avoided. In order to do the same, Artificial Intelligence and Machine Learning (AI&ML) technique or other analytical tools may be used effectively to predict the criticality or severity of the equipment in the grid using condition monitoring data sets and ranking or priority list of the equipment can be prepared for maintenance.

Such simulation tools would also be helpful in prediction of the requirement of maintenance in future time frame based on the real time condition monitoring & available historical data and annual maintenance plan of the same can be prepared accordingly. With the use of sensors for measuring various parameters of power system asset viz., oil temperature, winding temperature, DGA of a transformer, contact resistance of Circuit breakers etc. and robust high-capacity communication network, large volume of data is available at a central location, which can be analyzed through mathematical models based on AI/ML to assess its performance and accordingly plan its maintenance. Various pattern recognition and decision tree algorithms can be used for efficient operation planning and asset maintenance. This would bring both operational and maintenance efficiency for vast geographically spread transmission elements for high system availability and reliability enabling 24x7 quality power supply.

Outage management is a critical issue especially in critically loaded networks, metro cities, etc. Maintenance often requires outage of network element and ensuring necessary shutdown in time is essential for implementing required approach for maintenance. Outages/shutdowns of any lines/equipment shall be utilized in efficient manner by using modern technologies with the use of Outage Management System (OMS). Use of Modern technologies viz. Artificial intelligence and Machine Learnings (AI & ML) for outage management will definitely help in tackling critical issues.

5.4.3. Digital-Twin Model

A digital twin is a digital representation of physical operational asset like substation layout, equipment, transmission lines etc. in a 3-dimensional representation. A digital twin reflects the current asset condition and includes relevant historical data about the asset. It can be used to evaluate the current condition of the asset and, more importantly, predict future behavior, refine the control, or optimize operation with minimum human intervention. Complete substation 3-D model would be available in digitized form that would help in efficiency improvement in maintenance and optimized space allocation for future expansion, as shown in Figure-27 and 28 below.

Figure 27: Substation 3D Laser Scan Image

Figure 28: In Route Simulation

Combination of Digital Twin and LiDAR technique is useful for transmission line vegetation management in critical stretches with efficiency. Typical LiDAR aided transmission line vegetation management, electrical clearances etc. is depicted at Figure 29 below.

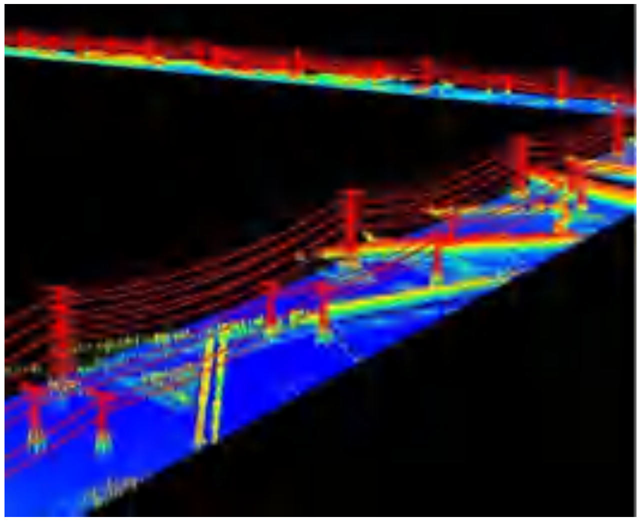


Figure 29: LiDAR aided transmission line vegetation management

5.4.4. Virtual and Augmented Reality

Virtual reality technology (VR) refers to a kind of computer simulation system, which can emulate reality in the form of a virtual world that can be interacted by users. It uses a computer to generate a virtual environment in which users can immerse themselves in an artificial environment.

Augmented reality (AR) is a technology that superimposes virtual information on the physical reality world, which can be perceived by people in many ways, such as seeing, listening, touching, etc. There are many kinds of virtual information, which can be two-dimensional plane label, three-dimensional object structure and three-dimensional surrounding audio signal. Virtual information is triggered and displayed according to certain rules, and the interaction is realized through human-computer interaction. It overlays relevant digital content into the physical world through the lens of smart devices such as wearable glasses, as shown in Figure-30. There are several aspects of AR which make it a powerful tool for industrial facilities and savings in time to address different issues. The digital information is not only displayed in real time, but also is interactive. This reduces the time to diagnose issues, communicate and schedule corrective actions with other personnel, identify viable spare parts, and perform other tasks. By combining real-world and digital content, the expert in particular equipment may remain available at their centralised work places and guide the maintenance staff in the field. This would avoid movement of experts and facilitate faster restoration in a cost-effective manner

Figure 30: Augmented Reality Example

Virtual Reality (VR) technology can allow full immersive scenarios, representing the real activity based on a 3D computer simulation. On the other hand, AR is the technology that superimposes virtual objects over the real environment in which the user is immersed through smartphones, tablets, PC, or connected glasses. It can for instance speed up power restoration or help address the challenge of an aging, retiring utility workforce by facilitating the preservation of institutional knowledge. The above technology may be suitably adopted in phased manner. Utilities may start adopting it by implementing as pilot project.

5.4.5. Building Disaster Resilient Infrastructure:

Transmission infrastructure traverse through geographically and climatologically varied terrain and are exposed to various kinds of natural hazards. The intensity of disastrous events such as cyclones, flood, dust storms, fog/smoke etc. is increasing. The response strategy for such weather variations are dynamic and continuous. It is prudent to retrofit existing transmission infrastructure to improve its climate change resilience as well as suitable standards for building new resilient infrastructure.

For addressing above challenge, transmission lines, substations and structural aspects of the design shall incorporate additional safety factors than prescribed in existing standards and codes. These are also need to be revised to fill the gaps based on dynamic changes occurring due to climate changes.

Mitigating measures required towards resilient transmission infrastructure are described as under in Table-2:

Table 3: Mitigating Measures Towards Resilient Transmission Infrastructure

Network Planning	• N-1-1 contingency for critical corridors • Selection of terrain category in critical locations
Underground cable	• In cyclone prone area
Wind zone as per revised Wind map	• Transmission line traversing through two wind zones, in the lower wind zone, higher of the two wind zones may be considered for design of towers.
Substation design in flood prone area	• Modular indoor GIS substation installation above Highest Flood Level (HFL)
Gas Insulated Line (GIL)	• Extra High Voltage (EHV) / Ultra High Voltage (UHV) level up to a maximum length of about 60 to 100km. • 20 to 25 times the cost of OHL with lattice structure. Utilities may explore the possibility of its use based on Techno-Economic Analysis.
Monopole transmission tower (with hollow alloy – carbon fibre reinforced) members	• For better strength and stability of towers.
Mobile GIS substation / bay	• Temporarily replaced the damage substation (up to 220kV) to restore the power supply
GIS Mapping of Transmission Assets	• Digital mapping of transmission lines and substations especially in the disaster-prone zones.
GPS mapped spare inventory	• Digitization of spares and inventory management of transmission system assets so that status of availability of the spares at any point of time could be assessed by the utility and necessary action for replenishment can be taken up accordingly.
Emergency Restoration System (ERS)	• In case of damaged, quick restoration of transmission towers.
Earthing & Lightning Protection of Transmission lines	• Line Surge Arrester in lightening prone area to prevent back flashover
Substation Building	• For resilient construction of buildings and other structures, use of high ductile strength steel as (Fe-500D)
Transmission Towers	• Narrow based lattice towers in cyclone prone areas

	• Epoxy-based coating (as per IS 13620) on the surface of reinforced steel to enhance corrosion performance of foundation in coastal areas. • Two (2) coats of bituminous painting of minimum 1.6kg/m2 per coat on all exposed faces of foundation (i.e. pedestal & base slab) • Pile type foundation/ embankment structure for towers in flood prone area based on soil investigation report and high flood data.
Capacity Building	• Utilities are required to continuously improve their operations based on lessons learned from past events. • Periodic training of employees, enhance their capacities to tackle the emergency situations.

5.4.6. Crisis Management

Crisis Management Plan by each utility for taking swift actions during pre and post disaster conditions for speedy restoration of damaged transmission infrastructure must be in place. It includes a hierarchical set up of crisis/disaster management at various levels for effectively and efficiently dealing with crisis as well as roles/responsibilities of different depts. Based on the advance inputs of India Meteorological Dept (IMD)/ other weather service providers and Geographic information system (GIS) based mapping of transmission assets, continuous tracing of cyclone path and related transmission towers & substations need to be monitor for taking preparatory steps before the onset of disaster. Preparedness activity includes:

- Early warning system : Enable preparation, evacuation etc. as a contingency plan in advance when an adverse event is anticipated.
- Element identification : Identification of critical transmission elements using satellite imagery and GIS mapping
- Control Rooms : Setting up of 24x7 control room for monitoring and taking necessary actions
- Resource Planning : Availability of resources in nearby stations such as workforce, DG sets, Backup 24 hours storage Batteries, T&P, Spares, Diesel etc.
- Special Patrolling : Special patrolling and defect liquidation of critical elements
- Logistic Tie-up : Advanced transportation tie-up for swift movement

Crisis management team need to rehearse crisis plan by developing a simulated scenario as mock drill periodically.

5.5. Recommendation-4: Smart & Future Ready Transmission System

A modern transmission grid needs to become smart in order to provide an affordable, reliable, and sustainable supply of electricity. The attributes of Smart and future ready grid are monitoring, analyzing, control and communication capabilities to the electricity delivery system to maximize the throughput of the system while maintaining stability with reduce energy consumption.

Smart means to incorporate intelligent technologies and human expertise embedded in the system itself which will take care of integration of variable renewable capacity, distributed energy resources, power and information flow in bi-directional way between source and load. Self-healing capability of the system will enable the system to reconfigure itself dynamically to recover from all types of failures and thus ensure grid security and uninterrupted power supply.

5.5.1. Flexibility through hybrid AC/ HVDC

A combination of AC and Voltage Source Converter (VSC) based HVDC system, especially in Intra State transmission would provide flexible and reliable transmission capabilities. Further, strategically placed FACTS devices like Power Flow Controller, STATCOMs etc. in the transmission network provides a flexible control to improve the dynamic performance and stability of the transmission network as per system requirement.

The integration of wind energy into existing electrical power system and large-scale use of non-linear devices (Inverters and converters) induces power quality problems like voltage regulation, harmonic distortion etc. In addition, it has impact on system inertial support for frequency regulations. FACTS device like STATCOM along with Battery Energy Storage System may be integrated with the inverter to address power quality problems, frequency regulation. For this, suitable Standards/Regulatory framework need to be developed.

5.5.2. Centralized Remote Monitoring and Operation of Substations

Transmission Asset Management Center through Centralized remote monitoring and operation of geographically spread large number of substations is the cost-effective way to maintain the transmission system with reliability and high availability. The application of sensors continuously monitors substation equipment condition and operate the equipment (Circuit Breaker & Isolator) remotely and transfer the information to the centralized location through robust fiber optic communication network or other communication system including Very Small Aperture Terminal (VSAT). It also includes SCADA and Energy Management System (EMS) to facilitate monitoring, outage / contingency planning. Besides, installation of PTZ camera at the strategic locations inside the substation integrated with fiber optic communication network facilitates enhanced visualization of each and every substation equipment and other accessories from centralized monitoring station.

To operate this large transmission network economically with reliability, the real time and off-line network study models have to be made uniform so that online studies could be performed on the full network available in the real time environment to avoid any network model mismatch and to ensure optimum usage without any model error. Complete network upto 132kV level should be mapped with SCADA system so that the model at real time environment shall be possible for the whole system. This would not only improve the short-term planning study but also improve the real time visualization. SCADA system along with the use of strong, reliable communication infrastructure will give complete visibility to centralized Transmission Asset Management Center to ensure 24x7 supply to consumer.

5.5.3. Fiberization of Transmission Lines

CEA, in the National Electricity Plan has acknowledged that "…the complexity in Grid operation has increased manifold, which necessitates dynamic monitoring of Grid parameters / conditions on real-time basis. The existing SCADA/EMS provides the data which are steady state in nature and not suitable for dynamic monitoring and control for the Grid due to high degree of latency of tele-metered data and also non-synchronized sampling of data." To overcome this situation, data has to flow from all lines and substations to control centres on real time basis. This in turn requires significant bandwidth and speed of communication. Traditional PLCC communication used by TRANSCOs is not able to provide that. Hence, Fiberization of the transmission lines (i.e. replacing existing earth wire with OPGW) is the need of the hour.

As of now less than 50% of the transmission lines (110kV and above) in the country, have OPGW. It is therefore very important to speed up this process, to have OPGW installed on 100% of high voltage lines by all TRANSCOs. Even 66 kV lines can also be considered for Fiberization through phase conductor wrapped with fibres. Such technologies are available. With additional bandwidth available with them, TRANSCOs can also lease out the spare bandwidth to telecom companies and earn additional revenues.

5.5.4. Wide Area Measurement System (WAMS)

Wide Area Measurement System using Phasor Measurement Units (PMU) at each 132kV and above substations integrated with OPGW communication network including V-Sat up to SLDC is essential for real-time monitoring and control of Intra State transmission facilities with reliability and stability. Synchro phasor measurement based on PMU provides enhanced network visualization and better situational awareness about the grid parameters, line loadings to both operators and planners. PMU technology along with necessary capacity building of people periodically would be essential for its successful deployment.

5.5.5. Adaptive Protection system

The integration of bulk renewables, which are intermittent nature will change the system fault level. Existing protection schemes may fail to operate to dynamically varying fault level.

Therefore, adaptive relay settings are very much essential for reliable control and operation of transmission system while ensuring equipment protection.

In addition, scenario based suitable System Protection Schemes (SPS) may be deployed to maintain the reliability and stability of the system under different operating conditions.

5.5.6. Cyber Security in Transmission

With the greater use of Information and Communication Technology (ICT), cybersecurity is considered to be one of the major challenges in transmission. The power system applications and ICT were developed in silos in the past. Therefore, the adoption of ICT in power domain is unstructured. This is causing greater challenges from cybersecurity point of view. A proper cybersecurity audit mechanism/standard needs to be built to address its challenges at device level, network level, and application level. Further, one of the most challenging vulnerabilities to address is cyber supply chain risk, given the increasingly far-flung and complex nature of the supply chain. Cyber supply chain accountability and ownership are not well-defined within companies, most CISOs have no control over their enterprises' supply chain, and they may have little access to supply chain cyber risk intelligence or visibility into suppliers' risk management processes. Add to that a lack of workforce and the sheer number of suppliers and transactions.

Transmission companies can start by identifying and mapping critical assets across the extended enterprise; using a cybersecurity maturity model to assess the maturity of the control environment; and building a framework that is secure, vigilant, and resilient. After reducing their own cyber risk profiles, power companies can collaborate with peers, governments, suppliers, and other industrial sectors to share intelligence, participate in practice exercises, develop new standards and frameworks, and pilot new technologies.

5.6. Recommendation-5: Capacity Building and Upskilling of Work Force

There is a paradigm shift in the way future power system will be developed and operated. For successful adoption of modern and advanced solutions / technologies outlined in the previous section, capacity building and upskilling of workforce at all levels is essential. Therefore, it is important that for the modernization of existing transmission infrastructure and making it smart and future ready, availability of skilled work force is ensured at all the levels through continuous hands-on training, tutorials, workshops, conferences, sharing of knowledges/experiences with other utility in the world etc. Immersive Virtual Reality may be used to facilitate problem-based learning methodology. In addition, review of old human resource structures may be required to align the workforce with modern system.

For effective utilization of modern infrastructure, capacity building of existing workforce along with addition of young professionals would play a significant role. So, HR policy should be duly reviewed and suitable capacity building provisions may be included to keep them abreast with latest technological development sharing of experience, knowledge with global experts etc. in the field of power transmission.

5.7. Summary of recommended technological intervention to make transmission system modern and future ready

An overview of deployment of modern transmission technology and its application is presented in following Table-3.

Table 4: Summary of Recommendation

Sl. No.	Technology	Application
1.	HTLS Conductors	Increasing the capacity of existing transmission corridors (1.8 -2 times)
2.	Refurbishment of old HVDC system	For life extension, high availability with better control and stability.
3.	Flexible AC Transmission devices (FACTs)	Enhancement of line loadability, improvement in stability, addressing the issue of uneven distribution of power flow on parallel corridors
4.	Dynamic Line Loading (DLL)	Dynamically enhancement of line loadability taken account of variation in atmospheric conditions
5.	Insulated Tower Cross Arm	Narrow ROW availability
6.	Energy Storage System	Higher utilization of Transmission, facilitate integration of Renewable generation, Ancillary service support
7.	Hybrid AC / HVDC system	Flexible transmission facility suitable for variable Renewable Integration, maintaining system parameters under various operating conditions.
8.	Conversion of AC line to HVDC Line	For enhancing the power transfer capacity of corridor by about 1.5 – 2.5 times.
9.	Photonic Coating on Conductor	Increasing the transmission capacity of 66 kV/132 kV lines by about 20-30%.
10.	Centralized Remote Monitoring, Operation of Substations including SCADA	Transmission Asset Management Center for remote monitoring and operation of all substations from single location, visualizing on Real time basis, outage / contingency planning.
11.	GIS/Hybrid Substation	Land optimization, Resilient infrastructure
12.	Process Bus Technology	Digital substations towards automation

Sl. No.	Technology	Application
13.	Fiberization of Transmission Lines	OPGW or phase conductor wrapped with fibres
14.	Wide Area Measurement System (WAMS)	Better Situational Awareness, Enhanced Visualization to system operators for reliable grid management, improve utilization of transmission infrastructure
15.	Drones	Survey, Stringing and Inspection of transmission assets
16.	Condition monitoring & Predictive maintenance using AI/ML algorithms	Data driven informed decision making for Maintenance, reduction in operation expenditure,
17.	Managing Age-old asset	Systematic identification, maintenance/ replacement of age-old asset
18.	Adaptive Protection System	Adaptive relay settings based on changing system configuration
19.	Helicopter in Line Construction	Material shifting in Wild Life & Forest area, Hilly terrain
20.	Robot	Minimize human intervention, minimize life risks/hazards, Time saving with accuracy during construction and maintenance
21.	Heavy duty Road Mat	Transport heavy equipment under adverse climatic conditions (rainy season, water logging)
22.	Augmented & Virtual Reality	Remote use of personal Skill, Capacity Building, Training
23.	Building Disaster Resilient Infrastructure	For less damage due to natural disasters
24.	Cyber Security	Prevention from Cyber threat and Information Security

Each of the above recommendations may be evaluated based on the system requirements, studies and techno-economic feasibility, implementation on case-by-case basis.

For effective utilization of modern infrastructure, utilities are required to make HR policies for capacity building of existing workforce along with addition of young professionals so that the personals involved in the planning, implementation, operation and maintenance can enhance their knowledge and managerial capability in association with the local technical/management institutes.

5.8. Benefits of Transmission Modernization

Modernization of transmission network would facilitate reduction in forced outages, minimize human intervention, enhanced visualization, centralized data driven decision making etc. thereby improving system availability and ensuring seamless transfer of power to the load centers. This would also help in optimal utilization of the transmission system.

Making transmission smart and future ready would enable increased penetration of renewable energy resources as well as defer investment in transmission.

5.9. Way Forward

1. The Task Force has suggested various technological interventions required to make transmission system modern and future ready. Further, the interventions have been categorized as essential and optional considering the flexibility and security requirement as presented in subsequent para.
2. Implementation of a particular technological intervention would depend upon the specific circumstances of each utility.
3. System performance audit, prioritization of utility requirement, workforce skill/knowledge assessment are also to be carried out prior to taking up implementation of specific recommendation to make the system smart and future ready.
4. Cost-benefit analysis for individual utilities would need evaluation on a case-to-case basis. A detailed cost benefit analysis would also be required to establish the viability of the proposed intervention.
5. Since, Investment requirements for adoption of suitable technology and benefits are case specific, the same have not been assessed by this Task Force.
6. **Suitable regulatory framework / enabling provisions may be ensured, wherever applicable, to promote investments for transition to smart and future ready grid.**

5.9.1. Categorization of Recommendations:

Implementation of above recommendations can be prioritized to phase out the outlays. Accordingly, the recommendations have been categorized as essential to address flexibility and cyber security as well as optional that may be considered by the utilities on the basis of enhanced reliability standards requirements for specified areas in their system.

(a) Essential Level:

1. Centralized Remote Monitoring, Operation of Substations including SCADA: Transmission Asset Management Center for remote monitoring and operation of all substations from single location, visualizing on Real time basis, outage / contingency planning.
2. Flexible AC Transmission devices (FACTs): Enhancement of line loadability, improvement in stability, addressing the issue of uneven distribution of power flow on parallel corridors, wherever feasible.
3. Increasing the capacity of existing transmission corridors through Reconductoring with HTLS conductors, wherever feasible
4. Fiberization of Transmission Lines through OPGW on EHV transmission lines or through phase conductor wrapped with fibres on lower voltage
5. Wide Area Measurement System (WAMS)
6. Integrated Cyber Security (Both IT & OT System)

(b) Optional Level:

Table 5: Optional Recommendations

Sl. No.	Technology	Application
1.	Refurbishment of old HVDC system	For life extension, high availability with better control and stability.
2.	Dynamic Line Loading (DLL)	Dynamically enhancement of line loadability taken account of variation in atmospheric conditions
3.	Insulated Tower Cross Arm	Narrow ROW availability
4.	Energy Storage System	Higher utilization of Transmission, facilitate integration of Renewable generation, Ancillary service support
5.	Hybrid AC / HVDC system	Flexible transmission facility suitable for variable Renewable Integration, maintaining system parameters under various operating conditions.
6.	Conversion of AC line to HVDC Line	For enhancing the power transfer capacity of corridor by about 1.5 – 2.5 times.
7.	Photonic Coating on Conductor	Increasing the transmission capacity of 66 kV/132 kV lines by about 20-30%.
8.	GIS/Hybrid Substation	Land optimization, Resilient infrastructure
9.	Process Bus Technology	Digital substations towards automation
10.	Drones	Survey, Stringing and Inspection of transmission assets
11.	Condition monitoring & Predictive maintenance using AI/ML algorithms	Data driven informed decision making for Maintenance, reduction in operation expenditure,
12.	Managing Age-old asset	Systematic identification, maintenance/ replacement of age-old asset

Sl. No.	Technology	Application
13.	Adaptive Protection System	Adaptive relay settings based on changing system configuration
14.	Helicopter in Line Construction	Material shifting in Wild Life & Forest area, Hilly terrain
15.	Robot	Minimize human intervention, minimize life risks/hazards, Time saving with accuracy during construction and maintenance
16.	Heavy duty Road Mat	Transport heavy equipment under adverse climatic conditions (rainy season, water logging)
17.	Augmented & Virtual Reality	Remote use of personal Skill, Capacity Building, Training
18.	Building Disaster Resilient Infrastructure	For less damage due to natural disasters

5.9.2. Benchmarking of transmission system parameters

The benchmark of transmission system parameters for improved reliability, security and stability of the grid in terms of system availability and maintaining system parameter i.e. voltages may be considered as follows:

a) Transmission system Availability

A comparison of the transmission system availability of global utilities for FY 2021-22 are given below :

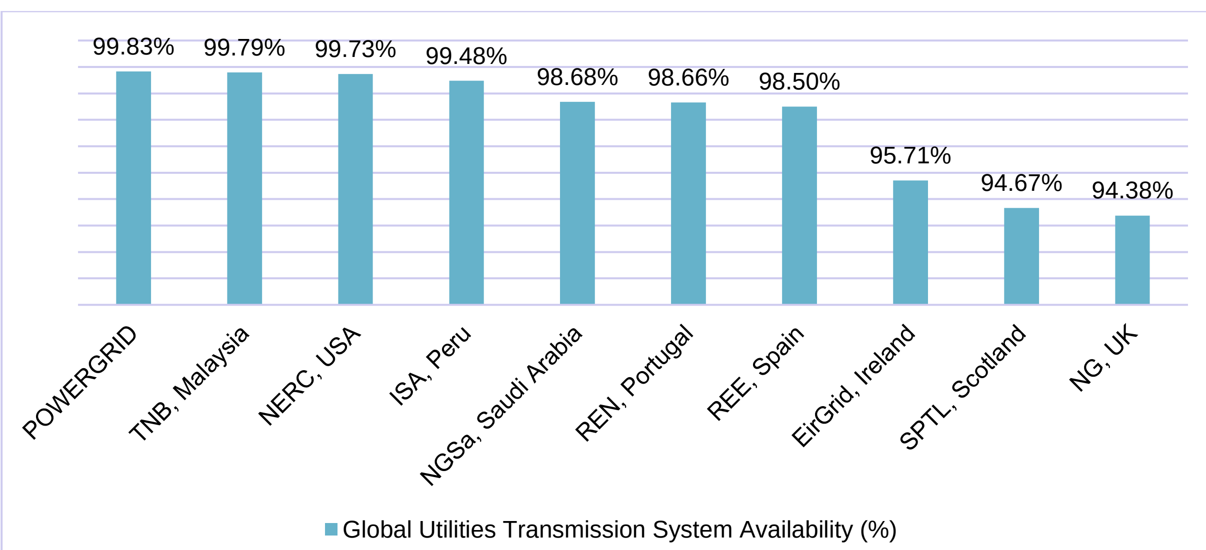


Figure 31: Transmission System Availability of Global utilities

Present Transmission system availability in Intra state network is in the range of 98% to 100%. In ISTS, transmission system availability is maintained above 99.8% (POWERGRID, the largest transmission licensee in India), which is higher than other major global transmission service providers. Further, as per CERC tariff regulation, incentive in tariff is allowed upto system availability at 99.75%. In view of the above, Transmission system availability may be benchmarked at 99.75% for transmission utilities in India.

b) Voltage fluctuations

There is wide variation in the voltage profile at various level. At 66 kV level, it is observed that voltages varies from 52 kV (-21.2%) to 74 kV(12.2%), at 132 kV it varies from 93 kV(-29.5%) to 143 kV(8.33%), at 220 kV level it varies from 191kV(-13.2%) to 245 kV(11.4%), and in the 400 kV level it varies from 390 kV (-2.5%) to 437 kV(9.25%).

As per International Standards as well as Indian Electricity Grid Code Regulation, allowable fluctuations at different voltage level are given below:

Table 6: Allowable voltage deviation at different voltage level in India

Voltage Level	%deviation
400 kV and above	± 5
220 kV/132 kV / 110 kV	± 10
66 kV	± 9

In view of the above, to maintain grid security, above voltage fluctuations may be considered by the utilities as benchmark.

Recommendations outlined in the section 5.7, would facilitate in achieving the above-mentioned Transmission system benchmark Parameters.

5.9.3. Road map for making the transmission system modern and smart in Metropolis / cities and rural areas:

a) Metropolis / Cities

i) Short Term (1-2 years):

1. Adequate reactive compensation in the form of shunt devices (Mechanically Switched Capacitor/ Reactor) or VSC / Thyristor based devices (STATCOM, SVC, TCSC etc.) for maintaining system voltage for grid stability and security.

2. Increasing the capacity of existing transmission corridors through Reconductoring with HTLS conductors, wherever feasible
3. Drone based Survey, Stringing and Inspection of transmission assets
4. Integrated Cyber Security (Both IT & OT system)

ii) Medium Term (2-3 years):

1. Centralized Remote Monitoring, Operation of Substations including SCADA
2. Fiberization of Transmission Lines through OPGW at 132 kV and above or phase conductor wrapped with fibres at 66 kV
3. Wide Area Measurement System (WAMS)
4. Dynamic Line Loading (DLL) System
5. Augmented & Virtual Reality facilitating remote use of personal skill, capacity building and training of workforce as well as maintenance and inspection
6. Drones & Robots in construction/inspection of transmission assets
7. Building Disaster Resilient Infrastructure

iii) Long Term (3-5 years) :

1. All new lines at 220 kV and below may be considered as Underground cable for 220kV and below network in Metropolis / cities areas (Only for the section witnessing ROW issue). Wherever feasible, overhead lines at 220 kV & below in Metropolis / cities areas may be converted into underground cables progressively in 3-5 years.
2. All new Substations and expansion may be considered as GIS/Hybrid Substation for Land optimization and resilient infrastructure in Metropolis / cities areas.
3. Insulated Tower Cross Arm / pole-based towers for narrow ROW for new transmission lines
4. Some Energy Storage System as part of transmission service.

b) <u>Rural areas</u>

In rural areas, to ensure reliability in power supply emphasis may be given on strengthening / modernization of distribution infrastructure. Nevertheless, to maintain transmission system reliability, following modernization efforts may be taken up in phased manner

i) Short Term (1-3 years):

1. Adequate reactive compensation in the form of shunt devices (Mechanically Switched Capacitor/ Reactor) or VSC / Thyristor based devices (STATCOM, SVC, TCSC etc.) for maintaining system voltage for grid stability and security.
2. Drone based Survey, Stringing and Inspection of transmission assets
3. Integrated Cyber-Physical Security (Both IT & OT system)

4. Building Disaster Resilient Infrastructure

ii) Long Term (3-5 years):

1. Centralized Remote Monitoring, Operation of Substations including SCADA.
2. Fiberization of Transmission Lines through OPGW at 132 kV and above or phase conductor wrapped with fibres at 66 kV
3. Augmented & Virtual Reality facilitating remote use of personal skill, capacity building and training of workforce as well as maintenance and inspection

5.9.4. Provisions to be considered in CEA regulations / guidelines

1. Optimization of ROW requirement for adoption of Insulated Tower Cross Arm especially in narrow corridors
2. Cyber-physical security especially at Operation Technology (OT) level
3. PMU based dynamic state monitoring of Transmission network
4. Building disaster resilient transmission infrastructure.

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Acknowledgement

This report on Modernization of Transmission Sector and making Smart and Future Ready would not have been completed without the support and data provided by the transmission utilities of various states namely AEGCL, BSPTCL, CSPTCL, GETCO, HPPTCL, HVPNL, JUSNL, KPTCL, KSEB, MPPTCL, MSETCL, MSPCL, OPTCL, Power Dept- Sikkim, PSTCL, RRVPNL, TANTransco, APTransco, TSTransco, UPPTCL, PTCUL & ED-DNH&DD as well as POWERGRID. The committee would like to thank all the officers and management of the utilities who have extended support in providing the data in the desired format and other relevant inputs within a very short time period.

The contribution of representatives from M/s Adani Transmission Ltd. and M/s Sterlite Power Transmission Ltd. in the Sub-groups with their valuable inputs and suggestions are sincerely acknowledged. Our thanks and appreciations also go to the officials of CTU & POWERGRID involved in collection & presentation of data as well as preparation of this report.

Sd/-
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COO, CTUIL
Convenor

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MD, UPPTCL
Member

Sd/-
Dr. N. Manjula
MD, KPTCL
Member

Sd/-
Shri Santanu Basu
MD, WBSETCL
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MD, AEGCL
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Chief Engineer, CEA
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Director (Trans), MoP
Member

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Member

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IIT, Kanpur
Member

Sd/-
Shri K. Sreekant
CMD, POWERGRID
Chair of the Committee

Annexures

No.15/3/2021Trans.
Government of India
Ministry of Power
Shram Shakti Bhawan, Rafi Marg, New Delhi
****

Dated the 22nd Septemher 2021

OFFICE ORDER

Subject: Constitution of Task Force for modernization of Transmission Sector and making it smart and future ready.

In pursuance of the directions of the Hon'ble Minister for Power & NRE to review the present status and activities of Smart Grid Knowledge Centre (SGKC) set up by Power Grid Corporation of India Ltd (PGCIL), a Task Force is hereby constituted under the Chairmanship of CMD, PGCIL for modernisation of Transmission Sector and making it smart and future ready. The composition of the Task Force shall be as under:

S.No.	Composition	Role
1	CMD, Power Grid Corporation of India Ltd (PGCIL)	Chairman
2.	CMD/MD, UP Power Transmission Corporation Ltd	Member
3	CMD/MD, Maharashtra State Electricity Transmission Company Ltd	Member
4.	CMD/MD, Karnataka Power Transmission Corporation Ltd	Member
5.	CMD/MD, West Bengal State Electricity Transmission Company Ltd	Member
6.	CMD/MD, Assam Electricity Grid Corporation Ltd	Member
7.	Chief Engineer (PSP&PA-I), Central Electricity Authority	Member
8.	A Smart Grid expert relating to Transmission nominated by Director, IIT, Kanpur	Member
9.	A representative nominated by Ministry of Electronics and Information Technology	Member
10.	Director (Transmission), Ministry of Power	Member
11.	A representative of transmission licensee nominated by EPTA	Member
12	Director, National Smart Grid Project Monitoring Unit	Member
13.	Chief Operating Officer, Central Transmission of Utility of India Ltd	Member Convenor

2. The Task Force may co-opt any other member, as deemed fit. The Terms of Reference of the Task Force are as under:

i. to suggest ways to make transmission system modern and future ready;
ii. to suggest technological innovation and adoption of new technologies in transmission sector; and
iii. any other issues deemed fit.

3. This issues with the approval of Hon'ble Minister for Power & New and Renewable Energy.

(Bihari Lal)
Under Secretary to the Govt. of India
Tel-011-23325242
Email: transdesk-mop@nic.in

To

The Chairperson and All Task Force Members

Copy to:-
1. **PS to Hon'ble Minister for Power & NRE.**
2. **PS to Hon'ble MoSP**
3. **Sr. PPS to Secretary (P)/ PS to JS(Trans)**

List of Utilities and Data Received Status

Sl. No.	Name of Utilities	Abbriviation	Transmission Utilities (State/National)	Data Received (Yes/No)
1	POWERGRID Corporation of India Limited	POWERGRID	National	Yes
2	Assam Electricity Grid Corporation Limited	AEGCL	State	Yes
3	Bihar State Power Transmission Company Ltd.	BSPTCL	State	Yes
4	Chhattisgarh State Power Transmission Company Ltd	CSPC	State	Yes
5	Delhi Transco Limited	DTL	State	No
6	Department of Power, Nagaland		State	No
7	Gujarat Energy Transmission Corp. Ltd	GETCO	State	Yes
8	H.P. Power Transmission Corporation Ltd.	HPPTCL	UT	Yes
9	Haryana Vidyut Prasaran Nigam Limited (HVPNL)	HVPNL	State	Yes
10	Jharkhand Urja Sancharan Nigam Ltd.	JUSNL	State	Yes
11	Karnataka Power Transmission Corp.Ltd.	KPTCL	State	Yes
12	Kerala State Electricity Board Ltd	KSEBL	State	Yes
13	Madhya Pradesh Power Transmission Company Ltd.	MPPTCL	State	Yes
14	Maharashtra State Electricity Transmission Company Ltd.	MSETCL	State	Yes
15	Manipur State Power Corporation Ltd.	MSPCL	State	Yes
16	Meghalaya Energy Corporation Ltd.	MeECL	State	Yes
17	Odisha Power Transmission Company Ltd.	OPTCL	State	Yes
18	Power & Electricity Department, Mizoram		State	No

Annexure-II

Sl. No.	Name of Utilities	Abbriviation	Transmission Utilities (State/National)	Data Received (Yes/No)
19	Power Department, Govt. of Sikkim	PD(Sikkim)	State	Yes
20	Power Development Department, Govt. of J & K	PDD	State	No
21	Power Transmission Corporation of Uttarakhand Ltd.	PTCUL	State	No
22	Punjab State Transmission Corp. Ltd.	PSTCL	State	Yes
23	Rajasthan Rajya Vidyut Prasaran Nigam Limited (RRVPNL)	RRVPNL	State	Yes
24	Tamilnadu Transmission Corporation Ltd.	TANTRANSCO	State	Yes
25	Transmission Corporation of Andhra Pradesh Ltd.	APTRANSCO	State	Yes
26	Transmission Corporation of Telangana Ltd.	TCTL	State	Yes
27	Tripura State Electricity Corporation Ltd.	TSECL	State	No
28	UP Power Transmission Corporation Limited	UPPTCL	State	Yes
29	Department of Power, Arunachal Pradesh		State	No
30	Department of Power, Goa		State	No
31	Department of Power, Dadra & Nagar Haveli	DNH	UT	No
32	Department of Power, Daman & Diu	DD	UT	Yes
33	Department of Power, Puduchery		UT	No
34	West Bengal State Electricity Transmission Company Ltd.	WBSETCL	UT	Yes

Number of Utilities from which data was requested	34
Number of Utilities from which data received	24

Data Collection format

Task Force
for
Modernization of Transmission Sector
&
making it Smart & Future Ready

Asset Base and Performance Parameters

Key Statistics				
Utility Name			As of 31.12.2021	Future Plan upto 2030
XXXX	1	Transmission lines in Ckm		
	2	Number of Lines		
	3	Number of Substations		
	4	System Availability (%)		
	5	Transformation capacity (MVA)		
	6	Transmission losses (%)		

Voltage wise Asset details								
Utility Name			66kV	132kV	220kV	400kV	765kV	Total
	Transmission Line							
XXXX	1	Number of Lines						
	2	Total line length in Ckm						
	3	Number of tripping/ year						
	Substations							
	1	Number of Substations (AIS)						
	2	Number of Substations(GIS)						
	3	Transformation Capacity (MVA)						

SCADA/Communication Details

Utility Name			66kV	132kV	220kV	400kV	765kV	Total
XXXX	**Transmission Line**							
	1	Number of lines with OPGW						
	2	Number of lines with out OPGW						
	Substations							
	1	Number of Substations with SAS						
	2	Number of Substation without SAS						

Age of Existing Assets

	< 5 Yrs	5 - 10 Yrs	10-15 Yrs	15-20Yrs	>20 Yrs
Transmission Lines in No. & Ckm					
66kV					
132kV					
220kV					
400kV					
765kV					
Substation in No. & MVA					
66kV					
132kV					
220kV					
400kV					
765kV					

Technology/Practices					
Utility name	Sl.No		Yes	No	Remarks
XXXX	**1**	**Transmission Line**			
	a)	High Temperature low sag conductor			
	b)	Multi-circuit tower			
	c)	Narrow based lattice tower			
	d)	Pole type tower			
	e)	Polymer Insulator			
	f)	Insulated cross arm			
	g)	Transmission line arrester			
	h)	Uprate or Re-conductoring of existing line			
	i)	XLPE cable used for above 220kV			
	2	**Substation**			
	a)	GIS (Outdoor/Indoor)			
	b)	Hybrid Substation (Switchgear GIS, Bus AIS)			
	c)	Mobile Substation			
	d)	Process Bus Technology for Protection & Control			
	e)	Bus Switching scheme at different voltage level			
		400kV (D-type/I-type for 1 & 1/2 Breaker scheme)			
		220kV (D-type/I-type for 1 & 1/2 Breaker scheme)			
		132kV (D-type/I-type for 1 & 1/2 Breaker scheme) or Double main-Transfer scheme			
	f)	Substation SCADA			
	g)	Substation remote operation & control			
	h)	Cyber Security features			
	i)	Transformer with ester oil			
	3	**Operation & Maintenance**			
	a)	On-line Condition Monitoring of			
		i) Transformer			
		ii) Reactor			
		iii) Circuit Breaker			
		iv) Lightning Arrester			
	b)	Online Fault Locator			
	c)	Thermal imaging of equipment, Transformer, Reactor			
	d)	Third Hermonic resistance measurement of SA			
	e)	Live line maintenance			
	f)	On-line tower patrolling			
	g)	Transmission line vegitation management digitally			
	h)	Use of drone for line and Substation inspection			
	i)	Use of Robot for inspection of Substation equipment avoiding routine/repetitive inspection			
	j)	Disaster Management Mechanism			

Technology/Practices					
Utility name	Sl.No		Yes	No	Remarks
	4	**Reactive Power management**			
	a)	Use of STATCOM, if yes, number and capacity (+/- MVAR)			
	b)	Use of shunt capacitor, Reactor, if yes, number and capacity			
	c)	Series capacitor, if yes, number and capacity, % compensation of line impedance			
	d)	Power flow controller			
		i)Phase shifting transformer			
		ii)Thyristor Controlled phase shifter			
		iii)Unified power flow controller			
	5	**System Operation at SLDC**			
	a)	Age of SCADA/EMS			
	b)	Use of Energy Management System for outage planning			
	c)	Cyber Security provision			
	d)	Back-up LDC			
		Any Other technology			
	6	**Any suggessions for improvement**			

Details of manpower

Utility Name	Total Manpower	Number
XXXX	Typical manpower	
	66kV Substation	
	132kV/220kV Substation	
	400/765kV Substation	
	Maintenance Team	

Average System Loading

Utility Name		MW
XXXX	Lines	
	66kV	
	132kV	
	220kV	
	400kV	
	765kV	
	Transformers	
	765/400kV	
	400/220kV	
	220/132kV	

Voltage (kV) Profile

Utility Name		Min	Max
XXXX	Lines		
	66kV		
	132kV		
	220kV		
	400kV		
	765kV		

Age of Transmission Asset

Annexure-IV

Sl.No	Type of Asset	Voltage(kV)	< 5 Yrs	5 - 10 Yrs	10-15 Yrs	15-20Yrs	>20 Yrs
	HVPNL						
1	No. of Lines	66	55	60	37	48	109
2	ckm	66	541.2	735.85	495.199	478.76	1281.27
3	No. of Lines	132	38	79	62	52	106
4	ckm	132	446.041	1281.149	910.364	741.907	1823.215
5	No. of Lines	220	56	54	46	31	34
6	ckm	220	1509.5	1459.074	1351.749	1152.117	979.432
7	No. of Lines	400	2	5	11		
8	ckm	400	100.97	253.62	661.02		
9	No. Substations	66	13	22	17	22	71
10	MVA	66	819	979	1594	1749	4542
11	No. Substations	132	9	25	49	44	60
12	MVA	132	900	1811	4369	3668	6038.5
13	No. Substations	220	18	16	19	11	19
14	MVA	220	4353	3986.5	5428.5	4315	6177
15	No. Substations	400	0	1	6		
16	MVA	400	0	846	5139		
	RRVPNL						
17	ckm	66	0	0	0		
18	ckm	132	1899	2404	2315	1514	10364
19	ckm	220	1736	3297	343	1510	75324
20	ckm	400	2962	1033	2285	333	287
21	ckm	765	0	425	0		
22	No. Substations	132	41	83	70	62	197
23	MVA	132	4924	8291	9362	3536	8294
24	No. Substations	220	8	38	26	12	42
25	MVA	220	4830	9130	8170	2400	8005
26	No. Substations	400	5	2	5	2	2
27	MVA	400	6445	3020	1890	1575	1380
28	No. Substations	765	0	2	0		
29	MVA	765		7500			
	MSPCL						
30	No. of Lines	132	4	6			10
31	ckm	132	129	138			433
32	No. of Lines	400	1				
33	ckm	400	90				
34	No. Substations	132	3	6			8
35	MVA	132	75	290			353
36	No. Substations	400	1				
37	MVA	400	315				
	PSTCL						
38	No. of Lines	132	5	6	12	11	124
39	No. of Lines	220	58	79	30	24	70
40	No. of Lines	400		19			
41	No. Substations	132		2	7	4	51
42	No. Substations	220	10	32	9	6	46
43	No. Substations	400		5			
	OPTCL						
44	No. of Lines	132	93	36	33	33	137
45	ckm	132	2003.74	572.429	502.07	363.607	4526.105
46	No. of Lines	220	28	25	23	11	60
47	ckm	220	369.728	426.777	1230.43	243.09	4016.443
48	No. of Lines	400	3	3	2	2	2
49	ckm	400	63.468	611.2	75.832	200.902	245.47
50	No. Substations	132	33	23	16	9	50
51	MVA	132	1442.5	885.5	453.5	297.5	4281.5
52	No. Substations	220	15	4	2	1	18
53	MVA	220	2432.5	840	600	440	7403

Age of Transmission Asset

Annexure-IV

Sl.No	Type of Asset	Voltage(kV)	< 5 Yrs	5 - 10 Yrs	10-15 Yrs	15-20Yrs	>20 Yrs
54	No. Substations	400	1	1	1	2	
55	MVA	400		970	1185	1605	
	JUSNL						
56	No. of Lines	132	18	12		3	25
57	No. of Lines	220	11	5		1	6
58	No. of Lines	400	1				2
59	No. Substations	132	10	2		21	6
60	No. Substations	220	8	1		1	3
61	No. Substations	400	1				
	GETCO						
62	No. of Lines	66	930	921	490	228	911
63	ckm	66	9208	9330.34	5337.7	2748.84	10234.17
64	No. of Lines	132	27	30	8	6	128
65	ckm	132	951.18	681.86	291	206.22	3340.25
66	No. of Lines	220	90	86	66	35	175
67	ckm	220	4290.29	4079.88	2381	1471.92	8522.67
68	No. of Lines	400	14	21	17	5	15
69	ckm	400	1218.85	3280.22	2426.83	453.26	1874.79
70	No. Substations	66	517	460	239	129	561
71	MVA	66	15510	14225	7280	4825	22857.5
72	No. Substations	132	5	4		2	41
73	MVA	132	700	300		225	7780
74	No. Substations	220	12	16	13	7	60
75	MVA	220	3140	5160	3420	2270	26010
76	No. Substations	400	4	3	3		8
77	MVA	400	3000	2705	3965		11100
	MPPTCL						
78	No. of Lines	132	184	124	94	64	330
79	ckm	132	4534.52	3182.62	2424.8	1679.1	9689.37
80	No. of Lines	220	46	25	39	17	153
81	ckm	220	1993.84	1224.7	2640.73	690.43	8328.13
82	No. of Lines	400	8	7	2	7	14
83	ckm	400	666.95	32.61	49	519.05	1694.92
84	No. Substations	132	71	63	36	46	91
85	No. Substations	220	11	11	14	12	36
86	No. Substations	400	4	2	3		5
	KSEB						
87	No. of Lines	66	22	12	15	11	110
88	No. of Lines	110	135	34	40	32	151
89	No. of Lines	220	33	8	6	7	24
90	No. of Lines	400	2				
91	No. Substations	66	10	6	8	9	24
92	No. Substations	110	25	22	39	31	58
93	No. Substations	220	8	3	4	2	11
94	No. Substations	400			1		
	TS Transco						
95	No. of Lines	132	165	57	72	71	222
96	No. of Lines	220	107	54	32	17	67
97	No. of Lines	400	65	6	7	4	4
98	No. Substations	132	42	48	25	39	81
99	No. Substations	220	28	16	10	4	28
100	No. Substations	400	15	2	3	1	1
	AEGCL						
101	No. Substations	132	8	10	13	1	26
102	No. Substations	220	2	2	1		6
103	No. Substations	400		1			
	ED, DNH&D						

Age of Transmission Asset

Sl.No	Type of Asset	Voltage(kV)	< 5 Yrs	5 - 10 Yrs	10-15 Yrs	15-20Yrs	>20 Yrs
104	No. of Lines	220	2.5	37.5			
105	No. Substations	220	1	2	1	2	
	KPTCL						
106	No. Substations	66	97	67	203	83	254
107	No. Substations	110	63	63	123	72	131
108	No. Substations	220	15	8	28	14	50
109	No. Substations	400	4			2	2
	PD(Sikkim)						
110	No. of Lines	66	5	5	6		14
111	No. of Lines	132		1	3	2	
112	No. Substations	66	4	5	1	2	13
113	No. Substations	132			1		
	BSPTCL						
114	ckm	132	3420	2496	1146	2337	2073
115	ckm	220	1580	1128	304	478	438
116	No. Substations	132	32	26	16	14	38
117	MVA	132	2950	2950	1880	1500	6100
118	No. Substations	220	5	7	2	1	5
119	MVA	220	1440	2990	760	400	2910
	TANTransco						
120	No. of Lines	132	160	141	126	90	327
121	ckm	132	2881.4	3016.96	2920.53	2272.35	9447.24
122	No. of Lines	220	66	72	59	24	180
123	ckm	220	2372	1835.49	2544.55	855	5959.59
124	No. of Lines	400	18	50	2		1
125	ckm	400	596	2276	16.3		38.33
126	No. Substations	66					
127	MVA	66					
128	No. Substations	132			4	12	31
129	MVA	132			325	1163	2217
130	No. Substations	220	23	21	15	10	46
131	MVA	220	4500	4810	4005	2450	12371
132	No. Substations	400	8	5	2	0	3
133	MVA	400	6580	5715	2375	0	3025

Annexure-V

Transmission Asset Summary (No of Lines, Ckm, No. of S/S, MVA, Reliability, Availability

STU	Ckm	Lines (No.)	Substations (No.)	Availability (%)	MVA	Losses (%)	Voltage levels	Reliability				
								66kV	132kV	220kV	400kV	765kV
HVPNL	16202.47	882	422	99.47	56714.50	1.57	66/132/220kV	0.11	0.30	1.86	**2.56**	
RRVPNL	41839.49	1080	597	99.70	88751.00	3.33	132/220kV		1.86	**2.62**	**1.98**	**4.00**
PSTCL	12562.60	438	172	99.84	39480.17	2.25	66/132/220kV		**6.19**	**2.39**	1.68	
HPPTCL	327.60	10	9	98.00	2473.50	0.75	132/220kV					
UPPTCL	47512.63	1303	610		135950.00		132/220kV		2.06	**4.43**	6.48	2.80
OPTCL	15451.29	491	176	99.98	22836.00	3.22	132/220kV		**5.11**	0.54	0.33	
PD(Sikkim)	516.95	36	26	98.45	417.50	2.40	66/132kV	1.12	**2.40**			
BSPTCL	15400.00	336	146	99.65	23880.00	2.42						
JUSNL	6240.00	84	53		9935.00							
GETCO	72330.05	4203	2084	99.69	143676.00	3.61	66/132/220kV	2.50	4.57	3.27	2.81	
ED, DNH&D		8	6	99.00	1320.00	1.65	220kV					
MPPTCL	40051.00	1113	405	99.14	72889.00	2.66	132/220kV		2.85	3.55	3.11	
MSETCL	50106.00	1510	884	99.68	129285.00	3.07	132/220kV	0.92	0.51	0.67	1.26	
KPTCL	39396.65		1279	99.53	72798.30	2.98	132/220/400kV					
TSTRANSCO	27036.00	950	343		75323.50		132/220/400kV		5.76	3.36	0.36	
APTRANSCO	31007.40	1076	351	99.82	59785.00							
KSEB	11851.31	642	261	98.20	22960.60	3.85	66/132kV	**32.49**	28.65	20.55	3.50	
MSPCL	699.34	20	17	99.00	718.30		132kV		31.25		8.00	
AEGCL	5782.00	139	70	99.19	7514.50	3.30	132kV	4.56	2.31	6.12	3.50	

Technology Adoption Details By STUs

Annexure-VI

Technology / Utility Name	HVPNL	RRVPNL	PSTCL	HPPTCL	UPPTCL
Transmission Line					
HTLS	Yes	No	Yes	Yes	Yes
Multi-Circuit Tower	Yes	Yes	Yes	Yes	Yes
Narrow Based Lattice Tower	Yes	Yes	Yes	Yes	Yes
Pole Type Tower	Yes	Yes	No	No	Yes
Polymer Insulator	Yes	Yes	Yes	Yes	Yes
Insulated Cross Arm	No	No	No	No	No
Transmission Line Arrester	Yes	Yes	No	No	No
Re-conductoring	Yes	Yes	Yes	Yes	Yes
XLPE cable (above 220kV)	No	No	No	Yes	No
Substation					
GIS	Yes	Yes	No	Yes	Yes
Hybrid Substation (Switchgear GIS, Bus AIS)	Yes	Yes	No	No	Yes
Mobile Substation	Yes	No	No	No	No
Process Bus Technology	No	Yes	No	No	No
1 & 1/2 Breaker scheme at 400kV	Yes	Yes	Yes	No	Yes
1 & 1/2 Breaker scheme at 220kV	No	Yes	No	No	No
1 & 1/2 Breaker or DMT scheme at 132kV	No	No	No	No	Yes
Substation SCADA	Yes	Yes	Yes	Yes	Yes
Substation Remote Operation & Control	Yes	Yes	Yes	Yes	No
Cyber Security at S/s	No	Yes	No	Yes	Yes
Transformer with Ester oil	No	No	No	No	No
Operation & Maintenance					
On-line Condition Monitoring of Transformer	No	Yes	Yes	Yes	No
On-line Condition Monitoring of Reactor	No	Yes	Yes	No	No
On-line Condition Monitoring of Circuit Breaker	No	No	No	No	No
On-line Condition Monitoring ofLightning Arrester	No	No	Yes	No	No
Online Fault Locator	No	No	Yes	No	No
Thermal Imaging of equipment, Transformer, Reactor	No	Yes	No	Yes	Yes
Third Hermonic resistance measurement of SA	No	No	Yes	Yes	No
Live line maintenance	No	No	Yes	No	No
On-line tower patrolling	No	No	Yes	No	No
Transmission line vegitation management digitally	No	No	No	No	No
Drone inspection - line & S/s	Yes	No	No	No	No
Robot Inspection - S/s equipment	No	No	No	No	No
Disaster Management Mechanism	No	Yes	Yes	Yes	No
Reactive Power management					
STATCOM/SVC	No	No	No	No	No
Shunt Capacitor/ Reactor	Yes	Yes	Yes	No	Yes
Series Capacitor	No	No	No	No	No
Phase Shifting Transformer	No	No	No	No	No
Thyristor Controlled Phase Shifter	No	No	No	No	No
Unified Power Flow Controller	No	No	No	No	No
System Operation at SLDC					
SCADA/EMS	No	No	Yes	No	No
EMS for outage planning	No	No	No	No	No
Cyber Security at SLDC	Yes	Yes	Yes	No	Yes
Back-up LDC	Yes	No	Yes	No	Yes

Technology Adoption Details By STUs

Annexure-VI

Technology / Utility Name	OPTCL	WBSERCL	PD(Sikkim)	BSPTCL	JUSNL
Transmission Line					
HTLS	Yes	Yes	No	Yes	Yes
Multi-Circuit Tower	Yes	Yes	Yes	Yes	Yes
Narrow Based Lattice Tower	Yes	Yes	No	Yes	No
Pole Type Tower	Yes	Yes	No	No	Yes
Polymer Insulator	Yes	Yes	No	Yes	Yes
Insulated Cross Arm	No	No	No	No	No
Transmission Line Arrester	No	Yes	Yes	No	No
Re-conductoring	Yes	Yes	No	Yes	Yes
XLPE cable (above 220kV)	No	Yes	No	No	Yes
Substation					
GIS	Yes	Yes	No	No	Yes
Hybrid Substation (Switchgear GIS, Bus AIS)	No	Yes	No	No	Yes
Mobile Substation	No	No	No	No	No
Process Bus Technology	Yes	No	Yes	No	No
1 & 1/2 Breaker scheme at 400kV	Yes	Yes	No	No	No
1 & 1/2 Breaker scheme at 220kV	No	Yes	No	No	No
1 & 1/2 Breaker or DMT scheme at 132kV	No	Yes	No	No	No
Substation SCADA	Yes	Yes	No	No	Yes
Substation Remote Operation & Control	Yes	Yes	No	No	No
Cyber Security at S/s	No	Yes	No	Yes	No
Transformer with Ester oil	No	No	No	No	No
Operation & Maintenance					
On-line Condition Monitoring of Transformer	No	No	No	No	No
On-line Condition Monitoring of Reactor	No	No	No	No	No
On-line Condition Monitoring of Circuit Breaker	No	No	No	No	No
On-line Condition Monitoring ofLightning Arrester	No	No	No	No	No
Online Fault Locator	Yes	Yes	No	No	Yes
Thermal Imaging of equipment, Transformer, Reactor	Yes	Yes	No	Yes	Yes
Third Hermonic resistance measurement of SA	Yes	Yes	No	Yes	No
Live line maintenance	No	No	No	No	No
On-line tower patrolling	Yes	No	No	No	No
Transmission line vegitation management digitally	No	No	No	No	No
Drone inspection - line & S/s	No	No	No	No	No
Robot Inspection - S/s equipment	No	No	Yes	No	No
Disaster Management Mechanism	Yes	Yes	Yes	Yes	No
Reactive Power management					
STATCOM/SVC	No	No	No	No	No
Shunt Capacitor/ Reactor	No	Yes	No	Yes	No
Series Capacitor	No	No	No	No	No
Phase Shifting Transformer	No	No	No	No	No
Thyristor Controlled Phase Shifter	No	No	No	No	No
Unified Power Flow Controller	No	No	No	No	No
System Operation at SLDC					
SCADA/EMS	No	Yes	Yes	No	No
EMS for outage planning	No	No	Yes	Yes	No
Cyber Security at SLDC	Yes	Yes	No	Yes	No
Back-up LDC	Yes	Yes	No	No	No

Technology Adoption Details By STUs

Annexure-VI

Technology / Utility Name	GETCO	MPPTCL	MSETCL	DNH&DD	KPTCL
Transmission Line					
HTLS	Yes	Yes	Yes	No	Yes
Multi-Circuit Tower	Yes	Yes	Yes	Yes	Yes
Narrow Based Lattice Tower	Yes	Yes	Yes	Yes	Yes
Pole Type Tower	Yes	Yes	Yes	No	No
Polymer Insulator	Yes	Yes	Yes	Yes	Yes
Insulated Cross Arm	No	No	No	No	No
Transmission Line Arrester	No	No	Yes	No	No
Re-conductoring	Yes	Yes	Yes	No	Yes
XLPE cable (above 220kV)	No	No	No	No	Yes
Substation					
GIS	Yes	Yes	Yes	Yes	Yes
Hybrid Substation (Switchgear GIS, Bus AIS)	Yes	No	Yes	Yes	Yes
Mobile Substation	No	No	No	No	No
Process Bus Technology	Yes	No	Yes	Yes	No
1 & 1/2 Breaker scheme at 400kV	Yes	No	Yes	No	Yes
1 & 1/2 Breaker scheme at 220kV	No	No	No	No	Yes
1 & 1/2 Breaker or DMT scheme at 132kV	No	Yes	Yes	No	No
Substation SCADA	No	No	Yes	Yes	Yes
Substation Remote Operation & Control	Yes	Yes	Yes	No	Yes
Cyber Security at S/s	Yes	No	Yes	No	Yes
Transformer with Ester oil	Yes	No	No	No	Yes
Operation & Maintenance					
On-line Condition Monitoring of Transformer	No	Yes	Yes	Yes	Yes
On-line Condition Monitoring of Reactor	Yes	No	Yes	No	Yes
On-line Condition Monitoring of Circuit Breaker	Yes	No	Yes	Yes	No
On-line Condition Monitoring ofLightning Arrester	No	No	No	Yes	No
Online Fault Locator	No	No	Yes	No	Yes
Thermal Imaging of equipment, Transformer, Reactor	No	Yes	Yes	No	Yes
Third Hermonic resistance measurement of SA	Yes	Yes	Yes	No	Yes
Live line maintenance	No	Yes	Yes	No	Yes
On-line tower patrolling	Yes	No	Yes	No	No
Transmission line vegitation management digitally	Yes	No	No	No	No
Drone inspection - line & S/s	No	No	Yes	No	No
Robot Inspection - S/s equipment	No	No	No	No	No
Disaster Management Mechanism	No	No	No	No	Yes
Reactive Power management					
STATCOM/SVC	No	No	No	No	No
Shunt Capacitor/ Reactor	Yes	Yes	Yes	No	Yes
Series Capacitor	Yes	No	No	No	No
Phase Shifting Transformer	No	No	No	No	Yes
Thyristor Controlled Phase Shifter	No	No	No	No	Yes
Unified Power Flow Controller	No	No	No	No	Yes
System Operation at SLDC					
SCADA/EMS	No	Yes	Yes	Yes	No
EMS for outage planning	Yes	Yes	No	No	Yes
Cyber Security at SLDC	Yes	Yes	Yes	Yes	Yes
Back-up LDC	Yes	Yes	No	Yes	Yes

Technology Adoption Details By STUs

Annexure-VI

Technology / Utility Name	TS Transco	KSEB	MSPCL	AEGCL
Transmission Line				
HTLS	Yes	Yes	No	Yes
Multi-Circuit Tower	Yes	Yes	No	Yes
Narrow Based Lattice Tower	Yes	Yes	No	No
Pole Type Tower	No	Yes	No	No
Polymer Insulator	Yes	Yes	Yes	Yes
Insulated Cross Arm	Yes	Yes	No	Yes
Transmission Line Arrester	No	Yes	Yes	No
Re-conductoring	Yes	Yes	Yes	Yes
XLPE cable (above 220kV)	Yes	No	No	No
Substation				
GIS	Yes	Yes	No	Yes
Hybrid Substation (Switchgear GIS, Bus AIS)	No	Yes	No	Yes
Mobile Substation	No	No	No	No
Process Bus Technology	No	Yes	No	No
1 & 1/2 Breaker scheme at 400kV	Yes	Yes	Yes	Yes
1 & 1/2 Breaker scheme at 220kV	No	No	No	Yes
1 & 1/2 Breaker or DMT scheme at 132kV	No	No	Yes	Yes
Substation SCADA	Yes	Yes	Yes	Yes
Substation Remote Operation & Control	Yes	Yes	No	Yes
Cyber Security at S/s	Yes	Yes	No	No
Transformer with Ester oil	No	Yes	No	No
Operation & Maintenance				
On-line Condition Monitoring of Transformer	Yes	Yes	No	No
On-line Condition Monitoring of Reactor	Yes	No	No	No
On-line Condition Monitoring of Circuit Breaker	No	No	No	No
On-line Condition Monitoring ofLightning Arrester	Yes	No	No	No
Online Fault Locator	No	No	No	No
Thermal Imaging of equipment, Transformer, Reactor	Yes	Yes	No	Yes
Third Hermonic resistance measurement of SA	Yes	Yes	Yes	No
Live line maintenance	Yes	Yes	No	No
On-line tower patrolling	No	Yes	Yes	No
Transmission line vegitation management digitally	No	No	Yes	No
Drone inspection - line & S/s	No	Yes	No	No
Robot Inspection - S/s equipment	No	No	No	No
Disaster Management Mechanism	Yes	No	No	Yes
Reactive Power management				
STATCOM/SVC	No	No	No	No
Shunt Capacitor/ Reactor	Yes	Yes	No	Yes
Series Capacitor	No	No	No	No
Phase Shifting Transformer	Yes	No	No	No
Thyristor Controlled Phase Shifter	No	No	Yes	No
Unified Power Flow Controller	No	No	Yes	No
System Operation at SLDC				
SCADA/EMS	Yes	Yes	No	Yes
EMS for outage planning	No	Yes	No	No
Cyber Security at SLDC	Yes	Yes	No	Yes
Back-up LDC	No	Yes	No	No