PROCEEDING

3 - DAYS TUTORIAL AND CONFERENCE ON

"Design & Construction of Transmission Line"

FGI, Vadodara, Gujarat

5-7 November, 2025 (Wed-Thurs-Fri)

ORGANIZED BY:

The Society of Power Engineers (I)
Vadodara Chapter
AND
Central Board of Irrigation & Power
New Delhi

The Society of Power Engineers (India)
Vadodara Chapter

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"Design & Construction of Transmission Line"

5-6-7 NOVEMBER, 2025 (WED-THURS-FRI), AT FGI, GOTRI, VADODARA

THE SOCIETY OF POWER ENGINEERS (I), VADODARA CHAPTER

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"Engineering The Grid: Practical Construction And Execution Of Overhead Transmission Lines"

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Transmission line construction is not merely an engineering activity; it is a multidisciplinary execution challenge combining design precision, logistics, manpower management, safety, and innovation. While theoretical design principles determine what must be built, practical planning and field techniques decide how efficiently and safely it is completed. In India, the diversity of geography, terrain, and climate—from hilly regions and deserts to coastal and flood-prone areas—adds layers of complexity to the process. Therefore, integrating sound design methodology with adaptable field execution and intelligent planning is essential for successful project delivery.

Pre-Construction Planning and Data Preparation

Every transmission line project begins with detailed planning supported by accurate field data. The pre-construction phase involves surveys, design validation, and logistics preparation. A thorough route survey establishes the alignment and identifies crossings such as rivers, roads, railways, and existing lines. Modern tools like Total Stations, drones, and LIDAR are increasingly used for profiling. Soil resistivity tests and geotechnical investigations classify foundations according to load and soil type.

A transmission line data summary consolidates voltage level, conductor configuration, wind and seismic zones, ruling spans, and statutory approvals such as PTCC, forest, and railway clearances. This document serves as the central reference for both design and execution teams. Once data is finalized, planners sequence the work—survey, foundation, erection, stringing, and testing—while identifying opportunities for parallel working among multiple teams. Effective pre-planning ensures uninterrupted progress and minimizes costly mobilization delays.

Execution Planning and Gang Management

In Indian conditions, the availability and retention of skilled erection and stringing gangs often define the project timeline. These specialized workers possess unique mechanical skills but frequently shift between projects depending on wages or work conditions.Losingtrainedgangsmid-projectcansignificantlyaffectschedules.Hence, execution planning focuses on minimizing idle time and maximizing resource utilization.

Key measures include merging or overlapping gangs, where erection and stringing teams operate concurrently; segmenting the line into manageable

blocks so multiple gangs can work simultaneously; and front-loading critical sections such as river or railway crossings. Equally important is ensuring material readiness by pre- transporting towers, conductors, and insulators near work fronts. Today, planners use integrated 3D project schedules combining Gantt charts with GIS mapping and drone-based progress tracking to monitor manpower productivity and logistics flow in real time.

Tower Foundations–Field Experience and Innovation

Foundations provide structural stability and vary with soil and load conditions. Common types include open-type foundations in normal soil, raft or undercut foundations in wet areas, pile foundations in loose alluvium, and pad-and-chimney or anchor block foundations in rocky terrain.

Practical innovations have evolved from decades of field experience. In waterlogged regions such as South Gujarat and Assam, engineers use Portadecks—modular steel platforms that support machinery and enable concreting in Marshy area. Sandbags and geo textile mats stabilize work areas, while reused conductor drum wheels often serve as makeshift road mats to move concrete mixers or vehicles. In rocky terrain, controlled blasting, chemical anchors, and grout-filled bolts are preferred over heavy excavation. In inaccessible forest or hill areas, materials are transported through ropeways or manual head-loads, maintaining progress where vehicular access is impossible.

Quality control remains crucial: stub centering, excavation depth, and reinforcement layout must adhere strictly to design drawings. Concrete is mixed, compacted, and cured properly, and pile foundations undergo integrity testing before erection. Sound foundation practices ensure long-term line stability and safety.

Tower Erection–Efficiency and Safety

Tower erection transforms the design into reality. Traditionally, Indian projects relied on manual erection using derricks, gin poles, and pulley systems. Although effective in difficult terrains, these methods are slow and labor-intensive. The adoption of hydraulic or lattice-boom cranes has revolutionized erection speed and safety. A tower that once required a week can now be completed within one or two days. Mechanized erection reduces fatigue, enhances alignment accuracy, and minimizes risk.

For safe crane operations, proper access roads and lifting plans are essential. Each site should undergo a pre-lift safety assessment. Tower members are color-coded and arranged sequentially to prevent errors, and once assembled, an "as-erected" survey confirms coordinates and alignment before stringing begins. All erection activities must comply with strict safety practices—helmets, harnesses, and reflective jackets are mandatory, and no work proceeds during high winds or thunderstorms.

Conductor Stringing–Precision with Innovation

Stringing involves pulling conductors, earth wires, and OPGW under controlled tension to maintain safe clearances and design sag. The mechanical relationship between tension, span, and sag governs conductor behavior, requiring temperature- specific calculations. Traditional stringing using manual or tractor-driven tensioners has largely been replaced by hydraulic tension stringing machines (TSM) that maintain uniform tension and prevent conductor damage.

Innovations like Sky Rollers—temporary overhead rollers for crossing rivers and highways—allow stringing without erecting tall scaffolds. Drone-assisted pilot rope laying has become common in congested or mountainous corridors, replacing rockets and balloons. In extreme terrains such as the Himalayas, helicopter stringing has enabled completion of otherwise inaccessible lines. These technologies reduce downtime, improve accuracy, and significantly cut labor dependency.

During stringing, phase sequence must be verified, compression joints crimped with calibrated tools, and vibration dampers installed near suspension points. Sag checking at reference temperature ensures compliance with design tables. Each tower should have an earth resistance below 10 ohms for adequate lightning protection.

Crossings and Special Locations

Crossings represent some of the most demanding execution points. River crossings use sky rollers, temporary towers, or pontoons for rope pulling, coordinated with the Inland Waterways Authority to maintain navigation clearance. Railway crossings require prior approval and are executed during sanctioned power blocks under supervision, with protective scaffolds or safety nets to prevent conductor drops. Highway and power line crossings use guard structures and close coordination with NHAI and local utilities to ensure uninterrupted traffic and system safety.

Adapting to Diverse Terrains

India's climatic variety necessitates adaptive construction approaches. In waterlogged regions like South Gujarat or Bengal delta, engineers employ portadecks, sandbags, and raft-type foundations to continue work during monsoons. In hilly terrain, ropeways, sledges, and anchor block foundations are used to overcome steep gradients. Desert regions demand deeper foundations with anti-tilt collars and enhanced curing methods to prevent early drying of concrete. Such site-specific techniques demonstrate the ingenuity and resilience of Indian field engineers.

Safety, Quality, and Environmental Care

Safety is paramount in transmission construction. Workers must use helmets, harnesses, and safety shoes at all times, and daily toolbox meetings reinforce awareness of site-specific hazards. Stringing near live lines requires strict permit-to- work procedures. Quality control includes foundation strength checks, bolt torque verification, insulator inspection, and sag-tension measurement. Environmentally, contractors should minimize deforestation, reuse excavated soil, and ensure proper disposal of concrete waste. Attention to safety and quality not only prevents accidents but also ensures the longevity of assets.

Reducing Execution Time through Innovation

Modern transmission projects focus on reducing execution time while maintaining safety and quality. Crane-based erection has cut tower erection time by up to 70 percent, while Sky Rollers and TSM shave halved stringing durations in crossings. In waterlogged areas, Portadecks, sandbags, and drum-wheel pathways keep works progressing through the monsoon. Drone-based inspection and merged gang deployment optimize manpower utilization. These innovations have collectively reduced overall project durations by 20–35 percent across several utilities, proving that innovation directly translates to efficiency.

Conclusion

Transmission line construction in India is a fine balance between engineering accuracy and field adaptability. Design manuals establish the technical framework for safety and reliability, but on-ground success depends on meticulous planning, innovation, and coordination. Effective planning boosts productivity; mechanization and improvisation improve efficiency; adaptive methods ensure continuity across diverse terrains; and safety remains the overriding priority.

By embracing modern techniques—such as crane-assisted erection, drone-based monitoring, and portadeck use in waterlogged zones—engineers have successfully merged precision with practicality. Efficiently executed projects not only save time and cost but also enhance the reliability of India's power transmission network, forming the backbone of its growing energy infrastructure. The future of transmission construction lies in uniting engineering excellence with practical ingenuity, ensuring that every tower standing across India's varied landscapes symbolizes progress, stability, and the relentless pursuit of innovation.

#######

Recent Trends in Electrical Design of Transmission Line & Transmission System

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Electrical Engineering Department SVIT –VASAD

Abstract:

Recent trends in transmission line electrical design focus on use of smart grid with digital technology such as AI and IOT, development of high-performance conductors like carbon-fiber reinforced aluminum for higher power transfer capacity, reconductoring (high-capacity conductors), operation of Dynamic Line Ratings (DLR) for better transmission line capacity utilization and modern tower design, reduced right of way needs, electrical design with integration of non conventional energy sources, advances in HVDC transmission. Moreover modern electrical design includes the use of high temperature low sag (HTLS) and nano saturated materials. This material allows the design engineer to re-conductoring existing line. High-Temperature Superconducting (HTS) cables and advanced conductors like composite-core and carbon-fiber-reinforced types are used for higher capacity and lower losses. High voltage direct transmission (HVDC) and Gas Insulated Lines (GILs) improves the efficiency of transmission line and also give more options in challenging territories. Digitization of grid using IOT (Internet of things) sensors enables real time monitoring. This paper focuses on various aspects for improvement in electrical design of a transmission line.

Index term: IOT, Dynamic Line Rating, reconductoring

1) Introduction:

As the world moves to more sustainable forms of electricity generation, the role of transmission line engineering and hence electrical design of a transmission line becomes very vital in ensuring that the power harnessed from non conventional sources reaches its anticipated destinations reliably and more efficiently. Latest technology in electrical design of extra high voltage transmission focuses on (i) advanced materials for conductor (ii) efficient and resourceful methods of transmission (iii) Digitization. A smart system for the meteorological monitoring of transmission line based on ZigBee and General Packet Radio Service (GPRS) technology was developed in order to overcome the shortcomings of the present system, such as the totally dependence on the limited coverage of communication network, the single monitoring parameters and the poor extensibility, etc. [1] Conventional transmission lines typically employ a circular symmetry for the arrangement of sub conductors in each phase. However, by altering the number and placement of these sub conductors, the power transfer capacity of the lines can be significantly increased, reduces surge impedance and enhances surge impedance loading [2].The electrical design of transmission line crossing scheme is studied, and the requirements of relevant codes and specifications, construction methods and technical principles are analyzed to provide reference and implementation basis for electrical design [3].For modern transmission line robotics inspection system is developed for a real-time monitoring of physical threats or damage to electrical transmission line towers and conductors [4]

1. **Methods and Recent Technology:**

a. Advanced Materials and Conductors:

- **Superconducting Cables:**
  HTS cables, which operate at near-liquid nitrogen temperatures, offer near-zero resistance, allowing for significantly higher current carrying capacity and reduced energy losses.

  HTS cable has following characteristic:

  i) **Superconducting Properties: HTS cables are made from high-temperature superconducting materials that exhibit zero electrical resistance.**
  ii) **High Power Capacity: Due to their low impedance and zero resistance, HTS cables can carry much higher electrical currents than conventional cables, allowing for more compact designs and greater power transmission.**
  iii) **Low Losses: The absence of electrical resistance means that very little energy is lost as heat, making HTS cables highly efficient for power transmission.**
  iv) **Cryogenic Cooling: To operate in their superconducting state, HTS cables must be cooled to very low temperatures, typically using liquid nitrogen.**
  v) **Advanced Designs: HTS cable technology requires sophisticated designs, including specialized cryogenic insulation and terminal connectors to transfer power to and from the cable.**
  vi) **High-Temperature Low-Sag (HTLS) Conductors:**
  Materials such as ACCC (Aluminum Conductor Composite Core) and ACSS (Aluminum Conductor Steel Supported) canhave double power transfer capacity and operate at higher temperatures with lower sag and line loss.

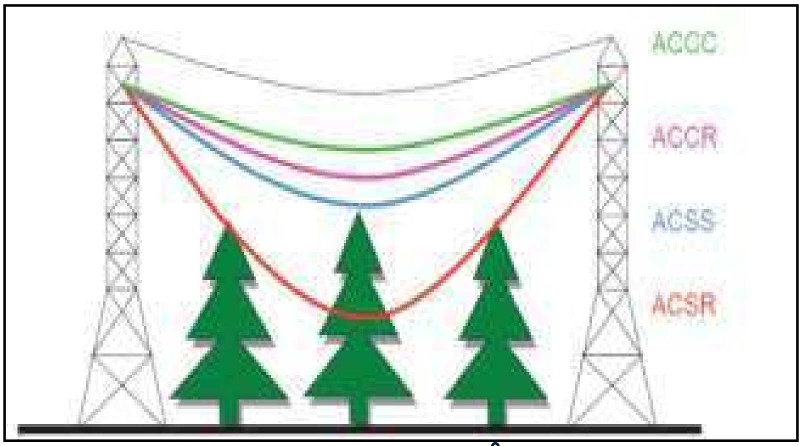

Fig:1 Sag comparison at 180^0 C Temperature

HTLS conductor costs are generally higher than conventional conductors. However, HTC can enhance (n-1) security reserves and transmission capacity without impacting the negotiated right-of-way, ideally with minor modifications of transmission towers (mostly clamps and mountings).

b. Carbon-Fiber-Reinforced Conductors:

Carbon-fiber-reinforced conductors are high-strength, lightweight transmission cables that use a core of carbon fiber composite to replace traditional steel cores. These advanced conductors improve line strength, robustness, and capacity in harsh environments. Examples of this type of conductor are ACCC (Aluminum Conductor Composite Core) and ACFR (Aluminum Conductor Fiber-Reinforced).

c. Digitalization and Smart Grids:

- IoT and Sensors:
  The integration of IoT devices and sensors along transmission lines provides real-time data, allowing for remote monitoring and control.

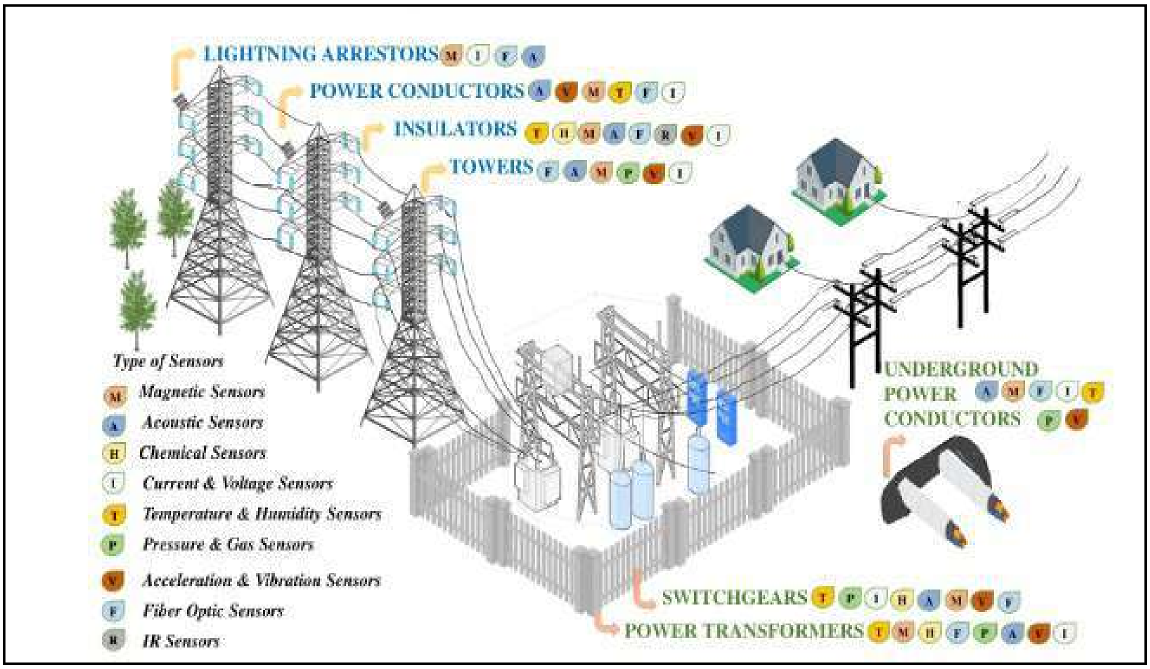

Fig2.Key sensing areas in transmission and distribution systems.[5]

- AI and Machine Learning:
  Artificial intelligence algorithms analyze this data to predict potential faults, which helps in predictive maintenance and reduces downtime.

- PLSCADD Software:
  Specialized software like PLSCADD enhances the design process for overhead lines, leading to more robust and efficient infrastructure.

d. Efficient Transmission Methods :

- HVDC Technology:

Newer Voltage Source Converter (VSC) based HVDC systems offer precise control of voltage and frequency, improving grid stability and reliability.

- **Subsea Cables:**
  These are vital for connecting offshore renewable energy sources to the grid, with dynamic cable designs enabling deeper water deployment.
- **Real-Time Thermal Rating (RTTR):**
  This technology helps optimize the current flow in existing lines, allowing for higher power transfer and improved asset utilization.

e. ***Monitoring and Risk Management :***

- **Non-Contact LiDAR(Light Detection and Ranging) Sensors:**

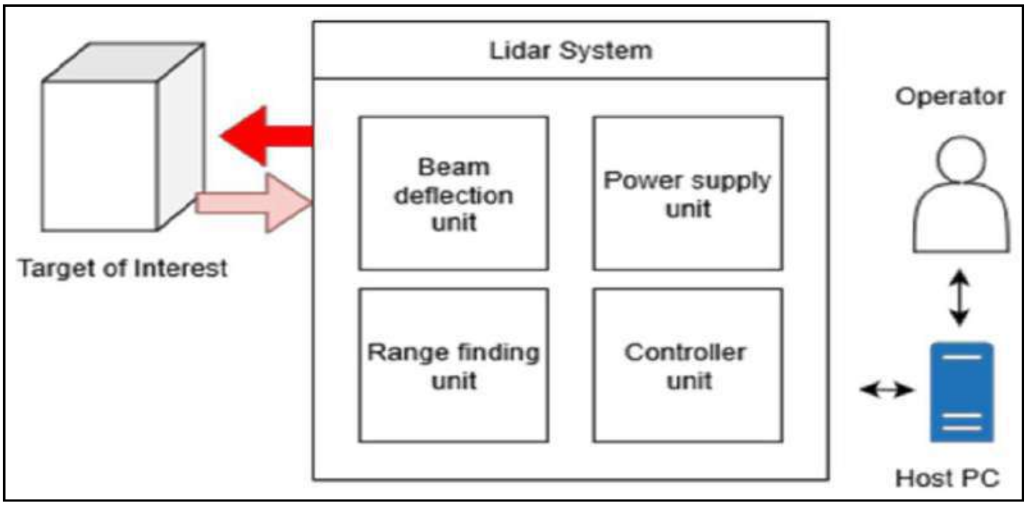

Fig 3: [6]

These sensors provide real-time monitoring of transmission lineswith a precise and detailed physical assessment of the transmission line corridor and its assets, detecting conductor health and identifying potential risks or anomalies without physical contact. LiDAR is a remote sensing technology that uses laser pulses to measure distance and create highly accurate 3D models. A LiDAR scanner, often mounted on a drone or helicopter, emits millions of laser pulses. By measuring the time it takes for the pulses to return, it can determine distances to create a 3D point cloud of the line, towers, terrain.

Major Application of LiDARin transmission line are

- Corridor mapping: Creates 3D digital twins to precisely map the entire transmission corridor, including the topography and terrain.
- Vegetation analysis: Identifies where trees and other vegetation are encroaching on the minimum safe clearance distance from power lines, a major cause of outages.

- Sag and clearance measurements: Precisely measures the sag of the conductor cables under various load conditions to ensure they meet clearance safety standards.
- Asset management: Creates a digital inventory of the physical assets, allowing for tracking and analysis of the line's condition.

- **Dynamic Line Ratings (DLR):**

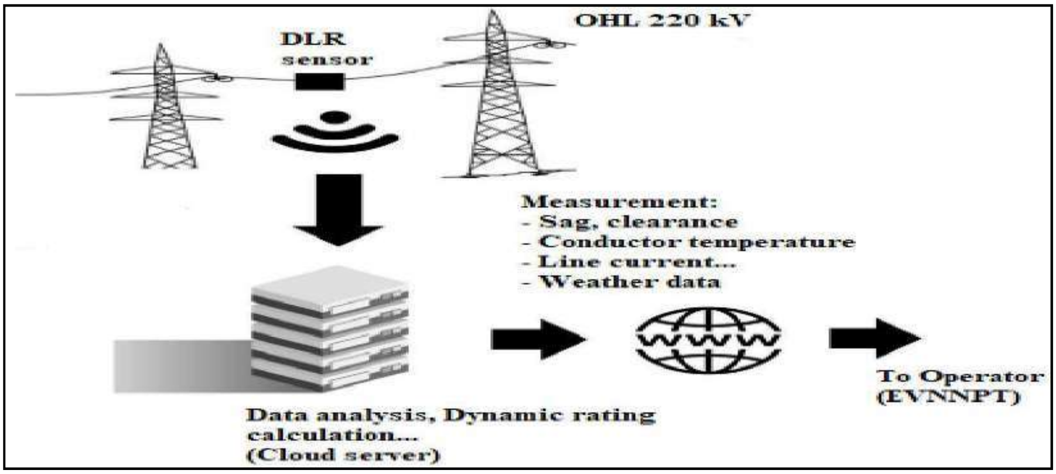

Fig 4 Overall Configuration Diagram of Dynamic Line Rating Monitoring System for Transmission Power Lines

This technology provides real-time insights into a line's performance, allowing grid operators to fully utilize network capacity.DLR is a system that calculates the real-time maximum current-carrying capacity (ampacity) of a transmission line, which can be significantly higher than its static rating under certain conditions. DLR Optimizes the use of existing infrastructure by safely increasing power flow when weather conditions permit.DLR systems use a combination of sensors and weather forecasts to measure environmental conditions like ambient temperature, wind speed, wind direction, and solar radiation. An algorithm then calculates the maximum heat dissipation to determine the real-time capacity of the line.Major Application of DLR in transmission line are:

- Increased capacity: Enables grid operators to temporarily push more power through lines during favorable conditions (e.g., cool, windy days) without exceeding safety limits.
- Grid reliability: Improves grid stability by giving operators accurate, up-to-the-minute data to inform their decisions, reducing the risk of overloading.
- Cost efficiency: Reduces the need for costly infrastructure upgrades by unlocking the unused potential of existing lines.

- Integration of renewable: Helps utilities integrate variable renewable energy sources like wind and solar by maximizing transmission during periods of high generation.

f. Modern technologies for future transmission network development

- High voltage alternating current (HVAC) power technologies
- High voltage direct current (HVDC) power technologies
- Hybrid HVAC/HVDC power technologies

g. Improved Tower Designs:

- Focus is on creating more robust, cost-effective, and durable tower designs to optimize right-of-way (RoW) and improve construction efficiency. LiDAR technology assists in aerial surveillance and topographic mapping, improving the accuracy of tower placement

h. Key Technologies :

- Digital 3D Design:
  This technology offers a virtual, intelligent platform for integrating design information from various specialties, leading to improved efficiency and shorter design cycles for transmission line projects.
- Artificial Intelligence (AI) and Big Data:
  These technologies are used to create intelligent solutions for transmission line design, including optimizing line paths, designing efficient tower shapes, and developing intelligent safety protection strategies.
- Unconventional Transmission Line Designs:
  Research focuses on developing innovative designs that use different configurations of conductors to improve total ampacity, reduce material costs, and increase efficiency.
- Advanced Monitoring and Sensing:
  Innovations in online monitoring and intelligent diagnosis systems are being implemented to improve the safety and reliability of transmission lines, using technologies like FBG (Fiber Bragg Grating) sensors for ice detection and AI for fault diagnosis

2) Conclusion:

In this paper, various advanced technologies for transmission lines performance improvement have been summarized. All technology gives the insight to understand how to design or redesign high voltage transmission line by considering various aspects of different emerging technologies.

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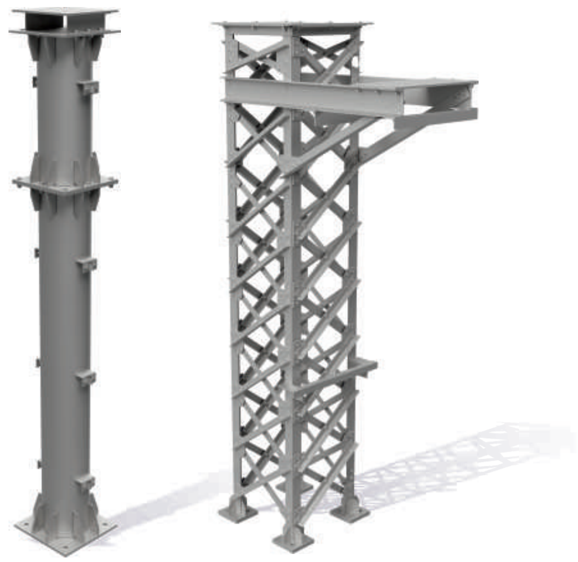

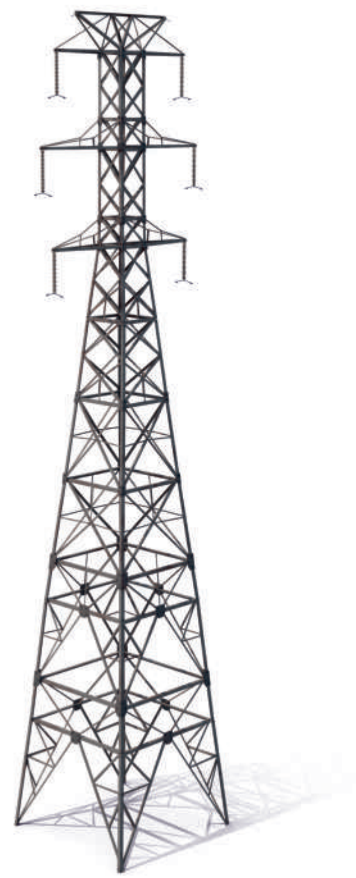

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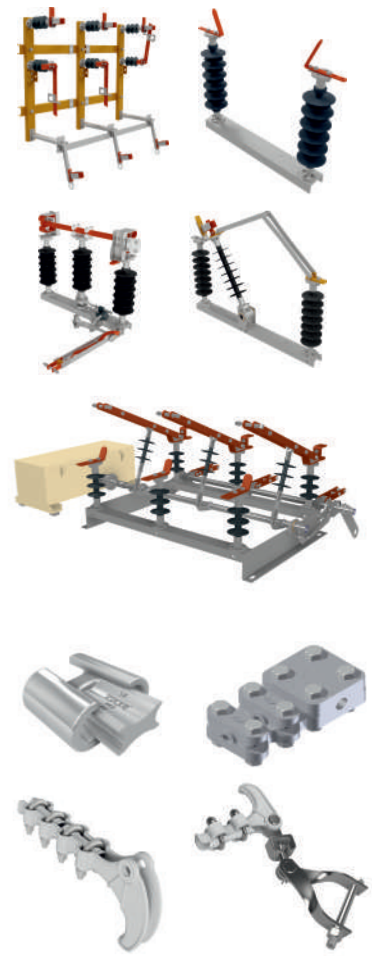

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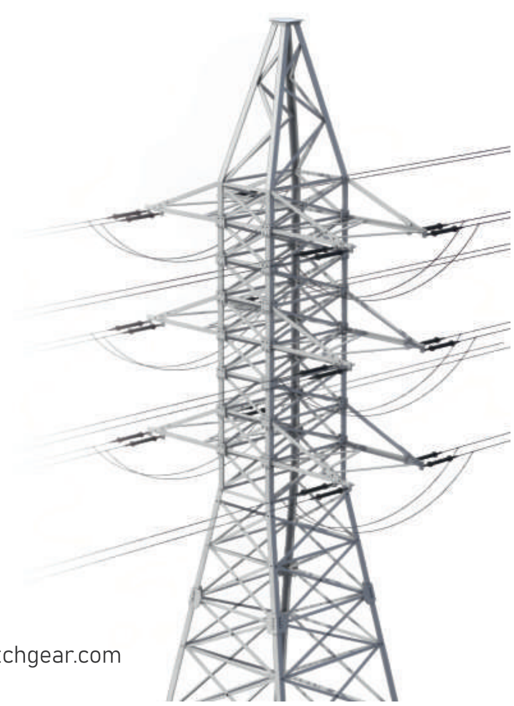

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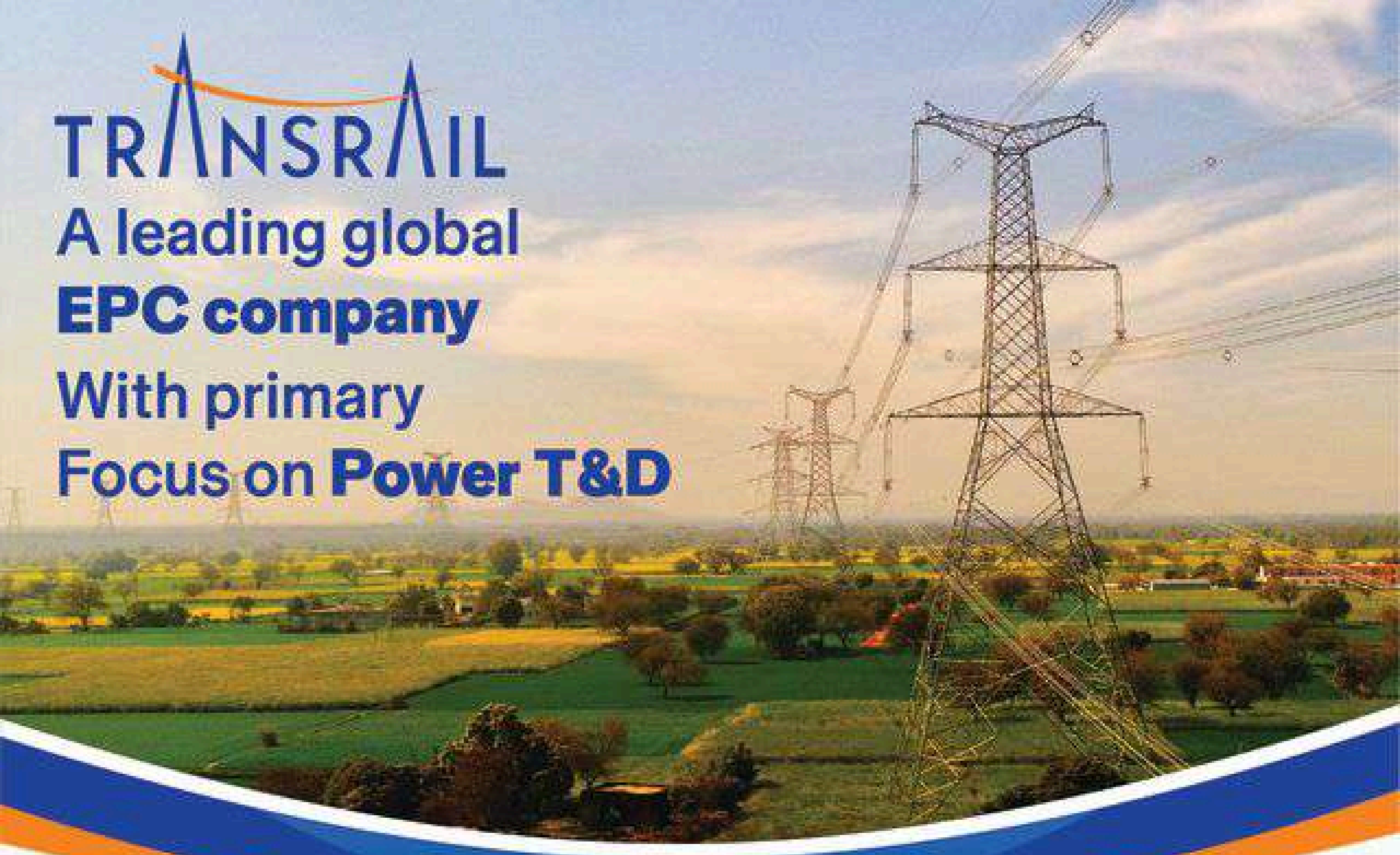

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1) INTRODUCTION

1.1 Need for Diversion-

Transmission lines may require diversion due to One or more of the following reasons

- Infrastructure development (e.g., Airports, Highways, Railways, Dams, Canals Roads)
- Establishment of Defense or Strategic Facilities
- Industrial or Commercial Parks
- Business or Residential Developments
- Construction of Dams or Canals
- Mining Activities

1.2 Preliminary Assessment

Before initiating diversion, it is essential tolook into the following

- Study the detailed development plan.
- Superimpose the existing transmission alignment on the proposed plan.
- Mark Northing-Easting coordinates of all towers and development plot elements.
- Conduct a site visit to assess feasibility and finalize the alignment.

Note: Priority is given to realigning the line within the premises of the new development area to minimize Right of Way (ROW) complications.

1.3 Technical Evaluation and Cost Estimation

Techno-Economical evaluation of the diversion may require the following

- A detailed technical assessment and cost estimate must be prepared.
- Typically, the developer (including government agencies) bears the full cost of the diversion.
- A 15% supervision charge is levied by the utility for monitoring and quality control.
- If the owner is other than State Power utility, the norms may change.

1.4 Execution Models:

Following Typical execution models are prevalent these days.

1. Departmental Execution – Done by the utility itself
2. EPC Contract – Engineering, Procurement, and Construction on contract basis
3. Beneficiary-Executed Diversion: (When Utility does not want to get involved in the time-consuming diversion work)
    - The beneficiary appoints anEPC contractor.
    - Only supervision charges (15%) are payable to the utility.

- No upfront recovery of cost estimate.

This model is often preferred as it allows the developer to meet tight project timelines and saves utility manpower.

1.5 Additional Considerations

- Some utilities may also include power loss cost during shutdown, significantly increasing the estimate.
- All standard transmission construction norms (tower design, clearance, profile, tower spotting, and foundation design) apply equally to diversions.
- Towers and line material shall be identical to those of existing line.

1.6 Following are the eventualities leading to line diversion scenarios

A. Line Raising Instead of Diversion

To maintain vertical clearance over new roads or overbridges may need:

- Two tall towers (or)
- Design Existing towers with extensions
- In such cases foundations can be constructed without shutdown; tower erection may require only minimal outage.
- Normally in such situations the alignment of the existing line section is maintained.

B. Diversion Due to Dam Construction

These needs following steps

- Requires careful alignment planning.
- Avoid submerged (upstream) or fast-flowing (downstream) zones.
- Ensure that no tower falls in water-flow zones.
- May involve significant length and number of angle towers.
- Environmental and forest clearance may be needed.
- If the tower is to be spotted on the upstream side of the dam. Hydrological study may be required. Pile or well type foundation may be needed.

C. Urban/Metropolitan Diversion

Following are the aspects of urban diversion
It is highly complex due to:

- Dense population
- High-rise structures
- Metro tracks and flyovers

It Requires:

- Precise survey
- Selection of compact tower types (e.g., narrow base towers, monopoles) or combination due to space constraints.
- Ease in construction is also an important aspect.

D. Temporary Diversion

Following are the aspects of temporary diversion.
Sometimes implemented to:

- Facilitate main diversion
- Reduce downtime during construction
- Especially useful when new rail/road alignment runs parallel to existing transmission line.

This framework ensures a comprehensive approach to managing transmission line diversions, balancing technical, financial, and logistical aspects efficiently.

E. Emergency Restoration

- This is required when there is a catastrophic failure of the tower and or a line section.
- Specially designed system with guy & temporary soil anchoring is used. This is a topic by itself.

2) CASE STUDY-I

2.1 Diversion of 400kv d/c Satpura Ashta transmission line between existing location no 133/0 to 134/0 at village Sasli in Madhya Pradesh.

2.1.1 Exsiting Line

At village Sasli, proposed RVNL Indore-Budhani Railway line corridor is crossing the existing 400kV DCDS Satpura-Ashta TL between existing location 133/4 and 133/5 at chainage 132+534M (approximately). To give Right-of-Way to proposed Rail Track, it is essential to divert existing 400kV D/C transmission line.

In the existing arrangement, both the circuits of the said TL are strung and in 'live 'condition.

The existing route and proposed diverted route of 400kV DCDS, Satpura-Ashta Transmission line Section-PPP Project and proposed RVNL (Indore-Budhani) corridor is shown below in fig-1.

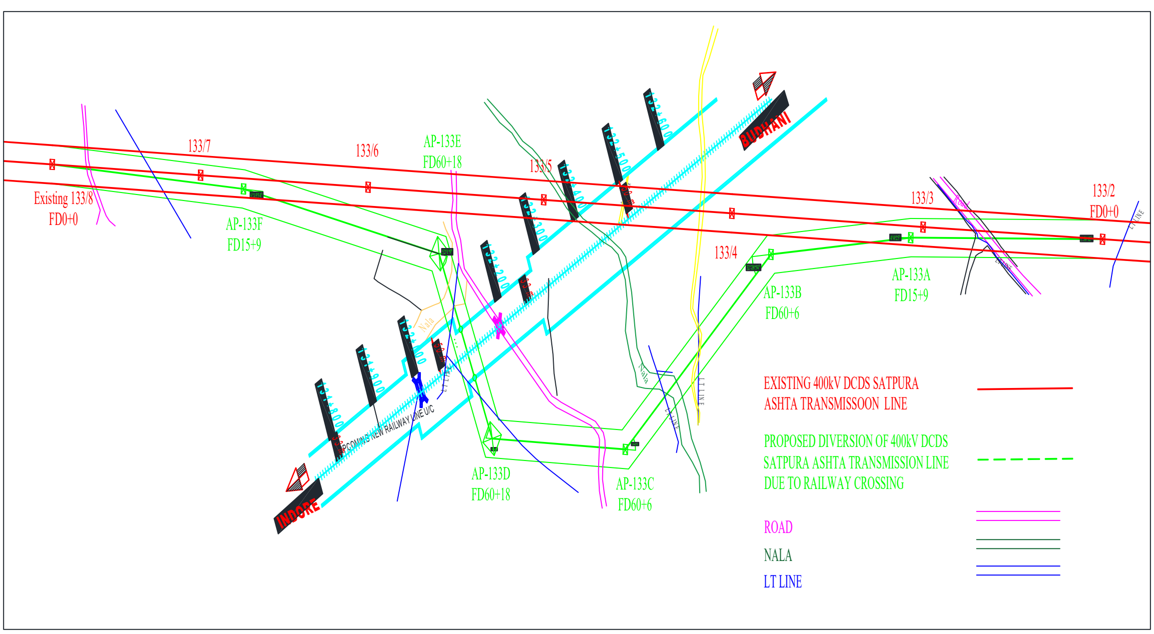


Figure-1: Satpura-Ashta Transmission line Section-PPP Project and proposed RVNL (Indore-Budhani) corridor

From existing arrangement, it can be seen that proposed RVNL corridor is crossing the Existing 400kV D/C line section between location 133/4 and 133/5, both the locations are suspension locations.

The tower location is 133/4 approximately. 195 m away from the center of the RVNL corridor and Tower location number 133/5 is approximately 217.2m away from the center of RVNL corridor. Though the towers are neither fouling nor infringing with the proposed corridor, it is necessary to modify/divert the existing 400kV D/C line section to meet the criteria of angle of crossing, clearance over proposed rail track level and height falling distance of the either side towers for rail crossing.

The tower schedule of existing 400kV DCDS Satpura-Ashta Transmission line between location no.AP-133 and AP-134 is shown below.

2.1.2 Existing Tower Schedule:

Loc. No	Angle Point	Tower Type	Angle Of Deviation	Span (m)	Zone-43Q (WGS-84)	
					Easting	Northing
408	AP133/0	FD15+00	04°40'11"(RT)		719015.42	2501281.38
				365		
409	133/1	FD0+00			718642.38	2501294.88
				380		
410	133/2	FD0+00			718278.76	2501308.61
				385		
411	133/3	FD0+00			717885.7433	2501323.203
				390		
412	133/4	FD0+00			717467.2846	2501339.616
				380		
413	133/5	FD0+00			717055.3179	2501355.778
				390		
414	133/6	FD0+00			716670.7339	2501370.866
				400		
415	133/7	FD0+00			716304.0228	2501385.214
				320		
416	133/8	FD0+00			715978.83	2501389.6
				380		
417	133/9	FD0+00			715599.61	2501409.13
				360		
418	AP134/0	FD15+00	13°49'50"(LT)		715264.88	2501426.37

2.1.3 Proposed Modification Arrangement

The diversion/Modification options are prepared considering following important points.

1) Angle of crossing with proposed RVNL corridor is kept between 60º to 90º.
2) The H+6 criteria with RVNL Rail track will be achieved to the extent possible. (H is height of the crossings towers)
3) Involvement of relocation of existing construction is avoided.
4) Requirement of tree cutting to the extent possible is avoided.
5) Minimum Shutdown of existing line to the extent possible.

The proposal for diversion of route is as under:

2.1.4 ***MODIFICATION/DIVERSION OF 400kv DCDS SATPURA-ASTHA TRANSMISION LINE BETWEEN EXISTING LOCATION 133/2 TO 133/8***

To cross the proposed RVNL corridor, it is proposed to modify/ divert the existing 400kV DCDS Transmission Line from Existing location 133/2 to the Existing location 133/8. Total 6 number of 400kV D/C towers are proposed between existing location number 133/2 and 133/8 (i.e from proposed location 133/A to 133/F) all the six towers are tension towers. Out of six towers 2 towers are FD15 type and balance 4 towers are FD60 type.

1) **It is proposed to take 1°54'10" L angle on existing Suspension tower 133/2.**
2) **It is proposed to construct location number 133/A (FD+9) tower to the left-hand side of the existing tower 133/3. The center of proposed tower will be 29.82 mtrs away from the existing tower 133/3 and center line to center line distance between proposed tower to existing line will be 13.71 mtrs. The span between existing tower 133/2 and proposed tower 133/A will be kept as 420mtrs. Angle of deviation on this tower will be 4°0'25" L.**
3) **It is proposed to place the next proposed tower 133/B (FD60+6) at 307 mtrs away from the proposed location 133/A. Angle of deviation on this tower will be 32°28'54"L**
4) **It is proposed to place the next proposed tower 133/C (FD60+6) at 395 mtrs away from the proposed location 133/B. Angle of deviation on this tower will be 38°46'56"R.**
5) **It is proposed to place the next proposed tower 133/D (FD60+18) at 292 mtrs away from the proposed location 133/C. Angle of deviation on this tower will be 59°44'1"R. This will be right hand side crossing tower of proposed RVNL corridor.**
6) **It is proposed to place the next proposed tower 133/E (FD60+18) at 250 mtrs away from the proposed location 133/D. Angle of deviation on this tower will be 52°1'9"L. This will be left hand side crossing tower of proposed RVNL corridor.**
7) **It is proposed to place the next proposed tower 133/F (FD15+9) at 435 mtrs away from the proposed location 133/E. Angle of deviation on this tower will be 6°15'34"L**
8) **It is proposed to take 1°47'01" L angle on existing Suspension tower 133/8.**

The Plan drawing of proposed Diversion/modification is shown in figure-2.

The Tower schedule from location AP-133/0 to AP-134/0 including towers involved in the proposed diversion is shown below.

A) Tower Schedule for Diversion/Modification of 400KV DCDS Transmission Line							
Sr. No.	**Angle Point / Tower No.**	**Type of Tower**	**Angle of Deviation (° ' " L / R)**	**Span (m)**	**Easting**	**Northing**	**Remark**
1	AP-133	FD15			719015.42	2501281.38	Existing Tower
				373			
2	133/1	FD0			718642.38	2501294.88	Existing Tower
				364			LT Line
3	133/2	FD0	1°54'10"L		718278.76	2501308.61	Existing Tower
				420			LT Line Road
4	AP-133A	FD15+9	4°0'25"L		717858.76	2501310.77	Proposed Tower
				307			LT Line
5	AP-133B	FD60+3	32°28'54"L		717552.74	2501290.47	Proposed Tower
				395			LT Line, Nala
6	AP-133C	FD60+3	38°46'55"R		717233.99	2501056.94	Proposed Tower
				292			Road
7	AP-133D	FD60+18	59°44'02"R		716942.36	2501069.94	Proposed Railway Crossing Tower
				250			PROPOSED INDORE-BUDHNI RLY LINE, NALA
8	AP-133E	FD60+18	52°01'10"L		716826.1	2501291.26	Proposed Railway Crossing Tower
				435			
9	AP-133F	FD15+9	6°15'34"L		716398.22	2501368	Proposed Tower
				420			
10	133/8	FD0	1°47'01"L		715978.83	2501389.6	Existing Tower
				380			
11	133/9	FD0			715599.61	2501409.13	Existing Tower
				335			
12	AP-134	FD15			715264.88	2501426.37	Existing Tower

2.1.5 <u>Important pointsneed to be kept in view</u>

1) **The angle of deviation on existing suspension location 133/2 and 133/8 is provided to avoid the shutdown of both the circuits of existing line at a time for longer duration.**
2) **By providing angle on existing suspension tower, it is proposed to construct the proposed location 133/A and 133/F out of alignment of existing line.**
3) **Foundation of all the six proposed towers can be carried out without taking shutdown of existing line.**
4) **Erection and stringing activity between proposed location 133B to 133E (3 spans including proposed railway crossing span) can be carried out without taking shutdown of existing line.**
5) **For Erection and stringing of proposed tower locations 133A and 133F it is proposed to take the shutdown of one circuit only. The Tower Erection activity has tobr carried out with utmost precaution and safety on these two locations. While carrying out the stringing shutdown of 1 circuit is envisaged.**

2.1.6 Details of the Railway crossing

With the proposed diversion arrangement following statutory requirement of railway crossing are complied.

1) **Angle of crossing achieved is 86°51'19".**
2) **Clearance available over proposed rail track level will be 24.2 mtrs against the minimum requirement of 20.26mtrs.**
3) **Height falling distance from the proposed track center to proposed tower structure innermost leg in respect of both the towers on either side of the rail track is also complied.**

3) CASE STUDY-II

3.1 DIVERSION OF 220KV TRANSMISSION LINES INFRINGING THE PROPOSED ALIGNMENT OF NHAI AT VILLAGE PARGAON IN MAHARASHTRA STATE

The proposed corridor of NHAI is crossing with the exiting towers of SS line and LS line of Adani Electricity Mumbai Limited. Proposed NHAI corridor is infringing with the Two numbers of tower locations of existing LS line and SS line, LS-156, LS-160 SS-160 and SS-162 respectively. The tower locations LS-156, LS-160, SS-160 and SS-162 are infringing with proposed road corridor at chainage 36+570M, 35+470M, 36+310M and 35+840M approximately.

To give clear Right-of-Way to NHAI, it is now essential to divert these 2 no. of 220 KV D/C transmission lines. In the existing arrangement, all the circuits are strung and 'live'. The plan drawing of existing 220kV D/C LS and SS line and proposed NHAI corridor is shown below fig.-2.

Form existing arrangement it can been seen that proposed NHAI corridor is crossing the existing LS and SS Line line between existing location LS-155, LS-156, LS 157 and SS line between existing location SS-159, SS-160, SS-161 then it is running parallel to existing line on Right hand side (if we view the alignment from Dahanu to Mumbai Direction), then again proposed NHAI alignment crossing the existing LS and SS Line between existing LS location LS-159, LS-160, LS-161 and SS Line between existing location SS-162 , SS163 As a matter of fact, existing locations LS-156, LS-160, SS-160 and SS-162 are directly infringing with the proposed NHAI corridor.

In view of the above it is necessary to realign both the lines for a span of about 1.75ms approximately in such a way that infringement of towers with the proposed NHAI alignment can be avoided as well as minimum clearance between both the lines and clearance with Proposed Road alignment is maintained. Also, while preparing the

modification/diversion scheme Right of way (ROW) issue, rapid development must be considered.

Tower schedule of existing LS and SS line is as below.

3.2 Existing Tower Schedule of Land-Side Transmission Line (LS Line):

Sr. No	Loc. No.	Tower Type	Easting	Northing	Span (m)
1	LS-155	DC+0	277197.95	2166194.53	
					335.16
2	LS-156	DA+0	277303.11	2165876.29	
					316.54
3	LS-157	DA+3	277403.24	2165576.00	
					196.61
4	LS-158	DD+0	277465.75	2165389.58	
					274.65
5	LS-159	DD+0	277367.79	2165133.00	
					372.85
6	LS-160	DD+6	277243.97	2164782.89	
					332.17
7	LS-161	DA+0	277103.79	2164479.74	

3.3 Existing Tower Schedule of Sea-Side Transmission Line (SS Line):

Sr. No	Loc. No.	Tower Type	Easting	Northing	Span (m)
1	SS-158	DC+0	277137.73	2166197.34	
					335.16
2	SS-159	DA+0	277252.78	2165856.83	
					316.54
3	SS-160	DB+0	277332.89	2165618.82	
					196.61
4	SS-161	DD+0	277400.44	2165419.22	
					274.65
5	SS-162	DD+3	277297.81	2165149.44	
					372.85
6	SS-163	DD+6	277193.78	2164846.44	
					332.17
7	SS-164	DA+0	277048.67	2164509.87	

3.4 Proposed Modification Arrangement:

Looking to the site constraint, involvement of forest land, maximum use of existing ROW of transmission and proposed ROU of Proposed NHAI corridor only one option is possible to divert /modify both the lines. While preparing the feasibility for diversion/Modification of both the lines following is taken into consideration.

1) **Use of existing transmission line ROW to the extent possible.**
2) **Use of proposed ROW / corridor of NHAI.**
3) **Distance between proposed transmission line center line to edge of the Road is kept minimum 15mtrs.**

4) Distance between center line of two lines to be kept as 29 mtrs minimum
5) Foundation of both the lines will be done in Existing / proposed ROW of Line/NHAI.
6) Requirement of tree cutting to the extent possible is avoided.

As the ROW issue is very acute at this site, only one option is explored for diversion of each line (i.e. LS and SS line)

The proposal is as under:

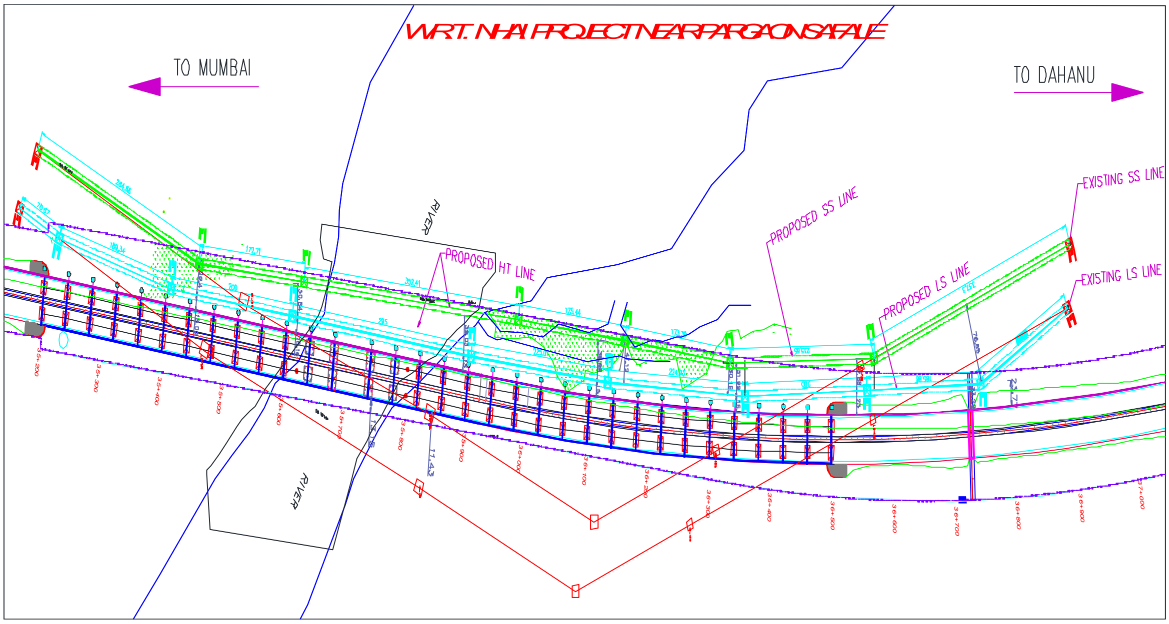


Figure-2: Diversion of 220kv Transmission lines infringing the proposed alignment of NHAI at village Pargaon in Maharashtra state

3.5 MODIFICATION/DIVERSION OF LS AND SS-LINE OF M/s AEML AT VANGAON LOCATION

3.5.1 MODIFICATION OF LS-LINE.

It is proposed to modify/ divert the existing 220kV D/C LS-Line from Existing location LS-155 to Existing location LS-161. The diversion/modification of LS line involve construction of 8 number 220kV D/C narrow base towers which are already type tested by AEML.

This proposal involves construction of 8 numbers of 220kV D/C Narrow Base towers. All the 8 towers will be constructed in proposed ROW of NHAI,

Above proposal will not require shutdown of existing LS and SS line for construction activity. However, minimum shutdown of LS line is required while doing erection and stringing activities. While doing the modification in LS line there will not be requirement of shutdown of SS

Line. The proposal involves the dismantling of existing D/C tower locations LS-156, LS-157, LS-158, LS-159 and LS-160, destringing of conductor and earth wire between location no LS-155 to LS-161 as well as demolition of foundations of existing towers LS-156, LS-157, LS-158, LS-159 and LS-160. Furthermore, very limited diverted ROW for Transmission line has to be acquired, most of the route of the proposed diversion/modification of Transmission line will pass through the existing ROW of LS-Line and proposed NHAI corridor. This proposal can be easily executed with the help of use of narrow base lattice towers or monopoles. Route length of proposed D/C Line diversion/modification is approx. 1.75 KM. This proposal will avoid the line crossing with Proposed NHAI corridor.

The drawing showing proposed diversion is shown in figure-2. Distance between center of towers to the Edge of NHAI Road corridor is tabulated below.

Sr. No.	Proposed Tower No.	Distance between Centre of towers to the Edge of the NHAI Road/ Bridge
1	Proposed-D/C-LS-156	23.29 m
2	Proposed-D/C LS-157	23 m
3	Proposed-D/C LS-158	15 m
4	Proposed-D/C LS-158A	15 m
5	Proposed-D/C LS-159	15 m
6	Proposed-D/C LS-159A	15.16m
7	Proposed-D/C LS-160	15 m
8	Proposed-D/C LS-160A	38.04 m

Tower schedule, Tower profile showing proposed angle of deviation on the tower locations, span between proposed towers, their proposed northing & easting have been prepared and scheme has been executed accordingly

3.5.2 PROPOSAL-II, MODIFICATIOTN OF SS-LINE.

It is proposed to modify/ divert the existing 220kV D/C SS-Line from Existing location SS-158 to Existing location SS-164. The diversion/modification of SS line involve construction of 6 number 220kV D/C narrow base towers which are already type tested by AEML.

This proposal will involve construction of 6 numbers of 220kV D/C Narrow Base towers. Out of 6 towers, 5 towers will be constructed in proposed ROW of NHAI and 1 tower will be constructed in existing Line ROW.

Above proposal will not require shutdown of existing LS and SS line for construction activity. However, minimum shutdown of SS line is required while doing erection and stringing activities. While doing the modification in SS line there will not be requirement of shutdown of LS Line. The proposal involves the dismantling of existing D/C tower locations SS-159, SS-160, SS-161, SS-162 and SS-163, destringing of conductor and earth wire between location no SS-158 to SS-164 as well as demolition of foundations of existing towers SS-159, SS-160, SS-161, SS-162 and SS-163. Furthermore, very limited diverted ROW for Transmission line has to be acquired, most of the route of the proposed diversion/modification of Transmission line will pass through the existing ROW of SS-Line and proposed NHAI corridor. This proposal can be easily executed with the help of use of narrow base lattice towers or monopoles. Route length of proposed D/C Line diversion/modification is approx. 1.75 KM. This proposal will avoid the line crossing with Proposed NHAI corridor.

The drawing showing proposed diversion is shown in figure-2. Distance between center of proposed SS line towers proposed LS-Center line is tabulated below.

Sr. No.	Proposed Tower No.	Distance between Centre line of proposed LS Line and SS line towers
1	Proposed-D/C-SS-158A	29.88 m
2	Proposed-D/C LS-159	30.15 m
3	Proposed-D/C LS-160	41.42 m
4	Proposed-D/C LS-161	43.17 m
5	Proposed-D/C LS-162	34.45 m
6	Proposed-D/C LS-163	29.4m

Tower schedule, Tower profile showing proposed angle of deviation on the tower locations, span between proposed towers, their proposed northing & easting have been prepared, and scheme has been executed accordingly.

#######

OPTIMIZATION OF TOWER SPOTTING IN PLSCADD

BY MEGHA PATEL

MAIL ID: meghap@jyotistructures.in

Megha Patel

PREPARATION BEFORE OPTIMAZATION:

PART-1: TERRAIN MODELLING

- CREATE PLSCADD FILE
- TO DEFINE FEATURE CODE LIST
- SURVEY DATA FILE FORMAT
- PROPER ROUTE ALIGNMENT
- PLAN VIEW ATTACHMENT

PART-2: DESIGN CRITERIA

- TO DEFINE WEATHER CASES
- CABLE TENSION CRITERIA
- WEATHER CONDITION SELECTION
- INSULATION SWING CHECK
- PREPARED CABLE FILES
- TO PREPARED STRUCTURES FILE

PART-3: TOWER SPOTTING

- FOE MANUAL TOWER SPOTTING
- FOR AUTOMATIC TOWER SPOTTING

PART-4: VARIOUS REPORTS

- STRUCTURES USAGE REPORT
- SECTION USAGE REPORT
- SURVEY POINT CLEARANCE REPORT
- WIND SPAN-WEIGHT SPAN REPORT
- STRUCTURE LONGITUDE-LATITUDE REPORT
- STRINGING CHART REPORT

PART-5: DRAFING SETTINGS

- SPECIFY PAGE SIZE

Megha Patel

- PLAN & PROFILE SHEET CONFIGURATION
- SHEET LAYOUT
- ATTACHEMENTS

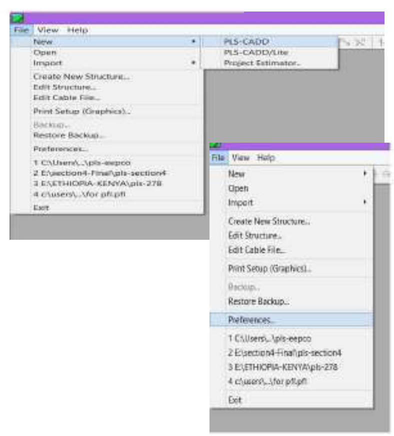
PART-6: CHECK LIST FOR THE TOWER SPOTTING USING PLSCADD

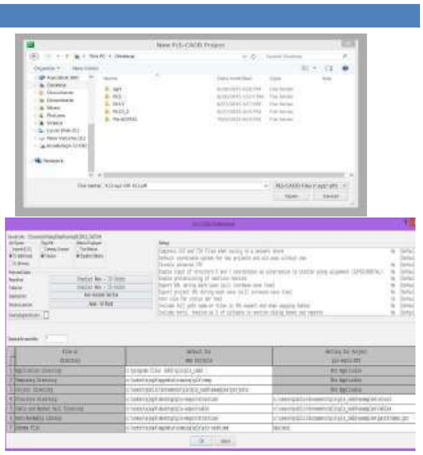
PART-7: OPTIMIZATION PARAMETERS

Megha Patel

PART-1: TERRAIN MODELLING

FIRST TO CREATE FILE:





Megha Patel

TO DEFINE FEATURE CODES:

Megha Patel

ENTER DESIRED VALUES AS SHOWN IN FIGURE:

	Feat. Code	Feature Description	Prof Symbol	Plan Symbol	Line From Feature Top To Bottom	Aerial Obst-acle	Point is on Ground	Req Vert Clear 220kV (m)	Req Horiz Clear 220kV (m)	Required Clearance fr. Base/Gr to Spotting Constraint (m)	Prof Label Feature code, Feature des., X,Y,Z,O,R,E,Z+H, Point des. Comment	Plan Label Feature code, Feature des., X,Y,Z,O,R,E,Z+H, Point des. Comment	Active XYZ Point Count	Inactive XYZ Point Count
1	200	Normal Ground			Yes	No	Yes	8	0	0	00000000000	00000000000	129	0
2	201	Track			Yes	No	Yes	8	0	0	00000000000	00000000000	463	0
3	202	Track traveled by vehical			Yes	No	Yes	8	0	0	00000000000	00000000000	152	0
4	203	Road			Yes	No	Yes	10	0	0	00000000000	00000000000	12	0
5	206	River			Yes	No	Yes	12	0	0	00000000000	00000000000	166	0
6	207	Waterway			Yes	No	Yes	12	0	0	00000000000	00000000000	0	0
7	208	House			No	Yes	No	5	0	0	00000000000	00000000000	231	0
8	209	house's roof accessible to peo			No	Yes	No	10	0	0	00000000000	00000000000	0	0
9	210	signs & chimneys			Yes	No	Yes	5	0	0	00000000000	00000000000	0	0
10	211	Lighting supports			Yes	No	Yes	5	0	0	00000000000	00000000000	148	0
11	221	220 KV			No	Yes	No	5.5	0	0	00000000000	00000000000	74	0
12	222	110 Kv Line			No	Yes	No	5.5	0	0	00000000000	00000000000	0	0
13	223	33 Kv & LT Line			No	Yes	No	4	0	0	00000000000	00000000000	13	0

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STANDARD SURVEY DATA FILE FORMAT FOR XYZ FILE:

A	B	C	D	E	F	G
Description of terrain point	x-cord EASTING m	y-cord NORTHING m	z-cord ELEVATION m	Obstacle Height **must be** m	Feature Code	Surveyor note to appear on plan
1	**356704.70**	**2665812.00**	**97.00**		**250**	**AP-1**
2	356687.22	2665842.39	96.99		200	
3	356685.72	2665844.99	99.65		200	
4	356665.03	2665880.97	99.35		200	
5	356661.54	2665887.04	96.45		200	
6	356660.84	2665888.25	96.35		201	Road
7	356656.17	2665896.41	94.45		201	Road
8	356652.72	2665902.50	98.24		200	
9	356617.86	2665905.81	98.13	2	211	Fence, height -2M
10	356615.22	2665910.69	98.99	2	211	Fence, height -2M
11	356619.78	2665906.57	99.00	2	211	Fence, height -2M
12	356622.96	2665914.87	98.24	3.5	211	Inside portable cabin ,height -3.5M
13	356625.77	2665910.09	98.35	2	211	Fence, height -2M
14	356629.61	2665912.34	98.65	2	211	Fence, height -2M
15	356628.66	2665890.34	98.21	2	211	Fence, height -2M
16	356638.49	2665896.11	99.13	2	211	Fence, height -2M
17	356651.82	2665903.94	98.99		200	
18	356659.29	2665926.54	98.72	9	224	Pole 3nos , height 9 M
19	356633.02	2665936.62	98.51		200	
20	**356598.96**	**2665995.82**	**98.23**		**250**	**AP-2**

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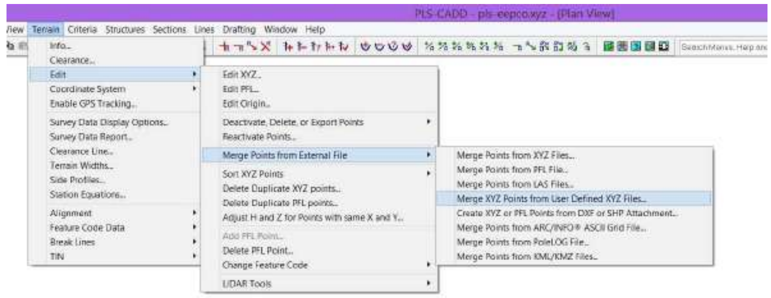
NOW TO IMPORT SURVEY DATA FOR '.XYZ' FILE:



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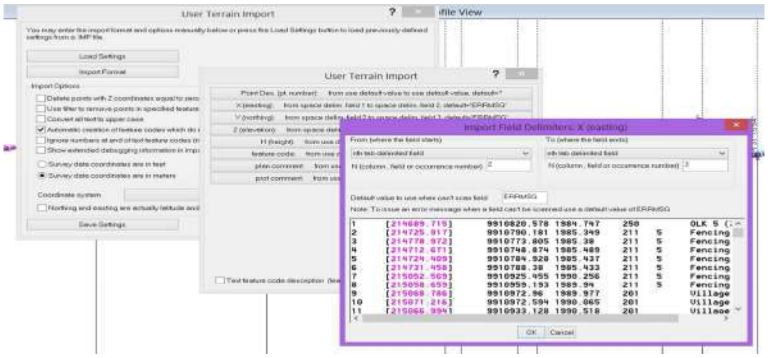
SETTING OF SURVEY DATA FIELDS BY IMPORT FORMAT:



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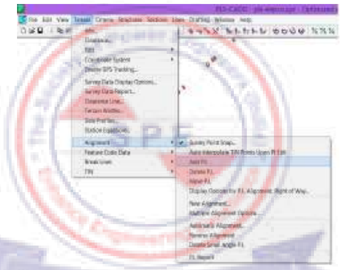
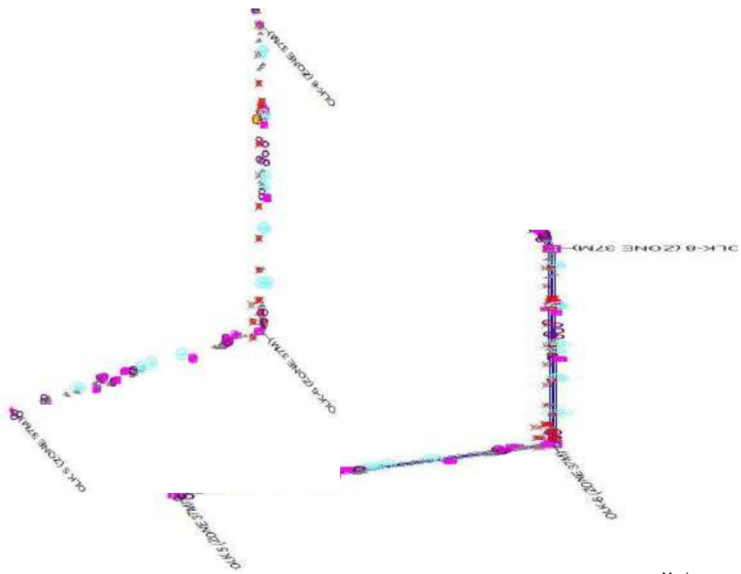
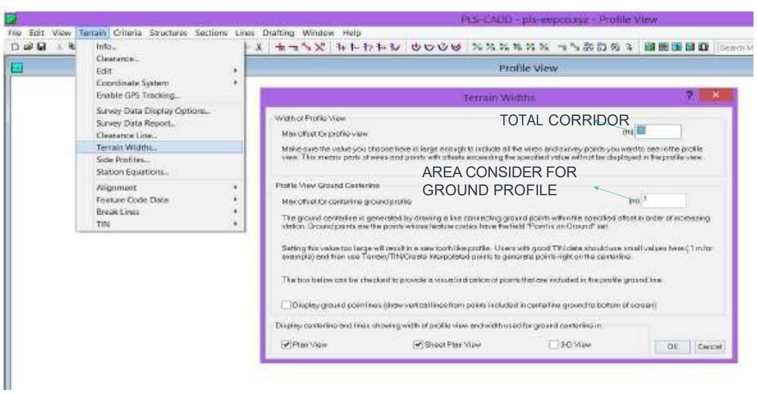


AFTER INPUT OF TERRAIN DATA TO MAKE ALL THE POINTS IN PROPER ROUTE ALIGNMENT:



Patel Megha

SET TERRAIN WIDTH FOR PROJECT:



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YOU CAN NOW SEE THE PROFILE VIEW OF PROJECT:

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PART-2 : DESIGN CRITERIA INPUT

TO START DESIGN CRITERIA INPUT, EITHER YOU ARE HAVING SAG TENSION CALCULATION READY WITH YOU OR HAVING WEATHER CASES AND LIMITING DESIGN CONDITIONS FOR BOTH CABLE AND STRUCTURE

This is for 0 degree max.

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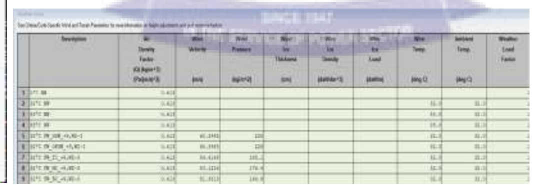
TO DEFINE WEATHER CASES:



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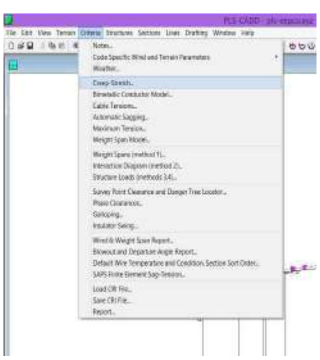
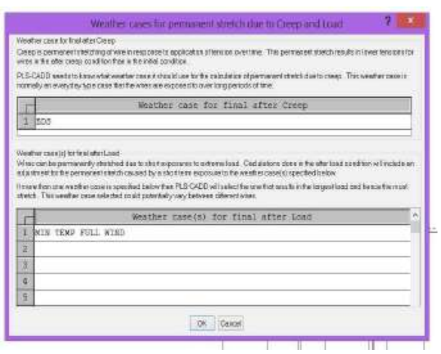
FOR CREEP-STRETCH CRITERIA OF CABLE:





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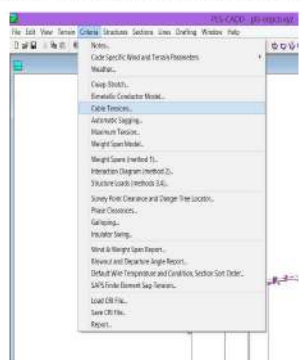
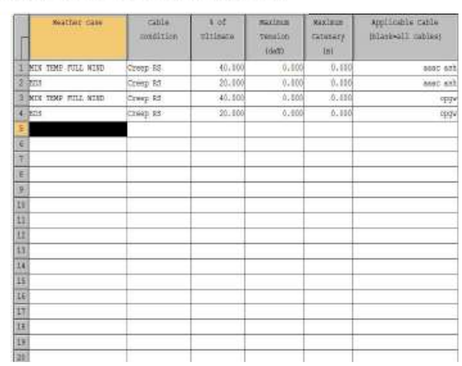
CABLE TENSION CRITERIA FOR TENSION RESTRICTION IN CABLES:





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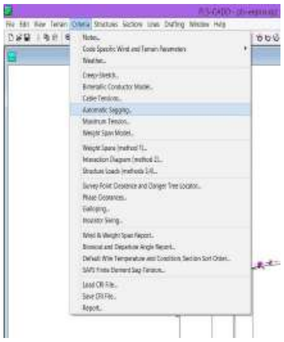
AUTOMATIC SAGGING CRITERIA FOR TENSION RESTRICTION ON STRUCTURES:



	Weather case	Cable condition	% of Ultimate	Maximum Tension (daN)	Maximum Catenary (m)	Applicable Cable (blank=all cables)
1	MIN TEMP NIL WIND	Creep RS	22.296	0.000	0.000	aaac ash
2	MIN TEMP FULL WIND	Creep RS	37.160	0.000	0.000	aaac ash
3	MIN TEMP OBLQ WIND	Creep RS	27.435	0.000	0.000	aaac ash
4	EDS	Creep RS	19.489	0.000	0.000	aaac ash
5	MAX TEMP NIL WIND	Creep RS	16.320	0.000	0.000	aaac ash
6						
7	MIN TEMP NIL WIND	Creep RS	22.065	0.000	0.000	opgw
8	MIN TEMP FULL WIND	Creep RS	29.904	0.000	0.000	opgw
9	MIN TEMP OBLQ WIND	Creep RS	24.522	0.000	0.000	opgw
10	EDS	Creep RS	20.000	0.000	0.000	opgw
11	MAX TEMP NIL WIND	Creep RS	17.361	0.000	0.000	opgw
12						

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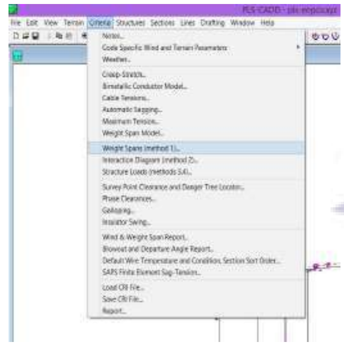
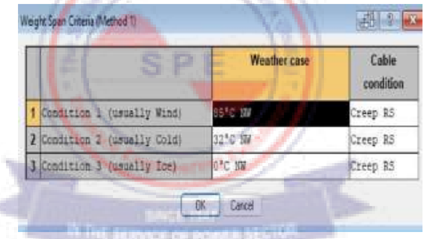
WEATHER CONDITION SELECTION FOR STRUCTURE STRENGTH CHECK:





Weight Span Criteria (Method 1)

		Weather case	Cable condition
1	Condition 1 (usually Wind)	85°C NW	Creep RS
2	Condition 2 (usually Cold)	32°C NW	Creep RS
3	Condition 3 (usually Ice)	0°C NW	Creep RS

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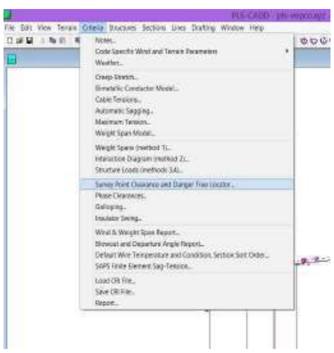
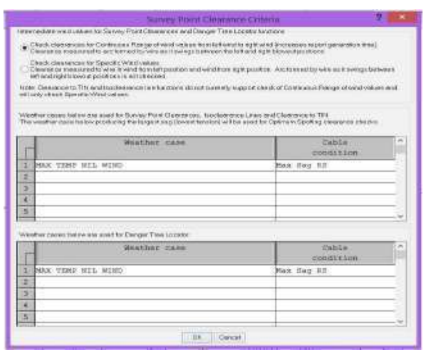
WEATHER CASE SELECTION FOR CLEARANCE SELECTION:





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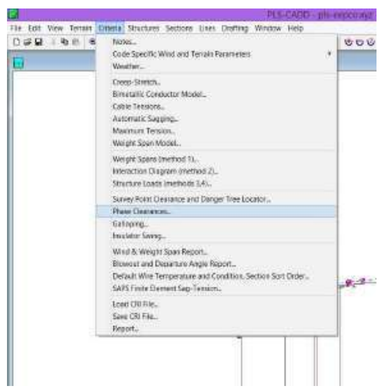
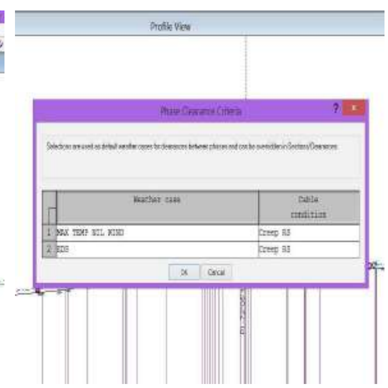
FOR PHASE CLEARANCE:





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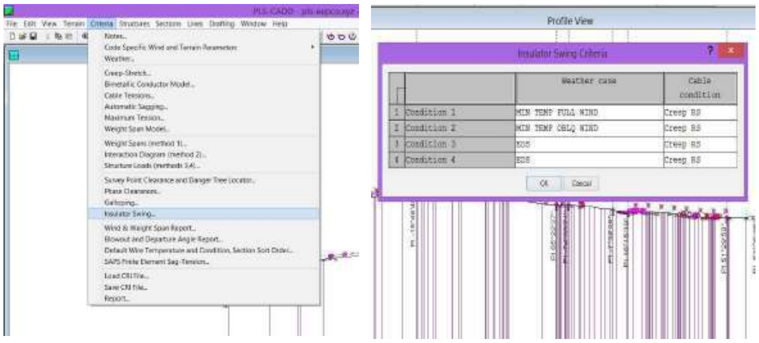
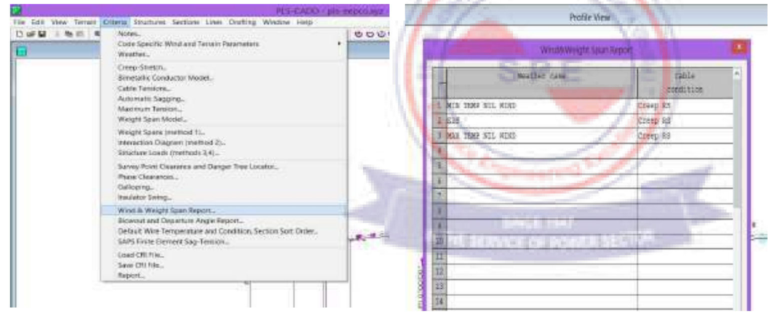
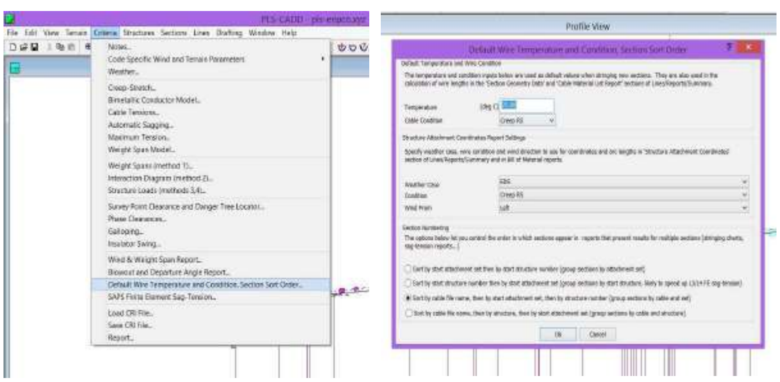
WEATHER CASE SELECTION FOR INSULATOR SWING CHECKING:



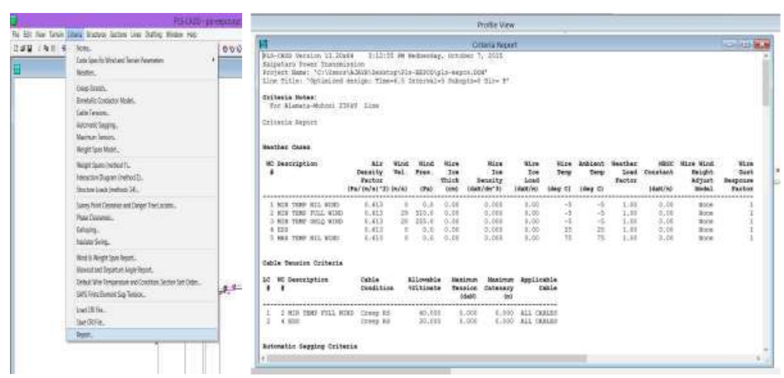
WEATHER CONDITION SELECTION FOR WIND-WEIGHT SPAN REPORT:



DEFAULT WEATHER CONDITIONS FOR SECTION TABLE:



OVERALL SUMMARY OF DESIGN CRITERIA ENTERED:



NOW TO PREPARE CABLE FILE:

There are three types of cable models that are available for modeling conductors in PLS-CADD. The first and most accurate is the **non-linear cable model** which uses separate polynomials for initial and creep behavior for inner and outer materials. The second is the **improved linear cable model** which models permanent stretch due to creep proportional to the creep weather case tension. The third is the **linear cable model** with permanent stretch due to creep specified as a user input temperature increase.

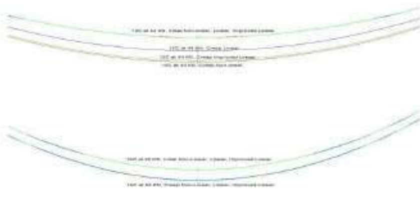


Figure 1

Linear Cable Models vs. Non-Linear Cable Model

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NON-LINEAR CABLE MODEL:

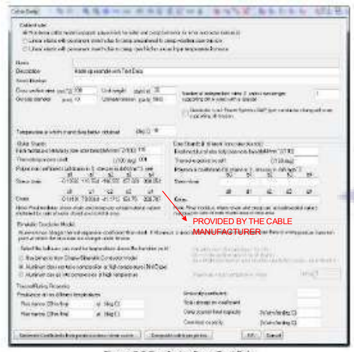

Figure G-2 Conductor From Test Data

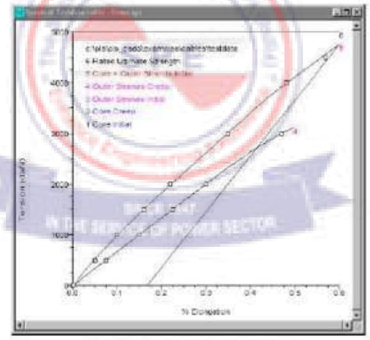

Fig. G-3 Graph of Data in Figs. G-1 and G-2

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SIMPLE LINEAR CABLE MODEL:

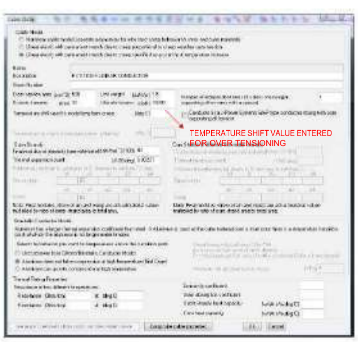

Fig. G-4 Linear Elastic Cable with Nominal Creep

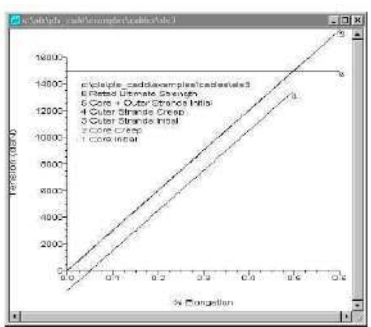

Fig. G-5 Graph of Cable in Fig. G-4

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TO PREPARE STRUCTURE FILE:

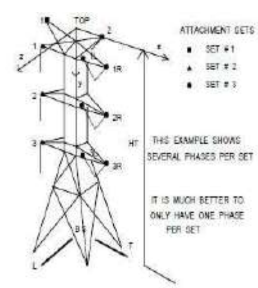
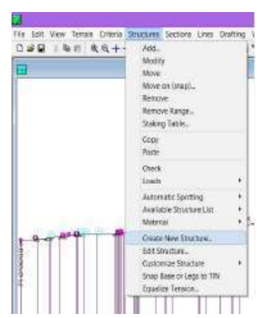
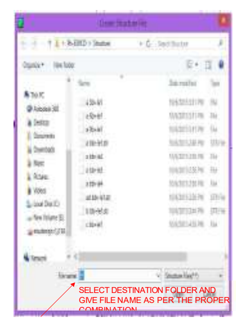


Fig. 8.2-1 Structure Top Geometry

NOW GO TO STRUCTURE MENU:





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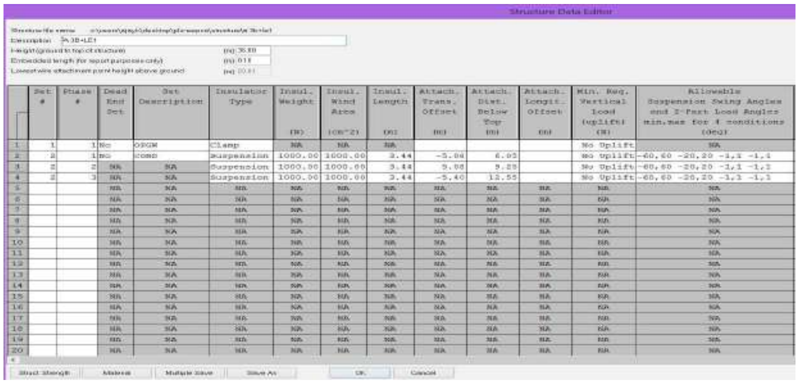
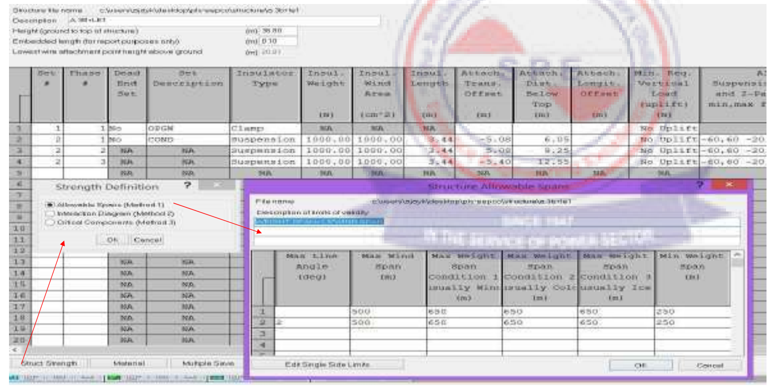
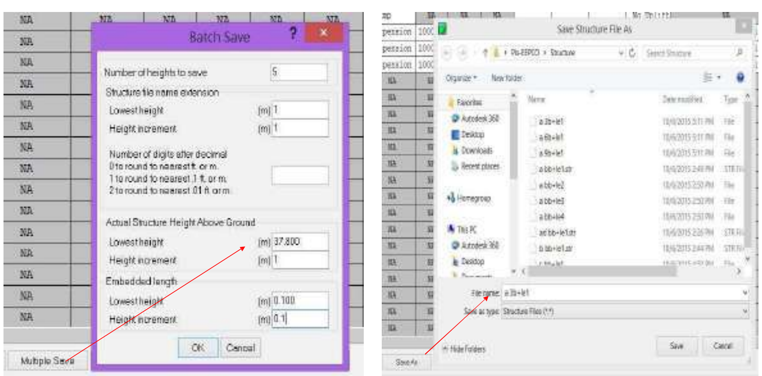
STRUCTUR FILE INPUT PARAMETER:



NOW TO SPECIFY STRUCTURE STRENGTH PARAMETERS:

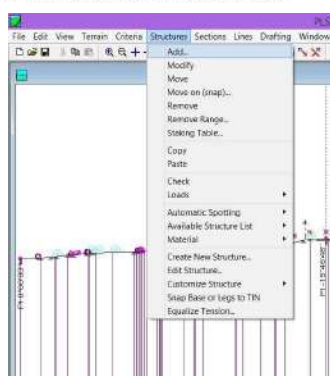


MULTIPLE SAVE AND SAVE AS OPTION:

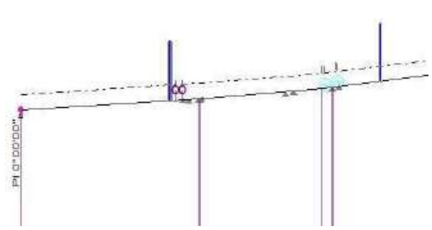


PART – 3: TOWER SPOTTING

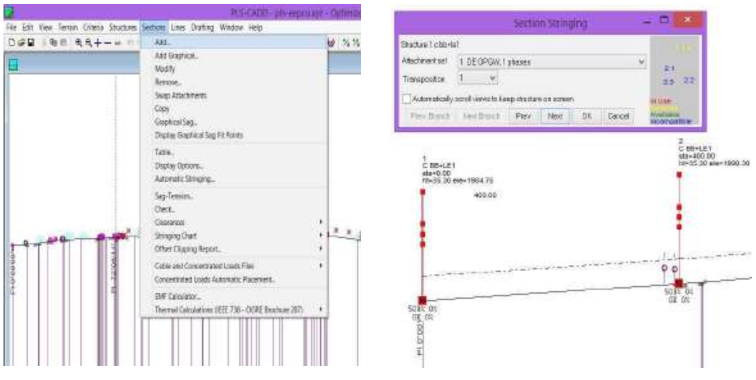
FOR MANUAL TOWER SPOTTING:



YOU CAN RANDOMLY PUT THE STRUCTURE WHERE YOU WANT



FOR THE MANUAL STRINGING:



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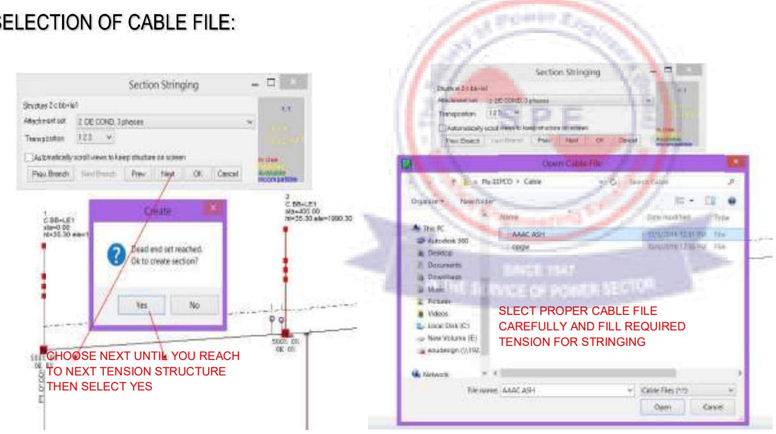
SELECTION OF CABLE FILE:



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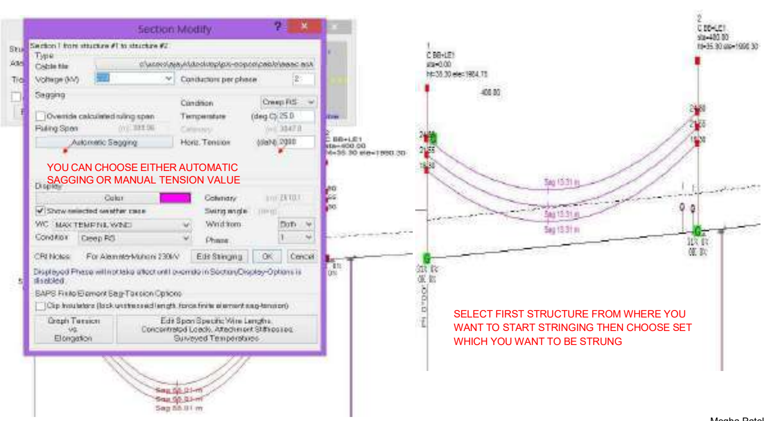
SECTION SAG TENSION CALCULATION INPUT:



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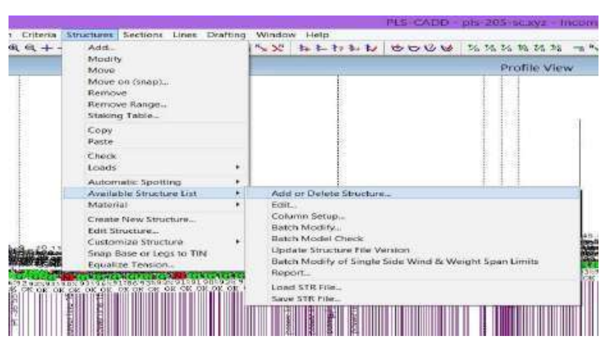
AUTOMATIC TOWER SPOTTING:



SELECT ALL THE STRUCTURE FILES FROM THE STRUCTURE LIST AND CLICK 'OK'.

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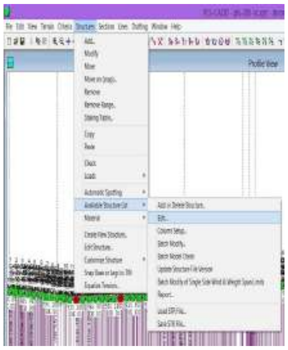
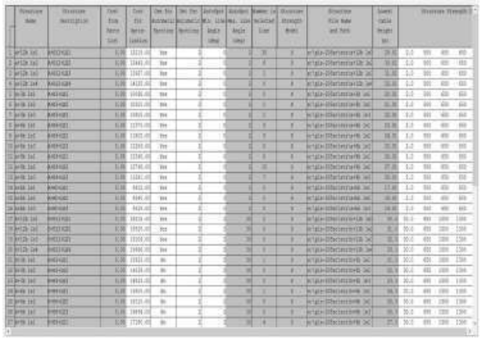
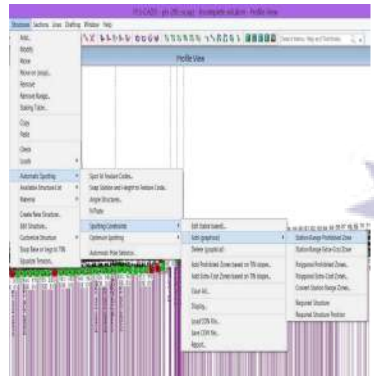
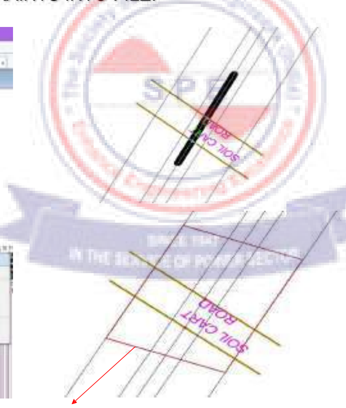
AFTER ADDING STRUCTURES INTO FILE ASSIGN THEIR COST AND SPOTTING PARAMETERS AS SHOWN:



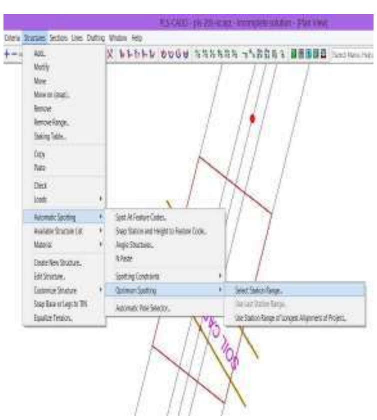


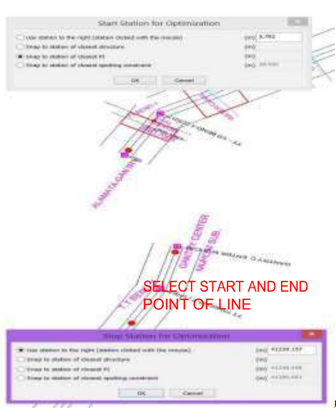
THEN DEFINE TOWER SPOTTING CONSTRAINTS INTO FILE:



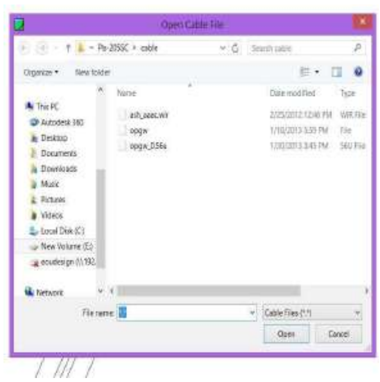


NOW TO START OPTIMUM TOWER SPOTTING:

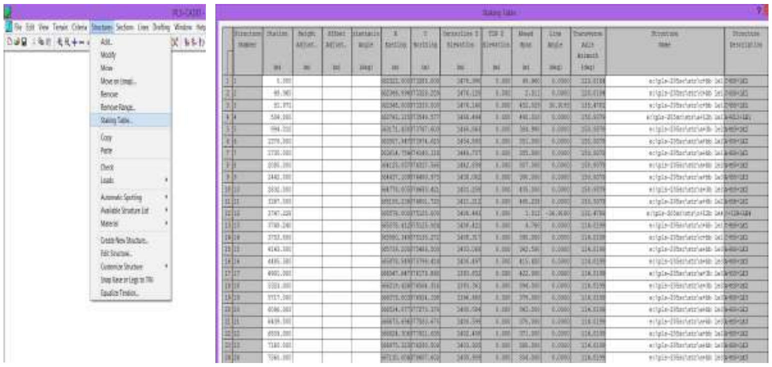




SELECT CABLE FILE FOR SPOTTING AND SPECIFY THE SAGGING DATA:



YOU CAN SEE ALL THE INFORMATION OF SPOTTTED STRUCTURES FROM STAKING TABLE



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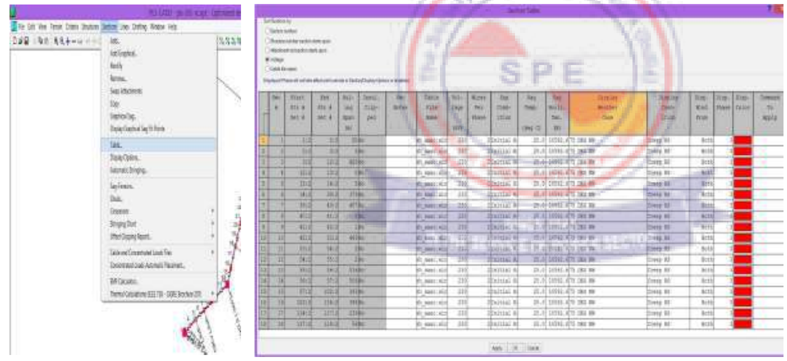
YOU CAN SEE THE INFORMATION OF ACTUAL SAGGING IN SECTION TABLE



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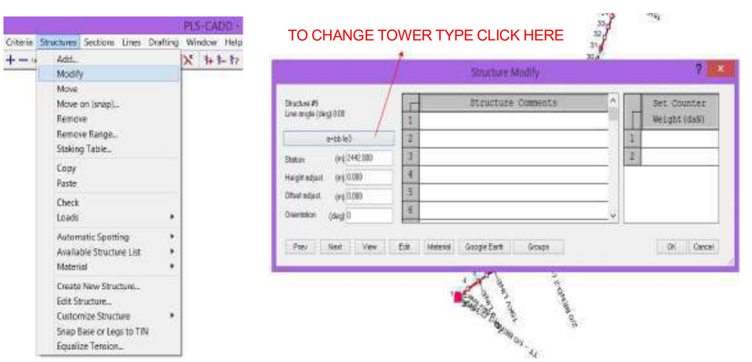
YOU CAN MOVE OR EDIT TOWER POSITION AND TYPE:



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PART – 4: VARIOUS REPORTS

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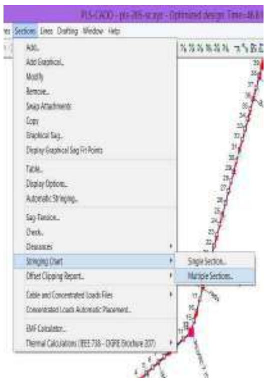
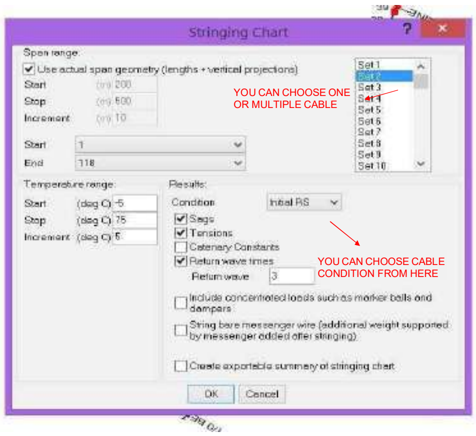
STRINGING CHART REPORT:





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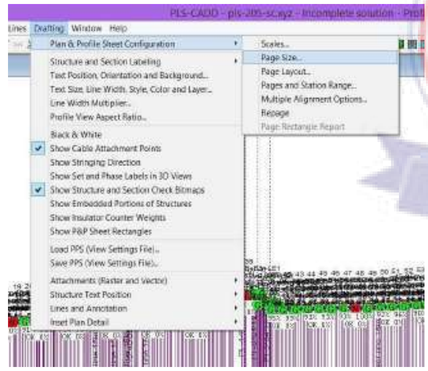
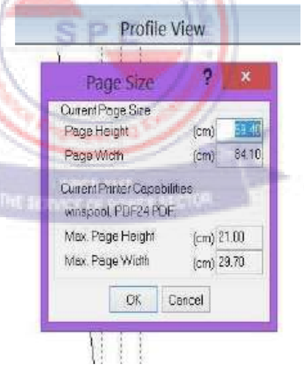
PART-5: DRAFTING SETTING

SPECIFY PAGE SIZE:





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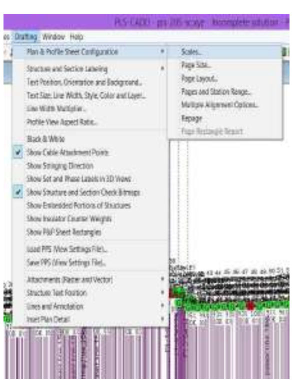
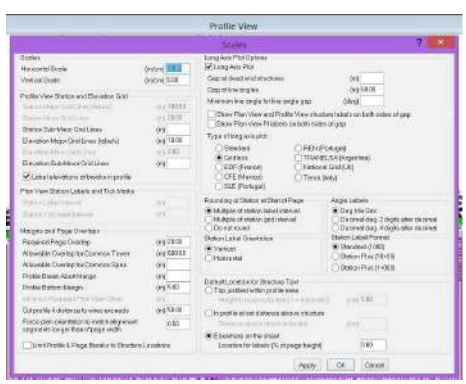
PLAN & PROFILE SHEET CONFIGURATION:





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SHEET LAYOUT TERMINOLOGY:

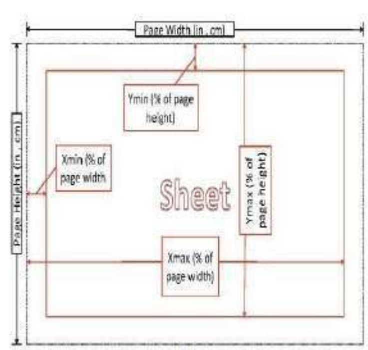

Fig. 13.2-3a Basic Sheet Layout

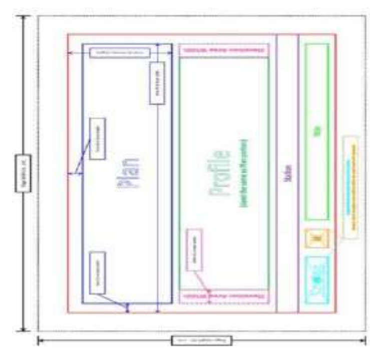

Fig. 13.2-3b Detailed Sheet Layout

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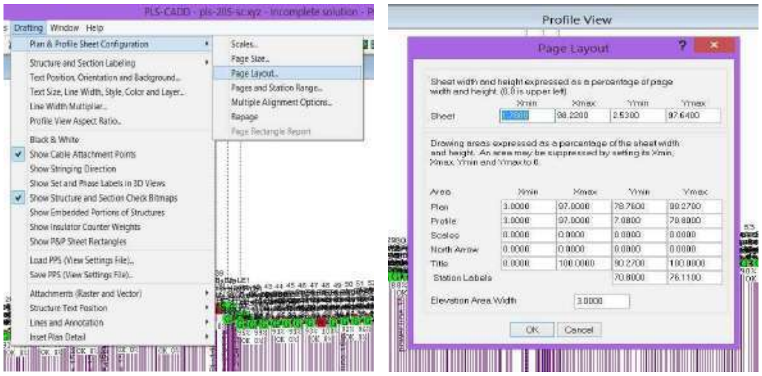
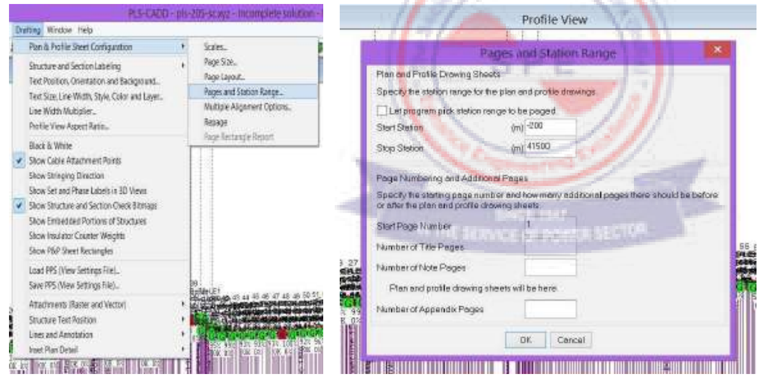
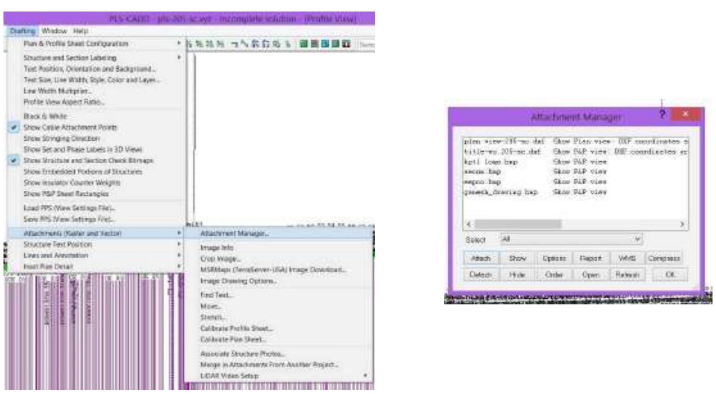
SHEET LAYOUT:



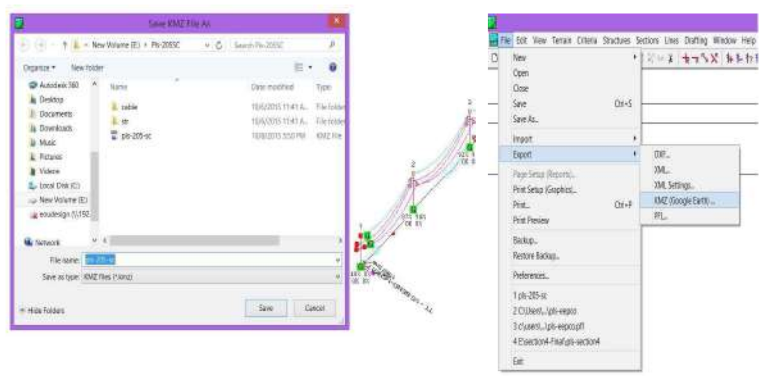
CUSTOM SETTING FOR NUMBER OF SHEETS TO DISPLAY:



ATTACHMENT OF RASTER ENTITIES:



TO EXPORT PROJECT IN GOOGLE EARTH, DXF FILE:



PART-: CHECK LIST FOR THE TOWER SPOTTING USING PLSCADD

CHECK LIST FOR THE TOWER SPOTTING (For Site Concern)

Sr. No.		DESCRIPTION	VERIFIED	
			YES	NO
1	RELATED TO SITE SURVEY	Given survey data is OK as per the plscadd required format ?		
2		Autocad plan-view file is given ?		
3		In excel data description of features are given ?		
4		Height of obstacles(Line x-ing,Houses,Fence etc..) are given ?		
5		Side profile data is given or not for hilly region ?		
6		Description of features are mentioned in the drawing ?		
7		For overcrossing of OHL height of both conductor and GW are given ?		
8		For undercrossing of OHL height of both L/R conductor are given ?		
9		Description of terrain in Autocad plan-view is mentioned ?		
10		Check whethere autocad file entities are in 2D ?		
11		Excel survey data is matching with Autocad file ?		
12				
1	RELATED TO TOWER SPOTTING	Clearance values taken are as per specification ?		
2		Easting values and Northing values are OK ?		
3		Survey point are in proper alignment ?		
4		Prohibited area marked from features ?		
5		Feature codes given in the data are matching with taken in Plscadd ?		
6		Minimum horizontal distance from obstacles are checked ?		
7		Tower falling height distance from major obstacles are checked ?		
8		For line crossing clearance checked under conductor ?		
9				
10				

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CHECK LIST FOR THE TOWER SPOTTING (For Design Concern)

Sr. No.		DESCRIPTION	VERIFIED	
			YES	NO
1	RELATED TO DESIGNER	Sag tension given ?		
2		Design span given ?		
3		Insulator details given ?		
4		Tower line diagram given ?		
5		Tower spotting data given ?		
6		Asked designer for the starting condition ?		
7		Order/Tender is Tonnage base or Lumpsum ?		
8				
1	RELATED TO TOWER SPOTTING	Given sag tension is matched with Plscadd input ?		
2		Lowest cable height including muff and insulator is verified ?		
3		Section tower requirement verified ?		
4		Transposition tower requirement verified ?		
5		Special requirement verified(Like Tension tower at Highway crossing etc..) ?		
6		Double suspension requirement verified ?		
7		Single span limitation verified ?		
8		In case of weight span violation Location is checked by designer ?		
9		In case of max. leg extn. confirm with site office regarding terrain level ?		
10		Inform designer incase of special extn or special arrangement ?		
11				
12		Tilte block taken is verified with standard title block of concern project ?		
13		Profile scale has been verified from specification ?		
14		CSD No. of Profile drawing is verified from project co-ordinator ?		
15				
16				

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PART-7: OPTIMIZATION PARAMETERS

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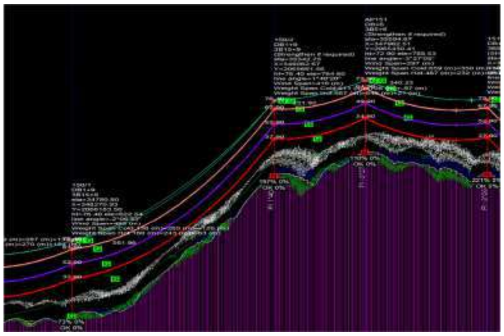
- WEIGHT SPAN VIOLATION: X-ARM STRNTHENING. NO NEED TO INCREASE TOWER/EXTENSION.



Generally done for angle towers.

- PROVIDE RAISED CHIMENY, IF GROUND CLERANCE IS VIOLATED BY FEW METERS. – TO AVOID HEIGHER EXTENSION, ADDINATIONAL TOWER, SHIFTING OF TOWER.

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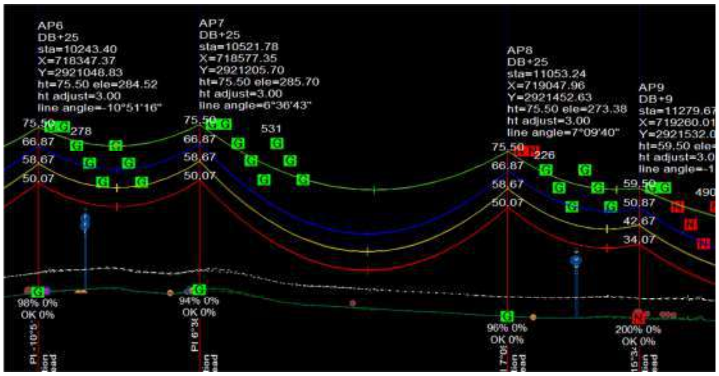

- SHIFTING OF ANGLE POINTS: TO REDUCE SUSPENSION TOWER QTY.
- TO REDUCE DEVIATION ANGLE & CONVERT TOWER FROM DB TO DA, DC TO DB & DD TO DC.

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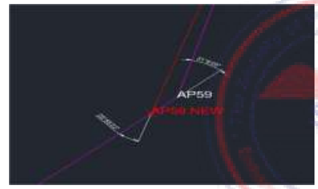
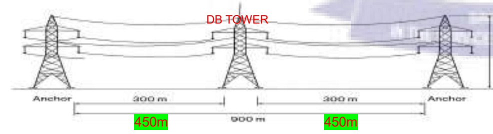


- CHECK USE OF DB TOWER INSTEAD OF 2 NOS. OF SUSPENSION TOWER:



- PROVIDE COUNTERWEIGHT: IN CASE OF MIN. WEIGHT SPAN VIOLATION/INSULATOR SWING VIOLATION.

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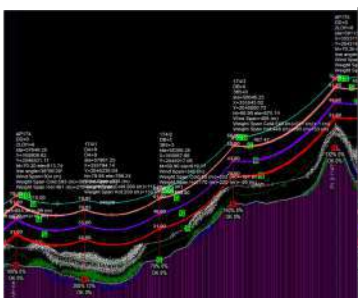
450M

450M

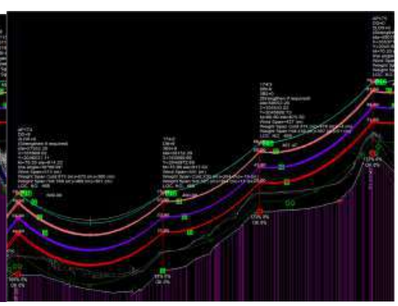
- REDUCE BENCHING/REVETMENT: BY ADJUSTING THE LOCATION IN HILLY/UNEVEN TERRAIN.

MINIMUM NUMBER OF STRUCTURES, ROUTE DIVERTED TO PLAIN TERRAIN TO AVOID HUGE BENCHING/REVETMENT.

WITHOUT REMOVING TOWER:



WITH REMOVING TOWER:



- REDUCE PILE LOCATIONS: BY INCREASING SPAN & PROVIDE HEIGHER EXTENSION TOWER. USE DB TOWER INSTEAD OF DA TOWER.

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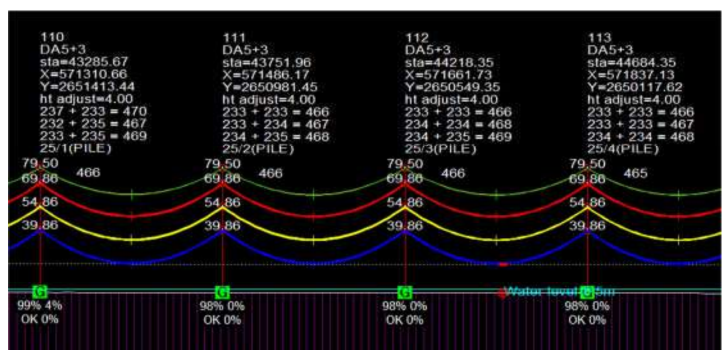

WZ-5 DA TOWER USED IN WZ-4 DA WITH HIGHER SPAN TO REDUCE PILE LOCATIONS.

TRAINER'S NOTE:

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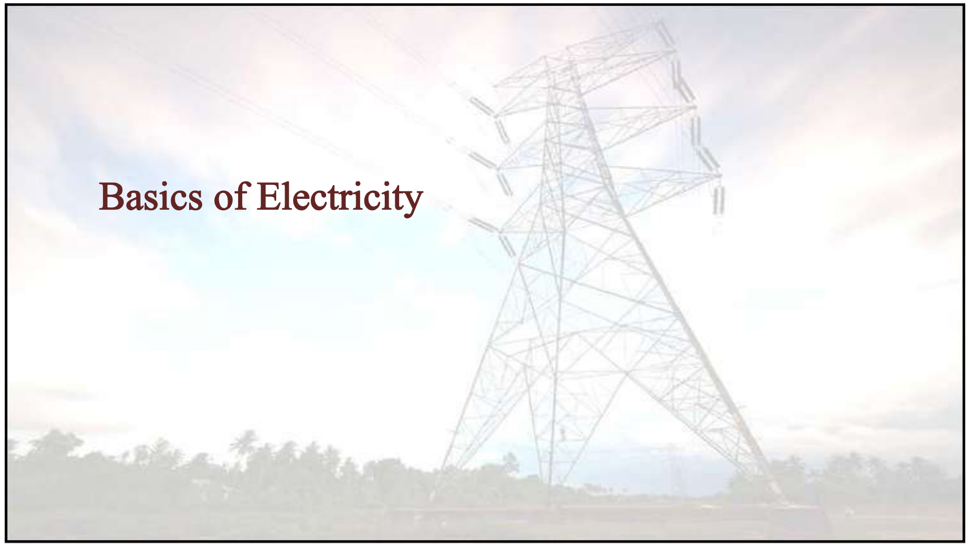
- Though pls-cadd software is having multiple function for transmission line design, we have included most commonly used functions into this procedure manual.
- For detail understanding of function, you are requested to review pls-cadd software manual which was already provided to you.
- Practice must be required for having GOOD command on it otherwise whatever learned shall be skipped during time being.
- In case of any query feel free to write on my email id: meghap@jyotistructures.in

THANK YOU VERY MUCH



Introduction

- ✓ Extra High Voltage(EHV) Alternating Current (AC) transmission lines are required for transfer of large quantum of power over a long distance. The EHV transmission lines also help in reducing the transmission line losses and provide good stability to the power system. Besides the voltage regulation is also fairly good. This is possible only because of the transformation of low voltage to high voltage. This is detailed in the topic here after.
- ✓ The EHV line has mainly the following components:
  - Transmission Line Support Towers & Accessories
  - Earth wire & Accessories/Optic Fiber Ground Wire(OPGW) & Accessories
  - Conductor & Accessories
  - Insulators & Hardware
  - Foundation

Introduction

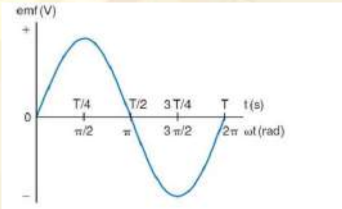
- ✓ The size of conductor to be used on EHV AC line depends upon the voltage and the current to be handled by the line. To be precise, the size of conductor and their numbers per phase, depend upon the quantum of power to be transmitted.
- ✓ Higher is the voltage, larger is the line distance over which the power can be transmitted. The presentation below gives the account of various types of conductors being currently used in the country and elsewhere.
- ✓ The presentation also gives fundamental principles of EHV Direct Current (DC) and Alternating Current (AC) power system.
- ✓ The presentation also gives fundamental idea of power generation and **transformation**.

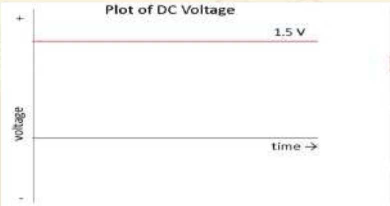
Direct and Alternating Currents

- ✓ It is well-known that in the Alternating current (AC) power system, the current & voltage become negative & positive 50 times in a short period of one second, which is called Frequency.
- ✓ In India and most of the countries in the world, the frequency is 50 cycles per second or 50 Hz. In US the frequency is 60 Hz.
- ✓ Direct current(DC) power system does not have frequency but only positive & negative poles.
- ✓ The AC & DC power is represented in the figures below.

Direct and Alternating Currents

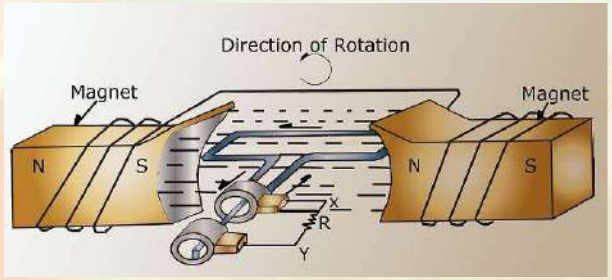
- ✓ The wave form of the current & voltage follows a sine curve in case of AC power system.
- ✓ In case of DC power system the magnitude of voltage and current remain constant with respect to time .
- ✓ AC & DC power (current & voltage) is represented in the figures below.





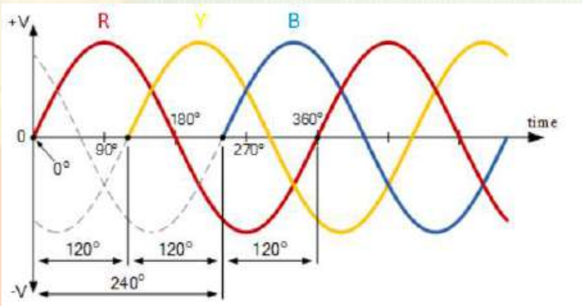
Direct and Alternating Currents

- ✓ The duration of one cycle in second = 1 / Frequency. During one cycle the rotor of alternator(Generator) completes a circle, therefore one cycle = 360º rotation. The rotor winding cuts the magnetic lines of force which results into generation of power.
- ✓ Power is generated due to cutting of magnetic lines by the rotor conductors. (Figure Below)



Direct and Alternating Currents

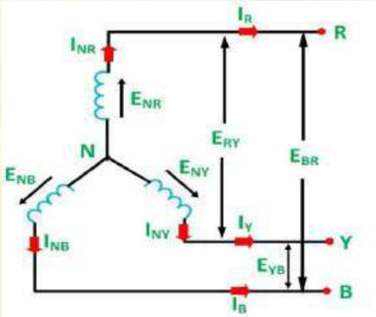
- ✓ In three phase, the three current or voltage waveforms are displaced by 120º rotation as shown in figure below. It may be noted that rotor & stator of generator have a 3 phase winding. They are denoted as Red , Yellow & Blue (RYB) Phases.



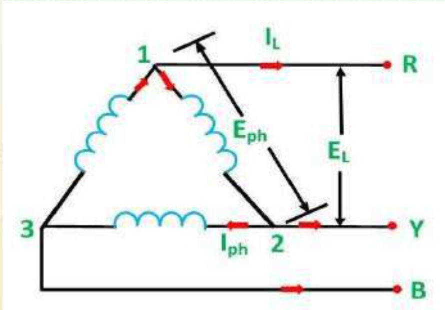
The Advantages of 3 phase power

- The size of Generator & Motor reduces for the same power capacity/rating.
- Large quantity of power can be transmitted on the same tower with 3 conductors per circuit.
- Similarly, distribution network also can be carried on single pole/support.
- The transformer size also reduces for 3-phase configuration.
- Substation size also reduces for the same installed capacity.
- The distribution company can supply bulk power with 3-phase system.

3 Phase Power System



Star Connection



Delta Connection

Difference in Star & Delta connections

- As shown in figure above, the Star system is denoted as Y. In this system the current in each phase is same but phase to neutral voltage reduces which is phase voltage divided by √3.To be precise, phase to neutral voltage is equal to phase to phase voltage/√3.(Vn=Vp/√3). However, phase current & line current will remain same ($I_p=I_l$).
- As shown in figure above, the Delta system is denoted as Δ. In this system the phase & line voltage are same(V_l =Vp).However, line current is divided by √3 for deriving phase current($I_p=I_l/\sqrt{3}$).
- Cross-section of conductor is proportional to the current to be handled, whereas the insulation level depends upon the voltage. Thus the star & delta system can be used for optimizing the size of power equipment and the level of insulation in the transmission lines & substations. This is also true for power distribution system.

Direct and Alternating Currents

- ✓ As known, current is denoted by ‘I’ and voltage by ‘V’. The DC Power P is calculated by formula P = V x I. In case of DC, V & I are vectorially in phase as shown above.
- ✓ The AC power is calculated by the formula P = V x I x cos Ø for single phase & P= √ 3 x V x I x cos Ø for 3-phases where Ø is the angle by which the current vector leads or lags the voltage vector.
- ✓ The DC power is independent of frequency & therefore the impediment to the power flow is only through the resistance of the conductor denoted as R.
- ✓ The AC power is frequency dependent & therefore the impediment to the power flow is through the Resistance, Inductive reactance & Capacitive reactance of the conductor.
- ✓ The inductive reactance makes the current vector to lag behind the voltage vector by an angle Ø & Capacitive reactance makes the current vector to lead the voltage vector by an angle Ø .

Vectorial representation of Resistive , Inductive & Capacitive loads

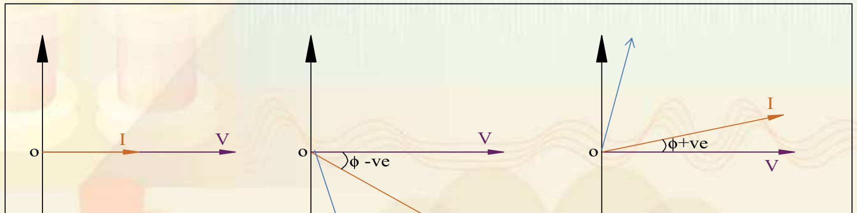


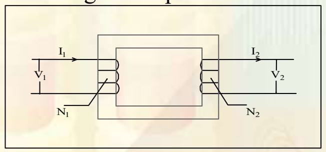
Fig 2-a
Pure Resistive load

Fig 2-b
Pure Inductive load

Fig 2-c
Pure Capacitive load

Transformation of Power

- The Alternating nature of current & voltage in AC system affords transformation to step-up the voltage or step-down the voltage.



- The transformation is governed by the equation $V_1/V_2=N_1/N_2=I_2/I_1$. Where V_1 & V_2 are primary and secondary voltages, N_1 & N_2 are the number of turns on primary & secondary winding respectively and I_1 & I_2 are currents on primary & secondary respectively. Thus, when voltage is stepped up by a particular ratio, the current is stepped down in the same ratio and similarly when the voltage is stepped down by a particular ratio, the current increases in the same ratio.

Transformation of Power

- As stated above, in any electrical system, the amount of insulation depends upon the voltage level whereas the cross section of the conductor depends upon the **quantum** of current to be handled.
  - Insulation level is proportional to the Voltage
  - Cross section of Conductor is proportional to the Current passing through it.
- Thus when voltage is stepped up, the current reduces in the same ratio. Therefore, the cross sectional area of the line conductor reduces, resulting into the reduction in cost of the transmission line for the same **quantum** of power transmitted. Decrease in current also reduces the line losses in the proportion of the square of current & the resistance of conductor = (I^2 x R).

Transformation of Power

- For example, if voltage is increased from 11kV to 220kV(20 times), the losses will decrease 400 times for the same **quantum** of power transfer. Therefore, the line efficiency will also increase substantially. Thus, the requirement of conductor cross-section will also reduce by 400 times. Similarly, the power loss (I^2R) will also reduce 400 times.
- When current reduces, the voltage drop reduces in proportion to the current and the resistance of the conductor (I x R). Therefore, the voltage regulation is improved for the same distance between two substations / switchyards.
- The resistance(R) indicated above is actually vectorial sum of resistance, inductive reactance & capacitive reactance of the transmission line denoted as Impedance(Z).

Distinct Advantages of AC transmission

- Cost of the conductor reduces and therefore the cost of hardware and tower as well as foundation reduces for a particular **quantum** of power transfer.
- The voltage drop (I x R) reduces and the power can be transmitted over a longer distance. Thus, the voltage regulation is better.
- EHV lines are better for in state and interstate transmission network
- EHV transmission affords bulk power transfer from one point to the other.

Distinct Disadvantages of EHV transmission

- EHV needs high insulation, and the cost of insulation increases.
- The EHV needs larger clearance from the ground and phase to phase. This has an adverse effect on the cost of tower and the foundation.
- The cost of EHV substation equipment increases with the increase in voltage.
- The EHV is dangerous for all forms of life (human, animals, flora & fauna).
- EHV also means risk of fire hazards.

Conductor Behavior, Flow of Current and Impediment

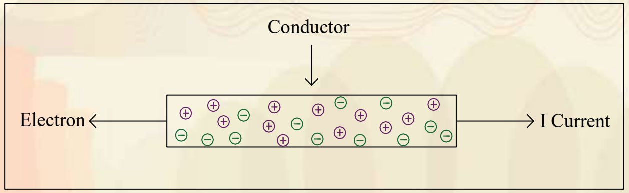
✓ The popular Ohms Law is I = V/R where 'R' is the resistance of the conducting medium (conductor in case of transmission system). So far as the conductors are concerned, there is some difference in the impediment **of** the **conductor** when it is carrying direct current (DC) and when it is carrying alternating current (AC).

✓ The conductor material offers resistance to the passage of current which is denoted as "R". It is also pertinent to note that when the current passes in one direction, the electrons embedded in the conductor material move in the reverse direction. Thus, the resistance (R) is inversely proportional to the reverse flow of electrons.

Conductor Behavior, Flow of Current and Impediment

✓ R is also inversely proportional to the conductivity of material. Faster the movement of Electron, higher is the conductivity of conducting material. Thus, Iron, Aluminum, Copper, Silver and Gold are in ascending order in conduction.

✓ The material like Wood, Bakelite, Plastic Porcelain do not have movement of electron and therefore, they are called insulating materials. There are some semi-conductors also, which have conductivity under different voltage conditions.



Conductor Behavior , Flow of Current and Impediment

✓ In case of DC, only resistance R is providing impediment to the passage of current, while in case of AC there are three elements denoted as "R", "L" and "C" respectively representing Resistance, Inductance & Capacitance.

✓ The alternating nature of current causes disturbance in the movement of electrons which ultimately results into a magnetic field. This field also provides impediment to the passage of current. This is called Inductive Reactance (X_L). The alternating current also builds up a capacity to store the current. This is called Capacitive Reactance (X_C).

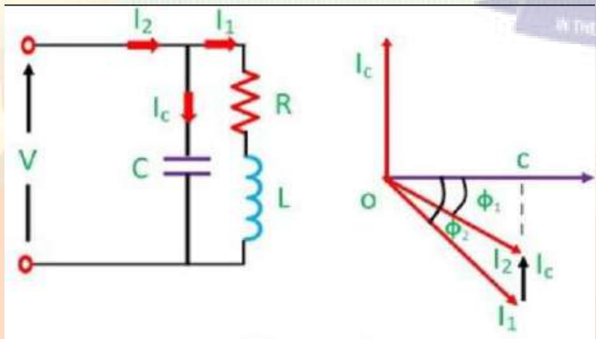
✓ This is also an indirect impediment to the current. The X_L and X_C are functions of frequency. Inductive Reactance $X_L = 2 \times \pi \times f \times L$ - where f is a frequency (50/60 Hz) and L is an inductance in Henry (normally in mili Henry denoted as mH).

Conductor Behavior , Flow of Current and Impediment

- ✓ Capacitive Reactance Xc = 1 / 2 x π x f x C - where f is a frequency (50/60 Hz) and C is a capacitance in Farad (normally in micro Farad denoted as μF).
- ✓ Thus, the total impedance to the Alternating Current "Z" is the vectorial sum of R, L & C. It is pertinent to note that the resistance R provides an impediment which makes the current I and the voltage V to follow vectorially to the line (0º). The L makes the current I to lag behind the voltage V vector by an angle Φ ,which depends upon the value of inductance L of the circuit.
- ✓ The C makes the current I to lead the voltage V vector by an angle Φ, which depends upon the value of capacitance C.
- ✓ Thus, the effective angle Φ by which the current I will lag or lead the voltage will be determined vectorially as shown in figure below.

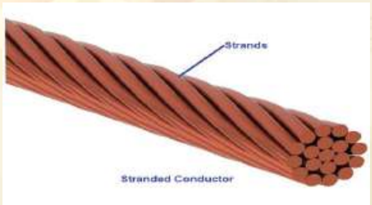
Conductor Behavior, Flow of Current and Impediment

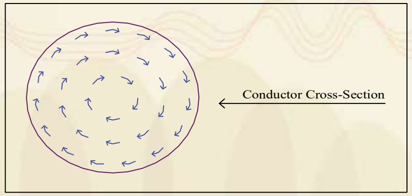
- ✓ Thus, the effective angle Φ by which the current I will lag or lead the voltage will be determined vertically as shown in below figure.



Conductor Behavior | Skin Effect

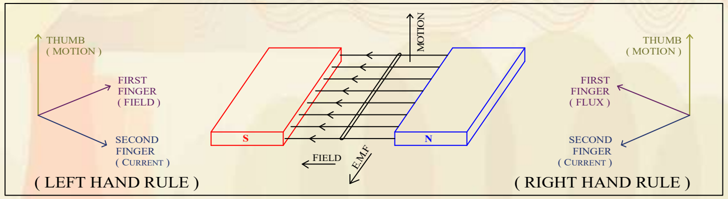
- ✓ Current always try to pass through the path of least resistance & therefore whenever current flows through the conductor, it has a tendency to cling to the outer surface of the conductor. Thus, the effective utilization of the cross section of the conductor reduces.
- ✓ This is called a "Skin effect" shown in figure.
  To reduce the skin effect, it is customary to use stranded conductor.





Conductor Behavior | Induction and Magnetic Filled

- ✓ The overhead line bare conductor when strung on the tower is also susceptible to the attack of the lightning discharges and other stray discharges. The conductor also developes induced voltages due to any line running parallel to it.
- ✓ While carrying current, the conductor also developes magnetic field around it.
- ✓ The Fleming's Right hand & Left–hand rules are described in figure.

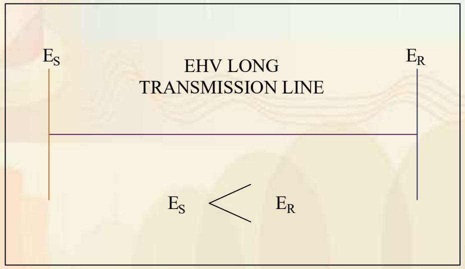


Conductor behavior , Induction and Magnetic Field

- ✓ It is pertinent to note that the magnetic field can generate motion (in case of motors) and vice versa the motion can also develope the magnetic field (in case of Generators) and produce current.
- ✓ The direction of current flow and resultant magnetic field will decide the motion in case of motors and field will decide the direction of flow of current in case of generators.
- ✓ Strong magnetic fields induce voltage on the surrounding objects & human/animal. The Ultra High Voltage (UHV) lines many times pose a serious problem along the route of the line.
- ✓ The design for EHV/UHV lines are required to take care of this situation by providing enough ground & live metal clearances as well as right of way corridor.

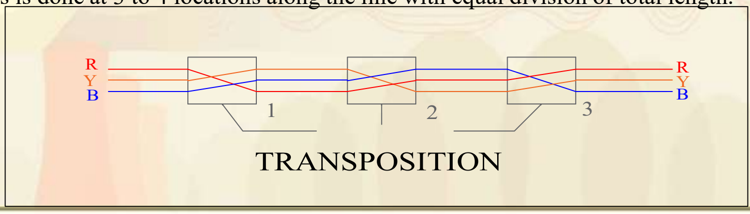
Conductor Behavior | Ferranti Effect

- ✓ When the Transmission line is very long (more than 100kM) the capacitive reactance "X_c" becomes predominant. This has a far–reaching effect on the voltage profile of the line. The voltage at receiving end becomes greater than the sending end voltage ($E_r > E_s$) under very small load or no–load condition. This is called "Ferranti effect".



Conductor Behavior | Ferranti Effect

- ✓ When load on transmission line is very less (say 10%) OR there is no load , the inductance due to the load reduces & thus the current vector tries to go near the voltage vector . These increases the power factor & therefore for the less load/no load power current reduces & voltage increases at the receiving end bus.
- ✓ To reduce the impact of Ferranti effect, it is very usual to provide Transposition on the line. Transposition means changing the physical position of the conductor on the tower body. This is done at 3 to 4 locations along the line with equal division of total length.



Short history of Power system & Transmission line

- **600BC: Static electricity**
  Thales, a Greek, found that when amber was rubbed with silk it attracted feathers and other light objects. He had discovered static electricity. The Greek word for amber is ëelectron', from which we get ëelectricity' and ëelectronics'.
- **1821: Michael Faraday's discovery that led to the invention of electric motors**
  Michael Faraday discovered that when a magnet is moved inside a coil of copper wire, a tiny electric current flows through the wire. This discovery later led to the invention of electric motors.
- **1826: André Ampère explained the electro-dynamic theory**
  André Ampère published his theories about electricity and magnetism. He was the first person to explain the electro-dynamic theory. The unit of electric current was named after.
- **1831: Michael Faraday demonstrated electromagnetic induction**
  Michael Faraday demonstrated electromagnetic induction by passing a magnet through a coil of wire.
- **1870s: Thomas Edison built a DC electric generator**
  Thomas Edison built a DC (direct current) electric generator in America. He later provided all of New York's electricity.

Short history of Power system & Transmission line

- **1880s: Nikola Tesla invented the Telsa Coil**
  Nikola Tesla used the ëTesla coil' to step up ordinary household current to produce extremely high frequency current. Tesla used this high frequency current to develop some of the first neon and fluorescent lights.
- **1881: The first public electricity supply**
  The first public electricity supply was generated in Godalming, Surrey using a waterwheel at a nearby mill.
- **1896: Nikola Tesla's hydroelectric power generators**
  Nikola Tesla's hydroelectric power generators at Niagara Falls came into operation. Within a few years, Tesla's generators at Niagara Falls were supplying electricity to New York City for the elevated railways, the subways and even the lights on Broadway.
- **1930-40s: Hydro-electric power stations**
  Hydro-electric power stations were built in Scotland and Wales, but the majority of electricity generation was from burning coal.
- **1930-40s: Electrical household appliances introduced**
  Mains powered radios, vacuum cleaners, irons and fridges were becoming part of every household.

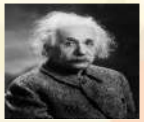
Short history of Power system & Transmission line

- ✓ In the beginning years of power system, Direct Current (DC) Generators were developed, and they were supplying lighting power in surrounding areas. The generators were rated in fraction of MW. The systems were stand alone type.
- ✓ Since the distributed generation system was found to be economically unviable, centralized power generating system came into existence. This was then associated with short distance DC transmission network. However, voltage drop was a major issue even after making a ring main. Therefore, long distance power transmission with a very large size power station was very difficult to establish.
- ✓ Alternating current (AC) power system was therefore born. Transformers were designed and put into service for stepping up and stepping down the voltage.

Thomas Edison was an American inventor who is considered one of America's leading businessmen and innovators. Edison rose from humble beginnings to work as an inventor of major technology, including the first commercially viable incandescent light bulb.

Ottó Bláthy was a Hungarian electrical engineer. In his career, he became the co-inventor of the electric transformer, the tension regulator (Voltage stabilizer), the watt meter, the alternating current (AC) electric motor, the turbo generator, and the high efficiency turbo generator.

Nikola Tesla was a Serbian-American inventor, electrical engineer, mechanical engineer, and futurist who is best known for his contributions to the design of the modern alternating current electricity supply system.



Albert Einstein theorized that, as light hits an object, there is an emission of electrons, which he deemed photoelectrons. This model formed the basis of how solar cells work - light causes atoms to release electrons, which generate a current, and then creating **electricity**.

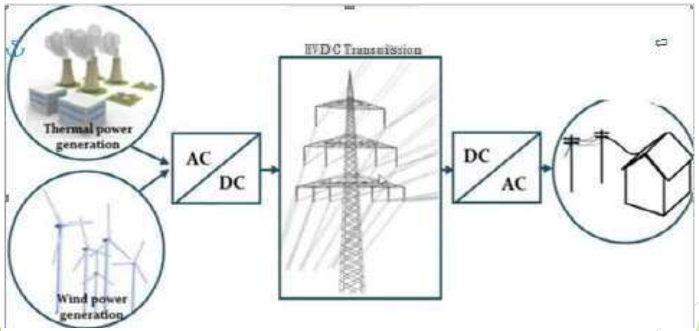
Thank You

BASICS of HVDC

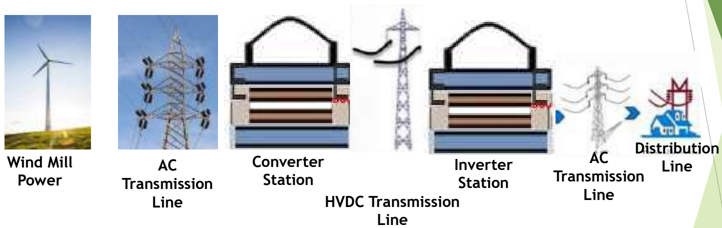
History of HVDC Transmission

- The first commercial HVDC scheme was connected between the island of Gotland to the Sweden mainland in 1954. During the subsequent 55 years, great advances in HVDC technology and economic opportunities for HVDC have been achieved.
- The first HVDC link to be commissioned in the country was Rihand-Dadri in 1991 connecting Thermal power plant in Rihand, Uttar Pradesh (Eastern Part of Northern Grid) with Dadri (Western Part of Northern Grid). It has a line length of about 816 km. It was built by ABB and is currently owned by PGCIL

HVDC TRANSMISSION SYSTEM



HVDC transmission system



WHY DC TRANSMISSION ?

- Losses are less in DC transmission while comparing to AC transmission.
- Only two conductors are required for DC with positive and negative polarities.
- DC overhead lines or cables are less expensive.
- DC lines are useful for long distances above 500km.

Limitations of HVAC

- Reactive power loss
- Stability
- Current carrying capacity
- Skin and Ferranti effect
- Power flow control is not possible.

Advantages of HVDC

- No reactive power loss
- No Stability Problem (Good stability in steady and transient state)
- No Charging Current
- No Skin & Ferranti Effect as there is no frequency
- Better Power control
- Requires less space compared to the AC Transmission for same voltage rating and size.
- Ground can be used as return conductor. However, electrode station will be required. These days metallic return is preferred.
- Less corona loss and Radio interference

Continues...

- Cheaper for long distance and bulk power transmission
- Asynchronous operation possible
- No switching transient
- No transmission of short circuit power and fast fault clearance
- No compensation required
- Low short circuit current
- HVDC is not prone to cascade tripping.

Disadvantages of HVDC

- Cost of terminal equipment is high
- Prone to harmonics
- Blocking of reactive power
- Point to point transmission
- Limited overload capacity
- Two large AC systems are required at both ends.
- Attracts pollution
- Huge reactive power requirement at the convert terminals.
- Special convertor transformers are required.
- HVDC do not have breakers transformers and independent power system.

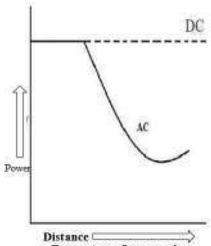
Comparison of AC and DC Transmission

- The relative merits of the two modes of transmission (AC and DC) which need to be considered by a system planner is based on the following factors:
  - Economics of Transmission
  - Technical performance
  - Reliability
- A major feature of power systems is the continuous
- expansion necessitated by increasing power demand.
- This implies that the establishment of a particular line may be considered as a part of overall long-term system planning.

STABILITY LIMITS

- The power transfer in AC lines is dependent on the angle difference between the voltage phasors at the two ends.
- For a given power level, these angle increases with distance.
- The maximum power transfer is limited by the considerations of steady state and transient stability.
- The Figure shows the power capability of the DC lines which is unaffected by the distance of transmission, and only its limited by the current carrying capacity of the conductors.

(Thermal Limit)



Power transfer capacity Vs Distance

VOLTAGE CONTROL

- The voltage control in AC lines is complicated by the line charging and inductive voltage drops.
- The voltage profile in an AC line is relatively flat only for the fixed level of power transfer corresponding to surge impedance loading (SIL).
- The voltage profile varies with the line loading.
- For the constant voltage at the line terminals, the mid point voltages reduced for the line loading higher then SIL and increase for loading less than SIL.

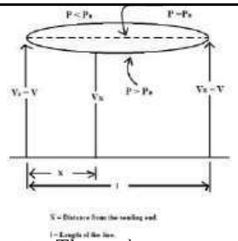
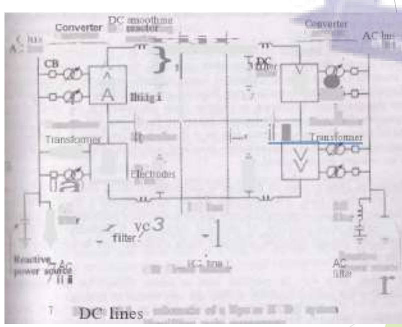


Fig - Variation of voltage along the line.

- The maintenance of constant voltages at the two ends requires reactive power control from inductive to capacitive as the line loading is increased.
- The reactive power requirements increase with the increase in the line lengths.
- Although de converter stations require reactive power related to the line loadings, the line itself does not require reactive power.
- The steady state charging currents in ac lines pose serious problems in cables this puts the breakeven distance for the cable transmission around 4 KM

Components of HVDC Transmission Systems

1. Converter Transformer
2. Converter
3. Smoothing reactors
4. Harmonics Filters
5. Reactive Power Supplies
6. Electrodes
7. DC Lines
8. AC Circuits Breakers



Converter transformer

- Connected between converter and the AC bus.
- Specially deigned as they have de component coming from converter side.
- They may be three single units or a 3-phase unit

Converters

- They perform AC/DC and DC/AC conversion.
- consist of thyristor bridges and transformers.
- Thyristor bridge consists of high voltage thyristor connected in a 6-pulse or 12-pulse arrangement.
- The transformers are ungrounded such that the DC system will be able to establish its own reference to ground.

Smoothing reactors

- They are high reactors with inductance as high as 1H in series with each pole
- They function to smooth out the DC output from the rectifier circuit.

Converter

- They perform ACDC and DC/AC conversion
- They consist of valve bridges and transformers
- Valve bridge consists of high voltage valves connected in a 6-pulse or I2-pulse arrangement
- The transformers are ungrounded such that the DC system will be able to establish its own reference to ground

Smoothing reactors

- They are high reactors with inductance as high as IH in series with each pole
- They serve the following:
  - They decrease harmonies in voltages and currents in DC lines
  - They prevent commutation failures in inverters
  - Prevent current from being discontinuous for light loads

Harmonic filters

- Converters generate harmonies in voltages and currents. These harmonies may cause overheating of capacitors and nearby generators and interference with telecommunication systems
- Harmonic filters are used to mitigate these harmonics

Reactive power supplies

- Under steady state condition conditions, the reactive power consumed by the converter is about 50% of the active power transferred
- Under transient conditions it could be much higher
- Reactive power is, therefore, provided near the converters
- For a strong AC power system, this reactive power is provided by a shunt capacitor

Electrodes

- Electrodes are conductors that provide connection to the earth for neutral. They have large surface to minimize current densities aid surface voltage gradients

DC Lines

- They may be overhead lines or cables
- DC lines are very similar to AC lines

AC circuit breakers

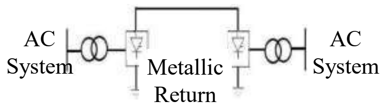
- They used to clear faults in the transformer and for taking the DC link out of service
- They are not used for clearing DC faults
- DC faults are cleared by converter control more rapidly

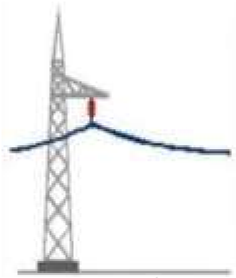
Types of DC link
HVDC links can be broadly classified into:

- Monopolar links
- Bipolar links
- Homopolar links
- Back-to-back links
- Multi terminal links

MONO POLAR LINK

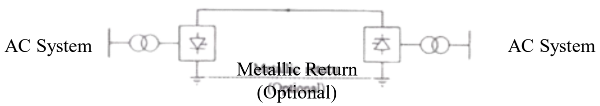
- It uses one conductor.
- The return path is provided by ground or water.
- Use of this system is due to cost considerations.
- A metallic return may be used where earth resistivity is too high.





Monopolar Links

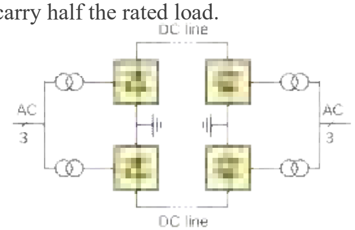
- It uses one conductor
- The return path is provided by ground or water
- Use of this system is mainly due to cost considerations
- A metallic return may be used where earth resistivity is too high
- This configuration type is the first step towards a bipolar link



Monopolar HVDC Link

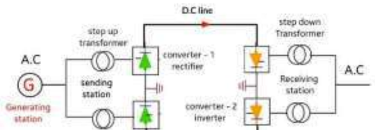
Bipolar Links

- It uses two conductors, one positive and the other negative.
- Each terminal has two converters of equal rated voltage, connected in series on the DC side
- The junctions between the converters is grounded
- Currents in the two poles are equal and there is no ground current
- If one pole is isolated due to fault, the other pole can operate with ground and carry half the rated load.



Homopolar Links

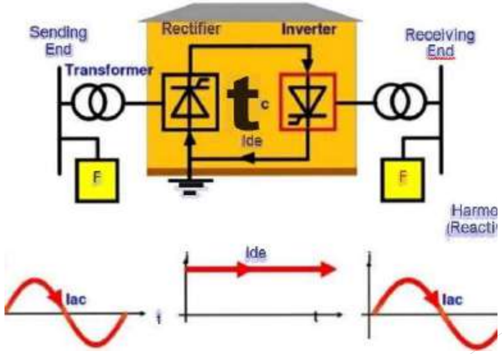
- It has two or more conductors all having the same polarity, usually negative
- Since the corona effect in DC transmission lines is less for negative polarity, homopolar link is usually operated with negative polarity
- The return path for such a system is through ground



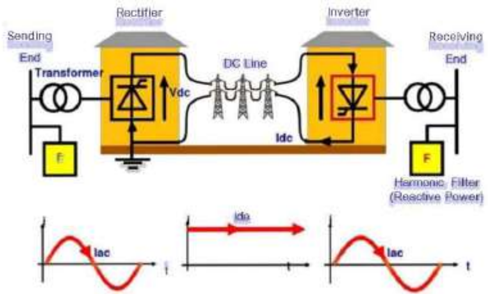
Back-to-back links

- For frequency conversion
- For asynchronous interconnection
- Both Rectifier & Inverter are at same place, connected in DC loop
- There is no DC transmission line

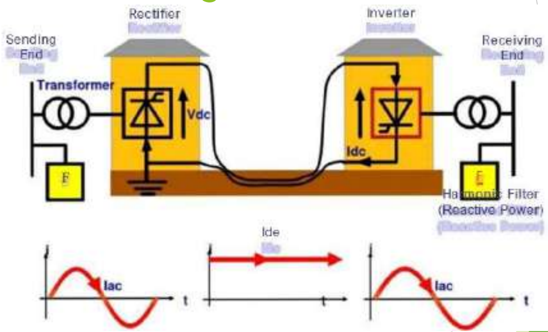
Basic HVDC Transmission Back-to-Back



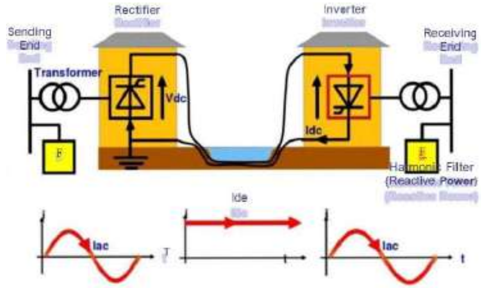
Basic HVDC Transmission Point to Point - Overhead Line



Basic HVDC Transmission
Point to Point - Underground Cable



Basic HVDC Transmission
Point to Point -Submarine Cable



Thank You

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Electrical Design of Transmission Lines

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Introduction

✓ Before embarking on the Mechanical, Structural & Civil(foundation) designs of transmission lines, it is necessary to work on Electrical designs of transmission lines. The electrical design of Transmission line revolves round the following:

- Minimum Clearances above Ground, River/Lakes, Railway tracks, Power Lines, Communication lines etc.
- Insulation coordination
- Overvoltage & Surges
  - Ampacity Calculation & AC Resistance Calculation
  - Inductance
  - Capacitance
  - Inductive Reactance
  - Capacitive Reactance
  - Impedance

Introduction

- A, B, C & D Parameters
- Sending End Voltage
- Sending End Current
- Sending End Power
- Receiving End Voltage
- Receiving End Power
- Voltage Regulation
- Efficiency
- Corona Losses
- Audible Noise
- Radio Interference

Introduction

✓ The conductor is the most important component of HV & EHV transmission line. Every transmission line is laid with a purpose of transmitting definite **quantum** of power (Generally in Mega Watt). Depending upon the power transfer requirement, voltage level of the line is decided. The selection of conductor depends upon continuous current rating requirement of the line under varying ambient conditions.

✓ As a matter of fact, in India, each voltage class of line (66kV, 110kV, 132kV, 220kV, 400kV, 765kV) is designated to transmit a pre-determined quantum of power over a pre-determined length. The quantum of power each voltage class of transmission line can transmit over different distances per circuit is given here.

Introduction

66 kV – 30 to 40 MW
132 kV – 80 to 100 MW
220 kV – 200 to 300 MW
400 kV - 300 to 400 MW
765 kV - 500 to 800 MW
±500 kV HVDC – 1,500 to 2,500 MW
±800 kV HVDC - 3,000 to 6,000 MW

- ✓ Figures given for HVAC lines are for an average length of 100 kM. Reduction in length may allow higher MW transfer & increase in length may allow lower MW transfer. HVDC lines can carry the above indicated quantum of power over a distance of 1000 kM & more. The figures given above are for general comparison & thumb rule. However, while using appropriate conductor size & the insulation, it is possible to evacuate/transfer higher quantum of power at lower voltages. However, the system needs to be designed accordingly.

Minimum Ground Clearance

- ✓ The minimum clearance above ground as per sub rule 4 of Rule 77 of IE rules 1956 (latest revision) for AC system and for ± 500kV HVDC systems adopted in India are as under:

Voltage(kV)	66	132	220	400	800	+/- 500
Minimum Ground Clearance (mm)	5,500	6,100	7,000	8,800	12,400	12,500

Minimum Clearance above Rivers/Lakes

- ✓ In case of accessible frozen rivers/lakes , the minimum clearance above frozen rivers/lakes should be equal to the minimum ground clearance given in 1.0 above.
- ✓ The minimum clearance of power conductor over the highest flood level in case of non navigable rivers shall be as follows

System Voltage (kV)	Minimum clearance above highest flood level (mm) *
72	3,650
145	4,300
245	5,100
420	6,400
800	9,400
± 500	6,750

Electrical Clearance Power Line Crossing Each Other

- ✓ The minimum electrical clearances(mm) between the lowest power conductor of crossing line over the crossed line as per rule 87 of IE rule 1956 is given as under.

Sr. No.	Nominal System Voltage	66kV	132kV	220kV	400kV
1.	66kV	2,440	3,050	4,580	5,490
2.	132kV	3,050	3,050	4,580	5,490
3.	220kV	4,580	4,580	4,580	5,490
4.	400kV	5,490	5,490	5,490	5,490

Power Line Crossing Communication Line

- ✓ The minimum clearances to be maintained between power lines and communication lines as per "Code of practice for protection of Telecommunication Line Crossings with overhead power lines" should be as follows:

Voltage kV						
	Nominal	**66**	**132**	**220**	**400**	**765**
	Highest	72	145	245	420	800
Minimum clearance between power conductor crossing telecommunication line (mm)		2440	2750	3050	4480	7900

Power Line Crossing Railway Tracks

- ✓ The minimum vertical clearance between the lowest conductor of a power line crossing the railway track as per "regulations for power line crossing of railway tracks-1987" shall be as follows:
- ✓ The minimum vertical clearances above rail track as also the highest working point of the jib when crane is deployed and the lowest point of any conductor of crossing including ground wire under condition of maximum sag are given as under.

Voltage (kV)	**Minimum clearance (mm)**	
	Above rail track	Above crane
66	14,100	2,000
132	14,600	2,500
220	15,400	3,500
400	17,900	6,000
800	22,000	9,500

Overview of Insulation Coordination

- ✓ Insulation Co-ordination is defined as a process of determining the appropriate insulation levels of various components in a power system as well as their arrangements. It is the selection of an insulation structure that will withstand voltage stresses to which the system, or equipment will be subjected to, together with the properly designed lightning surge arrester.
- ✓ Various parameters of Insulation co-ordination are as follows:
  - Basic Impulse Insulation Level (BIL)
    This is the reference insulation level expressed as an impulse crest (or peak) voltage with a standard wave not longer than a 1.2 x 50 microsecond wave.

    A 1.2 x 50 microsecond wave means that the impulse takes 1.2 microseconds to reach the peak and then decays to 50% of the peak in 50 microseconds.

Overview of Insulation Coordination

- ✓ Various parameters of Insulation co-ordination are as follows:
  - Withstand Voltage
    This is the BIL level that can repeatedly be applied to an equipment without flashover, disruptive charge or other electrical failure under test conditions.
  - Chopped Wave Insulation Level
    This is determined by using impulse waves that are of the same shape as that of the BIL waveform, with the exception that the wave is chopped after 3 microseconds. Generally, it is assumed that the Chopped Wave Level is 1.15 times the BIL level for oil filled equipment such as transformers. However, for dry type equipment, it is assumed that the Chopped Wave Level is equal to the BIL level.

Overview of Insulation Coordination

- If a lightning strikes on the incoming feeder, three scenarios are possible
  - 1st Scenario:
    Impulse voltage of lightning strike is less than the Discharge Voltage of the Arrester
    In this case, the lightning strike impulse never exceeds 350kV.
    The traveling impulse wave passes into the substation.
    Since the BIL of the transformer is much greater than the peak voltage magnitude of the lightning impulse, the transformer is not damaged.

  - 2nd Scenario:
    Impulse Voltage of lightning strike is less than BIL of arrester, but greater than Discharge Voltage
    In this case, the lightning strike peak voltage is such that 350kV < V(peak)< 650kV.
    Assume that the impulse is 600kV.

Overview of Insulation Coordination

- If a lightning strikes on the incoming feeder, three scenarios are possible
  - 2nd Scenario:
    Impulse Voltage of lightning strike is less than BIL of arrester, but greater than Discharge Voltage
    As the magnitude of the traveling impulse rises to 350kV, as it moves to the arrester, discharge begins to take place.
    The wave is clipped at 350kV.
    This clipped wave passes to the substation and since the BIL of the transformer is greater than 350kV, the transformer is not damaged.
    The balance of energy (600 - 350 = 250kV worth of energy) is discharged to ground.

Overview of Insulation Coordination

- If a lightning strikes on the incoming feeder, three scenarios are possible
  - 3rd Scenario:
    Impulse Voltage of lightning strike is greater than the BIL of arrester
    In this case, the lightning strike peak voltage is greater than 650kV.
    Since the peak voltage is greater than he BIL of the incoming feeder and the arrester, both are damaged.
    The arrester experiences flashover or disruptive charge and is destroyed.
    Since it is destroyed, and open circuit occurs between the incoming feeder and the transformer.
    None of the lightning impulse, therefore, reaches the transformer at the substation.
    The transformer, therefore, remains undamaged.

Overvoltage & Surges

- There are three types of over voltages that may occur on a plant:
  - Internal Over voltages
  - Switching Surges
  - External Over voltages

- Over Voltage Surge Protection
  - There are two methods of overvoltage protection:
    Rod or Spark Gaps
    Surge Arresters

Overvoltage & Surges

✓ Selection Procedure of Surge Arrester

- Determine the continuous arrester voltage. This is usually the system rated voltage.
- Select a rated voltage for the arrester.
- Determine the normal lightning discharge current. Below 36kV, 5kA rated arresters are chosen. Otherwise, a 10kA rated arrester is used.
- Determine the required long duration discharge capability.
- For rated voltage < 36kV, light duty surge arrester may be specified.
- For rated voltage between 36kV and 245kV, heavy duty arresters may be specified.
- For rated voltage >245kV, long duration discharge capabilities may be specified.
- Determine the maximum prospective fault current and protection tripping times at the location of the surge arrester and match with the surge arrester duty.

Overvoltage & Surges

✓ Selection Procedure of Surge Arrester

- Select the surge arrester having porcelain creep-age distance in accordance with the environmental conditions.
- Determine the surge arrester protection level and match with standard IEC 99 recommendations.

Overvoltage & Surges

✓ Common Ratings associated with Surge Arrester

- Following are the most common ratings for surge arrester

  Rated Voltage
  The power frequency voltage across the arrester must never exceed its rated voltage, otherwise the arrester may not reseal and may catastrophically fail after absorbing the energy of the surge.

  For effectively earthed system:
  Maximum phase to earth voltage = 80% maximum line voltage

  Rated Current
  Arresters are tested with 8/20 microsecond discharge current waves of varying magnitudes

Overvoltage & Surges

✓ Common Ratings associated with Surge Arrester

- Following are the most common ratings for surge arrester
  Normal Voltage
  Nominal continuous voltage that the arrester can with stand before failing or flashover.

  B.I.L.
  Basic Impulse Insulation Level which is the maximum impulse for a 1.2 x 50 microsecond waveform.

  Discharge voltage
  When the overvoltage impulse reaches this value, the arrester begins to channel energy to earth.

Electrical Parameters for Designing of Transmission Line

- ✓ Electrical Parameters Calculation of Transmission line:
  - Ampacity & AC Resistance Calculations
    ACSR Panther Conductor
    IEC 1597 Standard

AMPACITY CALCULATIONS

1. GENERAL

a. Ampacity means capacity of any conductor to carry amount of current under different ambient temperatures and loading conditions. The ampacity of a conductor is governed by the principle of heat balance. The conductor will always try to maintain heat balance under different loading conditions. The entities who cause imposition of temperature on the conductor are passage of current and the ambient temperature. The entitites which cause dissipation of heat are the heat dilivered to the atmoshphere and the heat which is convected along the length of the conductor of through its metal.

a. Heat balance equation

- ➢ The steady-state temperature rise of a conductor is reached whenever the heat gained by the conductor from various sources is equal to the heat losses. This is expressed by equation as follows:
- $P_j + P_{Sol} = P_{rad} + P_{conv}$ Eq.(1) from IEC 1597
- Where,

P_j is the heat generated by Joule effect

P_{Sol} is the solar heat gain by the conductor surface

P_{rad} is the heat loss by radiation of the conductor

P_{conv} is the convection heat loss

a. Joule Effect calculation (P_j)

- ➢ Power losses P_j (W), due to Joule effect are given by Equation
- $P_j = R_{ac} \times I_{CC}^2$ W Eq.(2) from IEC 1597
- Where;

P_j = Heat generated by Joule effect

R_{ac} = Electrical resistance of conductor in Ohm/M

I_{CC} = Conductor Current in Amp

a. Solar heat gain calculation (P_{sol})

- Solar heat gain, P_{sol} (W/M), is given by equation
- $P_{sol} = ϒ \times D \times S_i$ Eq.(3) from IEC 1597
- Where; P_{sol} = Solar heat gain
  - D = Diameter of the conductor in m
  - ϒ = Solar radiation absorption coefficient
  - S_i = Intensity of solar radiation in W/Sq.M

Radiated heat loss calculation (P_r)

- Heat loss by radiation, P_{rad} (W), is given by equation
- $P_{rad} = S \times п \times D \times K_e \times (T_2^4 – T_1^4)$ Eq.(4) from IEC 1597
  - S = Stefan-Boltzmann constant in $W{*}m^{-2}{*}K^{-4}$
  - D = Diameter of the conductor in m
  - K_e = Emissivity coefficient in respect to black body
  - T_2 = Final Equilibrium Temperature in Kelvin
  - T_1 = Ambient Temperature in Kelvin

a. Convection heat loss calculation (P_{conv}) Only forced convection heat loss, P_{conv} (W), is taken into account and is given by equitation

- $P_{conv} = λ \times Nu \times (T_2-T_1) \times п$ Eq.(5) from IEC 1597
- Where, λ = Thermal conductivity of the air film in contact with the conductor it is assumed constant
  - Nu = Nusselt number, given by equation
  - $Nu = 0.65R_e^{0.2} + 0.23R_e^{0.61}$ Eq.(6) from IEC 1597
- Where, R_e = Reynolds number given by equation
  - $R_e = 1.644 \times 10^9 \times V_w \times D\, [(T_1 + 0.5(T_2-T_1)]^{-1.78}$
  - Eq.(7) from IEC 1597
- Where, V_w = Wind speed in M/s
  - D = Diameter of the conductor in m
  - T_2 = Final Equilibrium Temperature in Kelvin

T_1= Ambient Temperature in Kelvin

Sr. No.	Parameters	Symbols	Unit	Value
1	Conductor Name	-	-	ACSR Panther
2	Conductor Diameter in mm	D	mm	21
		D	inch	0.82677
3	Temperature	t_1	^0C	20
4	DC Resistance of the Conductor at 20^0C	R_{dc20}	Ohm/kM	0.139
5	Velocity of Air Stream in M/s	V_W	M/s	0.6
		V_W	Ft./hr.	7086.61
6	Solar Absorptivity	ϒ	-	0.5
7	Emissivity co-efficient in respect to black body	K_e	-	0.6
8	Intensity of solar radiation	Si	W/sq.M	900
9	Ambient Temperature	T_1	^0C	45
10	Final Equilibrium Temperature	T_2	^0C	75

11	Constant of Mass Temperature Coefficient of resistant of conductor per ^0C	α	-	0.004
12	Frequency	f	Hz/sec	50
13	Stefan-Boltzmann constant	s	$W{*}m^{-2}{*}K^{-4}$	5.67E-08
14	Permeability (For Non-Magnetic Materials)	μ	-	1
15	Thermal conductivity of air film in contact with conductor, assumed constant	λ	$W{*}m^{-1}{*}K^{-1}$	0.02585
16	No of Conductor per phase	-	-	1
17	Total no of Circuit	-	-	1
18	Total length of line	L	kM	1

a. AC Resistance Calculation

$R_{dc(75)} = R_{dc20} \times (1 + \alpha (T_2 - t_1))$

$= 0.139 \times 1 + 0.004 (75 - 20))$

$= 0.1695800$

$R_{dc(75)} = 0.1695800\ \Omega/kM$

Also; $X = 0.063598 \left(\frac{\mu X f}{1.6 X R_{dc}(75)}\right)^{0.5}$

$X = 0.063598 \left(\frac{1X50}{1.6 X 0.16958}\right)^{0.5}$

$X = 0.86334$

Therefore, $K = 1.002888$

AC Resistance of conductor at 75^0C

$R_{ac(75)} = R_{dc75} \times K$

$= 0.16958 \times 1.002888$

$R_{ac(75)} = 0.1700697\ \Omega/kM$

Skin Effect Table – 1

X	K	X	K	X	K	X	K	X	K
0	1	0.22	1	0.44	1	0.66	1.001	0.88	1.003
0.01	1	0.23	1	0.45	1	0.67	1.001	0.89	1.003
0.02	1	0.24	1	0.46	1	0.68	1.001	0.9	1.003
0.03	1	0.25	1	0.47	1	0.69	1.001	0.91	1.004
0.04	1	0.26	1	0.48	1	0.7	1.001	0.92	1.004
0.05	1	0.27	1	0.49	1	0.71	1.001	0.93	1.004
0.06	1	0.28	1	0.5	1	0.72	1.001	0.94	1.004
0.07	1	0.29	1	0.51	1	0.73	1.002	0.95	1.004
0.08	1	0.3	1	0.52	1	0.74	1.002	0.96	1.004
0.09	1	0.31	1	0.53	1	0.75	1.002	0.97	1.005
0.1	1	0.32	1	0.54	1	0.76	1.002	0.98	1.005
0.11	1	0.33	1	0.55	1	0.77	1.002	0.99	1.005
0.12	1	0.34	1	0.56	1.001	0.78	1.002	1	1.005
0.13	1	0.35	1	0.57	1.001	0.79	1.002	1.01	1.005
0.14	1	0.36	1	0.58	1.001	0.8	1.002	1.02	1.006
0.15	1	0.37	1	0.59	1.001	0.81	1.002	1.03	1.006
0.16	1	0.38	1	0.6	1.001	0.82	1.002	1.04	1.006
0.17	1	0.39	1	0.61	1.001	0.83	1.003	1.05	1.006
0.18	1	0.4	1	0.62	1.001	0.84	1.003	1.06	1.007
0.19	1	0.41	1	0.63	1.001	0.85	1.003	1.07	1.007
0.2	1	0.42	1	0.64	1.001	0.86	1.003	1.08	1.007

Skin Effect Table – 2

X	K	X	K	X	K	X	K	X	K
1.1	1.008	1.32	1.016	1.54	1.029	1.76	1.048	1.98	1.075
1.11	1.008	1.33	1.016	1.55	1.03	1.77	1.049	1.99	1.077
1.12	1.008	1.34	1.017	1.56	1.03	1.78	1.05	2	1.078
1.13	1.009	1.35	1.017	1.57	1.031	1.79	1.051	2.01	1.08
1.14	1.009	1.36	1.018	1.58	1.032	1.8	1.052	2.02	1.081
1.15	1.009	1.37	1.018	1.59	1.032	1.81	1.054	2.03	1.083
1.16	1.01	1.38	1.019	1.6	1.033	1.82	1.055	2.04	1.084
1.17	1.01	1.39	1.019	1.61	1.034	1.83	1.056	2.05	1.086
1.18	1.01	1.4	1.02	1.62	1.035	1.84	1.057	2.06	1.088
1.19	1.011	1.41	1.02	1.63	1.036	1.85	1.058	2.07	1.089
1.2	1.011	1.42	1.021	1.64	1.037	1.86	1.06	2.08	1.091
1.21	1.011	1.43	1.022	1.65	1.038	1.87	1.061	2.09	1.092
1.22	1.012	1.44	1.022	1.66	1.039	1.88	1.062	2.1	1.094
1.23	1.012	1.45	1.023	1.67	1.039	1.89	1.063	2.11	1.096
1.24	1.012	1.46	1.023	1.68	1.04	1.9	1.064	2.12	1.097
1.25	1.013	1.47	1.024	1.69	1.041	1.91	1.066	2.13	1.099
1.26	1.013	1.48	1.025	1.7	1.042	1.92	1.067	2.14	1.101
1.27	1.014	1.49	1.025	1.71	1.043	1.93	1.069	2.15	1.103
1.28	1.014	1.5	1.026	1.72	1.044	1.94	1.07	2.16	1.104
1.29	1.014	1.51	1.027	1.73	1.045	1.95	1.071	2.17	1.106
1.3	1.015	1.52	1.027	1.74	1.046	1.96	1.073	2.18	1.108

Skin Effect Table – 3

X	K	X	K	X	K	X	K	X	K
2.2	1.111	2.42	1.157	2.64	1.211	2.86	1.274	3.08	1.344
2.21	1.113	2.43	1.159	2.65	1.214	2.87	1.277	3.09	1.348
2.22	1.115	2.44	1.161	2.66	1.217	2.88	1.28	3.1	1.351
2.23	1.117	2.45	1.164	2.67	1.219	2.89	1.283	3.11	1.354
2.24	1.119	2.46	1.166	2.68	1.222	2.9	1.286	3.12	1.358
2.25	1.121	2.47	1.168	2.69	1.225	2.91	1.29	3.13	1.361
2.26	1.123	2.48	1.171	2.7	1.228	2.92	1.293	3.14	1.365
2.27	1.125	2.49	1.173	2.71	1.23	2.93	1.296	3.15	1.368
2.28	1.127	2.5	1.175	2.72	1.233	2.94	1.299	3.16	1.372
2.29	1.129	2.51	1.178	2.73	1.236	2.95	1.302	3.17	1.375
2.3	1.131	2.52	1.18	2.74	1.239	2.96	1.305	3.18	1.378
2.31	1.133	2.53	1.183	2.75	1.242	2.97	1.309	3.19	1.382
2.32	1.135	2.54	1.185	2.76	1.245	2.98	1.312	3.2	1.385
2.33	1.137	2.55	1.188	2.77	1.248	2.99	1.315	3.21	1.389
2.34	1.139	2.56	1.19	2.78	1.25	3	1.318	3.22	1.392
2.35	1.141	2.57	1.193	2.79	1.253	3.01	1.321	3.23	1.396
2.36	1.144	2.58	1.196	2.8	1.256	3.02	1.325	3.24	1.399
2.37	1.146	2.59	1.198	2.81	1.259	3.03	1.328	3.25	1.403
2.38	1.148	2.6	1.201	2.82	1.262	3.04	1.331	3.26	1.406

Skin Effect Table – 4

X	K	X	K	X	K
3.3	1.42	3.52	1.499	3.74	1.581
3.31	1.424	3.53	1.503	3.75	1.585
3.32	1.427	3.54	1.507	3.76	1.588
3.33	1.431	3.55	1.51	3.77	1.592
3.34	1.434	3.56	1.514	3.78	1.596
3.35	1.438	3.57	1.518	3.79	1.599
3.36	1.441	3.58	1.521	3.8	1.603
3.37	1.445	3.59	1.525	3.81	1.607
3.38	1.449	3.6	1.529	3.82	1.611
3.39	1.452	3.61	1.532	3.83	1.614
3.4	1.456	3.62	1.536	3.84	1.618
3.41	1.459	3.63	1.54	3.85	1.622
3.42	1.463	3.64	1.544	3.86	1.626
3.43	1.467	3.65	1.547	3.87	1.629
3.44	1.47	3.66	1.551	3.88	1.633
3.45	1.474	3.67	1.555	3.89	1.637
3.46	1.477	3.68	1.558	3.9	1.641
3.47	1.481	3.69	1.562		
3.48	1.485	3.7	1.566		
3.49	1.488	3.71	1.57		
3.5	1.492	3.72	1.573		

a. Heat Balance Calculation:

The steady-state temperature rise of a conductor is reached whenever the heat gained by the conductor from various sources is equal to the heat losses. This is expressed by equation (1)

$P_j + P_{sol} = P_{rad} + P_{conv}$ ………… equation (1)

Where;

P_j is the heat generated by Joule effect

P_{sol} is the solar heat gain by the conductor surface

P_{rad} is the heat loss by radiation of the conductor

P_{conv} is the convection heat loss

a. Joule Effect Calculation

Power losses P_j (W), due to Joule effect are given by equation (2).

$P_j = R_{ac}(75) \times I_{ccc}^2$ W ……….. equation (2)

Where;

P_j = heat generated by Joule effect

R_{ac} (75) = Electrical resistance of conductor at 75^0C temperature in Ohm/M

I_{ccc} = Conductor Current in Amp

$P_j = 0.000171 \times 461$

$P_j = 36.15$ W

a. Solar Heat Gain Calculation

Solar heat gain, P_{sol} (W/m), is given by equation (3)

$P_{sol} = \Upsilon \times D \times S_i$

………. equation (3)

Where; P_{sol} = Solar heat gain

D = Diameter of the conductor in m

ϒ = Solar radiation absorption coefficient

S_i = Intensity of solar radiation in W/sq. M

Thus,

$P_{sol} = 0.5 \times 0.021 \times 900$

$P_{sol} = 9.45$ W/M

a. Radiated Heat Loss Calculation

Heat loss by radiation, P_{rad} (W), is given by equation (4)

$P_{rad} = S \times \pi \times D \times K_e \times (T_2^4 - T_1^4)$ ……. equation (4)

Where;

S = Stefan-Boltzmann constant in $W*M^{-2}*K^{-4}$

D = Diameter of the conductor in M

K_e = Emissivity coefficient in respect to black body

T_2 = Final Equilibrium Temperature in Kalvin

T_1 = Ambient Temperature in Kalvin

Thus;

P_{rad} = 5.67E-08 X 3.1416 X 0.021 X 0.6 X $\{(75+273)^4 - (45+273)^4\}$

P_{rad} = 9.965 W

a. Convection Heat Loss Calculation

Only forced convection heat loss, P_{conv} (W), is taken into account and is given by equitation (5)

$P_{conv} = \lambda \times Nu \times (T2-T1) \times \pi$ -------------- equitation (5)

Where

λ = Thermal conductivity of the air film in contact with the conductor it is assumed constant

Nu = Nusselt number, given by equation (6)

$Nu = 0.65R_e^{0.2} + 0.23R_e^{0.61}$ ………. equation (6)

Where,

R_e = Reynolds number given by equation (7)

$R_e = 1.644 \times 10^9 \times V_w \times D\, [(T_1 + 0.5(T_2-T_1)]^{-1.78}$ ………. equation (7)

Where, V_w = Wind speed in m/s

D = Diameter of the conductor in m

T_2 = Final Equilibrium Temperature in Kalvin

T_1 = Ambient Temperature in Kalvin

R_e = 1.644E+09 X 0.6 X 0.021[((45+273) + 0.5((75 + 273) – (45 + 273))]-1.78

Hence Nu = 0.65 X $670.3809^{0.2}$ + 0.23 X $670.3809^{0.61}$ (From equation -6)

Nu = 14.5726

Therefore P_{conv} = 0.02585 X 14.5727 X (75 + 273) - (45 + 273) X 3.1416

P_{conv} = 35.5034 W

a. Ampacity Calculation

From equation (1), the steady state current carrying capacity can be calculated.

$I_{ccc} = \left\{\frac{Prad + Pconv - Psol}{Rac(75)}\right\}^{0.5}$

Where; $R_{ac}(75)$ = AC Resistance of conductor at 75^0C in Ohm/kM

P_{rad} = Radiated heat loss in W

P_{conv} = Convection heat loss in W

P_{sol} = Solar heat Gain in W ^{0}C

$= \left\{\frac{9.9655 + 35.5034 - 9.45}{0.000171}\right\}^{0.5}$

I_{ccc} = 460 Amp (Current Carrying Capacity)

Now; Heat balance equation - $P_j + P_{sol} = P_{rad} + P_{conv}$

For heat balance, this equation must be zero

$P_j + P_{sol} - P_{rad} - P_{conv} = 0$

36.15 + 9.45 – 9.97 – 35.53 = 0

Ampacity Calculation(Method – II)

- Calculation of Continuous Maximum Current Rating Capacity at 75° C Corresponding to Ambient Temperature of 40° C for average span of the conductor considering Emissivity factor = 0.52
- All calculations are based on well known "**HEAT BALANCE EQUATION**".

$$I = \sqrt{(Qc + Qr - Qs) / (r)}$$

Where,

I = Current flowing in conductor in amp at 50 cycles per second

r = AC Resistance of conductor in ohm per linear resistance metre of conductor at 75° C
(For ACSR Moose value of r is equal to **0.06948 x 10^{-3} Ohm/metre**

Q_c = Convected Heat loss in watt per linear metre of conductor at 40°C
(For ACSR Moose the value of Q_c is **24.796623** watts per metre)

- **NOTE**: The value of Q_c is based on the formula **0.47588 + 13.333D$^{0.52}$** .
  Where 'D' is the diameter of the conductor in cm.

- Q_r is the Radial Heat loss in watt per linear metre of conductor at 40 ° C
  (For Moose the value of Q_r is **6.4073736** watt per linear metre).
  NOTE: The value of Q_r is based on the formula **2.0168D**
  Where 'D' is the diameter of the conductor in cm.

- Q_s is the Heat gain from the sun in watt per linear metre of conductor.
  (For Moose the value of Q_s is **1.14372** watts per metre).
  NOTE: The value of Q_s is based on the formula **3D** watts per foot.
  Where 'D' is the diameter of conductor in inches and thereafter converted into metre.

Calculation of AC resistance(r) at 75° C

- R_{dc} (at 75 °C) = [R_{dc} (at 20 °C) x $(1 + \propto \Delta t)$]
  (For ACSR Moose R_{dc} (at 20 °C) = 0.05595 Ω/ km) [Source : CBIP Manual]
  The value of Constant of Mass Temperature Coefficient of conductor per °C (∝)=0.004)
  = 0.05595(1 + 0.004 (75-20))
  = 0.05595(1.22)
  = **0.068259 Ω/ km**

Now, **X = 0.063598 x $\sqrt{(\mu \times f)/[1.6 \times R_{dc} (at\ 75\ °C)]}$**
Where, permeability(μ) = 1 , frequency (f) =50 Hz & R_{dc} (at 75 °C) = 0.068259 as above.
Now, value of X obtained is **1.36**.(i.e. **K=1.018**) **[From Skin effect table]**
Hence,
R_{ac} (at 75 °C)[r] = 1.018 x 0.068259
= 0.06948 Ω/ km
= 0.06948 x 10^{-3} Ω/m

Sample Ampacity calculations for ACSR Moose Conductor based on Method-II

- **For ACSR Moose conductor:**

$$I = \sqrt{(Qc + Qr - Qs)/ r}$$

$$= \sqrt{[(24.796623 + 6.407373 - 1.14372)x\ (103)]\ /(0.06948)}$$

$$= \sqrt{(30.060276)\ x\ (10^3)\ /(0.06948)}$$

= 658 Ampere

CREEP CALCULATIONS

a. Conductor Creep

As is known, the creep of the conductor is the result of the re-adjustment of the conductor over a period of time. The factors which affect the creep are innumerable. For ACSR Conductor, the proportion of steel in the total conductor plays an important role. Another factor is the everyday temperature & next is the time in hours. The percentage tension with respect to the Ultimate Tensile Strength (UTS) of the conductor at everyday temperature (termed as everyday tension) is also an important factor for the development of creep.

- The conductor creep due to the initial stresses of manufacturing, transport and storage is seen immediately after the conductor is paid out and hung on the rollers attached to Towers/Supports of the line. It is therefore customary to give an initial tension to the conductor which is higher than the final tension to be applied to the conductor as per stringing charts. After this initial tension, the conductor is allowed to hang on the rollers on support for 72 hours. The conductor takes natural catenary while it stretches. The conductor is then given final tension & transferred to hardware. It may be important to note that for taking care of the initial creep and time related creep, it is usual to provide a compensation of 150mm in the maximum sag of conductor under maximum temperature and no wind condition. To be precise while deciding the bottom conductor height above ground level the creep compensation is considered.

- After the conductor is transferred to the Hardware, the line is ready for energization. Creep is the tendency of a solid material to deform permanently under the influence of constant stress (tensile, compressive, shear, or flexural). It occurs as a function of time through extended exposure to levels of stress that are below the yield strength of the material. The conductor creep then becomes a function of time, the tension and the temperature.
- It may be important to note that for taking care of the initial creep and time related creep, it is usual to provide a compensation of 150mm in the maximum sag of conductor under maximum temperature and no wind condition. To be precise while deciding the bottom conductor height above ground level the creep compensation is considered.

a. Creep Calculation

The sample calculations (and applicable formula) for some ACSR conductors which are commonly used are given below. The creep is calculated for 1 year, 5 years, 10 years & 20 years.

- The calculations are based on everyday temp. 32ºC and everyday tension 22 % of UTS of MOOSE Conductor and 25% of UTS of ZEBRA Conductor & PANTHER Conductor. The mechanical parameters of these conductors are given hereunder.

Sr. No.	Code	Strands Al No./mm	Strands Steel No./mm	Ultimate Strength (Kg)	Overall Dia (cm)	Total Sectional Area (cm²)	Unit Wt. Kg/M	Co-efficient of linear expansion "α"/°C	Modulus of Elasticity kg/cm² E
1	Panther	30/3.0	7/3.0	9,144	2.100	2.615	0.974 (Steel 0.387 kg/M)	17.80×10^{-6}	0.816×10^{6}
2	Zebra	54/3.18	7/3.18	13,289	2.862	4.845	1.621 (Steel 0.435 kg/M)	19.30×10^{-6}	0.704×10^{6}
3	Moose	54/3.53	7/3.53	16,438	3.177	5.970	2.004 (Steel 0.540 kg/M)	19.30×10^{-6}	0.704×10^{6}

a. FORMULA: -

$e = 0.01165\ (t)^{0.2}\ (1.434 - W_a)\ (P_a)^{1.15}\ (106.58 + Q_a)$

Where,

e = creep in mm/kM

W_a = (Unit wt. of steel core / Unit wt. of Conductor)

a. Creep For ACSR Moose Conductor

Wt. of steel = 540 kg/kM

Conductor Wt = 2004 kg/kM

Wa = (540/2004) = 0.269461

t = Time in Hour.

For 1 year = 24 x 365 x 1 = 8,760 Hrs.

For 5 years = 24 x 365 x 10 = 43,800 Hrs.

For 10 years = 24 x 365 x 10 = 87,600 Hrs.

For 20 years = 24 x 365 x 20 = 1,75,200 Hrs.

Pa = Everyday Tension in percentage of UTS

25% UTS for MOOSE

Q_a = Everyday temp. 32°C

- **For 1 year** $e_1 = 0.01165 \times (8760)^{0.2} \times (1.434 - 0.269461) \times (22)^{1.15} \times (106.58 + 32)$
  $= 0.01165 \times (6.1447) \times (1.164539) \times (34.977234) \times (138.58)$
  = 404.07 mm/kM
  Say 404 mm per kM
- **For 5 years** $e_5 = 0.01165 \times (43800)^{0.2} \times (1.434 - 0.269461) \times (22)^{1.15} \times (106.58 + 32)$
  $= 0.01165 \times (8.47802) \times (1.164539) \times (34.977234) \times (138.58)$
  = 557.52 mm/kM
  Say 558 mm per kM
- **For 10 years** $e_{10} = 0.01165 \times (87600)0.2 \times (1.434 - 0.269461) \times (22)^{1.15} \times (106.58 + 32)$
  $= 0.01165 \times (9.7386963) \times (1.164539) \times (34.977234) \times (138.58)$
  = 640.42 mm
  Say 640 mm per kM
  P_a = Everyday Tension in percentage of UTS

a. Creep For ACSR Zebra Conductor

Wt. of steel = 435 kg/kM

Conductor W_t = 1621 kg/kM

W_a = (435/1621) = 0.26835

t = Time in Hour.

For 1 year = 24 x 365 x 1 = 8,760 Hrs.

For 5 years = 24 x 365 x 10 = 43,800 Hrs.

For 10 years = 24 x 365 x 10 = 87,600 Hrs.

For 20 years = 24 x 365 x 20 = 1,75,200 Hrs.

P_a = Everyday Tension in percentage of UTS

25% UTS for ACSR ZEBRA

Q_a = Everyday temp. 32ºC

- **For 1year**

  $e_1 = 0.01165 \times (8760)^{0.2} \times (1.434 - 0.26835) \times (25)^{1.15} \times (106.58 + 32)$

  $= (0.01165) \times (6.1447) \times (1.16565) \times (40.51641492) \times (138.58)$

  $= 468.51$ mm/kM

  Say 469mm per kM

- **For 5 years**

  $e_5 = 0.01165 \times (43800)^{0.2} \times (1.434 - 0.26835) \times (25)^{1.15} \times (106.58 + 32)$

  $= (0.01165) \times (8.47802) \times (1.16565) \times (40.51641492) \times (138.58)$

  $= 646.42$ mm/kM

  Say 647mm per kM

- **For 10 years** $e_{10} = 0.01165 \times (87600)^{0.2} \times (1.434 - 0.26835) \times (25)^{1.15} \times (106.58 + 32)$

  $= (0.01165) \times (9.738696269) \times (1.16565) \times (40.51641492) \times (138.58)$

  $= 742.54$mm/kM

  Say 743mm per kM

- **For 20 years** $e_{20} = 0.01165 \times (175200)^{0.2} \times (1.434 - 0.26835) \times (25)^{1.15} \times (106.58 + 32)$

  $= 0.01165 \times (11.18682438) \times (1.16565) \times (40.51641492) \times (138.58)$

  $= 852.96$ mm/kM

  Say 853 mm per kM

a. Creep For ACSR Panther Conductor

Wt. of steel = 387 kg/kM

Conductor W_t = 974 kg/kM

W_a = (387/974) = 0.39733

t = Time in Hour.

For 1 year = 24 x 365 x 1 = 8,760 Hrs.

For 5 years = 24 x 365 x 10 = 43,800 Hrs.

For 10 years = 24 x 365 x 10 = 87,600 Hrs.

For 20 years = 24 x 365 x 20 = 1,75,200 Hrs.

Pa = Everyday Tension in percentage of UTS

25% UTS for ACSR PANTHER

Q_a = Everyday temp. 32ºC

- **For 1 year**

  e_1 = 0.01165 x $(8760)^{0.2}$ x (1.434 – 0.39733) x $(25)^{1.15}$x (106.58 + 32)

  = (0.01165) x (6.1447) x (1.03667) x (40.51641492) x (138.58)

  = 416.67 mm/kM

  Say 417 mm per kM

- **For 5 years**

  e_5 = 0.01165 x $(43800)^{0.2}$ x (1.434 – 0.39733) x $(25)^{1.15}$ x (106.58 + 32)

  = 0.01165 x (8.47802) x (1.03667) x (40.51641492) x (138.58)

  = 574.9 mm/kM

  Say 575 mm per kM

- **For 10 years**

  e_{10} = 0.01165 x $(87600)^{0.2}$ x (1.434 – 0.39733) x $(25)^{1.15}$x (106.58 + 32)

  = (0.01165) x (9.738696269) x (1.03667) x (40.51641492) x (138.58)

  = 660.38 mm/kM

  Say 660 mm per kM

- **For 20 years**

  e_{20} = 0.01165x$(175200)^{0.2}$ x(1.434 – 0.39733)x$(25)^{1.15}$ x(106.58 + 32)

  = 0.01165 x (11.18682438) x (1.03667) x (40.51641492) x (138.58)

  = 758.58 mm/kM

  Say 759mm per kM

Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

- Inductance

  Inductance of the overhead bare conductor is an impediment to the passage of current which is dependent on the frequency. The inductance of the conductor results in to inductive reactance which is given by 2πfL.

  Where,

  f = Frequency in Hertz

  L = Inductance in Henry

  The inductance can be categorized as self inductance and mutual inductance. The self inductance is an impediment to the current flowing in the conductor itself.

Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

- Inductance

  To be precise this is an inductance generated by the magnetic field which is produced in the conductor material due to the alternating nature of current.

  The mutual inductance is the inductance between two or more conductors separated by a specific distance.

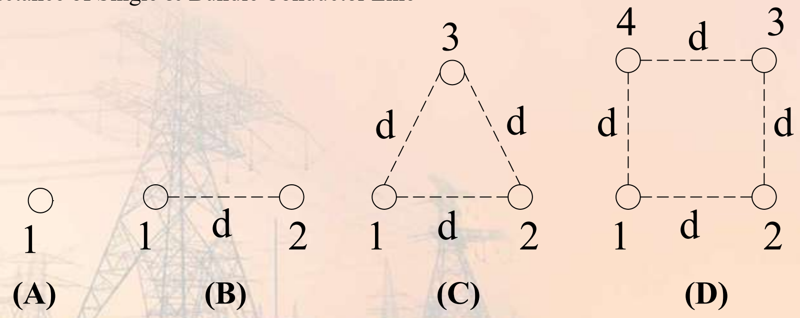
  To be precise this is an inductance which is developed in one conductor due to the passage of current in another conductor.

  Thus, in case of multiple conductors (Three phase single circuit or double circuit). The mutual capacitance is between all the conductors of one circuit as well as circuit to circuit.

Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

- Inductance of Single & Bundle Conductor Line



Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

- Inductance of Single Conductor Line

  $L = 2 \text{ X } 10^{-7} \ln (D_{eq}/D_s)$

  Self GMD=GMR=r'

  =0.7788 r

- Inductance of Bundle Conductor Line

The geometric mean radius of bundled conductors can be found in the same manner as that for stranded conductor.

For a two-conductor (duplex) arrangement (Figure -a):

$D^b_s = \sqrt[4]{(D_s. d)^2} = \sqrt{(D_s. d)}$

For a three-conductor (duplex) arrangement (Figure-b):

$D^b_s = \sqrt[9]{(D_s. d. d)^3} = \sqrt[3]{(D_s. d^2)}$

For a four conductors (quadruplex) arrangement (Figure-c):

$D^b_s = \sqrt[16]{(D_s. d. d \sqrt{2} \text{ x } d)^4} = 1.09 \text{ x } \sqrt[4]{(D_s \text{ x } d^3)}$

Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

- Inductance of Single Conductor Line

From the above equation for single conductor the geometric mean radius (GMR) and self geometric mean distance (GMD) are same as (0.7788 * radius of single conductor)

Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

- Inductance of Bundle Conductor Line

From the above equations D^bs denotes the geometric mean radius of bundled conductor, Ds denotes geometric mean radius of each sub conductor of bundle and d denotes the spacing between the sub-conductors of a bundle.

The geometric mean distance (GMD) of a bundled conductor line can be found by taking the root of the product of distances from each conductor of a bundle to every other conductor of the other bundles. However, it is sufficiently accurate to take the distance from centre of 1 bundle to the centre of the other bundles as the distances D12, D23 and D31.

Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

- Inductance of Bundle Conductor Line

The use of bundled conductor increases the geometric mean radius. In the formula for calculating inductance, the geometric mean radius is a factor in the denominator.

Therefore, the inductance of a bundled conductor line is less than the inductance of the line with one conductor per phase.

Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

- Inductance of Double Circuit Three Phase Line

A double circuit three phase line has two parallel conductors for each phase. The use of two three phase circuits on the same towers leads to a greater reliability and a higher transmission capacity. If the two circuits are very widely separated, the mutual inductance between the circuits can be neglected and the net inductance is half of the inductance of individual circuits.

In actual practice the separation is not very wide and the mutual inductance is not negligible.

Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

- Inductance of Double Circuit Three Phase Line

The method of GMD can be used to find the inductance per phase by taking the conductors of one phase to be the strands of one composite conductor. It is desirable to have a configuration which results in minimum inductance (enhance maximum transmission capability). This is possible if GMD is low and GMR is high.

Therefore, the individual conductors of a phase should be widely separately (to give high GMR) and the distance between phases should be kept low (to give low GMD).

Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

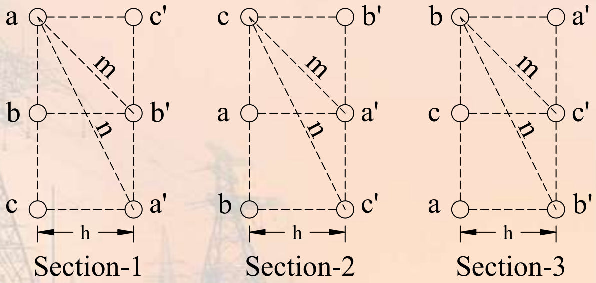
- Inductance of Double Circuit Three Phase Line

Below figure shows the three sections of a double circuit three-phase line, with vertical spacing over a transposition cycle. The conductors a and a' belong to one phase, b and b' to the second phase and c and c' to the third phase. In each case the conductors of two phases are placed diametrically opposite to each other and those of the third phase are placed horizontally opposite to each other. This configuration gives high value of GMR. To calculate inductance it is necessary to determine Deq or GMD and Ds or GMR.

Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

- Inductance of Double Circuit Three Phase Line



Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

- Inductance of Double Circuit Three Phase Line

GMR of conductors of phase a in section 1 is.
$D_{sa} = \sqrt[4]{r' . n . r' . n} = \sqrt{r' . n}$
GMR of conductors of phase b and c in section 1 are
$D_{sb} = \sqrt[4]{r' \text{ x } h \text{ x } r' \text{ x } h} = \sqrt{r' \text{ x } h}$
$D_{sc} = \sqrt[4]{r' \text{ x } n \text{ x } r' \text{ x } n} = \sqrt{r' \text{ x } n}$
Equivalent GMR is
$D_s = \sqrt[3]{D_{sa} \text{ x } D_{sb} \text{ x } D_{sc}} = [(r')^{1/2} (n)^{1/3} (h)^{1/6}]$

Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

- Inductance of Double Circuit Three Phase Line

It can be be verified that the value of Ds is the same in all the three sections GMD is given by.
$D_{eq} = \sqrt[3]{D_{ab} \text{ x } D_{bc} \text{ x } D_{ca}}$
Where,
Dab = Geometric mean distance between phases a and b in section 1.
$= \sqrt[4]{D.m.D.m} = \sqrt{D.m}$
Dbc = Geometric mean distance between phases b and c in section 1.
$= \sqrt[4]{D.m.D.m} = \sqrt{D.m}$

Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

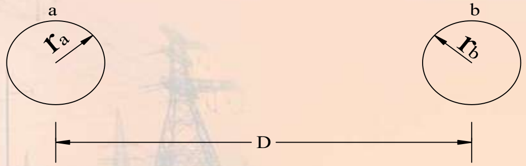
- Inductance of Double Circuit Three Phase Line

It can be be verified that the value of Ds is the same in all the three sections GMD is given by.
Dca = Geometric mean distance between phases c and a in section 1.
$= \sqrt[4]{(2D)(h)(2D)(h)} = \sqrt{2}\, Dh$
Deq = 6√ (Dm) (Dm)(2Dh) = 21/6 D1/2 m1/3 h1/6
The inductance per phase per m is
$L = 2 \text{ X } 10^{-7} \ln (D_{eq}/D_s)$

Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

- Capacitance
  Let us consider a two wire line shown in fig.1 below which is excited from a 1-phase source. The line develops equal and opposite sinusoidal charges on the two conductors which can be represented as phasors qa and qb in such a way that that qa = - qb.



Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

- Capacitance
  The line develops equal and opposite sinusoidal charges on the two conductors which can be represented as phasors qa and qb in such a way that that qa = - qb.
  Where qa and qb is charge in coulomb/M respectively in conductor a & b.
  The potential difference Vab can be written in terms of the contributions made by qa and qb by use of equation (1) given below
  Vab = (1/ 2πk) {(qa ln [D/ra] + qb ln [rb/D])}
  Where k is the permittivity* of the medium.
  (* In SI units the permittivity of free space is k0 = 8.85 x 10-12 F/M. Relative permittivity for air is kr = k/k0 = 1)

Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

- Capacitance
  The line develops equal and opposite sinusoidal charges on the two conductors Since, we have
  qa = - qb.
  Vab = (1/ 2πk) In (D2/rarb)
  The line capacitance Cab is then expressed by
  Cab = (qa/Vab) = {πk / In (D/rarb) 1/2} F/m length of line
  If ra = rb = r
  Cab = {0.0121 /[log (D/r)] } μF/km
  The associated line charging current is
  $Ic = j\omega C_{ab} V_{ab}$ A/km

Electrical Parameters for Designing of Transmission Line

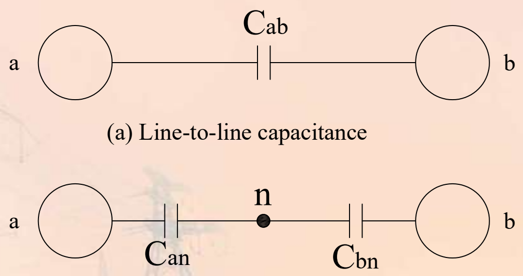
✓ Electrical Parameters Calculation of Transmission line:

- Capacitance
  Where, ω = Angular Frequency
  The two wires of line can carry phase currents or one can carry phase current and other will carry neutral current. The capacitive reactance will be different for both the cases as indicated below.

Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

- Capacitance



(a) Line-to-line capacitance

(b) Line-to-neutral capacitance

Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

- Capacitance
  As shown in figs 2 (a) and (b) the line-to-line capacitance can be equivalently considered as two equal capacitances in series. The voltage across the lines divides equally between the capacitances such that the neutral point n is at the ground potential. The capacitance of each line to neutral is then given by.
  $C_n = C_{an} = C_{bn} = 2C_{ab} = \{0.0242 / \log (D/r)\}$ µF/km
  The assumptions inherent in the above derivation are:
  The charge on the surface of each conductor is assumed to be uniformly distributed, but this is strictly not correct.
  If non uniformity of chare distribution is taken into account, then
  $C_n = \{0.0242 / \log \{(D/2r) + [(D^2/4r^2)-1]\}\}$ µF/km

Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

- Capacitance
  If non uniformity of chare distribution is taken into account, then
  $C_n = \{0.0242 / \log \{(D/2r) + [(D^2/4r^2)-1]\}\}$ µF/km
  If D/2r >> 1, the above expression reduces to that of Eq. stated above and the error caused by the assumption of uniform charge distribution is negligible.

Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

- Capacitance
  The cross-section of both the conductors is assumed to be circular, while in actual practice stranded conductors are used. The use of the radius of the circumscribing circle for a stranded conductor caused insignificant error.

Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

- Corona and Corona Losses
  Every conductor which allows A.C. power flow develops magnetic field.
  The overhead transmission line conductor can be compared to a solid cylindrical catenary.
- Factors and Conditions affecting Corona Loss
  Corona loss depends on a number of factors such as system frequency, system voltage, connectivity of air, density of air, presence of rain, dust, radius of conductor, surface of conductor, and heating of conductor by load current. The effect of these factors is as under:

Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

- Corona and Corona Losses
  Factors and Conditions affecting Corona Loss
  Effect of Frequency
  Effect of System Voltage
  Effect of Conductivity of Air
  Effect of Density of Air
  Effect of Rain and Dust
  Effect of Conductor radius
  Effect of Conductor surface

Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

- Critical Disruptive Voltage
  It is defined as the minimum phase neutral voltage at which corona occurs.Consider two conductors of radius r cm & spaced d cm apart. If V is the phase-neutral potential then potential gradient at the conductor surface is given by
  $g = V / (r \log_e d/r)$ volts / cm
  Where,
  g = potential gradient at the conductor surface
  V= phase-neutral potential
  r = radius of conductor
  d= spacing between conductor

Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

- Critical Disruptive Voltage
  In order that corona is formed, the value of g must be equal to the breakdown strength of air. The breakdown strength of air at 76cm pressure and temperature of 25º C is 30 kV / cm (max) or 21.2 kV/cm (rms) and is denoted by g0. If Vc is the phase-neutral potential required under these conditions, then,
  $g_0 = Vc / (r \log_e d/r)$ volts / cm
  Where,
  g_0 = breakdown strength of air at 76cm of mercury & 25º C
  Therefore, Critical Disruptive Voltage $Vc = g_0 \; r \log_e (d/r)$

Electrical Parameters for Designing of Transmission Line

- ✓ Electrical Parameters Calculation of Transmission line:
  - Critical Disruptive Voltage
    Thus the breakdown strength of air at a barometric pressure of b cm of mercury and temperature of t° C becomes $\delta \times g_0$,
    Where,
    $\delta = 3.92b / (273 + t)$ = air density factor
    Under standard conditions, the value of $\delta = 1$
    Therefore, Critical Disruptive Voltage $V_c = g_0\ \delta\ r\ \log_e (d/r)$

Electrical Parameters for Designing of Transmission Line

- ✓ Electrical Parameters Calculation of Transmission line:
  - Critical Disruptive Voltage
    Correction must be made for the surface condition of the conductor. This is accounted for by multiplying the above equation by M_0
    Where,
    M_0= 1 for polished conductor
    = 0.98 to 0.92 for dirty conductors
    = 0.87 to 0.8 for stranded conductors

Electrical Parameters for Designing of Transmission Line

- ✓ Electrical Parameters Calculation of Transmission line:
  - Visual Critical Voltage
    It is the minimum phase-neutral voltage at which corona glow appears all along the conductors and is visible by an added eye.
    It has been seen that in case of parallel conductors, the corona glow does not begin at the disruptive voltage V_c but at a higher voltage V_v, called Visual Critical Voltage. The phase-neutral effective value of visual critical voltage is given by the following formula:
    $V_v = M_v\ g_0\ \delta\ r\ [1 + (0.3/\sqrt{(\delta r)})]\ \log_e (d/r)$ kV/phase
    Where, M_v is another irregularity factor having a value of 1.0 for polished conductors and 0.72 to 0.82 for rough conductors.

Electrical Parameters for Designing of Transmission Line

- ✓ Electrical Parameters Calculation of Transmission line:
  - Corona Loss Calculation
    Formation of corona is always accompanied by energy loss which is dissipated in the form of light, heat, sound and chemical action. When disruptive voltage is exceeded, the power loss due to corona is given by:
    $P = 242.2 \times [(f + 25)/ \delta] \times \sqrt{(r/d)} \times (V-V_c)^2 \times 10^{-5}$ kW / kM / phase
    Where,
    f = supply frequency in Hz
    V= phase-neutral voltage (rms)
    V_c =disruptive voltage (rms) per phase

Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

- Radio Interference due to Corona
  The radio interference due to corona refers to the adverse effect produced by corona on wireless signals. It has been found that the current pulses generated by corona discharges, as they propagate along the conductor, cause interference with the wireless signals.
  Amplitude modulated broadcasting, power line carrier, aviation, marine, ship to shore SOS calls and other similar services are affected due to this interference. The interfering field, at any point, is dominated by the aggregation of the effect of all corona discharges spread over many kilometers of line on both sides of the point and not by the direct effect of local discharges at that point.

Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

- Radio Interference due to Corona
  The increase in radio interference field is gradual up to a voltage slightly below the minimum voltage at which measurable corona loss occurs. Above this voltage the increase in radio interference is very rapid. The rate of increase in radio interference is affected by conductors.
  Above a certain voltage the magnitude of radio interference field tends to level off. However, for practical conductors the leveling off value is too high to be acceptable and the lines have to be designed to operate below the voltage at which radio interference starts rapidly during fair weather.

Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

- Radio Interference due to Corona
  A transmission line with clean conductors, with good hard ware and having the fair weather gradient less than corona inspection gradient, should not present radio interference problems during fair weather.
  However, experience has shown that line conductors are always not clean and radio interference may occur. It is known that mechanical defects like scratches rise from dents and other surface discontinuities exist. The weather processes attack this project service and corona activity hastens the attack.

Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

- Radio Interference due to Corona
  After these initial conditions the conductor surface intercepts or attracts a varying amount of airborne material. Some material adheres to the conductor surface and forms a transient source of radio interference generation.
  Later on, the remains of airborne particles cease as corona sources and the remains become a layer of semi-carbon ferrous material producing a darkish quote on the conductor surface.

Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

- Radio Interference due to Corona
  This layer can be beneficial since it may cover some of the initial mechanical imperfections. Thus, during the life of a line a gradual surface stabilization occurs with respect to corona surfaces but the degree of the surface stabilization is different for different lines.
  In determining the RI (Radio Interference) performance of a propose line the magnitude of RI factors for the entire frequency range of communication sources has to be evaluated.

Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

- Radio Interference due to Corona
  An evaluation of these factors in terms of their effect on the various communication services must take in to account many factors like available signal intensities along the line, satisfactory signal to noise ratios, effect of weather on RI factors and the importance of the communication services, etc.
  The radio interference field generated from a transmission line varies mostly as the inverse of the audio frequency. Thus, services in the higher frequency band (television, frequency modulated broadcasting, radar, microwave relay, etc.) are less likely to be affected.

Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

- Radio Interference due to Corona
  The directional antenna which is generally used at these frequencies increase the signal to radio. The degree of acceptable radio noise is not an entirely technical decision and depends on factors like density of population, radio listening habits of people, powers of radio transmitters, other noise levels presents in the area, and effective coverage, etc.
  The radio interference due to corona assumes importance for line above 200kV. For EHV lines the line design is affected to a large extent by this phenomenon.

Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

- Corona in Bundled Conductor Line
  The maximum surface electric field is less for bundled conductor lines than for single conductor lines. It is, therefore, possible, by replacing a single conductor by two or more conductors with the same total cross-section to obtain an increase in corona starting voltage.
  This leads to reduction in corona loss and radio interference. Alternatively a higher working voltage can be used.

Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

- Surge Impedance Loading
  The characteristic impedance of a line, denoted by Z_c is given by
  $Z_c = \sqrt{z/y}$
  Where,
  Z_c = characteristic impedance, Ω
  $Z = r + j\omega L$ = line series impedance per phase per unit length
  $Y = j\omega C$ = line shunt admittance per unit length per phase to neutral
  If the line resistance is neglected,
  $Z_c = \sqrt{L/C}$

Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

- Surge Impedance Loading
  When the line resistance is neglected, the characteristic impedance is known as surge-impedance. A line is said to be operating at natural load (or surge impedance load) when it is terminated by a resistance equal to characteristic impedance. If the line to line voltage at receiving end is Vr, under the condition of sure impedance loading is
  $I_r = V_r / \sqrt{3} Z_c$
  Surge impedance loading is also the ideal loading. The voltage and current are equal at all points along the line (i.e. line voltage and current profiles are flat). The voltage and current are in phase at all points along the line.

Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

- Surge Impedance Loading
  Moreover no reactive power is generated or absorbed at the line ends. The total reactive power absorbed by line inductance is equal to total reactive power generated by line capacitance. i.e.
  $I^2\omega L = V^2 / \omega C$
  $V/I = \sqrt{(L/C)} = Z_c$

Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

- Voltage Regulation
  Voltage Regulation of a transmission line is defined as the rise in the receiving end voltage when full load at a specified power factor is removed while the sending end voltage is kept constant.
  It is expressed as percentage (or per unit) of full load rated receiving end voltage. For the short line, the no load receiving end voltage equals Vs.
  Therefore, regulation is
  $\{|V_s| - |V_r|\} / |V_r| = \{(I_r R\cos\Phi_r + I_r X \sin\Phi_r) / V_r\}$ p.u.
  Where,
  V_s = Sending end voltage
  V_r = Receiving end voltage

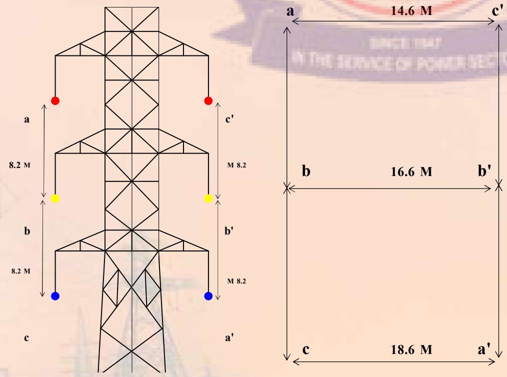
Electrical Parameters for Designing of Transmission Line

- ✓ Electrical Parameters Calculation of Transmission line:
  - Case Study of Detailed Electrical Parameters Calculation for 400kV D/C Satpura- Asta Transmission line

Case Study

Electrical Parameters for Designing of Transmission Line

- ✓ Electrical Parameters Calculation of Transmission line:
  - Case Study of Detailed Electrical Parameters Calculation for 400kV D/C Satpura-Asta Transmission line



Case Study

Electrical Parameters for Designing of Transmission Line

- ✓ Electrical Parameters Calculation of Transmission line:

Description	Unit	Values
Data Sheet to be entered by client		
Enter Voltage Level	V	400000
Enter Power Factor	---	0.85
Ampacity of Line [Single Conductor per Bundle]	Amp	343
AC Resistance at 64 temp while transferring 344 Amp	ohm	0.06654453
Enter Percentage Load	%	100
Enter Total Length of Transmission line	kM	240
Enter Transposed Length of Transmission line	kM	122
Enter Inter Conductor Spacing	M	0.45
Enter Dimension of Conductor		
Diameter	mm	31.77
Radius	mm	15.885
Enter Number of Subconductor	Nos.	2
Enter Number of Circuits	Nos.	1

Electrical Parameters for Designing of Transmission Line

- ✓ Electrical Parameters Calculation of Transmission line:

Description	Unit	Values
Enter Frequency	HZ	50
Enter Barometric Pressure (P)	cm	75.99
Enter Temperature	°c	64
Enter Surface Factor (m_0)		0.85
Sending End Power for Twin Conductor & Double Circuit Arrangement	MVA	924
Sending End Power for Twin Conductor & Double Circuit Arrangement	MW	784
Sending End Power for Twin Conductor & Single Circuit Arrangement	MVA	462
Sending End Power for Twin Conductor & Single Circuit Arrangement	MW	392

Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

Description	Unit	Values
Horizontal & Vertical Distances between Conductors [Ref Network Configuration]		
Horizontal distance between Conductor a & c'	M	14.6
Horizontal distance between Conductor b & b'	M	16.6
Horizontal distance between Conductor c & a'	M	18.6
Vertical distance between phases	M	8.2

Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

Description	Unit	Values
Electrical Calculation Parameters of Transmission Line		
Calculation of Geometric Mean Distance (GMD)		
Dac'	M	14.60
Dab'	M	17.62
Daa'	M	24.06
Dab	M	8.26
Dac	M	16.52
Dbc'	M	17.62
Dbb'	M	16.60
Dba'	M	19.42
Dba	M	8.26
Dbc	M	8.26
Dca'	M	18.60
Dcb'	M	19.42
Dcc'	M	24.06
Dcb	M	8.26
Dca	M	16.52
Geometric Mean Distance (GMD)	M	14.88

Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

Description	Unit	Values
Calculation of Geometric Mean Radius (GMR_L) [For Inductance Calculation]		
Fictious Radius of Conductor (r')	M	0.01
Daa	M	0.07
Dac'	M	14.60
DSA	M	0.98
Dbb	M	0.07
Dbb'	M	16.60
DSB	M	1.05
Dcc	M	0.07
Dca'	M	18.60
DSC	M	1.11
Geometric Mean Radius (GMR_L)	M	1.04
Inductance (L)	H/phase/m	5.32E-07
Inductance (L)	H/phase/kM	0.0005316

Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

Description	Unit	Values
Calculation of Geometric Mean Radius (GMR_C) [For Capacitance Calculation]		
Daa	M	0.0845
Dac'		14.60
DSA	M	1.11
Dbb	M	0.085
Dbb'		16.60
DSB	M	1.18
Dcc	M	0.085
Dca'		18.60
DSC	M	1.25
Geometric Mean Radius (GMR_C)	M	1.18
Capacitance (C)	F/phase/m	2.20E-11
Capacitance (C)	uF/phase/kM	0.02195

Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

Description	Unit	Values
Total Inductance of Complete Transmission Line	H/Phase	0.127584
Total Capacitance of Transposed Transmission Line	μF/phase	2.667260

Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

Description	Unit	Values
AC Resistance @ Ampacity of 344 & temperature of 64 of ACSR Moose Conductor	ohm/kM	0.06654453
AC Resistance @ Ampacity of 344 & temperature of 64 of ACSR Moose Conductor for Complete Transmission Line	ohm	7.985343547
Total Line Losses	kW	12288.10
Inductive Reactance of line (X_l)	ohm	40.0816
Capacitive Reactance of line (Xc)	ohm	1193.40
Impedance Z	ohm	7.9853435472384+40.0816099325264i
Magnitude	ohm	40.87
Angle		78.74
Admittance Y	mho	0.000837944319900359i
Magnitude	mho	0.000837944
Angle		90

Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

Description	Unit	Values
Zc=sqrt(Z/Y)		219.780085287317-21.6800415677827i
1/Zc		0.00450615479810557+0.000444506258181117i
ZY		-0.0335861573754223+0.0066912732678614i
Magnitude		0.034246213
Angle		168.7326537
rl=(al+jbl)=Sqrt(ZY)		0.0181666676869272+0.184163474093723i
al= real part		0.018166668
bl=img part		0.184163474
cosh(al+jbl)		
cosh(al)*cos(bl)		0.983252011
sinh(al)*sin(bl)		0.00332694
cosh(al+jbl)=cosh(al)*cos(bl)+i(sinh(al)*sin(bl))		0.983252010683541+0.0033269397970958i
sinh(al+jbl)		
sinh(al)*cos(bl)		0.017860448
cosh(al)*sin(bl)		0.183154436
sinh(al+jbl)		0.0178604477589704+0.183154436499195i
Zc=sqrt(Z/Y)		219.780085287317-21.6800415677827i
1/Zc		0.00450615479810557+0.000444506258181117i
ZY		-0.0335861573754223+0.0066912732678614i

Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

Description	Unit	Values
A=D=cosh(al+jbl)		0.983252010683541+0.0033269397970958i
magnitude		9.83E-01
B=Zcsinh(rl)		7.89616652836255+39.8664824247099i
C=(1/Zc)(sinhrl)		-9.31350872129835E-07+0.000833261323627949i
A=D		1.00E+00
magnitude		1.00E+00
B=Z		7.9853435472384+40.0816099325264i
C		0.00E+00
Sending End Voltage V_s	volts	230940.11
Magnitude	volts	230940.11
Angle		0
Sending End Current I_s	Amp	667
magnitude	Amp	666.8395609
angle		-31.78833062
real		566.8136268
img		-351.2795361
Is rectangular form		566.814-351.28i
Sending End Power	MW	393

Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

Description	Unit	Values
Receiving End Voltage V_r	volts	208592.371824219-19054.7911482916i
magnitude	volts	209460.8857
angle		-5.219449834
No load Voltage V_0(magnitude)	volts	2.35E+05
Full load Voltage V_r (magnitude)	volts	209460.8857
Receiving End Current I_r	amp	558.70477886836-535.944471996137i
magnitude	amp	774.2012058
angle		-43.80885896
Receiving End Power Factor ($\cos\Phi_r$)		0.78163578
Receiving End Power	MW	380.26
Voltage Regulation (Considering medium length line)	%	12.13
Efficiency of Line(Considering medium length line)	%	96.87

Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

Description	Unit	Values
CALCULATION FOR CORONA LOSS		
Air density factor δ		0.870389911
		0.884167326
		0.680978635
Critical Disruptive Voltage (V_d)	volts	239978.7917
Eon	Kv/cm	20.77221802
V / V_d		0.96234
F		0.0420
Corona loss Pc (Peterson's)	kW/phase/km	0.5383137469
Corona loss Pc (Peek's)	kW/phase/km	1.5053
Corona loss Pc (CPRI)	KW/mile/cond	0.16588
	KW/km/cond	0.26697
J		0.000000000437
Corona in rainy weather (srao p834)	KW/3ph/km	41.1371
Mc carthy corona loss (begm p115)	KW/3ph/km	41.3816

Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

Description	Unit	Values
CALCULATION FOR CORONA LOSS		
Total Corona Loss of the line (Peterson's)	kW	387.59
Total Corona Loss of the line (Peek's)	kW	1083.81
Total Corona Loss of the line (CPRI)	kW	0.800905867
Corona loss in rainy condition	kW	9872.914306
	kW	9931.575104
Line Losses per phase	kW/Ph	3764.98
Total Line Losses per Circuit-Normal Condition	kW/Ckt	11294.94
Total Line Losses per Circuit-Rainy Condition	kW/Ckt	21226.51
Total Line Losses per Circuit-Normal Condition (90% availability)	kW/Ckt	10165.44
Total Line Losses per Circuit-Rainy Condition (10% availability)	kW/Ckt	2122.65
Total Line Losses per Circuit-Normal Condition & Rainy Condition	kW/Ckt	12288.10

Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

Description	Unit	Values
% Efficiency	%	96.77
Heavy rain efficiency %	%	94.49

Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

Description	Unit	Values
CALCULATION OF AUDIBLE NOISE		
Radius of whole cond (R)	m	0.225
Req	m	0.084547324
Height of the cond from gnd level	m	22.00
Spacing bet cond	m	8.26
Distance from bottom of line to AN cal point	m	20
Max. Outer surface volt gradient (Eom)	KV/cm(rms)	15.92487734
Max. Center surface volt gradient (Ecm)	KV/cm(rms)	17.04915926
Surface volt gradient C phase (both ckt)		16.61356124
Surface volt gradient B phase (both ckt)		16.95083584
Surface volt gradient A phase (both ckt)		15.24520399
Surface volt gradient C phase		16.61356124
Surface volt gradient B phase		16.95083584
Surface volt gradient A phase		15.24520399
Kn (If n=1;7.5 or n=2;2.6 else n=>3;0)		2.6

Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

Description	Unit	Values
CALCULATION OF RADIO INTERFERENCE		
		fair weather
RI outer A		33.416102
RI inner B		40.00142179
RI outer C		39.11659816
RI outer a CKT2		30.81890742
RI inner b CKT2		36.11960323
RI outer c CKT2		33.35997779
Total A phase RI level		35.31912751
Total B phase RI level		41.49080703
Total C phase RI level		40.13979347
Total RI level	db	42.31530025
		41.49080703
		42.31530025
		41.49080703
		0
		0
1 means 1st formulae (RI max), 2 means 2nd formulae (avg(RImax+RI(2nd max))+1.5)		2

Electrical Parameters for Designing of Transmission Line

✓ Electrical Parameters Calculation of Transmission line:

Description	Unit	Values
Summary		
Sending End Voltage	kV	400
Receiving End Voltage	kV	362.80
Sending End Power Factor	-----	0.85
Receiving End Power Factor	-----	0.78
Sending End Current	Amp	666.84
Receiving End Current	Amp	774.20
Sending End Power	MW	392.70
Receiving End Power	MW	380.41
Voltage Regulation	%	12.13
Efficiency	%	96.77
Total Line Losses	MW	12.29
Radio Interference	db	42.32
Audible Noise	db	56.07
Summary		
Sending End Voltage	kV	400

Power Transfer Capability of the Transmission line

✓ Power Transfer Capability of the Transmission line:

- Voltage Regulation
- Thermal Rating
- Power Factor
- Surge Impedance Loading
- High Conductivity Material

Power Transfer Capability of the Transmission line

- ✓ Power Transfer Capability of the Transmission line:
  - Voltage Regulation
    Voltage regulation is the %age difference between Sending end and Receiving End voltages. For a given length of line the impedance Z is fixed. Thus, the voltage drop depends upon the amount of current flowing through the conductor.
    If the %age regulation is reduced without capacitive compensation at Receiving end, the power transfer capability will reduce. Contrary to this, if higher %age regulation is allowed, the power transfer capability will increase. Therefore, in case of long lines, it is better to provide series capacitive compensation for better power transfer capability.

Power Transfer Capability of the Transmission line

- ✓ Power Transfer Capability of the Transmission line:
  - Thermal Rating
    If the thermal rating is increased, we can transfer more power on the same conductor. Higher temperature means, you allow more amount of current. Thus, the power P = √3 x V x I x Cos Φ will increase.
    Taking conductor to higher temperature means increase in Sag and increase in height/weight of tower and extra cost of foundation.
    If, the line is passing through a region experiencing sub-zero temperatures, the load ability of the line will increase. However, care is required in designing the tower for sub-zero temperature.

Power Transfer Capability of the Transmission line

- ✓ Power Transfer Capability of the Transmission line:
  - Power Factor
    If the power factor is low the power capability will reduce and vice-a-versa.
    However, when more power is transferred, the current is also more and voltage is low. Therefore, the power factor is bound to be low. Adequate series compensation can increase the load ability.
  - Surge Impedance Loading
    Under the unloaded condition if the line is charged, the flow of current will be proportional to the no load impedance of the line. The capability will therefore depend upon the surge impedance.

Power Transfer Capability of the Transmission line

- ✓ Power Transfer Capability of the Transmission line:
  - High Conductivity Material
    If the conductivity of the material of conductor is increased, the resistance will come down and therefore the load ability will increase. This also means that the surface temperature of the conductor can be increased.

Conclusion

- ✓ The electrical design of bare conductor for overhead EHV Transmission Line is governed by various factors such as the conductor material, the reactance, the corona, surge impedance, voltage regulation, etc.
- ✓ The power transfer capacity of the line depends much on the electrical properties of the conductor. The transfer capability also depends upon the transmission line parameters.
- ✓ For better efficiency of the transmission line, it is necessary to evaluate all the electrical parameters in depth.

PROCEEDING

3 - DAYS TUTORIAL AND CONFERENCE ON

"Design & Construction of Transmission Line"

FGI, Vadodara, Gujarat

5-7 November, 2025 (Wed-Thurs-Fri)

CONFERENCE

ORGANIZED BY:

The Society of Power Engineers (I)
Vadodara Chapter
AND
Central Board of Irrigation & Power
New Delhi

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Integrated Design for Transmission line tower Foundation - Unified Approach for Reliable Transmission System

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Abstract

Transmission lines are the arteries of the modern power system, ensuring reliable evacuation of energy across vast geographies. Yet, their safety and longevity are fundamentally linked to one element often underestimated: soil and foundation behavior. This paper explores a holistic design framework where soil investigation, structural foundation design, and electrical loading calculations are integrated from the outset. The interplay of safe bearing capacity (SBC), liquefaction risk, and water table with tower type, spotting, and sag–tension analysis is described in depth.

1) Introduction

India's ambition to evacuate 500 GW of renewable power by 2030 will require thousands of kilometers of new transmission corridors. These lines will traverse black cotton soils, deserts, river valleys, and coastal belts—each with unique geotechnical hazards. Civil engineers provide the foundation safety, while electrical engineers optimize sag, tension, and clearances. Failures in transmission lines are not always due to electrical faults; many catastrophic collapses have been traced to foundation inadequacies, erosion, or underestimated soil behavior. Thus, the Integrated Design Approach (IDA) connects geotechnical realities to structural and electrical parameters from day one, reducing risks and optimizing costs.

2) Scope of design-Transmission line Tower

Electrical Scope (Line Design Team)

- Responsible for overall line design and tower configuration.
- Decides tower type and family (suspension, tension, angle, dead-end, river crossing, narrow-base, monopole, etc.).
- Defines conductor & earth wire selection (type, size, HTLS/ACSR/AAAC, OPGW).
- Provides sag–tension calculations under all operating conditions.
- Specifies tower loading cases (normal, wind, seismic, broken wire, erection loads).
- Delivers tower geometry, leg spacing, stub plan, and load sets at the tower base to the civil team.
- Ensure electrical clearances (to ground, buildings, rivers, highways, railways) are met in tower spotting.

Civil Scope (Foundation & Structural Design Team)

3) Reasons for Transmission Tower Foundation failures

A. Geotechnical / Soil-Related Causes

1. Inadequate soil investigation – insufficient boreholes, shallow exploration (not reaching hard strata), or missing liquefaction risk.
2. Low Safe Bearing Capacity (SBC) – foundations designed on overestimated SBC, leading to shear failure or settlement.
3. Liquefaction during earthquake – sudden loss of soil strength in sandy, saturated soils (notably in Zone V regions).
4. High groundwater table – uplift, buoyancy, reduction in effective stress, accelerated stub corrosion.
5. Differential settlement – uneven compression of soil under different legs of lattice towers.
6. Soil erosion/scour – riverbanks, floodplains, and coastal sites where currents remove supporting soil.
7. Expansive soils (black cotton soil) – shrink-swell action causing seasonal heave, cracks, or stub uplift.
8. Slope instability/landslides – in hilly terrain, tower legs move due to mass soil movement.
9. Soil creep – slow long-term lateral soil displacement on gentle slopes, displacing foundations.

B. Structural / Civil Design Deficiencies

10. Improper foundation type selection – shallow pad used in weak/liquefiable soils where deep piles were required.

11. Under-design of foundation size/depth – neglecting adverse load combinations or SBC reduction factors.
12. Poor reinforcement detailing – inadequate anchorage, cover, confinement, or ties in pile heads and rafts.
13. Punching/shear failure of raft – under designed slabs unable to transfer concentrated stub loads.
14. Group pile failure – piles placed too close, leading to reduced efficiency and block failure.
15. Stub anchorage failure – insufficient embedment length, poor stub–concrete bond, or inadequate gusset/cleats.
16. Improper consideration of uplift loads – especially at angle/dead-end towers.
17. Lack of seismic detailing – brittle reinforcement, absence of ductility provisions per IS 456/IS 1893.

C. Construction & Execution Issues

18. Poor concreting quality – honeycombing, segregation, weak cube strength, or improper curing.
19. Stub setting errors – wrong levels or inclinations leading to eccentric load transfer.
20. Defective pile installation – pile collapse, poor socketing, improper tremie concreting under high water table.
21. Inadequate dewatering during construction – leading to soil collapse and loss of embedment.
22. Deviation in pile verticality – reducing lateral and vertical load capacity.
23. Use of substandard materials – poor quality cement, corroded reinforcement, or contaminated aggregates.

D. Environmental & Climatic Effects

24. Flooding – seasonal river floods exceeding design high flood level (HFL).
25. Scour during cyclones/tsunamis – rapid erosion around river/sea tower bases.
26. High wind/cyclone – excessive overturning moments transferred to inadequate foundations.
27. Seismic shaking – Zone V events leading to combined lateral + vertical soil deformations.
28. Permafrost / freeze-thaw action (in cold regions) – seasonal ice lensing leading to foundation heave.

E. Corrosion & Durability Issues

29. Stub corrosion at ground level – the most common failure cause (especially in coastal/saline soils).
30. Chloride/sulphate attack on concrete – loss of bond and cracking of foundation concrete.
31. Poor waterproofing/drainage – foundations exposed to stagnant water, accelerating corrosion.
32. Electrochemical corrosion – in areas near railways/industrial zones due to stray currents.

F. Operational / Maintenance Deficiencies

33. Overloading beyond design life – heavier HTLS conductors or OPGW added later without re-checking foundation capacity.
34. Foundation undermining by excavation – local villagers or contractors digging near stubs for farming, drains, or road works.
35. Neglect of maintenance – failure to apply protective coatings, drainage, or stub encasement.
36. Unmonitored tilt/settlement – absence of routine survey monitoring leading to progressive unnoticed failures.

4) Soil Investigation and Its Influence

4.1 Safe Bearing Capacity (SBC)

Soil investigation is the first and most important step in designing safe and economic foundations for transmission towers. It determines the soil type, bearing capacity (SBC), and stratification at different depths, which are essential inputs for foundation selection. Standard Penetration Tests (SPT) and Plate Load Tests are commonly conducted to assess SBC, while laboratory tests provide key soil parameters such as cohesion, angle of internal friction, bulk density, and compressibility. Groundwater level and its seasonal variations are carefully recorded, as they critically influence foundation stability. Typically, boreholes are drilled up to 10–20 meters or until hard strata or refusal is encountered. In seismic zones, special emphasis is given to evaluating liquefaction potential. The soil investigation data guides engineers in selecting the appropriate foundation type—whether pad, raft, pile, or under-reamed—based on ground conditions. In riverbeds or sandy stretches, additional evaluations for scour depth and erosion risk are carried out to ensure long-term safety. Accurate soil investigation not only aids in optimizing design but also minimizes the risks of differential settlement, tilt, and eventual transmission tower failure:

Table: Effect of SBC on Selection of Transmission Line Tower Foundation:

SBC Range (t/m²)	Soil Condition Example	Recommended Foundation Type	Remarks
< 10 t/m²	Soft clay, loose sand, alluvium	Pile foundation / Raft foundation / Pile–raft hybrid	Transfer load to deeper strata; ground improvement may be required.
10 – 20 t/m²	Medium dense sand, stiff clay	Raft foundation/Isolated footing	Increase plan area; ensure control of settlement.
20 – 25 t/m²	Dense sand, weathered rock	Isolated footing	Economical
> 25 t/m²	Hard clay, gravel, rock strata	Isolated shallow footing (pad or chimney)	Most economical; minimal settlement risk.
Expansive soils	Black cotton soil, clay with high PI	Under-reamed piles / Soil replacement with pad footing	SBC alone not sufficient; swelling/shrinkage must be addressed.
River bed/Scour zone	Sandy bed, riverbank locations	Pile foundation / Raft + scour protection (riprap, gabion)	SBC must be combined with scour depth and hydrological studies.

List of test to be carried out and covered in Geo technical investigation for foundation design of transmission line tower for zone - v, river, and sea and for tower crossing railway etc.

Field / In-Situ Tests

- Boreholes drilled up to refusal or hard strata (generally 15–30 m or as per tower load and site condition).
- Standard Penetration Test (SPT) at regular intervals (as per IS 2131).
- Cone Penetration Test (CPT / DCPT) for continuous soil profiling and liquefaction potential (IS 4968).
- Plate Load Test (PLT) for direct determination of Safe Bearing Capacity (SBC) and settlement (IS 1888).
- Vane Shear Test in soft clays for shear strength (IS 4434).
- Permeability Test (Falling Head / Pumping Test) to determine seepage and uplift risks.
- Seismic Refraction / MASW Survey for shear wave velocity (Vs30) to classify seismic site response (IS 1893).
- Geophysical Resistivity Test for groundwater depth, soil stratification, and corrosivity.
- Field Density Test (Sand Cone / Core Cutter / Nuclear Gauge) for compaction assessment.
- Scour Depth Estimation in rivers/sea crossings to assess foundation embedment depth.

2. Laboratory Tests

- Moisture Content, Bulk Density, Specific Gravity (IS 2720 Part 2–3).
- Grain Size Analysis (Sieve + Hydrometer) for soil classification (IS 2720 Part 4).
- Atterberg Limits (Liquid, Plastic, Shrinkage) for soil plasticity (IS 2720 Part 5).
- Direct Shear Test and Triaxial Shear Test (UU, CU, CD) for shear strength parameters (c, ϕ).
- Unconfined Compression Test (UCC) for cohesive soils.

- Compaction Test (Proctor / Modified Proctor) to determine OMC & MDD (IS 2720 Part 7–8).
- Consolidation Test for settlement analysis (IS 2720 Part 15).
- Chemical Tests on Soil & Water – pH, chlorides, sulphates, resistivity (corrosion of steel & concrete durability).
- Cyclic Triaxial / Resonant Column Test (for advanced liquefaction studies in seismic Zone V).
- Salinity / Sulphate Content in marine/sea crossings for concrete mix design durability.

3. Special Considerations by Site Condition

- Seismic Zone V (High Risk Area):
  - Liquefaction analysis using SPT/CPT data.
  - Dynamic soil properties (shear modulus, damping).
  - Ground response analysis for tower–soil interaction.
- River / Sea Crossings:
  - Scour depth and riverbed mobility studies.
  - Submerged soil testing for strength and settlement.
  - Marine geotechnical sampling (grab/core sampling).
  - Long-term tidal fluctuation and salinity profile.
- Railway / Highway Crossings:
  - High-precision borehole logs near embankments.
  - Vibration susceptibility analysis.
  - Plate load test for shallow foundation feasibility.
  - Dewatering requirement for shallow/high water table zones.

Codal References

- IS 1892: 1979 – Code of practice for subsurface investigations.
- IS 2131: 1981 – Standard Penetration Test.
- IS 1888: 1982 – Plate Load Test.
- IS 2911 (Parts 1–4): 2010 – Design & construction of pile foundations.
- IS 6403: 1981 – SBC determination for shallow foundations.
- IS 1893 (Part 1): 2016 – Seismic design & liquefaction considerations.
- IS 2720 series – Methods of soil testing.
- PGCIL / CEA Guidelines – Transmission line foundation investigations.

4.2 Liquefaction

Liquefaction is the sudden loss of soil strength that occurs when saturated, loose sandy soils are subjected to earthquake shaking. During this phenomenon, pore water pressure rises, causing the soil to behave like a liquid rather than a solid. Transmission tower foundations located in liquefiable zones face severe risks of tilt, settlement, or even complete overturning. Lattice towers are particularly prone to differential settlement between legs, which compromises structural stability, while monopoles are highly vulnerable because all loads are concentrated through a single shaft that can lose lateral support. Liquefaction may also trigger lateral spreading of soil, displacing foundations horizontally and weakening their resistance. In extreme cases, foundation failures in liquefiable ground have caused cascading collapse of multiple spans of towers, as observed in case studies of riverbank towers affected by combined liquefaction and scour during earthquakes. To mitigate these risks, engineers adopt deep pile foundations, stone columns, vibro-compaction, and other ground improvement techniques. Proper soil investigation, seismic assessment, and design in line with IS 1893 (Seismic Design) and IS 15284 (Ground Improvement) are essential to ensure the safety of transmission line foundations in liquefaction-prone areas.

4.3 Groundwater Table

Groundwater table depth is a critical parameter influencing both the type and depth of transmission tower foundations. A high groundwater table reduces the effective bearing capacity of soil and can create uplift pressure and buoyancy effects on shallow foundations such as pads or rafts. Seasonal rises in groundwater after the monsoon further weaken soil strength and increase the risk of settlement. Excavation in areas with high water tables often requires dewatering, which may lead to instability of side slopes. In addition, corrosion of steel reinforcements and stubs is accelerated in saline or high groundwater conditions, posing long-term durability issues. In coastal and riverbank locations, fluctuating groundwater levels also aggravate the risk of liquefaction during earthquakes. Pile foundations may lose skin friction when surrounded by saturated soft soil layers, reducing their load-carrying capacity. To counter these challenges, proper waterproofing, drainage measures, and chemical treatments are essential for protecting foundations in high water table zones. Standards such as IS 2911 (Pile Foundations) and IS 456 (Concrete) provide essential guidance for designing safe and durable foundations under such conditions.

5) Seismic effect on foundation Design of Transmission line Towers in Zone.V

Transmission line towers located in Seismic Zone V—the highest seismic risk classification as per IS 1893—require special consideration in foundation design due to the combined impact of vertical and lateral earthquake forces. Seismic shaking induces additional horizontal and vertical loads that act simultaneously with dead load, wind, and conductor tensions. In saturated sandy soils, liquefaction is a major concern, as it can cause sudden loss of soil bearing capacity, lateral spreading, and tilting of tower foundations.

For lattice towers, uneven settlement or lateral movement of one or more legs may lead to severe secondary stresses, jeopardizing structural stability. Monopole towers, due to their concentrated base loads, are even more vulnerable to rotation or overturning if foundation stiffness is not sufficient. Foundations in Zone V must therefore be designed to resist both seismic inertia forces from the tower mass and dynamic soil-structure interaction effects.

Preferred solutions include deep pile foundations socketed into non-liquefiable strata, raft–pile hybrids to distribute loads, and ground improvement techniques such as stone columns, vibro-compaction, or seismic drains to mitigate liquefaction. In hilly or sloping terrain, slope stability and potential for seismic-induced landslides must also be evaluated.

Design must comply with IS 1893 (Part 1): 2016 for seismic forces, IS 2911 for pile design, and IS 456 for reinforced concrete detailing. PowerGrid (PGCIL) guidelines further mandate seismic safety checks in tower spotting, ensuring conductor clearances are maintained even under foundation deflections. Incorporating seismic load combinations into sag–tension calculations is essential to avoid clearance violations.

Ultimately, adopting an integrated design approach that couples geotechnical investigations, soil improvement, and structural-electrical considerations ensures transmission line towers in Zone V achieve long-term safety, resilience, and service continuity during major earthquakes.

6) Threats to Transmission Towers & Foundations

Transmission towers and their foundations are exposed to a wide range of geotechnical and environmental threats, including settlement, erosion, liquefaction, and extreme climatic loads. They are subjected to combined actions of wind, earthquakes, and environmental effects that can compromise their stability. Strong winds and cyclones generate high overturning moments, placing severe stress on both tower members and foundations, while earthquakes induce lateral shaking and may trigger soil liquefaction, leading to sudden loss of bearing capacity and potential foundation failure. A high groundwater table further reduces soil strength, creating uplift pressures and accelerating corrosion of tower stubs. Differential settlement beneath the legs of lattice towers results in tilt, unbalanced forces, and secondary stresses, whereas monopoles are particularly vulnerable to base rotation and overturning due to their concentrated load transfer. Scouring at riverbanks and streams can erode foundation embedment, while liquefaction during seismic events may also cause lateral spreading of soil. To mitigate these risks, preventive measures such as deeper pile foundations, ground improvement, riprap protection, and effective drainage systems are adopted. Integrated design, guided by IS 802, IS 2911, IS 1893, and PowerGrid guidelines, ensures that transmission towers achieve resilience under multiple hazards.

7) Tower Types and Integrated Response

7.1 Lattice Towers

Lattice towers are the most widely used structures for transmission lines ranging from 132 kV to 765 kV. They are constructed using bolted steel angle members arranged in a trussed framework, which distributes loads to four legs, providing both redundancy and structural stability. An integrated response approach is essential, as it considers soil conditions, foundation behavior, structural design, and electrical requirements together. In weak soils, uneven settlement of tower legs can induce secondary stresses in lattice members, while sag–tension calculations for conductors must include allowances for tower deflections and foundation tolerances. Lattice towers also provide flexibility to carry multiple circuits and adapt to varying span lengths, making them suitable for a wide range of terrains. In ROW-constrained urban or highway corridors, narrow-based lattice towers are increasingly being adopted to minimize footprint. The design and installation of these towers are guided by standards such as IS 802 and IS 5613, ensuring compliance with safety and performance criteria. With integrated civil–electrical design, lattice towers remain highly reliable even under wind, seismic, and geotechnical hazards.

7.2 Narrow based lattice type tower

Narrow-base lattice towers are specifically developed for use in urban, highway, railway, and forest corridors where Right-of-Way (ROW) is severely constrained. By reducing the plan footprint compared to conventional broad-base towers, they help minimize land acquisition requirements and tree cutting, while still distributing structural loads across four legs to preserve redundancy. However, an integrated response approach is essential, as the smaller base area results in higher vertical loads and greater overturning moments on the foundation. To counter these concentrated stresses, deep piles or pile–raft hybrid foundations are commonly adopted. Wind-induced sway is more critical in narrow-base towers, requiring stiffer bracing systems, while sag–tension calculations must account for foundation deflection limits and tilt tolerances. PowerGrid (PGCIL) has already standardized multi-circuit narrow-base lattice towers for dense transmission corridors, reflecting their growing importance. Relevant standards such as IS 802 and IS 5613 provide design guidance, but integrated geotechnical and electrical assessments are vital. With proper civil–electrical integration, narrow-base lattice towers serve as a reliable and space-efficient solution for modern transmission networks

7.3 Monopoles

Monopole towers are single tubular or polygonal steel shafts that support conductors through cross-arms, and they are increasingly used in urban areas, highways, and corridors with severe Right-of-Way (ROW) constraints. Their compact footprint minimizes land acquisition and visual impact compared to lattice towers, making them particularly suitable for space-limited environments. However, because all vertical and lateral loads are concentrated at a single base, the foundation design becomes critically important. An integrated design approach must consider soil safe bearing capacity (SBC), groundwater levels, seismic forces, and overturning moments simultaneously. Typical foundation solutions include deep bored piles, large monopiles, or pile–raft hybrids, which provide the necessary resistance against heavy loads. Wind and earthquake forces induce high bending moments, requiring robust base plates and anchor bolts for stability. Conductor sag–tension is highly sensitive to monopole tilt, so foundation tolerances must be kept very strict. Utilities such as PGCIL and several international transmission companies are adopting monopoles for multi-circuit compact configurations in dense corridors. While monopoles are sustainable and efficient in terms of ROW management, they generally demand higher steel tonnage and more expensive foundation systems compared to lattice towers.

8) Alternatives to Deep Piles in Liquefiable Soils

Deep pile foundations are a proven solution for transmission line towers in liquefiable soils, as they transfer loads to non-liquefiable strata at depth. However, they are expensive, time-consuming, and often difficult to execute in remote or waterlogged areas. With the growing emphasis on economy, speed, and constructability, engineers are increasingly adopting ground improvement methods and hybrid foundation systems as effective alternatives to deep piles in liquefaction-prone zones.

1. Stone Columns / Vibro-Replacement

Stone columns are installed in weak sandy soils to densify and reinforce the ground while simultaneously providing vertical drainage paths. During an earthquake, they dissipate excess pore water pressure and reduce liquefaction risk. This method is widely recommended under IS 15284 (Part 1): 2003 for ground improvement.

2. Vibro-Compaction:

For loose sandy deposits, vibro-compaction increases relative density, thereby improving shear strength and reducing liquefaction potential. It is suitable where the groundwater table is shallow, and uniform sandy deposits exist.

3. Raft Foundations with Soil Improvement:

Where shallow foundations are desired, raft foundations can be combined with soil replacement or improvement techniques. By spreading the loads over a larger area, stress concentrations are reduced, making the system less vulnerable to localized bearing failures during seismic shaking.

4. Hybrid Raft–Pile Systems:

Instead of deep piles, shorter piles are combined with a raft foundation to resist both vertical loads and uplift or overturning during earthquakes. This hybrid system reduces pile length while maintaining seismic safety.

5. Soil Replacement:

Weak, liquefiable soils can be excavated and replaced with well-compacted granular material or cement-stabilized backfill. This creates a stronger stratum beneath the tower foundation, improving both bearing capacity and seismic resistance.

6. Seismic Drains / Wick Drains:

Installation of vertical drains accelerates pore pressure dissipation during an earthquake, reducing the chance of liquefaction. These drains are often used in combination with stone columns or soil densification.

7. Dynamic Compaction:

Heavy tamping on the ground surface densifies shallow sandy layers, improving stiffness and reducing liquefaction potential. This method is best suited for open areas where large equipment can be operated.

8. Other Ground Improvement Techniques:

Chemical grouting, deep soil mixing, and cement stabilization may also be employed in select cases, though these are costlier and typically used where site conditions are highly challenging.

9) Codes and Guideline References

- IS 1893 (Part 1): 2016 – Criteria for Earthquake Resistant Design of Structures (liquefaction considerations).
- IS 15284 (Part 1): 2003 – Ground Improvement by Stone Columns.
- IS 6403: 1981 – SBC determination for shallow foundations.
- IS 2911 (Part 1–4): 2010 – Pile foundation design provisions.
- PowerGrid Guidelines – Recommendations for adopting ground improvement methods in transmission line projects.

10) Points to consider in Pile foundation design of Liquefiable soil

a) Detailed Geotechnical Investigation

- Carry out boreholes to sufficient depth (up to non-liquefiable strata).
- Conduct Standard Penetration Tests (SPT), Cone Penetration Tests (CPT), and laboratory tests to assess liquefaction susceptibility.

b) Liquefaction Analysis

- Evaluate cyclic stress ratio (CSR) and cyclic resistance ratio (CRR) as per IS 1893 (Part 1): 2016.
- Identify depth and thickness of potentially liquefiable layers under design earthquake conditions.

c) Pile Type Selection

- Prefer bored cast-in-situ piles or driven piles socketed into dense sand, gravel, or rock.
- Avoid reliance on skin friction within liquefiable strata; end-bearing piles are preferred.

d) Pile Length and Embedment

- Ensure piles extend well below the liquefiable layer into competent strata.
- Provide adequate socketing length for stability and load transfer.

e) Group Pile Behaviour

- Consider group effects, as lateral spreading during liquefaction can induce additional forces on pile groups.
- Provide sufficient pile spacing (typically 3–4 times diameter) to minimize group reduction factor.

f) Lateral Load Resistance

- Design for large lateral forces due to soil movement during liquefaction.
- Consider use of pile caps with tie beams to improve stability.

g) Dynamic Loading Considerations

- Account for seismic-induced bending moments and shear forces on piles.
- Check pile–soil interaction models for lateral spreading effects.

h) Scour and Groundwater Effects

- For river crossings, evaluate scour depth in addition to liquefaction.
- Consider uplift and buoyancy effects if groundwater table is high.

i) Construction Quality

- Ensure proper concreting, cover, and use of tremie methods under waterlogged conditions.
- Adopt high-quality reinforcement detailing as per IS 456 and IS 2911.

j) Ground Improvement Measures

- Combine piles with stone columns, vibro-compaction, or soil replacement around pile groups to reduce liquefaction risk.

k) Codal Provisions & Guidelines

Follow IS 2911 (Part 1–4): 2010 for pile design, IS 1893 for seismic provisions

Pile Foundation in Liquefiable Soils — Design Checklist:

#	Design Step	Requirement / Action	Key Parameters	IS / Guideline Reference	Notes / Deliverables
1	Desktop study & scope	Define Zone, PGA, flood/scour regime, utilities, ROW limits	Seismic zone (Zone V?), DHFL, scour, GWT	IS 1893 (Part 1); CEA/PGCIL corridor manuals	Inputs to GI plan & load cases
2	Geotechnical investigation (GI)	Drill to non-liquefiable/competent stratum; in-situ & lab testing	Boreholes, SPT/CPT, grain size, Atterberg, γ, c–ϕ	IS 1892 (site investigations); IS 6403; IS 1888	GI plan with BH logs & lab reports
3	Liquefaction screening	Establish CSR–CRR; identify liquefiable layers & thickness	amax, σ'v, rd, FSliq profile	IS 1893 (Part 1)	Provide depth-wise FSliq and triggering magnitude
4	Groundwater & seasonal effects	Capture GWT fluctuations; assess buoyancy/uplift	GWT min/max, salinity	IS 2911; IS 456	Reflect in construction method (tremie, cover)
5	Foundation concept selection	Prefer end-bearing piles or socketed piles; avoid skin friction in liquefiable zones	Pile type/diameter/length; socket L	IS 2911 (Part 1–4)	Consider hybrid raft–pile if loads/settlement demand
6	Pile length & capacity	Extend below liquefiable layer into dense	Qa (end), Qs (non-liq.), Lateral p–y	IS 2911; IS 6403	Provide capacity calc sheet & safety factors

#	Design Step	Requirement / Action	Key Parameters	IS / Guideline Reference	Notes / Deliverables
		sand/rock; verify axial & lateral			
7	Group effects & spacing	Check group reduction; ensure adequate spacing	s/D (≥3–4), block action	IS 2911	Layout drawing with pile schedule
8	Lateral spreading & kinematic loads	Model soil movement on piles; check combined lateral + moment	Δh, kinematic curvature, M–ϕ	IS 1893; PGCIL guidance	Use p–y curves modified for liquefaction
9	Scour at rivers/streams	Add scour depth to unsupported length; design erosion protection	Scour depth (ys), freeboard	IS 8408 (guidance), MoWR/IRC; PGCIL	Detail riprap/gabion apron & toe level
10	Structural detailing & durability	Reinforcement, cover, lap, confinement; corrosion protection	fck, fy, cover, exposure class	IS 456; IS 2911	Epoxy/FRP coating, CP in saline zones
11	Construction method & QA/QC	Tremie concreting, integrity tests, load tests	CSL/ PIT, RLT/MLT	IS 2911; IS 516; ASTM/IS NDT refs	ITP, pour records, test certificates
12	Ground improvement (if adopted)	Stone columns, vibro-compaction, drains around pile cap	Spacing, diameter, area replacement	IS 15284 (Part 1); IS 1893	Show extents & QA (DP logs, densification)
13	Integration with tower + E	Limit foundation deflection/rotation for sag–tension	θallow, δtop, ΔLspan	IS 802; IS 5613; PGCIL	Feed tolerances into sag-tension model
14	Load combinations	Include seismic, wind, broken wire, construction loads	ULS/SLS combos	IS 802; IS 1893; PGCIL	Document governing cases & margins
15	Handover package	As-built GI, design calcs, test results, O&M notes	All above	Utility/PGCIL templates	Binder + digital archive (PDFs/CAD/BIM)

11) Integration with Electrical Sag–Tension

Foundation design for transmission line towers must always be integrated with electrical sag–tension analysis to ensure reliable performance. Soil conditions such as safe bearing capacity (SBC), settlement, and groundwater level directly affect foundation stiffness and permissible tolerances. Even small foundation tilts can alter span geometry, increase conductor sag and reducing ground clearance. In weak soils, differential settlement of lattice tower legs induces unequal conductor tension, while in monopoles, a slight base rotation can greatly amplify sag–tension effects due to concentrated load transfer. Therefore, sag–tension calculations should include allowable deflections derived from soil–structure interaction. Conditions like liquefaction or the presence of soft clays may lead to a sudden loss of stiffness, drastically affecting clearances. An integrated design approach ensures civil engineers specify foundation deflection limits that are compatible with electrical safety requirements. Relevant standards such as IS 802 (tower design), IS 5613 (overhead lines), and IS 2911 (foundations) provide guidance for this assessment. By coupling soil behavior with sag–tension models, utilities can prevent clearance violations and reduce the risk of cascading tower failures.

12) Case Study – Foundation Failure due to Wind & Erosion

Location: Coastal Andhra Pradesh, 220 kV D/C line.

Problem: Cyclone winds eroded 1.2 m of soil around stubs; reinforcement was exposed. Impact: Progressive tilt over 18 months, eventual tower failure. Remedy: Retrofitted concrete collars around stubs, installed riprap and geotextile, shortened spans.

13) Conclusion

Transmission line safety depends equally on civil and electrical inputs. Soil SBC, liquefaction, and groundwater must guide tower selection and spotting. Lattice towers offer stability, monopoles save ROW but impose severe foundation loads. Alternatives to deep piles (stone columns, hybrid raft–pile) are cost-effective in liquefaction zones. Civil tolerances must be built into sag–tension analysis to avoid clearance failures. By adopting an Integrated Design Approach, utilities can improve reliability, economy, and resilience of transmission networks.

14) Relevant IS Code References

- The following Indian Standards (IS) are particularly relevant for investigations, design, and construction in special crossings:
- IS 6403:1981 – Determination of Safe Bearing Capacity of Shallow Foundations.
- IS 1888:1982 – Method of Plate Load Test on Soils (for SBC evaluation).
- IS 2911 (Part 1 to 4): 2010 – Design and Construction of Pile Foundations.
- IS 1893 (Part 1): 2016 – Criteria for Earthquake Resistant Design of Structures (liquefaction considerations).
- IS 15284 (Part 1): 2003 – Design & Construction for Ground Improvement – Stone Columns (for liquefaction mitigation).
- IS 802 (Part 1/Sec 1): 2015 – Use of Structural Steel in Overhead Transmission Line Towers – Materials and Loads.
- IS 5613 (Part 2/Sec 1 & 2): 1985 – Design, Installation, and Maintenance of Overhead Power Lines.

#######

Use of Stone Column Foundation for Transmission Line towers

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ABSTARCT

Stone columns are a widely used ground improvement technique suitable for strengthening weak, compressible soils that can't adequately support shallow foundations on their own.For the support of transmission structures, use of stone columns is increasing day by day. Stone columns are used for the improvement of settlement and bearing capacity of soft soils in reasonable fare and friendly towards the environment. In present paper, soft/ liquifiable soils for which stone columns can be used effectively is reviewed. Further, this paper deals with stone column installation procedure and its field tests for itsvalidation.

1) INTRODUCTION

Ground improvement techniques are the techniques used to improve and alter poor ground conditions in order construction can meet project performance requirements in an economical way. The high cost of conventional foundations coupled with environmental concerns has made development of week soil deposits a necessity. Out of various techniques stone columns is trending technique for improving the weak strata. Based on past experiences the stone column design is still empirical and always needs field trials before execution. Stone columns are significant in soil stabilization and are ideally welcome for improvement of soft clays, silts and loose silty sands. They provide a cost-effective method for ground improvement. As India is a developing country, it requires more land for infrastructure development. For construction the availability of land is depleting, hence it is necessary to develop soil of low shearing strength, bearing capacity and high compressibility. Stone columns work more effectively in large area of stabilization of soil mass. On the load application column rapidly drains the excessive pore water pressure originated. Stone columns behave as rigid element to carry higher shear stresses to reduce settlement and improving the deformability and strength properties of soft soil. Stone column techniques are proved successful in improvement of stability of slopes, increasing the bearing capacity, reducing the differential and total settlements, reducing liquefaction property of sands and increasing the settlement time. This method was initiated in France in 1830's and is widely used especially in Europe since 1950's.

A stone column foundation refers to a ground improvement technique used to enhance the load-bearing capacity of weak or soft soils (like clay or loose silt) by installing vertical columns made of crushed stone or graveland compacted by a shaker.

2) LOCATION

Stone column foundation was used by Jyoti Structures Limited recently for Creek Area in 765 kV Khavda Bhuj Transmission Line.

3) TYPE OF SOILS

Stone columns are most commonly and effectively used in the following soil types:

Cohesive Soils (Fines)

Stone columns are very effective in treating soft, cohesive soils. In these soils, the stone columns function as both reinforcement and vertical drains, accelerating the consolidation process and increasing shear strength.

- **Soft Clays: Including marine clay deposits, soft silty clays, and expansive soils like black cotton soil.**
- **Silts: Especially soft and loose silts.**

Cohesionless Soils (Granular)

Stone columns can also be used to densify loose granular soils, particularly to mitigate the risk of liquefaction.

- Loose Sands and Silty Sands: The vibration during installation helps to compact the surrounding soil, increasing its density and stiffness, which reduces the potential for liquefaction during an earthquake.

Soil Strength Considerations

The technique is generally suited for soils with a low undrained shear strengthbut with some limitations at the extremes:

- Suitable Range: Subsurface soils whose undrained shear strength typically ranges from 10 kPa to 50 kPa are prime candidates for stone column treatment.
- Soils Not Suited: Stone columns are generally not recommended for:
  - Very Sensitive Clays and Silts (sensitivity ratio greater than 2.4), as the vibration from installation can cause a significant loss of strength.
  - Very Soft Clays (undrained shear strength less than 10 kPa) due to inadequate lateral confinement and failure by bulging.
  - Very Stiff Soils (undrained shear strength greater than 50 kPa), as the improvement is often not necessary or the high lateral stiffness makes installation difficult.

4) Liquefaction Criteria for soil

In terms of the soil types most susceptible to liquefaction, Ishihara (1985) states: “The hazard associated with soil liquefaction during earthquakes has been known to be encountered in deposits consisting of fine to medium sand and sands containing low-plasticity fines. Occasionally, however, cases are reported where liquefaction apparently occurred in gravelly soils.” Thus, the soil types susceptible to liquefaction are nonplastic (cohesionless) soils. An approximate listing of cohesionless soils from least to most resistant to liquefaction is clean sands, nonplasticsilty sands, nonplastic silt, and gravels. There could be numerous exceptions to this sequence. For example, Ishihara (1985, 1993) describes the case of tailings derived from the mining industry that were essentially composed of ground-up rocks and were classified as rock flour. Ishihara (1985, 1993) states that the rock flour in a water-saturated state did not possess significant cohesion and behaved as if it were a clean sand. These tailings were shown to exhibit as low a resistance to liquefaction as clean sand. Seed et al. (1983) stated that based on both laboratory testing and field performance, the great majority of cohesive soils will not liquefy during earthquakes. Using criteria originally stated by Seed and Idriss (1982) and subsequently confirmed by Youd and Gilstrap (1999), in order for a cohesive soil to liquefy, it must meet all the following three criteria:

- The soil must have less than 15 percent of the particles, based on dry weight, that are finer than 0.005 mm (i.e., percent finer at 0.005 mm <15 percent).
- The soil must have a liquid limit (LL) that is less than 35 (that is, LL < 35).
- The water content w of the soil must be greater than 0.9 of the liquid limit [that is, w > 0.9 (LL)].

If the cohesive soil does not meet all three criteria, then it is generally considered to be not susceptible to liquefaction. Although the cohesive soil may not liquefy, there could still be a significant undrained shear strength loss due to the seismic shaking.

COMPONENTS

- Crushed stone (typically 20–40 mm in size)
- Compaction equipment (vibratory probes or mandrels)

ADVANTAGES

- Faster and more economical than deep foundations

- **Environmentally friendly (uses natural materials)**
- **Minimal excavation and spoil generation**
- **Effective in improving soft soils**

5) STONE COLUMN INSTALLATION TECHNIQUE:

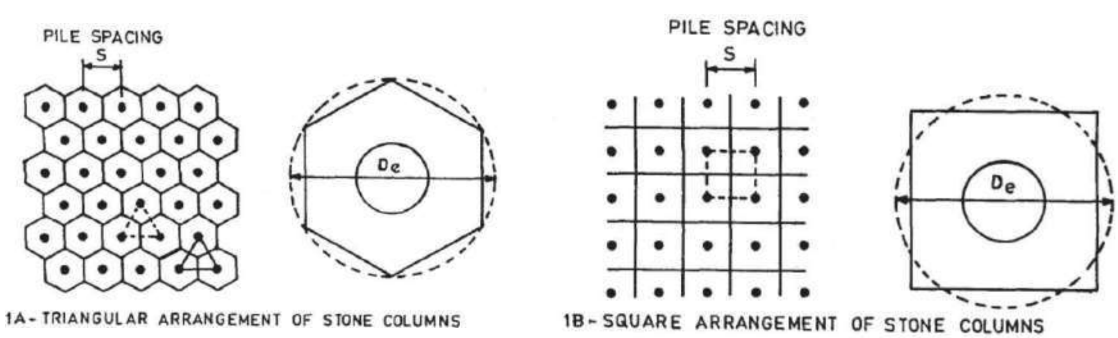
The construction of stone columns involves creation of a hole in the ground which is later filled with granular material. The granular fill consisting of stone or stone sand mixture of suitable proportion, is compacted by suitable means to create a compacted column of required strength. The recommended installation technique of Vibro- replacement method was recommended as ground is silty sand in nature and detailed description is given in Annex C (C-3) of IS 15284 (Part1) – 2013.

A granular Blanket layer of 500mm thickness is laid over the top of the stone columns which consist of clean medium to coarse sand compacted in 2 to 3 layers to a relative density of 70 to 80 percent. After ensuring complete removal of slush deposited during boring operations, a minimum depth of 500mm below the granular blanket should be compacted by suitable means such as rolling/tamping to the specified densification criteria.

Stone columns should be installed preferably in an equilateral triangular pattern which gives the densest packing although a square pattern may also be used. A typical layout in an equilateral triangular pattern is shown in figure below:

Fig.1 Various Patterns of Stone columns

The general practice is to provide stone columns up to a compact stratum with N value of Standard Penetration test around 15. However, if compact stratum is not available at greater depth, and strength of subsoil is found to increase gradually with depth, stone columns can be terminated at critical length.



6) DESIGN OF C/C SPACING OF STONE COLUMN USING IS 15284 (PART1) - 2013:

Load Capacity of treated ground using stone columns may be obtained by summing up the contribution of each of the following components as:

a) Capacity of the stone column resulting from the resistance offered by surrounding soil against its lateral deformation/bulging under axial load,
b) Capacity of stone column resulting from increase in resistance offered by the surrounding soil due to surcharge over it, and
c) Bearing support provided by the intervening soil between the columns.

1.1 Capacity based on Bulging of columns:

Limiting axial stress is given by following:

$\sigma v = \sigma rLKpcol$

$\sigma v = (\sigma ro + 4\sigma ro)pcol$

where, σv = Limiting axial stress in column when it approaches shear failure due to bulging

σrL = limiting radial stress

σro = initial effective radial stress = Ko. σvo

Ko = average co-efficient of lateral earth pressure for clays equal to 0.6 or alternately determined from the relationship as Ko = 1 – sinØ, where Ø is effective angle of internal friction of soil

σvo = average initial effective vertical stress considering an average bulge depth as 2 times diameter of column

$Kpcol = \tan^2(45 + \emptyset/2)$

Yield load = $\sigma v. \pi/4\ D^2$

Safe load on column alone $Q_1 = (\sigma v. \pi/4\ D^2)/\ 2$ where, 2 is the factor of safety.

1.2 Capacity based on Surcharge Effect:

The increase in capacity of the column due to surcharge may be computed in terms of increase in mean radial stress of the soil as follows:

$\Delta\sigma ro = qsaf(1 + 2K0)/3$

where$\Delta\sigma_{ro}$ is the increase in mean radial stress due to surcharge, and qsafe is the safe bearing pressure of soil with the factor of safety of 2.50

$qsafe = CuNc/2.5$

Increase in ultimate cavity expansion stress = $\Delta\sigma_{ro}$. Fq' where, Fq = vesic's dimension less cylindrical cavity expansion factor Fq' = 1 for $\emptyset = 0$

Increase in yield stress of column = $\Delta\sigma ro Kpcol$

Increase in safe load of column $Q2 = (Kpcol \Delta\sigma ro As)/2$where,2 is the factor of safety

1.3 Bearing support provided by the Intervening Soil:

This component consists of the intrinsic capacity of soil to support a vertical load which may be computed as follows:

Effective area of stone column including the intervening soil for triangular pattern = 0.866 S^2 Effective area of stone column including the intervening soil for square pattern = 1.0 S^2

Area of intervening soil for each column for triangular pattern $Ag = 0.866\ S^2 - \pi D^2/4$

Area of intervening soil for each column for square pattern $Ag = S^2 - \pi D^2/4$

Safe Load taken by the intervening soil, $Q3 = qsafeAg$

Overall Safe load on each column and its tributary soil = Q1 + Q2 + Q3

7) SETTLEMENT ANALYSIS BY HEINZ J. PRIEBE APPROACH:

This approach of settlement analysis is given by Heinz J. Priebe for the design of stone column for vibro-replacement method of installation.

2.1 Determination of Basic Improvement Factor

$$n_0 = 1 + \frac{A_C}{A} \cdot \left[\frac{1/2 + f(\mu_S, A_C/A)}{K_{aC} \cdot f(\mu_S, A_C/A)} - 1 \right]$$

$$f(\mu_S, A_C/A) = \frac{(1-\mu_S)\cdot(1-A_C/A)}{1-2\mu_S + A_C/A}$$

$$K_{aC} = \tan^2(45° - \varphi_C/2)$$

where, Ac = c/s area of column A = grid area

Kac = co-efficient of active earth pressure

$$n_0 = 1 + \frac{A_C}{A}\cdot\left[\frac{5 - A_C/A}{4\cdot K_{aC}\cdot(1 - A_C/A)} - 1\right]$$

$$\left(\frac{A_C}{A}\right)_1 = -\frac{4\cdot K_{aC}\cdot(n_0 - 2) + 5}{2\cdot(4\cdot K_{aC} - 1)} \pm \frac{1}{2}\cdot\sqrt{\left[\frac{4\cdot K_{aC}\cdot(n_0 - 2) + 5}{4\cdot K_{aC} - 1}\right]^2 + \frac{16\cdot K_{aC}\cdot(n_0 - 1)}{4\cdot K_{aC} - 1}}$$

$$n_1 = 1 + \frac{\overline{A_C}}{A}\cdot\left[\frac{1/2 + f(\mu_S, \overline{A_C/A})}{K_{aC}\cdot f(\mu_S, \overline{A_C/A})} - 1\right]$$

$$\frac{\overline{A_C}}{A} = \frac{1}{A/A_C + \Delta(A/A_C)}$$

$$\Delta(A/A_C) = \frac{1}{(A_C/A)_1} - 1$$

2.2 Consideration of Over-burden pressure

where, fd = depth factor, Ps = external load on footing, kPa

γS = unit weight of soil, kN/m3

γC = unit weight of granular material in column, kN/m3

1.4 Shear values of improved ground

$$\tan\overline{\varphi} = m'\cdot\tan\varphi_C + (1 - m')\cdot\tan\varphi_S$$

$$m' = (n - 1)/n$$

$$f_C' = (1 - m')\cdot c_S \cdot \frac{1}{1 + \frac{K_{0C} - W_S/W_C}{K_{0C}}\cdot\frac{W_C}{p_C}}$$

$$p_C = \frac{p}{\frac{A_C}{A} + \frac{1 - A_C/A}{p_C/p_S}}$$

$$\frac{p_C}{p_S} = \frac{1/2 + f(\mu_S, \overline{A_C/A})}{K_{aC}\cdot f(\mu_S, \overline{A_C/A})}$$

$$W_C = \Sigma(\gamma_C\cdot\Delta d), \qquad W_S = \Sigma(\gamma_S\cdot\Delta d)$$

$$K_{oC} = 1 - \sin\varphi_C$$

Total settlement of ground is calculated as:

$$s_\infty = p\cdot\frac{d}{D_S\cdot n_2}$$

8) FIELD LOADING TESTS

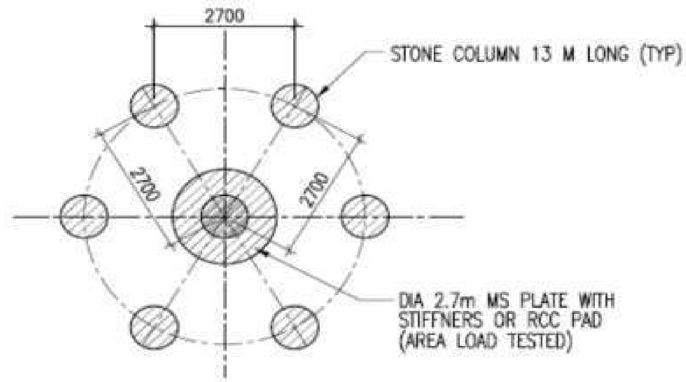
Irrespective of the method used to construct the stone columns, the initial load tests should be performed at a trial test site to evaluate the load settlement behaviour of the soil-stone column system. The tests should be conducted on a single andalso on group of minimum of three columns.

The initial and final soil conditions at the trial site should be investigated by drilling at least one borehole and one static cone test / pressure meter test/dynamic cone test prior and subsequent to the installation of columns as per Fig. 2. All these tests Including the standard penetration test, field vanes hear tests and collection of undisturbed/disturbed samples and laboratory testing on the samples should be as per relevant Indian Standards. The load test site shall be closer to critical loading locations as far as possible. Blanket of stone / sand, minimum 500 mm thick shall be spread over the test area before the commencement of the load tests. The blanket shall be compacted to a relative density of 80%. Rigid reinforcement concrete footing of required / appropriate size shall be either cast over the stone columns as per the specifications or may be cast away from the test site and transported to the test location so as to fix it properly over the sand blanket. Design and details of the footing shall be furnished by the contractor for approval. The diameter of the reinforced concrete footing shall be equal to tributary area of single stone column area. The spacing of stone columns in the case of a single column test with the center of the concrete footing coinciding with the center of the stone column. In the case of a group column test the diameter of the concrete footing shall be equal to 3 times tributary area of single stone column area. The spacing of the columns with its center coinciding with the center of area of the three columns laid in a triangular pattern. If the area is waterlogged, the water level shall be maintained at the concrete footing base level throughout the tests by dewatering. However, care shall be taken to prevent drawing out of water by centering the blanket or the subsoil.

Following procedure should be followed for application of load: The load should be applied to the footing by a suitable kentledge (see Fig. 3), taking care to avoid impact, fluctuations or eccentricity. The kentledge should be minimum 1.30 times the maximum test load. Load settlement observations should be taken to 1.5 times the design load for a single column and three column group test respectively. The settlements should be recorded by four dial gauges (sensitivity less than or equal to 0.01 mm) fixed at diametrically opposite ends of the footing. Each stage of loading should be near about1/5 of the design load and should be maintained till the rate of settlement is less than 0.05 mm/h at which instant the next stage of loading should be applied. The design as well as the maximum test load should be maintained for a minimum period of 12 h after stabilization of settlement to the rate as given in the above clause. Load settlement and time settlement relationships should be plotted from the settlements observed for each increment of load at intervals of 1 min, 2 min, 4 min,8min,16min, ½ H, I H, 1½ H,2 H,3 H,4 H, and so on till the desired rate of sttlementas been achieved. The time intervals maybe suitably modified if so desired after getting prior approval from the EIC. The test load should be unloaded in five stages. At each stage enough time should be allowed for settlements to stabilize. The load test should be considered acceptable if it meets the following settlement criteria: ➢ 10 to 12 mm settlement at design load for a single column test, and ➢ 25 to 30 mm settlement at the design load for a three-column group test.

9) LOADING TESTS ON WORKING STONE COLUMN

In order to ascertain the quality of job columns, a few single column tests shall be performed on the working columns depending upon the discretion of the Engineer-in-carge. For routine load test few job columns maybe tested upto 1.1 times the design load intensity with minimum kentledge of 1.3 times the design load.



Typical layout of load test on a single column

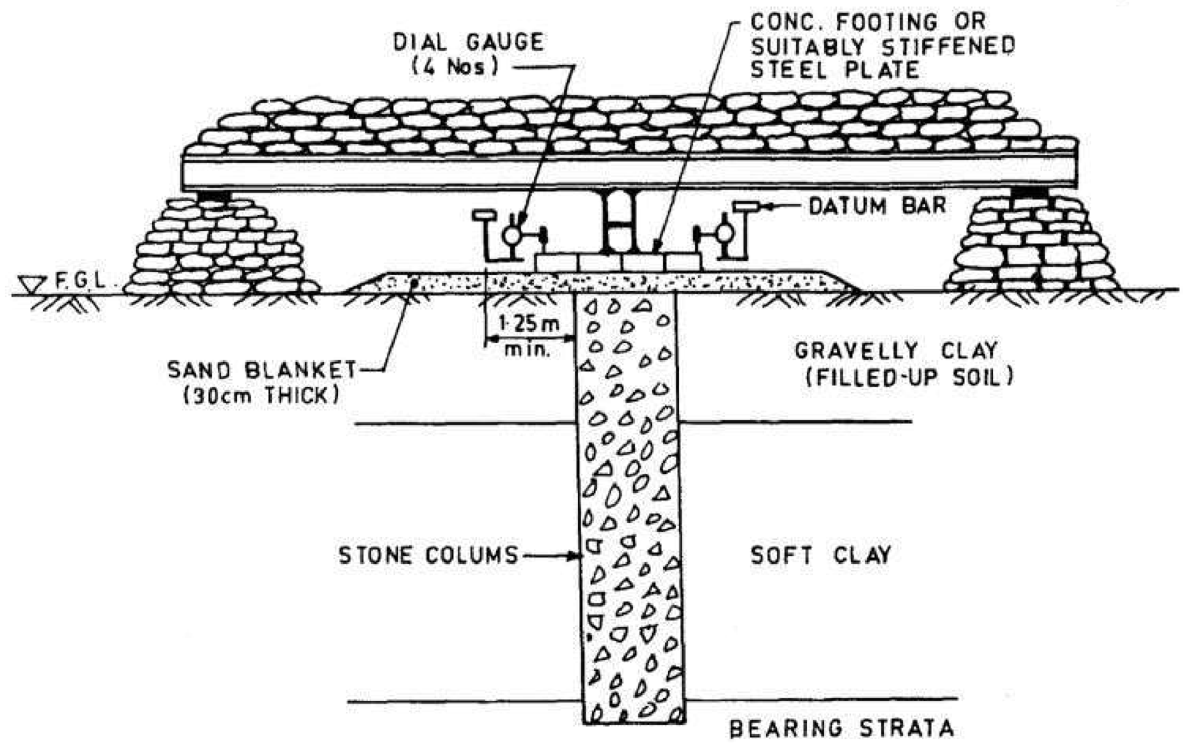
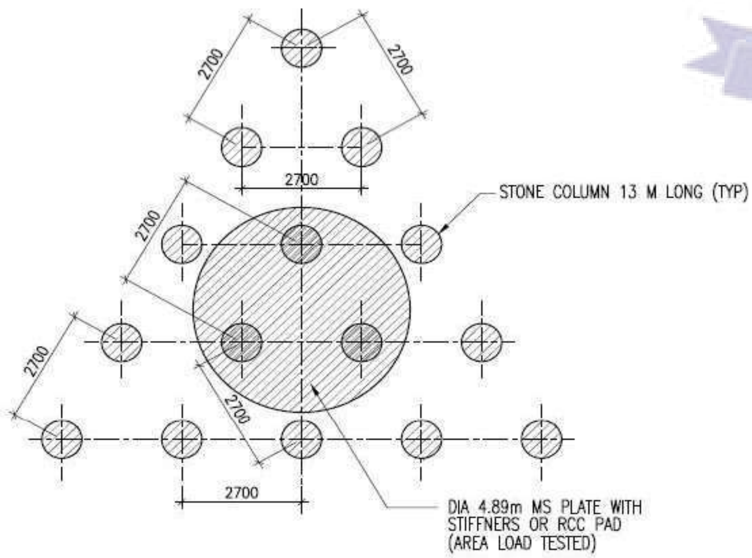


Fig.2



Typical layout of load test on a group of three stone columns

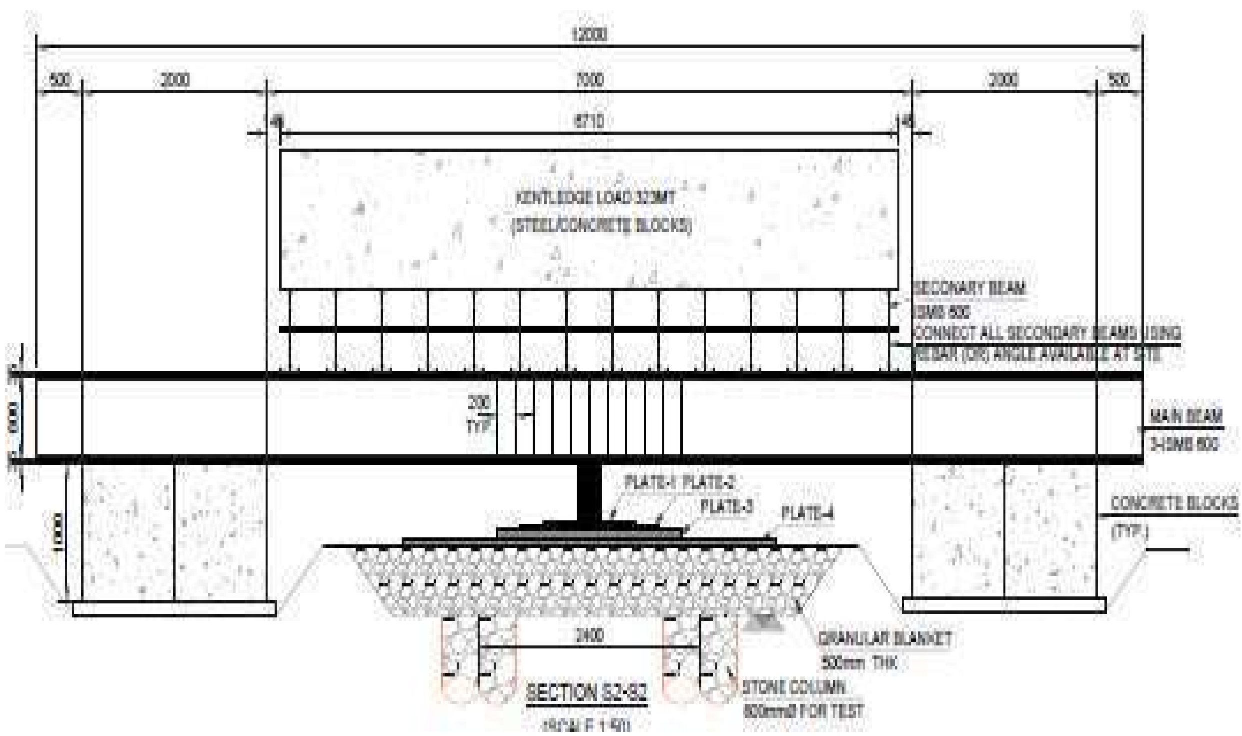
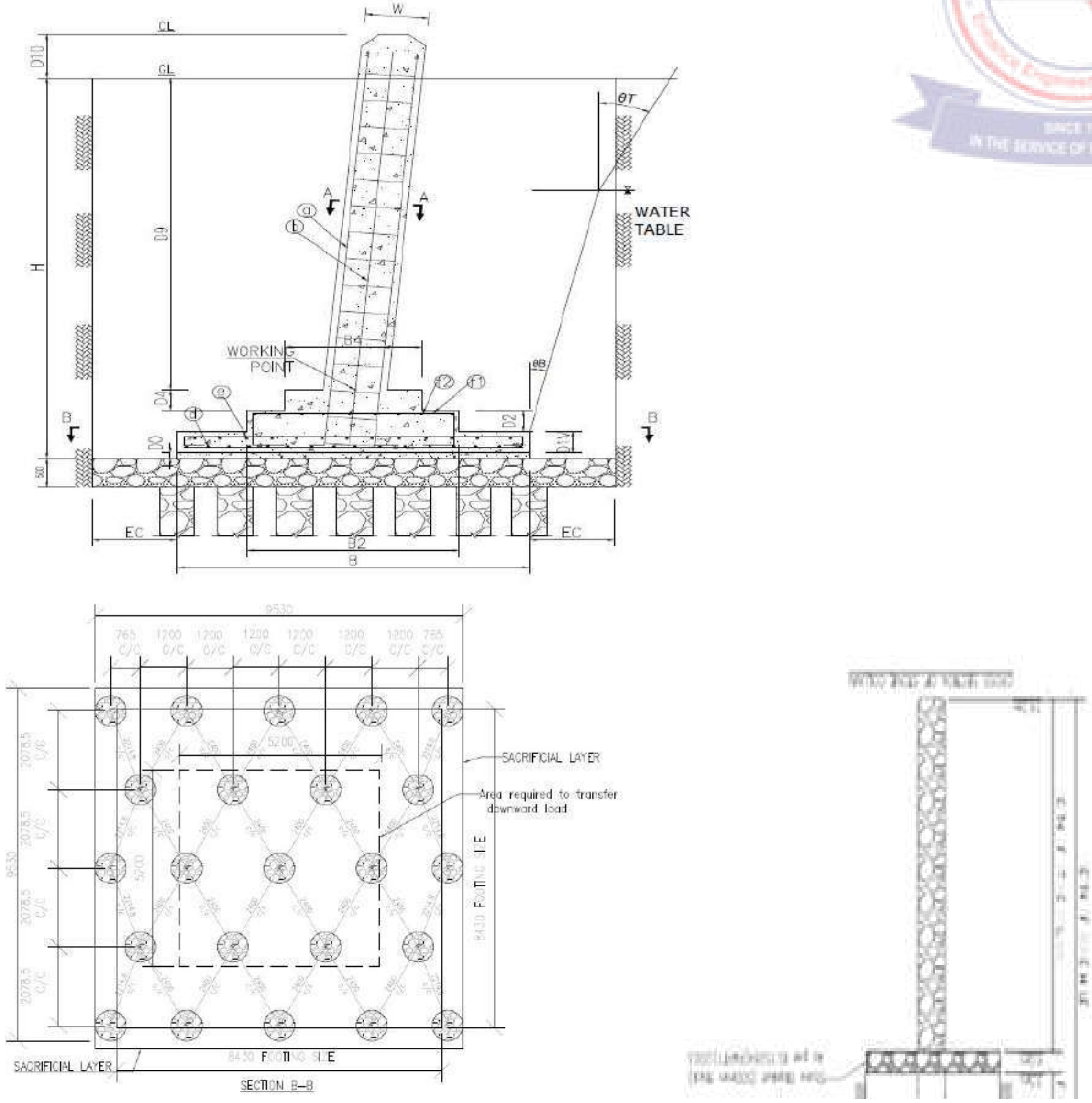


Fig. 3



Stone Column Foundation of 765kv D/C Khavda- Bhuj Transmission line

10) CONCLUSION

Stone columns provide an economical and effective alternative to traditional deep foundations (like driven piles or large drilled shafts) by creating a composite soil-stone mass with significantly improved geotechnical properties. After installation of stone columns, soil bearing capacity have increased from 3 to 5 T/m² to 12 to 15 T/m². Also, Foundation volumes have decreased considerably due to increase in bearing capacity of soil strata on which foundation rests. Stone columns are a preferred ground improvement solution for transmission line foundations where poor ground conditions (e.g., loose sands, soft clays) exist. The final decision requires a thorough geotechnical investigation and design that accounts for the specific tower loads (vertical, uplift, and lateral), soil profile, and seismic risks.

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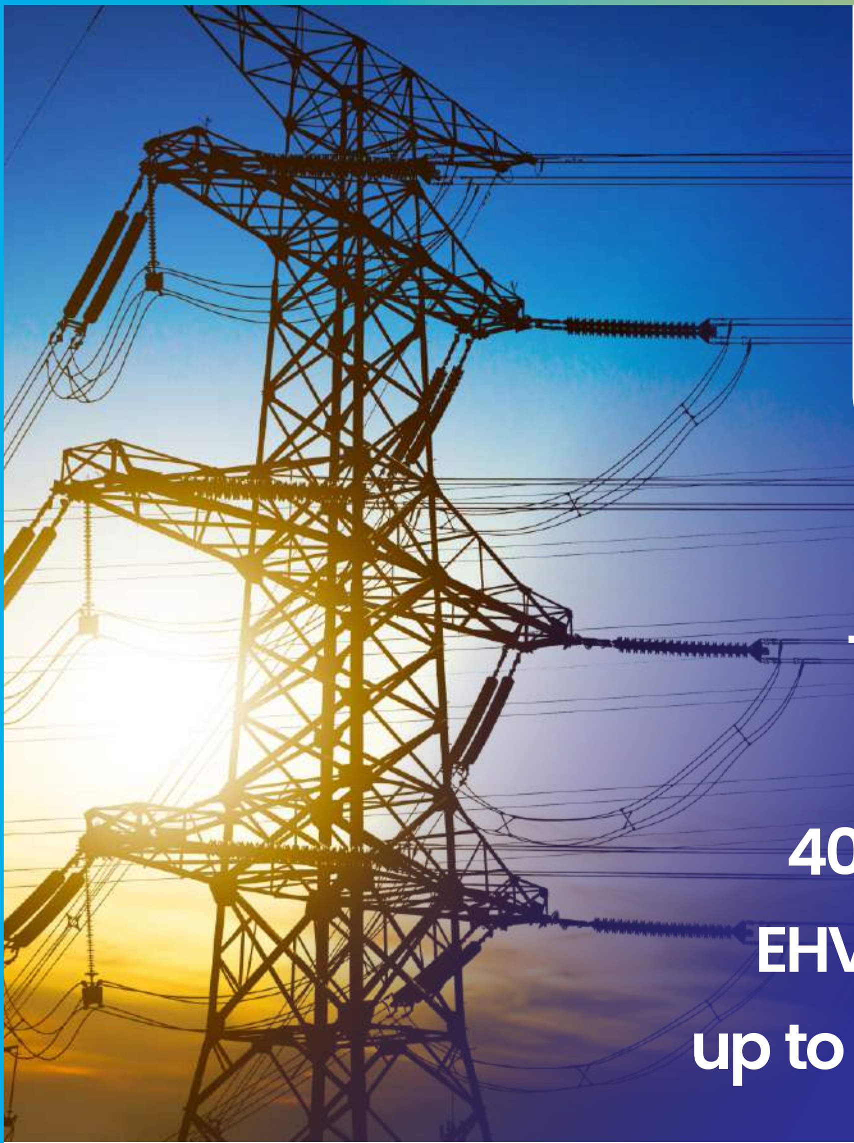

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Optimization of Right-of-Way (RoW) in Overhead Power Transmission Lines

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1. Introduction

The power sector remains the foundational infrastructure for a nation's socio-economic advancement. It encompasses three interlinked pillars—generation, transmission, and distribution—each playing a vital role in delivering reliable, affordable, and sustainable electricity. Among these, **transmission is the silent enabler**—bridging distant generation resources with growing and increasingly urbanized demand centers. As nations progress toward decarbonization and electrification, the transmission grid must not only expand in capacity but also advance in architectural sophistication and operational efficiency.

India’s transmission experience provides a compelling case study. With ambitious targets to integrate 500 GW of non-fossil fuel-based generation by 2030 and achieve net-zero emissions by 2070, the country has had to rethink its traditional transmission paradigms. Conventional 220 kV and 400 kV networks were insufficient to handle the high-capacity, geographically dispersed renewable generation. The adoption of 765 kV HVAC and ±800 kV HVDC corridors has enabled high-volume, long-distance power transfer while maintaining system stability, reducing losses and reducing RoW need.

This paper focuses on the **optimization of Right-of-Way (RoW)** for overhead transmission lines, exploring engineering strategies such as tower design innovation, conductor selection, multi-circuit layouts, and digital engineering. The objective is to demonstrate how systematic optimization can **maximize corridor efficiency, minimize environmental and social impact, and reduce project cost and execution time**. Case studies from Indian EHV projects illustrate how incremental and iterative innovations have resulted in measurable RoW reductions and improved transmission performance.

2. Evolution of India’s Transmission Infrastructure

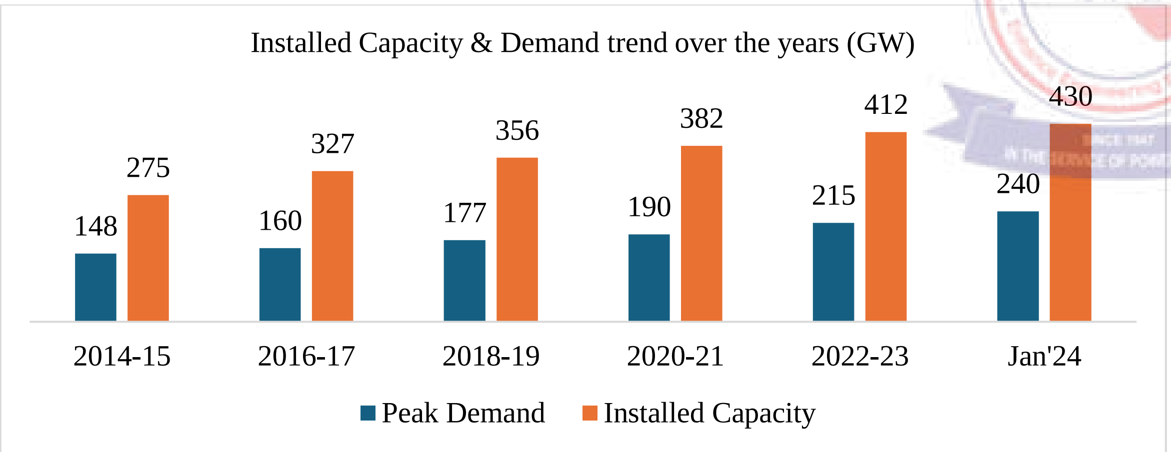
India’s transmission network has progressed from **33 kV regional systems in the 1950s** to a robust **EHV backbone**, enabling long-distance bulk power transfer across the country. This voltage evolution—through **132 kV, 220 kV, 400 kV, 765 kV HVAC**, and **±800 kV HVDC**—has been shaped by rising demand, uneven geographical distribution of generation resources, and increasing renewable integration.

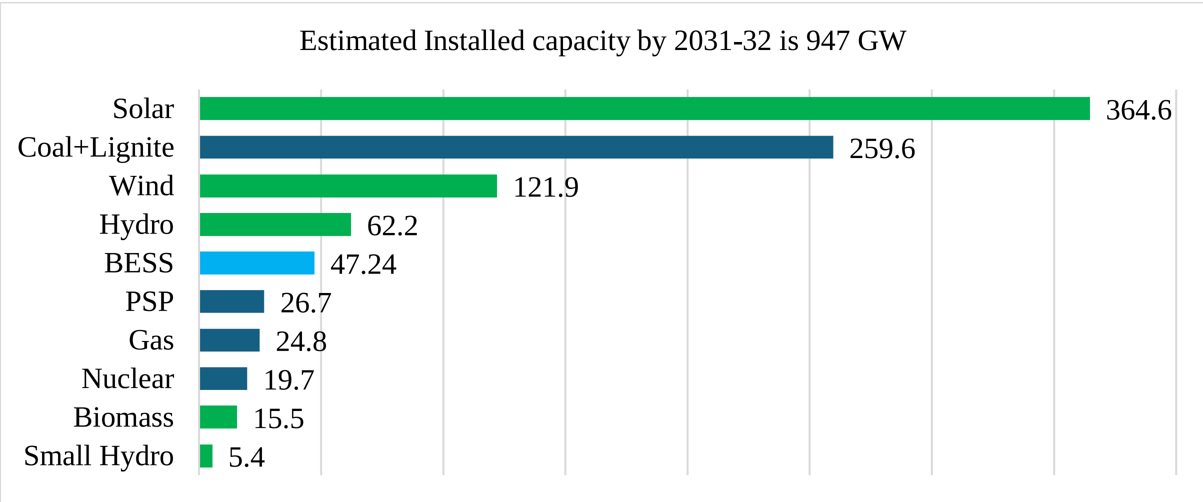
Each upgrade brought complex design and operational challenges, driving innovations in **tower structures, bundled conductors, insulation coordination**, and **protection philosophies**. With corridor availability limited, **multi-circuit towers** and **compact configurations** became essential for maximizing transfer capacity per RoW.

A landmark achievement in this journey was the realization of the **“One Nation, One Grid”** initiative [3], culminating in the full synchronization of India’s regional grids in **2013**. This unified grid platform now facilitates seamless power flow, real-time balancing, and optimal utilization of generation assets—particularly critical with the influx of variable renewable energy. This unification laid the groundwork for coordinated planning and seamless integration of EHV corridors.

India’s current EHV network spans the subcontinent, reliably evacuating power from **coal belts, hydro basins, and RE zones** to distant load centres. It serves as a globally replicable model for countries pursuing large-scale renewable integration, grid unification, and high-efficiency transmission planning.

The following graphs indicates the demand & capacity requirements:



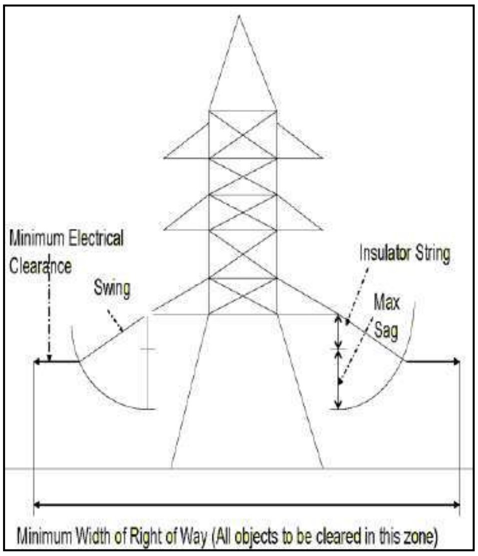


3. Right-of-Way (RoW)

In power transmission, **Right-of-Way (RoW)** refers to the legal and physical corridor of land allocated for constructing and operating overhead transmission lines. It defines the **width of land** that the utility or EPC company can use for towers, conductors, and associated infrastructure while maintaining **safety clearances** from people, buildings, roads, and other utilities.

Key points:

- **Width varies by voltage and tower design:** Higher voltages typically require wider RoW for safety clearances.
- **Purpose:** Ensures safe operation of lines, access for maintenance, and protection from external interference.
- **Influences cost and design:** Wider RoW increases land acquisition costs; constrained RoW drives design innovation (compact towers, multi-circuit lines).
- **Environmental and social impact:** Proper RoW planning minimizes deforestation, wildlife disruption, and community displacement.



In short, **RoW is the corridor "footprint" of a transmission line**, and optimizing it is critical for cost, safety, and environmental sustainability.

4. Challenges in Right-of-Way Acquisition

Transmission RoW acquisition in India is influenced by multiple socio-technical factors:

1. **Densely Populated Areas:** Urban expansion has encroached on traditional transmission corridors. Conventional towers require large setbacks for safety, increasing corridor widths beyond feasible limits.
2. **Environmental and Forest Zones:** Many corridors traverse reserved forests, wildlife sanctuaries, or tribal lands, necessitating minimal ground disturbance and preservation of flora and fauna.
3. **Topographical Constraints:** Hilly terrain, river crossings, and narrow valleys restrict the placement of conventional towers.
4. **High Land Costs:** In urban and peri-urban areas, land acquisition costs can escalate project budgets substantially.
5. **Regulatory and Safety Norms:** Proximity to airports, highways, and human habitation imposes additional height and clearance constraints.

These challenges underscore the necessity for engineering approaches that optimize corridor use without compromising system reliability or safety. Reducing RoW is no longer optional—it is a critical enabler for timely project execution and cost efficiency in EHV transmission programs.

5. Right-of-Way Optimization: Engineering and Execution Strategies

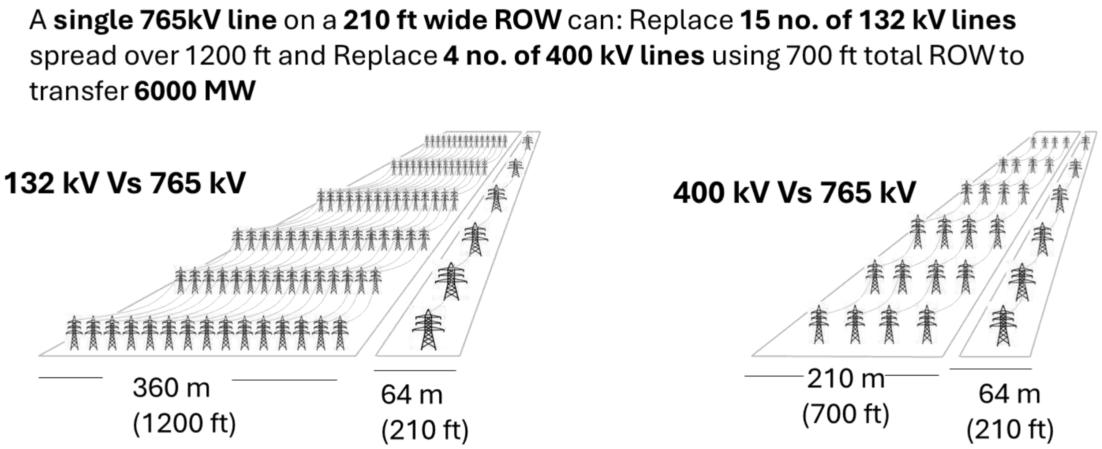
Optimizing RoW requires a holistic approach that integrates voltage selection, tower configuration, conductor technology, multi-circuit layouts, structural weight reduction, and digital engineering. These elements interact to maximize corridor efficiency while maintaining system reliability.

5.1 Voltage Selection and Power Transfer Efficiency

Higher voltage levels enable greater power transfer per circuit, reducing the number of circuits required for a given load. For example, a 765 kV D/C line can carry approximately 6,000 MW, compared to 1,500 MW for a 400 kV D/C line, while occupying only slightly more corridor width. Similarly, ±800 kV HVDC bipoles can deliver up to 8,000 MW across long distances with lower line losses and improved controllability.

Parameter	400 kV HVAC	765 kV HVAC	±800 kV HVDC
Typical Power Transfer Capacity	~1,500 MW (D/C)	~6,000 MW (D/C)	6,000–8,000 MW (Bipole)
Line Losses over 1000 km (621 miles)	6–7%	3–3.5%	<3%
Right of Way (D/C line)	~52 m (170 ft)	~64 m (210 ft)	~65–70m (213 – 230 ft)
Corridor Efficiency in MW/m RoW (MW/ft RoW)	~29 (9)	~94 (29)	~86-93 (21-28)
System Stability Support	Moderate	High (improved voltage profile)	Very High (controllable power flow)
Interconnection Type	Synchronous	Synchronous	Asynchronous
Controllability	Limited	Improved	Excellent
Reactive Power Compensation	High requirement	Moderate requirement	Not required (no reactive power flow)
Typical Application	Regional power transfer	Backbone grid, RE corridors	Long-distance, high-volume corridors

This voltage-based optimization directly contributes to **RoW efficiency**, as higher capacity per corridor reduces the number of parallel lines required. In practice, utilities increasingly adopt double or multi-circuit configurations on high-voltage towers to consolidate power transfer and minimize land use.



Power utilities have increasingly adopted **Double Circuit (D/C)** and **Multi Circuit (M/C)** configurations over **Single Circuit (S/C)** lines to maximize power transfer per meter of corridor width. Innovative tower designs, including **765 kV D/C**, **±800 kV HVDC monopole/bipole**, and **experimental 1200 kV S/C**, have been introduced to meet this demand with improved mechanical and electrical performance.

4.2 Tower Configurations and Structural Innovations

Innovative tower designs reduce footprint while maintaining electrical and mechanical performance:

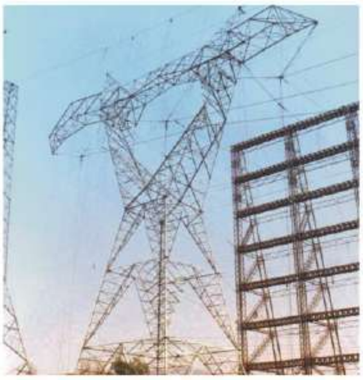
Case Study 1: Evolution of 765 kV Tower Configurations for RoW Optimization and Constructability

In the early planning stages of 765 kV transmission corridors, the standard Right of Way (RoW) was envisaged at approximately **85 meters (280 ft)** using conventional **horizontal tower configurations**. While structurally sound, these towers demanded expansive corridors—posing land acquisition challenges, higher compensation costs, and environmental concerns in forest and densely populated regions.

To mitigate this, the sector adopted **Compact Cross Arm Tower (CAT)** designs, aimed at reducing RoW without compromising on electrical clearances. These towers brought down RoW significantly but introduced a new set of field challenges. **Erection required specialized tools and skillsets**, particularly for stabilizing the tower body during installation. **Dummy members** were often used for temporary bracing to ensure safety until full assembly, increasing execution time and operational risk.

Based on field feedback and safety audits, the industry moved toward the adoption of **Vertical Configuration Towers**. These designs not only **maintained compact RoW profiles** but also **simplified the erection process**, reduced dependency on specialized labor, and **enhanced safety margins**. Vertical towers have now become the de facto standard across most 765 kV projects in India due to their **constructability, modularity, and standardization potential** across diverse terrains and contractors.

This three-stage design evolution—**from Horizontal to Compact CAT to Vertical configurations**—exemplifies how India's transmission engineering has matured through iterative optimization, balancing design innovation with execution practicality.

Initial Horizontal Towers	**Compact CAT Towers**	**Vertical Configuration Towers**
		
RoW: 85 m (279 ft)	RoW: 64 m (210 ft)	RoW: 64 m (210 ft)
land-heavy & costly	Special tools, dummy members, higher risk	Ease of erection, modularity, safer execution
Typical Power Transfer Capacity: ~3000 MW	Typical Power Transfer Capacity: ~3000 MW	Typical Power Transfer Capacity: ~6000 MW

Case Study 2: Winged Tower with Wide/Rectangular Base
This tower incorporates an innovative structural layout to achieve material efficiency, visual appeal, and clearance compliance:

- Wing-shaped cross-arms preserve necessary electrical clearances without increasing projection or vertical separation
- Optimized peak and lean body structure enhance aerodynamic stability
- Aesthetic improvement over bulky conventional towers—favorable for urban and scenic zones
- Key Technical Gains:
  - 20% reduction in steel weight:
  - Conventional Tower: 37.2 MT (82012 lbs)
  - Winged Tower: 31.04 MT (68432 lbs)
- Lean body design: Body height increased from 9 m (30ft) to 20 m (66ft), allowing for reduced cross-arm span and improved RoW usage

This design exemplifies the shift toward functional plus form-driven engineering, accommodating mechanical, electrical, and visual considerations simultaneously.

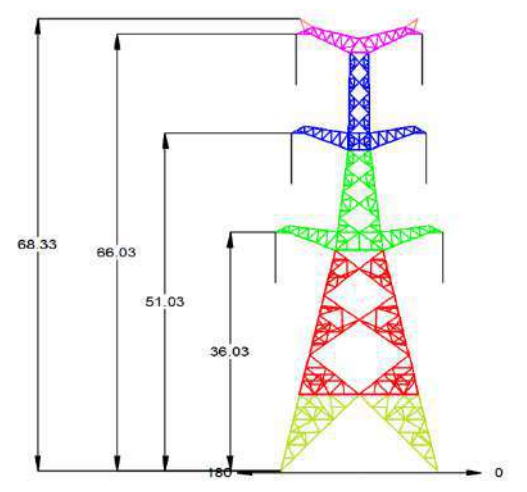
 Early Generation 765 kV Over Designed tower	 New Design of 765 kV – 20% Reduction in Weight

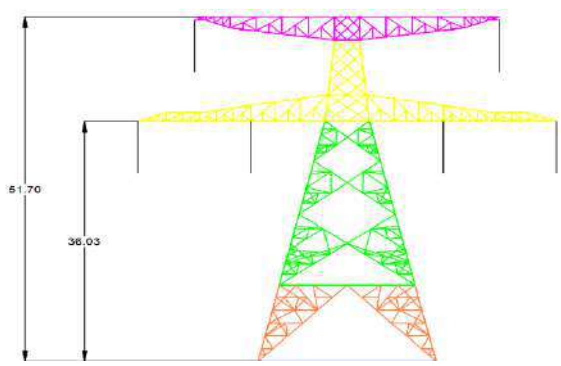
Case Study 3: Design Adaptation near Sensitive Airspace – Fatehgarh Double Delta Tower
In proximity ~16 km (~10 Miles) to an airport near Fatehgarh, the construction of 765 kV transmission lines posed a unique challenge: **tower height had to be reduced** to comply with aviation safety norms while maintaining high-capacity power transfer.

Design Challenge:
Standard **vertical configuration towers** tend to have taller profiles, which conflicted with **airport airspace clearance (Obstacle Limitation Surfaces – OLS)**. Regulatory constraints required substantial **reduction in tower height** without sacrificing structural integrity or electrical performance.

Engineering Innovations:

- Transition from Vertical to Double Delta configuration: This allowed the same number of sub-conductors per phase to be maintained while lowering the overall tower height.
- Cross-arm redesign and optimized tower peak further reduced total elevation.
- Modified tower spotting and profiling ensured minimum impact on flight path surfaces while preserving standard electrical clearances.





Standard Vertical Tower (~68 m)	Double Delta Tower (~52 m) Tower Height: ↓ ~25%

Benefits:

- Eliminated requirement for rerouting, saving significant time and land acquisition effort.
- Avoided potential delays in clearance from aviation authorities.
- Demonstrated engineering flexibility and multi-disciplinary coordination (transmission + civil aviation).

Broader Implication:
This case showcases the importance of **context-sensitive tower design**, especially in zones with air traffic restrictions, urban encroachments, or other vertical limitations.

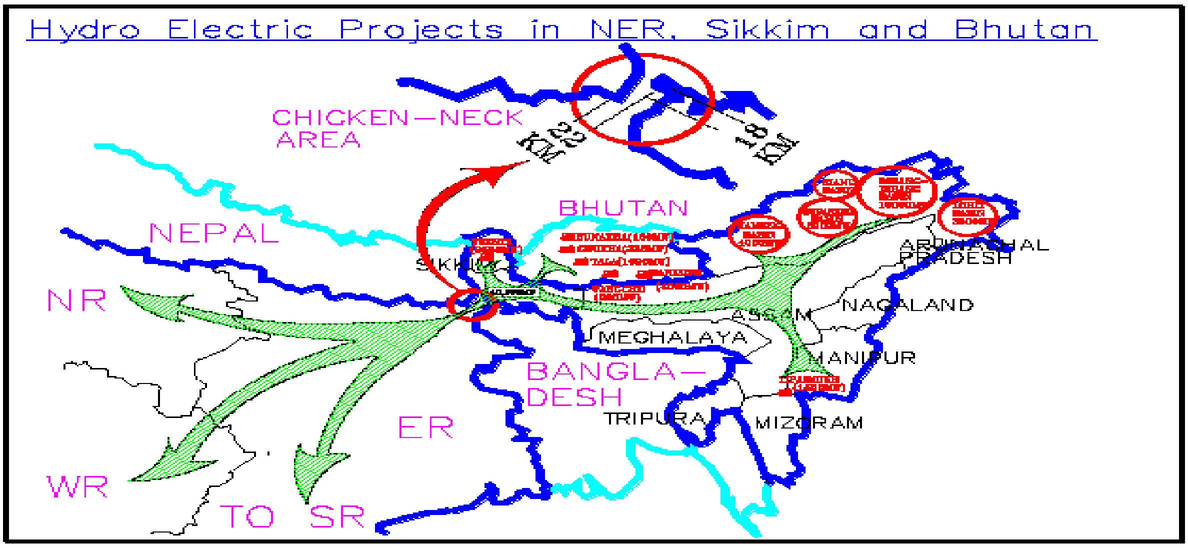
4.3 Conductor Technology

High-Temperature Low-Sag (HTLS) conductors increase thermal rating and reduce sag, enabling higher power transfer within the same RoW. These conductors can be operated at 200° C. Steel core (High strength) carries most of the load and hence less sag when compared to conventional ACSR conductor under high temperature. High temperature low sag conductors can carry around 2.5 times the power capacity when compared to normal ACSR conductor. Some conductors HTLS conductors are below:

- ACSS (Aluminium Conductor Steel Supported)
- ACCC (Aluminium Conductor Composite Core)
- INVAR Conductor

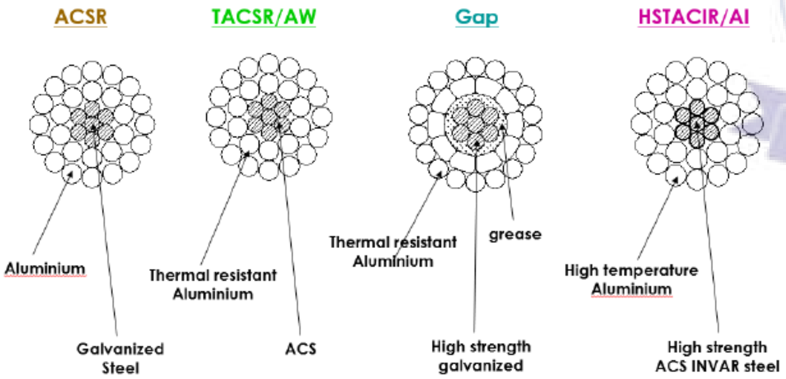
Case Study 4: 400 kV Siliguri-Purnea Line Upgrade, Chicken Neck Corridor

- **Challenge:** Narrow corridor with strategic constraints; existing line required capacity increase.
- **Solution:** HTLS conductor replacement enabled 2.5× power transfer without widening RoW.
- **Outcome:** Operational capacity increased, zero land acquisition, project completed within schedule.



Earlier generations of EHV lines used ACSR Moose and Dove conductors. However, with the push toward 765 kV systems, newer alloys like **AL-59 Zebra** emerged as the preferred choice. Compared to ACSR Moose, ACSR and AAAC Zebra conductors, AL-59 offers:

- Comparable performance at a **lower overall cost** by 6%
- Adequate sag performance (13.17 m) with reduced weight and improved corrosion resistance.
- Enhanced current capacity and thermal stability at 85°C operating temperature.
- Lower magnetic losses—leading to **reduced line losses and better energy efficiency**.



This transition aligns with the industry's goal of total cost optimization, balancing **mechanical strength, sag characteristics, and economic efficiency**.

4.5 Environmentally Optimized Tower Design and ESG Integration

A growing portion of new lines traverse ecologically sensitive areas—including reserved forests, wildlife corridors, and densely vegetated tribal zones. The engineering response has evolved beyond conventional design to embrace Environment, Social, and Governance (ESG) principles as a core part of infrastructure development. ower design and alignment strategies now aim to minimize ecological disruption while meeting technical performance standards.

Case Study 5: Eco-Sensitive 765 kV Design—Engineering for Forest and Wildlife Corridors
In a 765 kV project crossing a Reserved Forest zone, multiple eco-sensitive measures were implemented:

- Compact, narrow-base towers to reduce physical footprint and excavation area.
- Extended spans (up to 500 m (1640 ft)) to lower tower count in vegetated zones.
- Elevated tower base clearances (up to 18 m (59 ft)) designed for wildlife crossing—particularly in elephant corridors.
- GIS-based realignment to avoid tree-dense patches and ecologically significant terrain.

Quantifiable ESG Impact:

- Over 3,000 matured trees saved, significantly reducing deforestation.
- Reduction of 2,000–2,500 m^3 of concrete due to optimized foundations.
- Reduction of 500–600 MT of steel through tower geometry.
- Water savings of approximately 1,800,000–2,000,000 liters, assuming 700–800 liters per cubic meter of concrete.
- Project clearance timeline reduced by 12–18 months

4.6 Digital Engineering for RoW Optimization

Digital platforms developed in-House by KEC have transformed tower and foundation design. Automation enables evaluation of thousands of design permutations, optimizing steel tonnage, foundation forces, and material usage. Digital engineering accelerates design cycles by up to 60% and standardizes quality across multiple sites.

By embedding simulation, AI/ML tools, and automated structural validation, EPC firms can deliver **future-ready, high-efficiency transmission corridors**, ensuring RoW optimization is embedded from early planning through execution.

6. Role of EPC Firms in Accelerating Transition

EPC firms play a critical role in realizing RoW optimization, translating design innovations into field execution. Integrated platforms connect engineering, procurement, and logistics workflows, enabling:

- Terrain-specific tower configuration and spotting
- Structural weight reduction and modular design
- Efficient use of prefabricated components to accelerate timelines

By combining **engineering innovation with execution intelligence**, EPC firms compress project cycles from 36–48 months to 15–18 months, maintain quality and safety standards, and ensure optimal use of land, steel, and concrete. Modular construction, mechanized erection, and parallel execution fronts further enable deployment even in constrained or difficult terrains.

7. Results and Discussion

The combined strategies—higher voltage, compact tower designs, multi-circuit layouts, HTLS conductors, ESG integration, and digital engineering—have yielded tangible results:

- **RoW Reduction:** 20–40% compared to conventional designs, enabling deployment in urban, forest, or constrained terrains.
- **Cost Efficiency:** Reduced land acquisition, steel, and concrete consumption.
- **Operational Reliability:** Electrical clearances maintained with higher thermal and mechanical performance.
- **Environmental and Social Benefits:** Minimal deforestation and wildlife disruption, reduced resettlement, and alignment with ESG goals.

- **Scalability:** Applicable across 400 kV, 765 kV, and ±800 kV corridors, supporting hybrid HVAC/HVDC networks.

Field experiences validate that RoW optimization is not just an engineering exercise but a **strategic enabler for timely, cost-effective, and environmentally responsible transmission development**.

8. Conclusion

Optimization of Right-of-Way is a critical enabler for India's rapidly expanding transmission network. Lessons from 400 kV, 765 kV, and ±800 kV corridors indicate that:

- Compact and vertical tower designs, multi-circuit layouts, and advanced conductor technology collectively reduce RoW by 25–50%
- Digital engineering tools accelerate design cycles, enable precise load and clearance calculations, and improve constructability
- Field implementations in constrained corridors demonstrate significant savings in land, cost, and schedule
- RoW optimization contributes to environmental and social compliance, supporting ESG objectives in infrastructure development

Strategic Recommendations:

- Incorporate RoW optimization in early-stage transmission planning.
- Leverage HTLS conductors and bundle optimization for enhanced corridor efficiency.
- Adopt vertical and multi-circuit tower configurations in constrained terrains.
- Use digital engineering platforms to simulate design permutations and optimize material usage.
- Integrate RoW strategies with renewable corridor planning to maximize capacity per meter of land.

References:

[1] https://cea.nic.in/wp-content/uploads/irp/2022/09/DRAFT_NATIONAL_ELECTRICITY_PLAN_2022_27_JULY_2022_COMPRESSED_FINAL-1.pdf

[2] https://ctuil.in/annual-rolling-plan/reports

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Hitachi Energy

HITACHI

Enhancement of Power Transfer Capacity with New Generation Conductor

Uprating of Existing Transmission Line

HITACHI

Keval Velani

Hitachi EnergyTEC

30+	Training
650+	Participants
300+	Training Hours
2	Trainer Appreciation Award

Energy Consulting

14+ Years	Experience in Substation as well as Transmission Line Planning, Feasibility, Design Engineering, R&M and Digitalization
35+ Designed	AIS and GIS Substations up to 765 kV within India and outside India
30+ Designed	Transmission Lines up to 765 kV within India and outside India
20+ Publication	Technical Papers at National & International Conferences
Associate Member	Institutions of Engineers (India)
Life Member	The Society of Power Engineers (India)

2 Public

HITACHI

Contents

HITACHI

1 Network Details & Overview

Network Details & Overview - Existing

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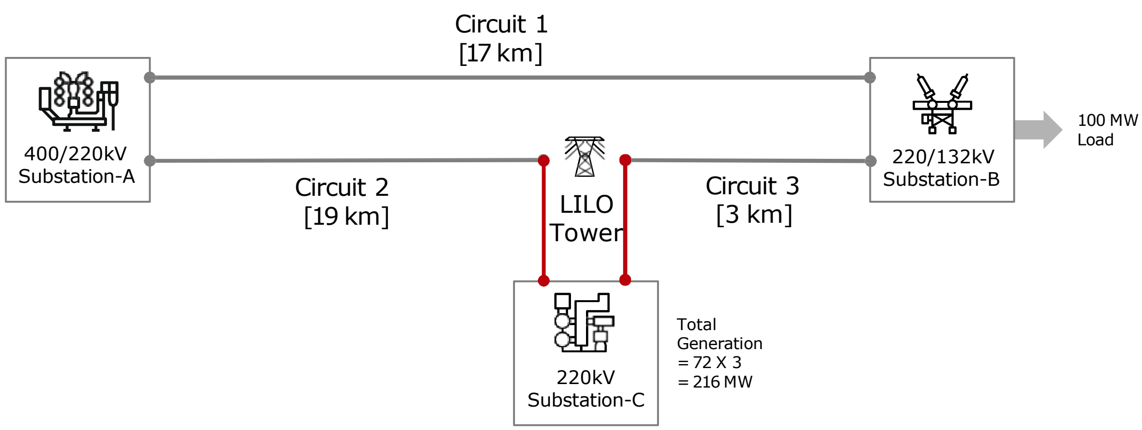
220 kV D/C SS-A to SS-B & SS-C LILO Connectivity Network



Network Details & Overview - Existing

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220 kV D/C SS-A to SS-B & SS-C LILO Connectivity Network

Circuit 1

400/220kV SS-A to
220/132kV SS-B

Line Length : 17 km

Conductor : ACSR Zebra

Circuit 2

400/220kV SS-A to
220kV SS-B

Line Length : 19 km

Conductor : ACSR Zebra

Circuit 3

220/132kV SS-B to
220kV SS-C

Line Length : 3 km

Conductor : ACSR Zebra

Network Details & Overview - Proposed

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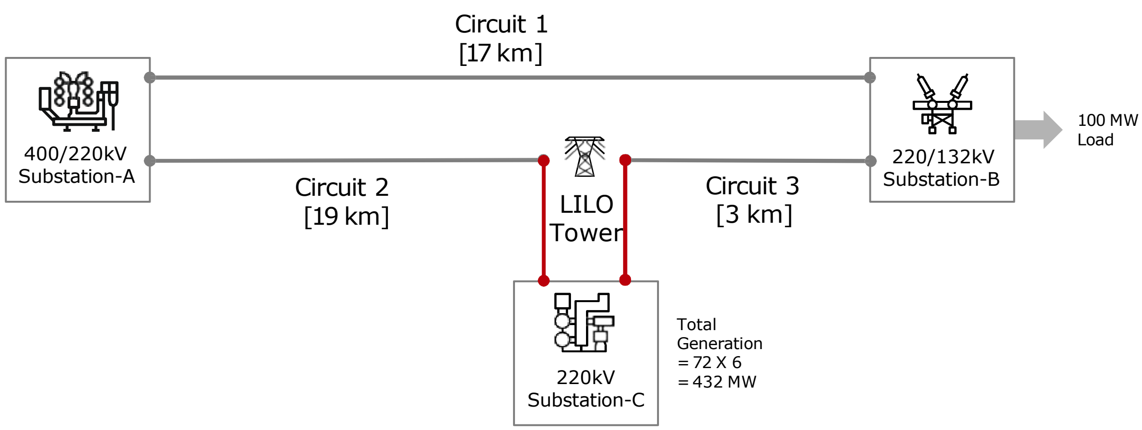
220 kV D/C SS-A to SS-B & SS-C LILO Connectivity Network



Network Details & Overview - Proposed

HITACHI

220 kV D/C SS-A to SS-B & SS-C LILO Connectivity Network

Circuit 1

400/220kV SS-A to
220/132kV SS-B

Line Length : 17 km

Conductor : ACCC Drake HTLS

Circuit 2

400/220kV SS-A to
220kV SS-B

Line Length : 19 km

Conductor : ACCC Drake HTLS

Circuit 3

220/132kV SS-B to
220kV SS-C

Line Length : 3 km

Conductor : ACCC Drake HTLS

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2 Input Details

Input Details

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Details form Customer & OEM

Input details for Substation

- Single Line Diagram
- Plan & Section Layout
- Erection Key Diagram
- Clamps & Connectors details
- Protection Single Line Diagram
- Existing Protection Settings

Input details for Transmission Line

- Transmission Line Profile
- Tower Schedule
- Existing Conductor details / GTP
- Transmission Loading details

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3 Case Study & Analysis

Case Study & Analysis

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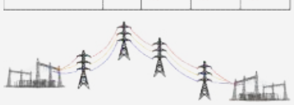
Methodology - Enhancement of Power Transmission Capacity

Uprating of OHTL

Description / Equation	Unit	ACSR Moose	STACIR Moose	ACSS Moose
Case - 1				
Final Equilibrium Temperature	°C	75	74.35	76.1
Current to be Maintained	Amp	750	750	750
AC Resistance	Ω/km	0.0698	0.0672	0.0735
Line Losses	kW / ckt	39.2	37.8	41.4
Power Factor	-	0.9	0.9	0.9
Power Transferred	MW / ckt	468	468	468

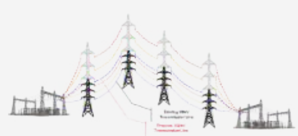


Description / Equation	Unit	ACSR Moose	STACIR Moose	ACSS Moose
Case - 2				
Final Equilibrium Temperature	°C	75	210	210
Current to be Maintained	Amp	750	1864	1786
AC Resistance	Ω/km	0.0698	0.0961	0.1047
Line Losses	kW / ckt	39.2	333.9	334
Power Factor	-	0.9	0.9	0.9
Power Transferred	MW / ckt	468	1163	1114

Additional RoW : Not Required
Tower Modification : Not Required
Conductor : Replacement
Hardware : Replacement

01

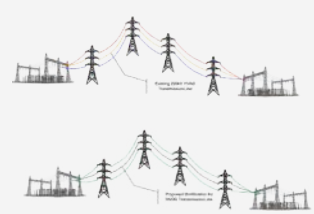
Upgrading of OHTL



Additional RoW : Not Required
Tower Modification : Required
Conductor : Replacement
Hardware : Replacement

02

AC to DC Conversion



Additional RoW : Not Required
Tower Modification : May be Required
Conductor : May be Required
Hardware : May be Required

03

Case Study & Analysis

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Methodology - Uprating of OHTL

Description	Unit	ACSR Zebra	ACCC Drake	ACCC Drake	ACCC Drake
Final Equilibrium Temperature	**°C**	**85**	**79.2**	**176.7**	**180**
Current to be Maintained	**Amp**	**709**	**709**	**1580**	**1598**
AC Resistance	Ω/km	0.0867	0.0665	0.0875	0.0882
Line Losses	kW / ckt / km	130	100	66	68
Power Factor	-	0.9	0.9	0.9	0.9
Power Transferred	**MW / ckt / km**	**244**	**244**	**542**	**549**

✗	✗	✓	✓
Additional RoW	Tower Modification	Conductor Replacement	Hardware Replacement

Current Carrying Capacity & Line Loss Calculation as per IEEE 738-2006 Standard

Case Study & Analysis

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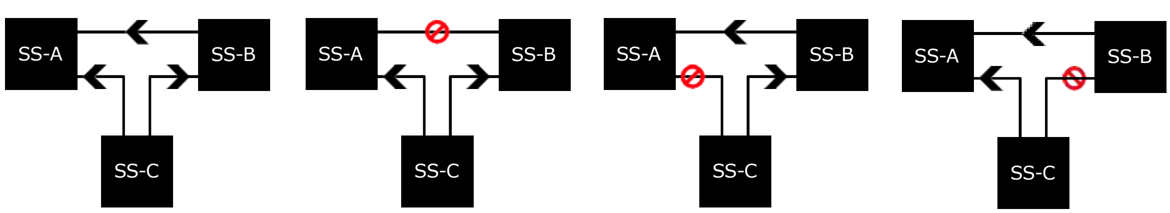
220 kV D/C SS-A to SS-B & SS-C LILO Connectivity Power Flow Analysis

Case-1 Circuit 1-2-3 (In Services)

Case-2 Circuit 1 (Zero Power)

Case-3 Circuit 2 (Zero Power)

Case-4 Circuit 3 (Zero Power)



Case Study & Analysis - Existing

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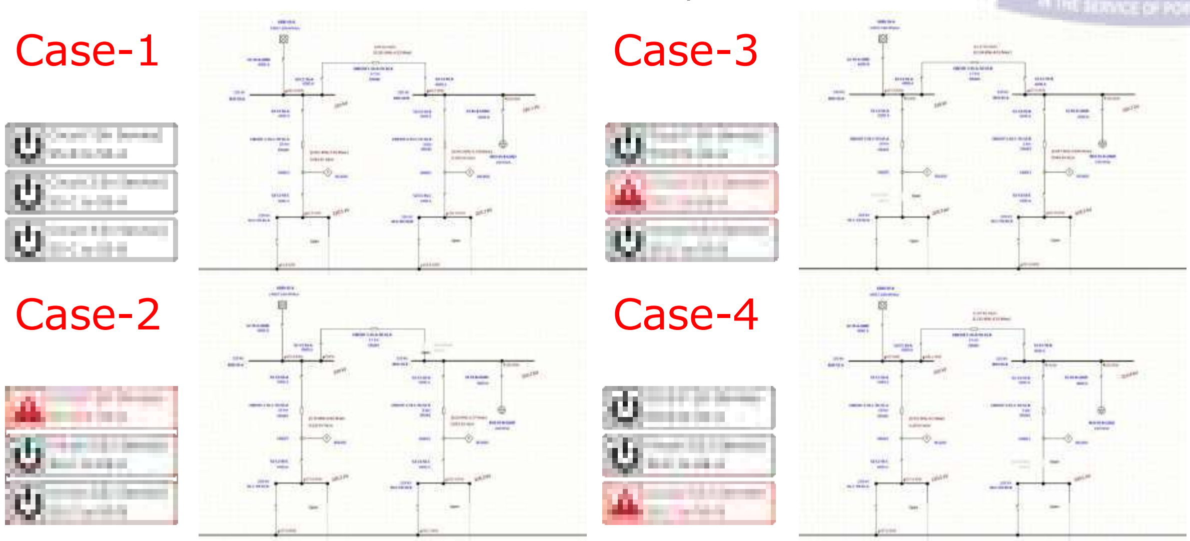
220 kV D/C Transmission Line Power Flow Analysis Normal & N-1 Condition



Case Study & Analysis

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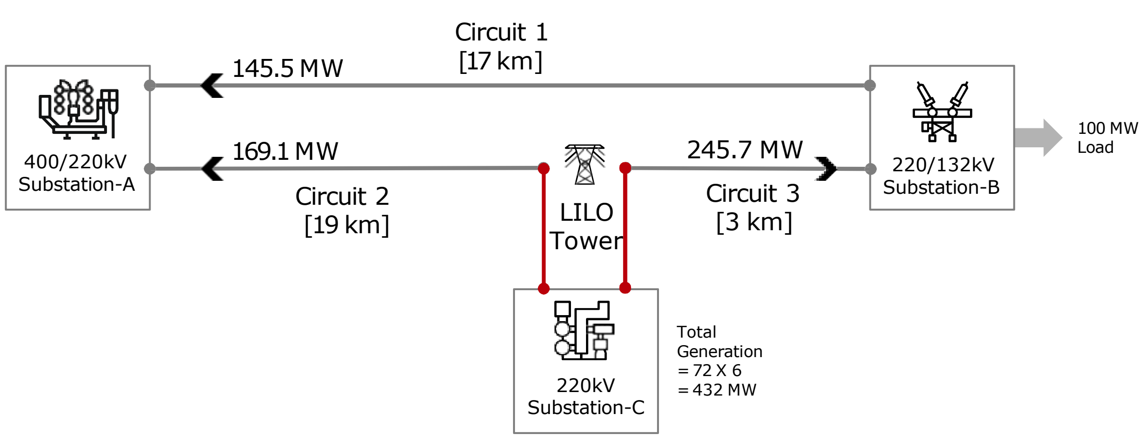
220 kV D/C Transmission Line Power Flow Analysis
Case-1 | Normal Condition



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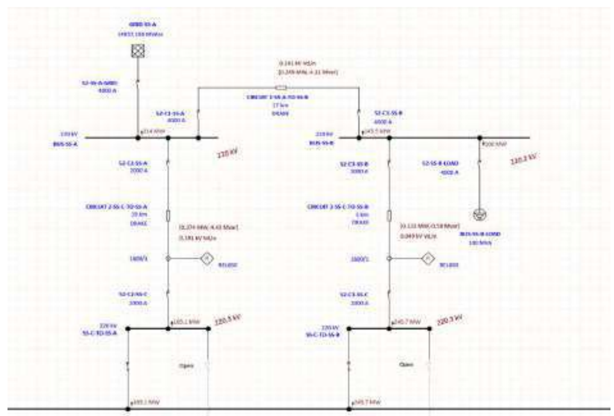
220 kV D/C Transmission Line Power Flow Analysis
Case-1 | Normal Condition

All Circuits Under Normal Condition

- Circuit 1 [In Service] SS-B to SS-A
- Circuit 2 [In Service] SS-C to SS-A
- Circuit 3 [In Service] SS-C to SS-B



Case Study & Analysis

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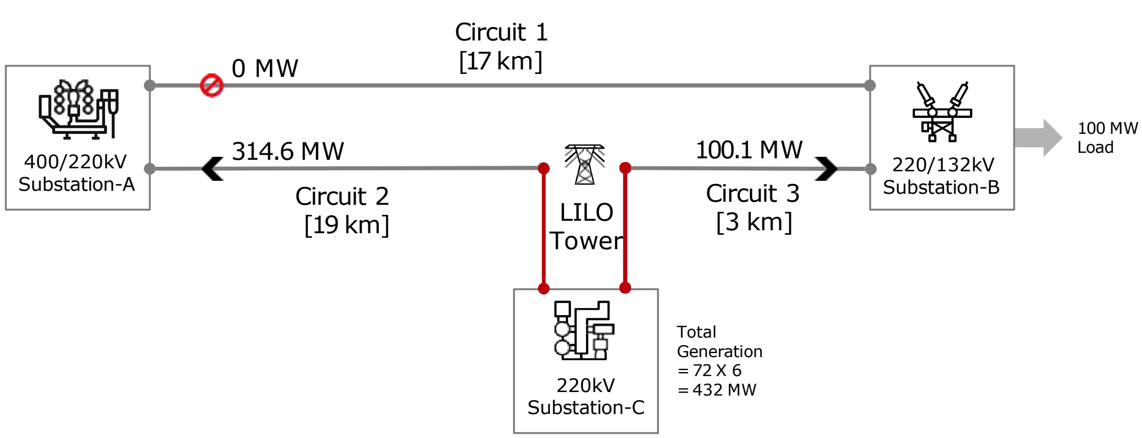
220 kV D/C Transmission Line Power Flow Analysis
Case-2 | N-1 Condition

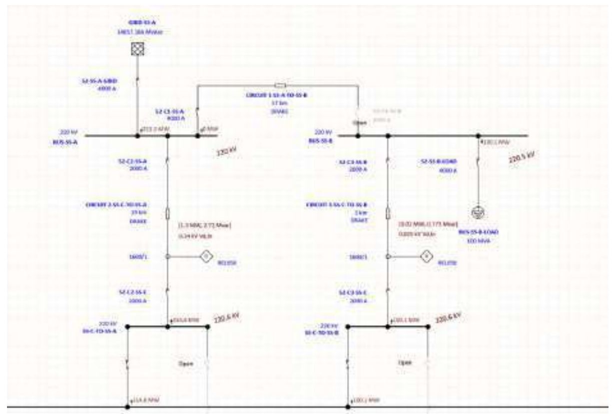


Case Study & Analysis

HITACHI

220 kV D/C Transmission Line Power Flow Analysis
Case-2 | N-1 Condition

Outage of Circuit-1



Circuit 1 [In Service]
SS-B to SS-A

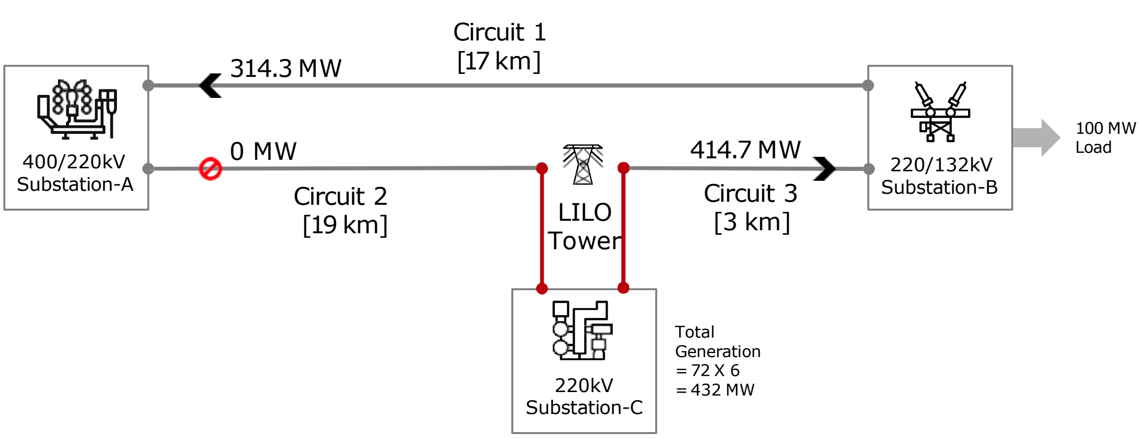
Circuit 2 [In Service]
SS-C to SS-A

Circuit 3 [In Service]
SS-C to SS-B

Case Study & Analysis

HITACHI

220 kV D/C Transmission Line Power Flow Analysis
Case-3 | N-1 Condition



Case Study & Analysis

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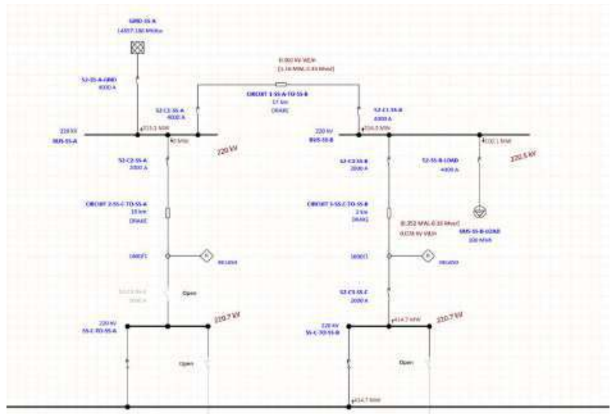
220 kV D/C Transmission Line Power Flow Analysis
Case-3 | N-1Condition

Outage of Circuit-2

Circuit 1 [In Service]
SS-B to SS-A

Circuit 2 [In Service]
SS-C to SS-A

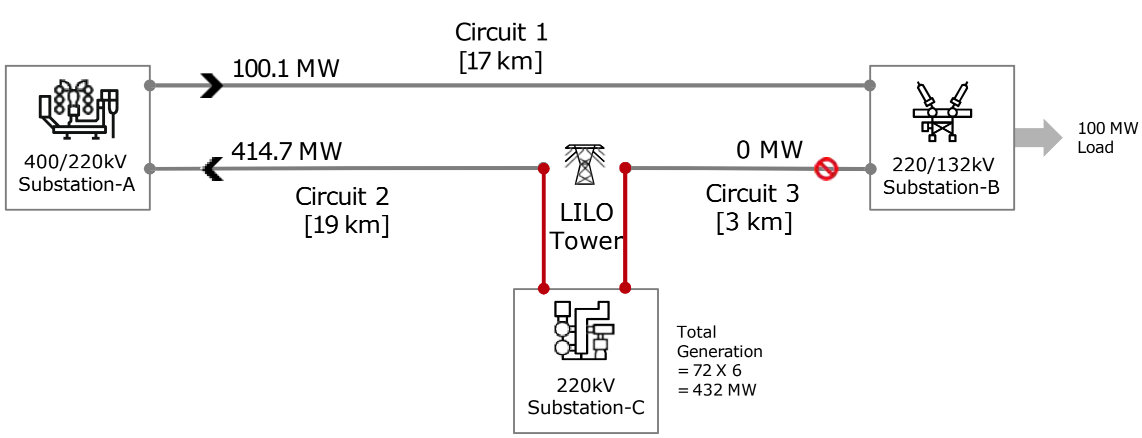
Circuit 3 [In Service]
SS-C to SS-B



Case Study & Analysis

HITACHI

220 kV D/C Transmission Line Power Flow Analysis
Case-4 | N-1Condition



Case Study & Analysis

HITACHI

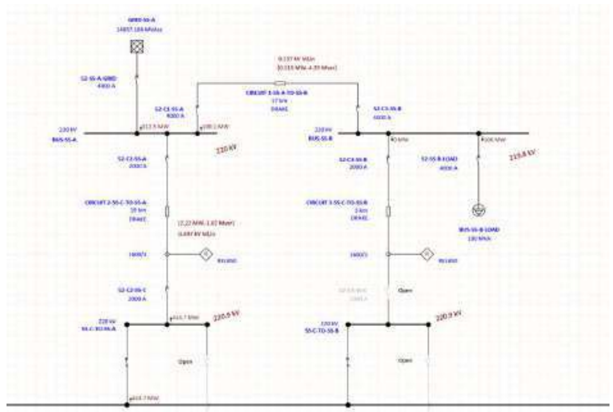
220 kV D/C Transmission Line Power Flow Analysis
Case-4 | N-1Condition

Outage of Circuit-3

Circuit 1 [In Service]
SS-B to SS-A

Circuit 2 [In Service]
SS-C to SS-A

Circuit 3 [In Service]
SS-C to SS-B



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4 Outcome

Outcome - Executive Summary – Existing

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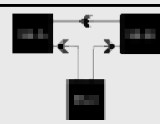
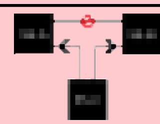
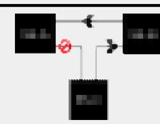
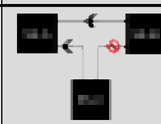
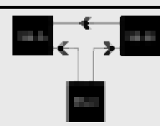
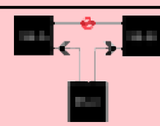
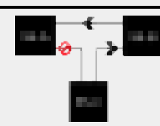
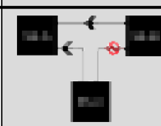
220 kV D/C Transmission Line Power Flow Analysis Normal & N-1Condition

Description	Calculation	Case – 1	Case – 2	Case – 3	Case – 4
Network Diagram					
Power Generation at SS-3 [MW]	**A**	**216**	**216**	**216**	**216**
Auxiliary Consumption at 4% at [MW]	B	8.64	8.64	8.64	8.64
Net Power Generation [MW]	C = A - B	207.36	207.36	207.36	207.36
Load at 220kV SS-B Substation [MW]	D	100	100	100	100
Actual Power Transfer - Circuit 1 (SS-B to SS-A) [MW]	E	44.7	0	107.5	100.1
Actual Power Transfer - Circuit 2 (SS-C to SS-A) [MW]	F	62.9	100.1	0	207.6
Actual Power Transfer - Circuit 3 (SS-C to SS-B) [MW]	G	144.8	107.6	207.6	0
Actual Power Loss - Circuit 1 (SS-B to SS-A) [MW]	H	0.023	0	0.134	0.115
Actual Power Loss - Circuit 2 (SS-C to SS-A) [MW]	I	0.051	0.15	0	0.551
Actual Power Loss - Circuit 3 (SS-C to SS-B) [MW]	J	0.042	0.02	0.087	0
Total Power Loss - Circuit 1 + Circuit 2 + Circuit 3 [MW]	K	0.116	0.17	0.221	0.666

Outcome - Executive Summary – Proposed

HITACHI

220 kV D/C Transmission Line Power Flow Analysis Normal & N-1Condition

Description	Calculation	Case – 1	Case – 2	Case – 3	Case – 4
Network Diagram					
Power Generation at SS-3 [MW]	**A**	**432**	**432**	**432**	**432**
Auxiliary Consumption at 4% at [MW]	B	17.28	17.28	17.28	17.28
Net Power Generation [MW]	C = A - B	414.72	414.72	414.72	414.72
Load at 220kV SS-B Substation [MW]	D		100	100	100
Actual Power Transfer - Circuit 1 (SS-B to SS-A) [MW]	E	145.5	0	314.3	100.1
Actual Power Transfer - Circuit 2 (SS-C to SS-A) [MW]	F	169.1	314.6	0	414.7
Actual Power Transfer - Circuit 3 (SS-C to SS-B) [MW]	G	245.7	100.1	414.7	0
Actual Power Loss - Circuit 1 (SS-B to SS-A) [MW]	H	0.249	0	0.302	0.115
Actual Power Loss - Circuit 2 (SS-C to SS-A) [MW]	I	0.374	1.3	0	2.22
Actual Power Loss - Circuit 3 (SS-C to SS-B) [MW]	J	0.123	0.02	0.352	0
Total Power Loss - Circuit 1 + Circuit 2 + Circuit 3 [MW]	K	0.746	1.32	0.654	2.335

Outcome

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Details form Customer & OEM

Study Activities for Substation

- Single Line Diagram
  - Review equipment ratings as per augmented power flow
- Plan & Section Layout
  - Review statutory clearances as per new proposed equipment
  - Review and validation of structural & civil design
- Erection Key Diagram
  - Review conductor replacement as per augmented power flow
- Clamps & Connectors details
  - Review clamps & connectors as per augmented power flow
- Existing Protection Settings
  - Review and validation of protection settings as per augmented power flow

Study Activities for Transmission Line

- Transmission Line Profile
  - Review and validation of sag & tension as per augmented power flow
- Transmission Loading details
  - CCC & Line Loss Calculation
  - PNZ Impedance Calculation
  - Power Flow Analysis
  - Short Circuit Analysis

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Technical Aspects of Insulated Cross Arms

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ABSTRACT

This paper discusses about challenges faced in designing and making Insulated Cross Arms & Methodology followed to test and validate the design.

INTRODUCTION

The utilities world over face following issues in their existing network

1) **Need to transmit more power in the same corridor.**
2) **Increase ground clearance due to human activity under the tower**
3) **Right of Way**

Now more power can be transmitted by upgrading voltage of the line. We can upgrade 66kV to 132 kV and 132 kV to 220 kV and so on.
The ground clearance can be increased by raising height of the conductor.
Right of Way issue can be resolved by making line compact and doing work on the same tower without any need to put another tower.

All of above can be achieved by putting " Insulated Cross Arms"

WHAT IS INSULATED CROSS ARM?

The metallic Cross arm of tower is removed and replaced with long Rod Insulators. This enables raising of the conductor from ground level. It also helps in Upgradation to next level.

(See image 1)

STATIC LOAD ANALYSIS

First thing which was done was to find out as to what loads the Cross Arm of tower is subjected to.
Following 4 situations were studied

1) Reliability Condition
2) Security Condition
3) Safety Normal Condition
4) Broken wire condition.

It was observed that while rigid Assembly will be able to take first 3 conditions the broken wire condition was the issue. It was not possible for the Crossarm Assembly to withstand the reverse load which it would be subjected to. The various options like increasing core diameter of strength member and reducing size of the inclined memberconsidered.
After much deliberation the solution of providing " hinges " was selected. The hinges to be mounted on tower so that the whole cross Arm Assembly can sway without subjecting the same to sudden impact.

DESIGN OF ASSEMBLY

While designing Insulated Cross Arm which is combination of Long Rod Insulators following general guidelines were followed.)

1) The hardware components were selected which were available in the market.
2) Same insulator was used as strength member and inclined member to avoid any interchange while erecting in the field.
3) We opted for tongue & clevis arrangement.

LOADS ON CROSS ARM ASSEMBLY

The Cross Arm Assembly is subjected to Wind Pressure, Self-Weight , Electromagnetic force & sag tension.

1)Loads on Strength Member
(Horizontal Member)

a) Trans Load = 869 kg
b) Vertical Load = 447 X (1700 /1200) = 623 kg

Total Load = 1492 kg
Ultimate Load = 1.05 X 1492 = 1567 kg
15.36 kN is safe

2) Load on Tie Member
(Inclined Member)

a) Trans Load = (2092/1700) X 869/2 = 535 kg
b) Vertical Load = 447 X (1700/1220) = 623 kg

Total Load = 1158 kg
Ultimate Load = 1.05 X 1158 = 1216 kg
11.92 kN is Safe.

THE DESIGN OF HINGE

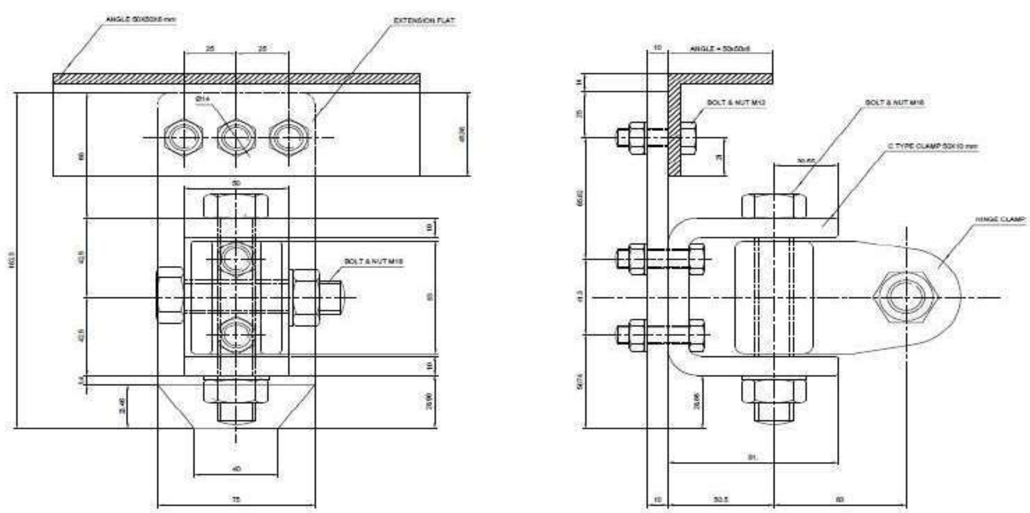
This is most crucial part of Insulated. Cross Arm. The hinge was required to hold the dead weight of the Insulator, conductor clamp and yoke plate. It was also required to withstand wind load, self-weight of assembly &electromagnetic force which it is subjected to.
The component was made considering all these aspects. Hinge bolt of M16. (See Fig 2)

It was also subjected to field test by actually erecting.

THE MOUNTING OF HINGE ON THE TOWER.

This was another challenge as tower is normally made of L angles and sufficient width is not available.

We planned to install the steel plate of 80 mm width and 10 mm thickness on the tower. The fixing bolt of M12.



TITLE :- MOUNTING ARRANGEMENT
TOWER.

STANDARD COMPONENTS

The other components selected were yoke plate , expansion joint ,nuts and bolts , conductor clamps as available in the market.

TESTING

The entire Assembly was tested at NABL approved lab.

TEST PROCEDURE

1) Mechanical Strength Test

Insulator and hardware were subjected to tensile load of 70%value than what was specified.

2) Slip Strength Test

**Conductor fixed at the clamp on Cross Arm Assembly.
Load at one end applied Value at which conductor or clamp slips is noted.**

3) Mechanical Test on Assembly

Complete Cross Arm Assembly was erected. Load applied at fulcrum point. The value of load was 25% of conductor UTS. The load was held for 1 minute and then released.

TEST RESULTS

All tests were passed successfully.

INSULATED CROSS ARMS USING COMPOSITE INSULATORS

**ICA with porcelain long Rod Insulators is called PICA.
ICA with Composite Insulators is called CICA.**

The advantage of Composite Insulators is that it is light in weight. This makes the product easy to install and corresponding weight which gets transmitted on other tower members is less.

However it has buckling phenomenon and same needs to be overcome.

In case of CICA there are 4 members which are required to make Cross Arm Assembly. Also mounting is rigid.

The strength member used is Composite Post Insulator and not Composite Long Rod Insulators.

CONCLUSION

The product Insulated Cross Arm is the field innovation. There are no standards available. It was a big challenge which was overcome by tenacity, experience & field trials.

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3) Insulating Cross Arm for Lattice Towers
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University of Manchester , UK.
4) Stability Analysis by Takalkar Power Engineers & Consultants Pvt lt'd.
5) Static Load Analysis by Arcon Powertrans Pvt lt'd.
6) KNIL India Group - hardware manufacturer.
7) Concept paper on Insulated Cross Arm by CEA.

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Uprating of existing HV Transmission Lines by HTLS conductor – GETCO initiatives as well as experiences thereof

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Introduction

Gujarat Energy Transmission Corporation Ltd. (GETCO), being State Transmission Utility, entrusted to develop & maintain Power Transmission network of Gujarat. Gujarat Transmission Network consist of 66 kV, 132 kV, 220 kV & 400 kV network. Transmission network as on March 2024 is as below.

Voltage Class	Sub-Station	Line in ckm.
400 kV	20	7063.47
220 kV	121	22090.23
132 kV	59	5951.12
66 kV	2170	40304.66

Govt. of Gujarat in 2020-21, implemented adoption of an innovative approach to provide agricultural electricity during the day time to meet the demand of farmers under scheme named Kisan Suryoday Yojna (KSY). It is planned to provide power supply to the agricultural sector during day time from 5.00 am to 9.00 pm. and to be implemented in a phase manner. In parallel, GoG & GoI have implemented promotion of Solar power generation under RE policy. It is necessary to leverage this power at voltage level it is feed to grid to reduce loss.

Developing scenario

Lowest voltage level of transmission network is 66 kV. Conventionally GETCO uses ACSR Dog & Panther conductors with H frame structure or tower structure for 66 kV lines. The share of 66 kV lines with ACSR Dog conductor was appx. 25888 ckm. out of 40305 ckm. i.e. appx. 65% of total ckm. With implementation of KSY scheme, congestion faced in this area as overloading will result.

The most challenging issue of the today's transmission sector is the Right of Way (RoW). Hence, strengthening of existing 66 kV ACSR Dog conductor network is required to implement KSY. Based on above planning, detailed system study was carried out and system strengthening as well as congestion management is emerging as an evident need.

Exploring methodology

Various options available for network strengthening are explored as below,

1) Re-conductoring of ACSR Dog line to ACSR Panther line in same corridor.
2) Addition of line - by conversion of S/C line to D/C ACSR Dog line in same corridor.
3) Addition of line - by laying underground cable line.
4) Re-conductoring of existing ACSR Dog line with HTLS conductor.

These options were evaluated on following parameters,

1) Increase in Ampere Capacity.
   It is very important parameter to consider as the final value shall meet short term as well as long term load growth. As in certain pockets, industrial load growth is also expected & issuance of technical feasibility is hampered due to network congestion along with GoG KSY project. It is emphasized to increase line thermal capacity by almost 2x (two times) to avoid network congestion.
   GETCO follows IEEE Standard 738 for Ampere capacity calculation of conductor. Parameters considered are,
   i) Ambient temperature = 40 ºC
   ii) Solar Absorption co-efficient = 0.8
   iii) Solar Radiation = 1045 Watt/sq. mtr.
   iv) Emissivity Constant = 0.45
   v) Wind Velocity = 0.56 meter/sec (considering angle between wind and conductor axis as 90)
   vi) Effective angle of incidence of Sun's rays = 90 degrees.
   Accordingly, Ampere capacity of ACSR Dog conductor is 230 Amps. and ACSR Panther conductor is 340 Amps.
2) Requirement of construction of new line or line bay at respective sub-stations.
   The preferred way of network strengthening is addition of line connecting sub-station facing line thermal capacity restriction. However, the biggest challenge faced is Right of Way. Also, this solution requires construction of new line bays at feeding & receiving sub-stations. Space availability is required to check for the same.
3) Project Timeline.
   It is a major factor. The solution shall be such that minimum project time period is preferred.
4) Efficient use of RoW & reduce footprint.
   GoG and GOI is emphasize on efficient use of RoW. It is preferred to increase power transfer capacity of line within same RoW.
5) Project Cost.
   It is last but not the least consideration. The solution shall be cost effective & the project pay-back period shall be reasonable.

Analysis of methodologies

Each of the options available are evaluated for above parameters & briefly described as below.

1) Re-conductoring of ACSR Dog line to ACSR Panther line in same corridor – Conventionally this practice adopted by GETCO using ACSR Panther conductor. However, re-conductoring existing ACSR Dog span with ACSR Panther, will increase loadings on existing structures & also increase sag in spans. For re-conductoring, any other High Performance conductor such as AAAC or AL59 conductor can be considered. However, issue of sag increase will remain. Practically, this solution requires erection of additional H-frame or tower structures in between existing spans, except for smaller spans or replacement of existing towers by higher capacity designed towers.
   Analysis :
   a) Increase in Ampere capacity – new line will have appx. thermal capacity of 340 Amps.
   b) New line / bay requirement – additional H-frame or tower structures in between existing spans, except for smaller spans or replacement of existing

towers by higher capacity designed towers required. New feeder bay not required.

c) Project Time – Higher, as addition of new structures may face RoW issue.
d) Efficient use of RoW & reduce footprint – partially achieved. Power transfer within same RoW will increase compare to existing line.
e) Project Cost – Tentative cost is 46.1 Lac. /km.

2) Addition of line - by conversion of existing S/C line to D/C ACSR Dog line in same corridor. This option is mostly applicable in existing S/C line with H frame or having S/C tower structures. In such case, new D/C tower be provided in existing corridor. ACSR Dog conductor is considered for new line as least minimum requirement.

   Analysis :

   a) Increase in Ampere capacity – new D/C line will have appx. thermal capacity of 450 Amps.
   b) New line / bay requirement – Yes. New line & feeder bay one each at respective sub-stations are required.
   c) Project Time – Higher. As construction of new line in existing corridor require load management, frequent outages of existing line, new bay construction at respective ends & RoW issues.
   d) Efficient use of RoW & reduce footprint – partially achieved. As power transfer within same RoW will increase compare to existing line but foot print will increase.
   e) Project Cost – Tentative cost is 40.86 Lac. /km. Additionally, appx. 100 Lac. for 2 nos. of bays.

3) Addition of line - by laying underground cable line. This option is preferred when overhead line construction is not possible especially in urban or semi-urban areas. As per GETCO practice, 66 kV 1Cx630 sq.mm. Aluminium conductor cable is being used.

   Analysis :

   a) Increase in Ampere capacity – new cable line will have appx. thermal capacity of 450 Amps. Operation in parallel to existing ACSR Dog line is not preferred due to unequal load sharing as UG cable is having very low impedance compare to overhead conductor, say D.C. resistance of cable is 0.0469 ohms/km. against that of ACSR Dog 0.2792 ohms/km. However, parallel operation may have appx. cumulative thermal rating of 550 Amps.
   b) New line / bay requirement – Yes. New UG Cable line & feeder bay one each at respective sub-stations are required.
   c) Project Time – Lower compare to that required for constructing overhead line. However, new bay construction at respective ends is required.
   d) Efficient use of RoW & reduce footprint – may not be applicable as UG cable do not require RoW.
   e) Project Cost – Tentative cost is 155.43 Lac. /km. Additionally, appx. 100 Lac. for 2 nos. of bays.

4) Re-conductoring of existing ACSR Dog line with HTLS conductor – Re-conductoring existing line with HTLS conductor equivalent to ACSR Dog conductor, will not increase sag in spans. Use of HTLS conductor matching existing conductor parameters will not increase loadings on existing structures. Hence, addition of structure or replacement of existing structure by higher strength structure in spans is not required.

   Analysis :

   a) Increase in Ampere capacity – new line will have appx. thermal capacity of 550 Amps. as requirement laid by GETCO.
   b) New line / bay requirement – not required.

c) Project Time – Lower, as no addition of new structures or addition of bay is required. RoW issue may be faced normal as job is equivalent to conductor replacement.
d) Efficient use of RoW & reduce footprint – Majorly achieved. Power transfer within same RoW will increase by appx. 2.4 times compare to existing line.
e) Project Cost – Tentative cost is 59.29 Lac. /km.

Summary of the evaluation criteria of key attributes tabulated as below,
Table 1 :

Sr. No.	Parameter	O-1	O-2	O-3	O-4
1	Increase in Ampere capacity	340 A.	450 A.	550 A.	550 A.
2	New line / bay requirement	Additional structure required in longer spans	Yes. Both.	Yes. Both.	No
3	Project Time	Higher	Higher	Lower	Lower
4	Efficient use of RoW & reduce footprint	Partially achieved	Partially achieved	Not applicable being UG	Majorly achieved. Increased by x2.4
5	Project Cost	Appx. 46.1 Lac./km.	Appx. 40.86 Lac. /km. + appx. 100 Lac. for 2 nos. of bays	Appx. 155.43 Lac. /km. + appx. 100 Lac. for 2 nos. of bays	Appx. 59.29 Lac./km.
6	Tentative cost for 15 ckm. line	691.5 Lac.	712.9 Lac.	2431.45 Lac.	889.35 Lac.

Adoption based on analysis

Considering increase of thermal capacity by 2.4 times, lower project time period, achievement of efficient use of RoW & comparatively cost effective solution w.r.t. new UG Cable solution, solution of re-conductoring of existing ACSR Dog line with equivalent HTLS conductor was opted.

Salient features of GETCO Technical Specifications for uprating of existing ACSR Dog line with HTLS conductor are as below,

1) No restrictions of technology. HTLS conductor of any technology meeting technical requirements can be proposed.
2) Proposed conductor shall have diameter & weight equal to or less than that of ACSR Dog conductor.
3) Proposed conductor shall have UTS equal to or more than that of ACSR Dog conductor.
4) Proposed conductor shall offer continuous current capacity of 550 Amp. with corresponding temperature not more than 210 °C without violating Sag-Tension parameters of existing line structures. Limiting values are specified.
5) HTLS Conductor shall be retrofitted on existing structure.
6) Ampacity calculation shall be as per IEEE Standard 738.

7) Ratio of AC to DC resistance shall be as per CEA guidelines.
8) Bid evaluation includes Evaluation of Ohmic losses & Differential Price Loading as per CEA guidelines at 450 Amps. (appx. 80% of 550 Amps.)
9) Type Test requirement as per CEA guidelines.
10) Acceptance Testing 100% drums for visual examination, measurement of diameter & weight, DC Resistance test for conductor.
11) Guarantee period of 5 years.

With these specifications, GETCO invited bid for 6 EPC tenders for re-conductoring of various 18 lines having ckm. ranging from 2 ckm. to 25 ckm. Bids were invited with scope of re-conductoring existing ACSR Dog line with HTLS conductor equivalent to ACSR Dog conductor along with suitable hardware-accessories & replacement of insulators on turnkey basis. Bids were finalized with proposed HTLS ACCC-Daman conductor. Comparison table of various technical parameters is tabulated below,

Sr. No.	Technical Parameter	ACSR Dog	ACCC Daman
1	Conductor diameter	14.15 mm.	14.15 mm.
2	Conductor weight	394 kg./km.	394 kg./km.
3	Conductor UTS	32.41 KN	46.9 KN
4	Ampere Capacity	230 Amp.	550 Amp. @ 140°C
5	D. C. Resistance @ 20°C	0.2792 Ω/km.	0.2141 Ω/km.
6	A. C. Resistance @ design temperature	0.3454 Ω/km. @ 67°C	0.3178 Ω/km. @ 140°C
7	Sag @ design temperature	5.33 meters @ 67°C (Tower)	4.78 meters @ 140°C (Tower)
8	Tension @ 32 °C FW	1223 kgs.	1223 kgs.
9	Tension @ 0 °C 67% FW	1329 kgs.	1190 kgs.
10	Voltage Regulation @ design temperature for 25 ckm. line	3%	6.62%

Actual cost of project comes out to be 60.33 Lac. /ckm. average based on these tenders against estimated cost of 59.29 Lac. /ckm.

Cost Benefit Analysis

(1) Cost Benefit on account of enhanced power transfer : for say 15 km. line

Sr. No.	Particulars	With ACSR Dog	With ACCC-Daman conductor
1	Ampere capacity of conductor (in Amp.)	230	550
2	Considering 50% average loading (in Amp.)	115	275
3	Power transfer of S/C line (in MW) @0.95 p.f.	12.489	29.864
4	Loss for S/C line due to I^2R loss (in MW)	0.197	0.867
5	Net power transfer (in MW)	12.292	28.997
6	Additional power transfer due to ACCC-Daman (in kW)	**	16705
7	Additional power transfer due to ACCC-Daman (in kWh) in a year	**	146335800

	(for 8760 Hrs.)		
8	Revenue earned at ₹ 0.39 per kwh as Transmission tariff (in Rs. lacks)	**	570.710
9	Expenditure incurred (in ₹ Lacks)	**	904.95
10	Payback period (in days)	**	579
11	Say	**	19.5 months

(2) Cost Benefit on account of Transmission loss: for 15 km. line

Sr. No.	Particulars	With ACSR Dog	With ACCC-Daman conductor
1	Ampere capacity of conductor (in Amp.)	230	230*
2	Load (in MW) for S/C @0.95 p.f.	24.977	24.977
3	Loss for S/C line due to I^2R loss (in MW)	0.822	0.598
4	Net power transfer (in MW)	24.155	24.379
5	Saving on a/c of loss (in MW)	**	0.224
6	Saving on a/c of loss (in kW)	**	224
7	Saving in loss due to ACCC-Daman (in kWh) in a year (for 8760 Hrs.)	**	1962240
8	Revenue earned @2.45 ₹ Per kwh (in ₹)	**	48,07,488
9	Revenue earned @2.45 ₹ Per kwh (in Lac ₹)	**	48.075

* The actual ampere capacity of ACCC-Daman conductor is 550 Amp.

As per the calculation above, even if the Ampacity of ACCC-Daman is considered same as that of ACSR Dog conductor i.e. 230 Amp. then there is saving of about 224 kW in terms of power loss due to resistance of ACCC-Daman conductor is less than that of ACSR Dog conductor. The saving of 224 kW power loss is equal to revenue earning of about ₹ 48.075 Lac per annum.

Based on above, cost of ₹ 904.95 Lac for re-conductoring with ACCC Daman conductor in place of ACSR Dog conductor is recovered within 19.5 months, even if we do not consider Transmission loss benefit.

Implementation Summary

GETCO awarded 6 tenders for re-conductoring with HTLS conductor for 18 lines in 06.2024. Being new conductor, fresh type testing of conductor & hardware-accessories carried out. That resulted in to late start of project execution. However, till 09.2025, re-conductoring work of 15 lines out of 18 are completed, taking total period of 9 to 15 months. Work of 1 line is completed 50% due to RoW being faced, whereas 2 lines are pending due to non-availability of shut down. However, in successive tenders, the project completion period is reduced to 6 months.

Key takeaways

- With re-conductoring of existing line with HTLS ACCC-Daman conductor, the network congestion issue can be resolved with capacity addition up to 2.4 times i.e. 550 Amps. against existing 230 Amps.
- ACCC-Daman conductor being similar to ACSR Dog conductor, it is retrofitted in existing structures & uprating is achieved without addition / alteration of existing structures. It resulted into minimum RoW issue & faster completion of projects.
- Considering 18 mtr. RoW for 66 kV line, net power transfer capacity of line increased from 1.39 MW per mtr. RoW to 3.32 MW per mtr. RoW. Net power transfer capacity within same RoW is increased by appx. 2.4 times compare to existing line resulting in to efficient use of RoW.
- Payback period as calculated above is less than 2 years with added benefit of savings on account of loss reduction.
- For same power flow condition, 25% lower loss is observed due to lower resistance of conductor.
- ACSR Dog conductor is having steel core which is susceptible to corrosion on account of saline atmosphere / pollution environment. Also, the ACSR conductor gets rusted due to galvanic corrosion. However, in case of ACCC conductor, core being non-metal, chances of galvanic corrosion are eliminated. Also, it is claimed to be advantageous against saline atmosphere / industrial pollution environment, as Aluminium being annealed, do not contribute to conductor strength and core is non-metallic.
- In case of ACCC conductor, indigenous conductor (core is imported) manufacturers are available. Also, few indigenous hardware-accessories manufacturers are available & have supplied in GETCO projects.
- Re-conductoring project execution time observed is 9 to 15 months from LOA to charging in initial projects, which is reduced now to 5 to 6 months. This is very less compare to new overhead line construction. It is even comparable with new underground line, as in case of UG line new bays are required at respective sub-station end. whereas, in cost comparison it is 2.7 times cheaper solution compare to cable.
- HTLS conductor is advantageous solution, where network congestion is observed and where thermal capacity of line is required to increase using same structures & heavy RoW lines. Though voltage regulation criteria is not a design criteria for Transmission lines, it may be a limiting factor for longer lines to consider for re-conductor with HTLS. It is preferred to adopt short lines, even based on I^2R loss considerations.
- However, for new lines, other high performance conductors such as AL59 is still a better solution as being practiced by GETCO.

Conclusion

HTLS conductor is tailor made solution to congestion faced in existing network by most utilities. It is a cost efficient solution with shorter project time with efficient use of existing RoW. GETCO experience shared with a view to help other utilities take appropriate decision.

Case Studies of Tailor-Made Design, Engineering & Construction of Transmission Line

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1. INTRODUCTION

1.1 Government of India (GoI) is having ambitious plan to add 500 GW of non-fossil fuel renewable energy by the year 2030. The power sector in the country is experiencing a great rush in establishing Solar & Wind Power Generation units almost in every part of the nation.

1.2 However, there are states like Gujarat, Rajasthan and Tamil Nadu where renewable energy sources are in abundance. The power generated here has to be transmitted to the Power Deficient States.

1.3 For evacuating large quantum of power, 400kV, 765kV, ± 500kV HVDC &± 800kV HVDC lines are required to be constructed on war footing.

1.4 Similarly, from the Seven Sister States, Nepal & Bhutan large quantity of Hydro Power is to be evacuated through the chicken neck(barely 100kM wide). This also needs bulk Power Transmission.

1.5 For more than a decade the transmission lines are constructed on Public Private Partnership (PPP) model or Tariff Based Competitive Bidding (TBCB) model. The Line has to be constructed by the developer at his own cost and then maintain it for 35 years. The line has to be constructed in specified time only.

1.6 All the above pose a challenge in Design, Engineering, construction and maintenance. The presentation covers various case studies based on the rich experience of the author in the power transmission segment.

2. BASIC ABOUT TOWER DESIGN

2.1 Towers are designed as per the IS 802 P-1 (Section 1&2). Generally in transmission line four types of towers are designed which are as under

- 2° suspension tower
- 15° Angle (Small angle) Tension tower
- 30° Angle (medium angle) Tension tower
- 60° Angle (Large Angle) Tension tower

(out of above 60° tower is also designed as dead end tower)

(Photos above tower)

2^0Suspension	15^0 Tension	30^0 Tension	60^0 Tension

3m, 6m, 9m, 12m, 15m, 18m, 21m 24m, 30m&35m extension to above family of towers are also designed

- In addition, transposition towers are also designed

2.2 The sets of tower and extensions as described above are designed for various wind zones as follows.

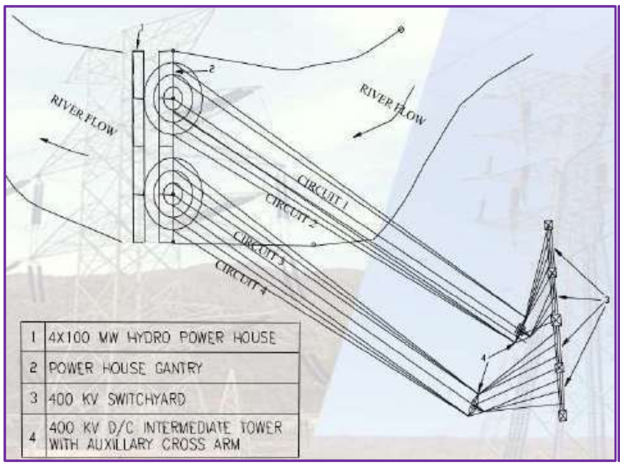
Zone	Wind Velocity	Zone	Wind Velocity
1	33 m/s	4	47 m/s
2	37 m/s	5	50 m/s
3	44 m/s	6	55 m/s

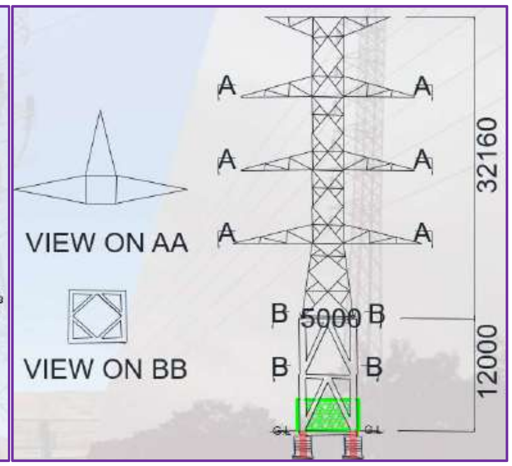
2.3 The design is dependent upon the voltage, number of circuits, type of conductor, type of Earth Wire/OPGW and the Span.

2.4 In addition to the standard tower and extension designs as above, there are some special towers for special purpose suchas River crossing &creek crossing. They are designed based on the actual crossing requirement. They can be on shores or in themid-stream (River/Creek)

3. CASE STUDIES ON SPECIAL DESIGNS

3.1 Koteshwar Hydro Electric Projects have an installed capacity of 4x100MW. The powerhouse is underground with a pothead yard on the top ofthe hill. Theswitchyard is across the river on the other hill. The horizontal distance between the pothead yard and the switchyard is 305M with an elevation difference of 85M.





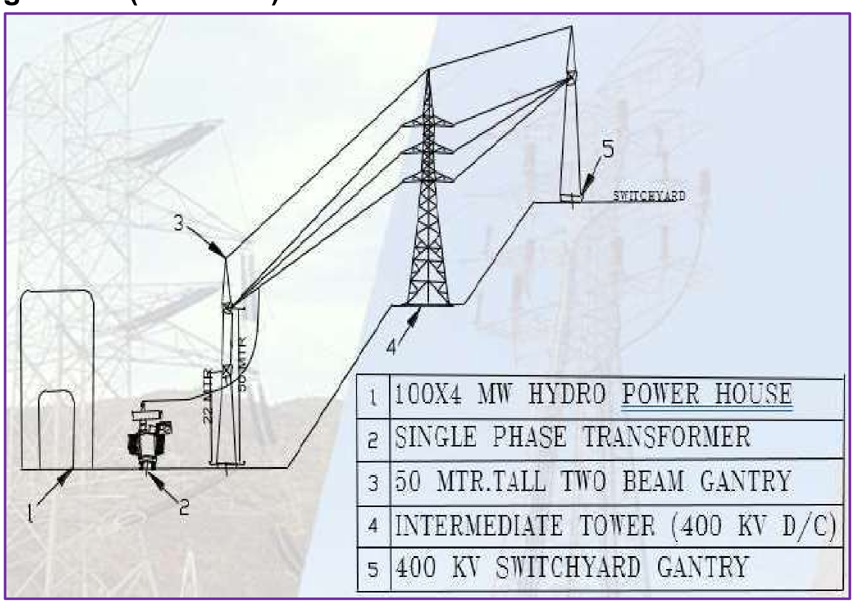
The gantries at pothead yard and the takeoffswitchyard were designed for only 8Metric Tonnper Phase loading (Tension).

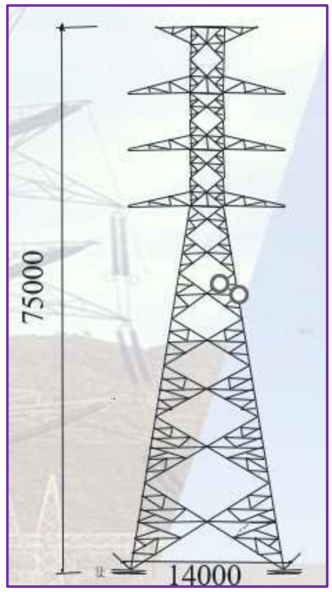
Thus, the gantries were not in a position to withstand the conductor loadings. It was therefore decided to erect two towers near the switchyard and relieve the gantries from over loadings. The challenge was the availability of space for 2 number of 400kV D/C dead-end towers. It was necessary to spot the towers in a space of 9M X 9M on the steps (berms) near the main switchyard. After allowing for working space &foundation, the maximum back-to-back of tower worked out to 5M X 5M. It was difficult to design 400kV D/C tower with such base dimension. However, this was accomplished by providing a trestle of 12M / with two panels of 6M each).

3.2 In Alknanda Hydro Electric project at Srinagar(Uttarakhand) 2x100 mw Powerhouse on a bypass–canal is commissioned. The Elevation difference between the powerhouse and the switchyard is more than 200M & the horizontal distance is more than 600M.

4X100MW powerhouse is a fabricated steel structure. Therefore, it was not possible to connect the generator transformer to the switchyard gantries by anchoring the conductors directly on the powerhouse structure.

Keeping in view the ground profile and canal valve heads it was decided to erect two tier (beam) gantries near generator transformersand then evacuate the power through a 75M tall 400kV D/C tower to the substation gantries (4 circuits).





Intermediate Tower

3.3 **In Goregoan (West), Mumbai, AEML wanted to construct state of art G.I.S sub-station in a very small space. One multi circuit, multi voltage transmission line of the company passes through the same premises. The towers have 220kV D/C on top & 33kV D/C at the bottom. The G.I.S envisages LILO of 220kV D/C and 33kV D/C for the G.I.S by means of cables.**

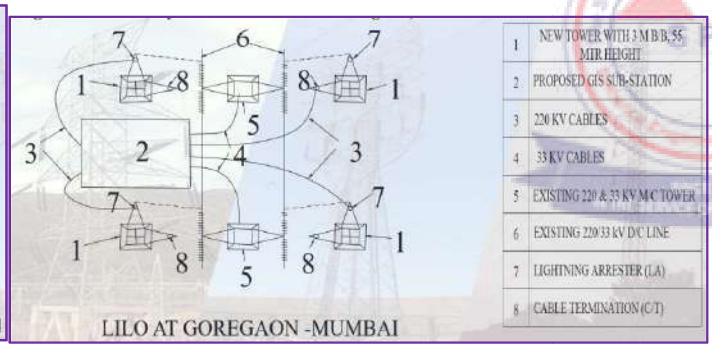
There are two existing multi circuits, multi voltage angle towers carrying 220kV D/C & 33kV D/C lines and passing through the premises of AEML. The line divides the premises in two parts.

220kV & 33kV tapping was to be done from both the multi-circuit towers.

The 220kV circuits are tapped directly from line using small jumpers from the existing towers to the new LILO towers and there after 220KV cables are run up to GIS. 33KV cables are connected to the conductor and then run on the existing towers up to GIS. The 220kV Cable Termination(CT) and LA are provided on new towers. 33kV C/T & LA are provided on existing Towers.

For maintaining the electrical clearance and effective tapping arrangement, four single circuit LILO towers have been provided near to the existing 220kV / 33kV D/C towers, one each on either side of each angle tower.

Four LILO towers of 220kV have only 3Mx3M base with height of 55 m. All the four towers have two cross arms at 90° to each other, one cross arm supports C/T and the other L.A.



3.4 In second case in Gorai, Mumbai, the line of M/s. AEML having 220kV D/C and 33kV D/C on the same tower passes through a garbage dump-yard. AEMLwas to constructa 220/33kV G.I.S near the dump yard. Due to the decision of Mumbai Municipal Corporation to convert the dump-yard into a garden, AEML was asked by MMC to construct LILO Towers for G.I.S within a very short time. For making a 220kV D/C & 33kV D/C LILO, it was proposed to construct two LILO towers on either side of the existing 220kV D/C / 33kV D/C tower.

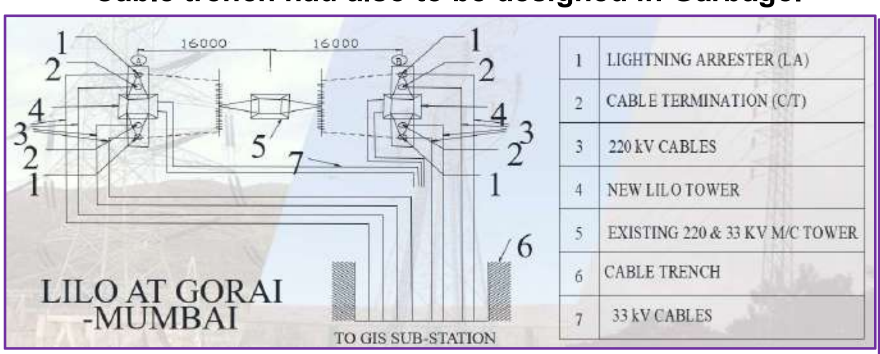
The tower had to be found on garbage. Since time was short, pile foundation could not to be done and instead open type of foundation had to be designed on garbage. Besides driving a pile in the garbage was a difficult proposition.

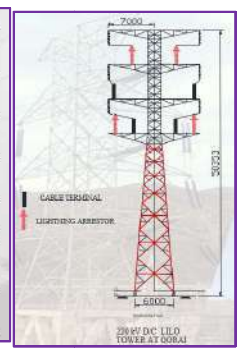
Due to constraint on the transverse side, the two LILO towers on either side had to be spotted at a distance of only 16M from the existing Tower.

Due to very wide base of existing 220kV D/C tower, accommodating Cable Termination(CT) and LA on 33kV cross-arms and routing of the cable through tower body was difficult.

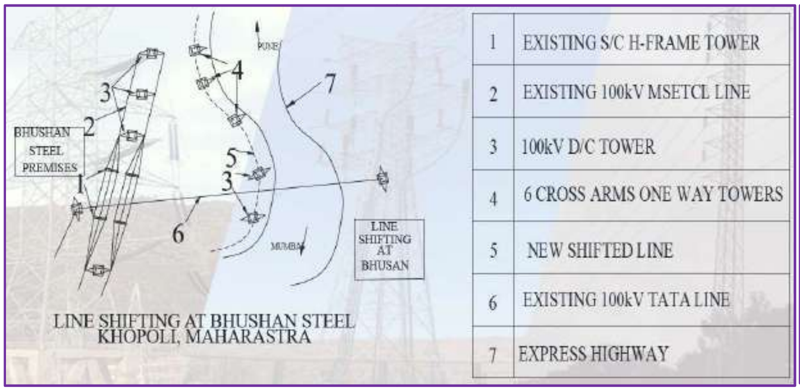
The weight of 220kV cable is 35kg/M and the bending radius is 3mtrs. The cross-arms and tower body had to be designed considering the same.

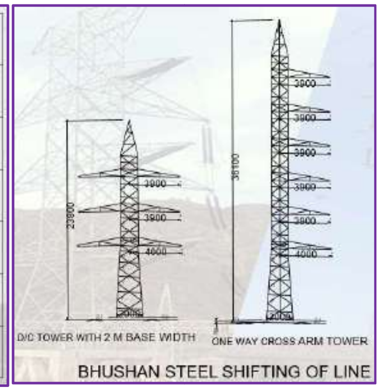
Cable trench had also to be designed in Garbage.



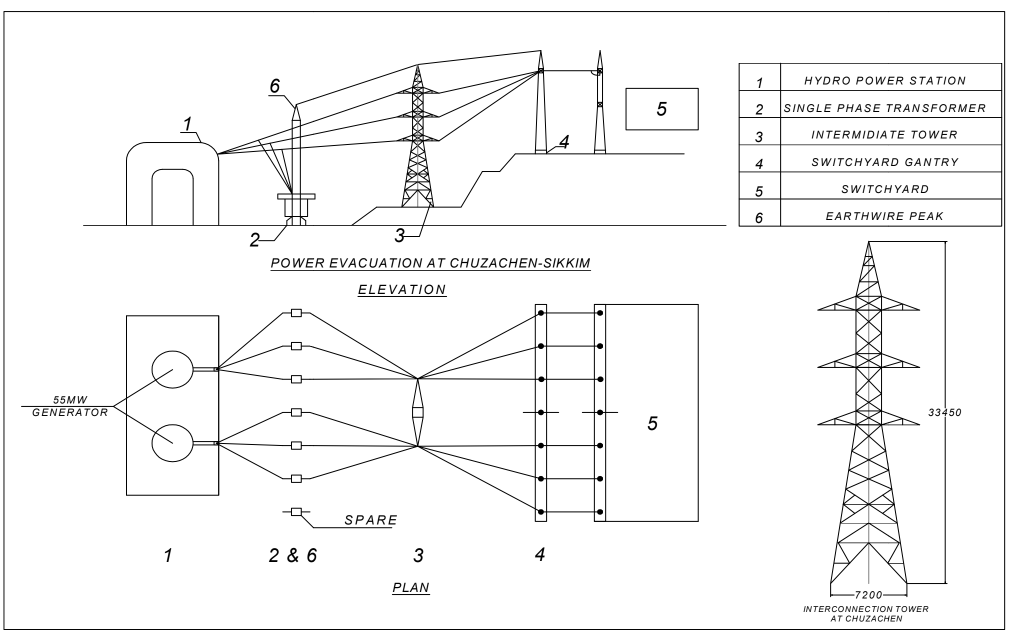


3.5 M/s Bhushan Steel at Khopoli (Maharastra) wanted to shift 100kV transmission line belonging to MSETCL. The shifting was to be done in such a way that it permits maximum availability of free land for the expansion of the steel plant of the company. The Mumbai-Pune express highway is skirting the factory wall. The company wanted the towers to be designed for a very narrow base with 132kV voltage level. In order to maximize the utilization of land, the company requested that all the six cross-arms of the tower be on the roadside. Further, the company also requested that the base width of the tower should not be more than 2M. The proposed shifting also required to cross existing 100kV line of M/s Tata Electric Company. To cross these lines, two D/C Towers of 132kV were required to be erected by cutting the hillock by 9M. These towers were also with 2M base width having 3 cross arms on each side.





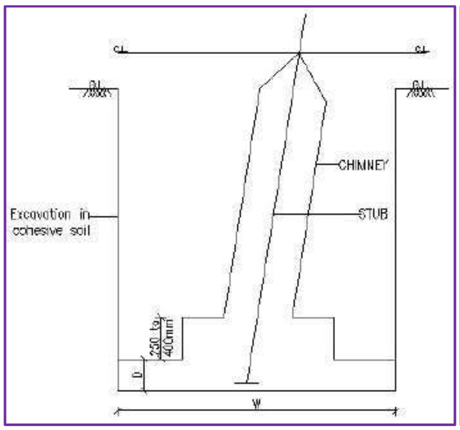
3.6 **In Chuzachen(Sikkim) 2X55MW Hydro Electric Project, there are two Hydro Units. The transformers are single phase units. The 132kV switchyard is on the back side of the powerhouse with an elevation difference of about 25M. For carrying the power from the powerhouse to switchyard, an intermediate tower was required to be erected on slope. The power has to be conveyed through the 132kV D/C Tower with single unit connections on one side of the cross-arm and second side terminating on the gantry with one conductor only. The special tower was thus designed to take different deviation angles on each cross arm and three numbers of earth wires on each circuit. It may be interesting to know that the entire design & engineering was done with the help of the contour maps only, without any site visit.**

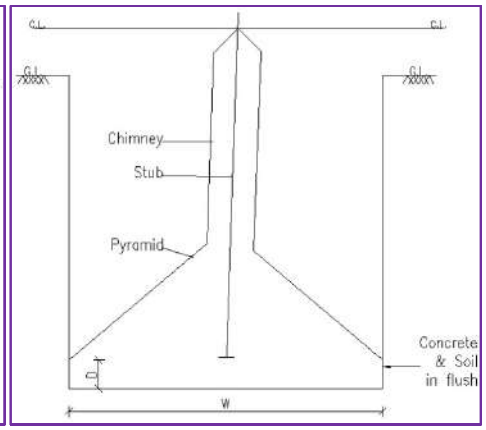


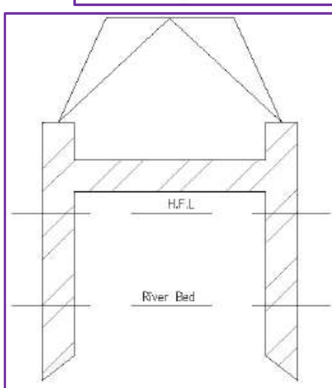
4. **CONVENTIONAL AND UNCONVENTIONAL DESIGNS FOR TOWER FOUNDATIONS**

4.1 **Transmission line towers are provided with shallow foundations. Normally, the depth varies from 1.5M to 3.5M depending upon the soil/strata. In most of the cases, individual leg foundation is cast. Where, base width of the steel support structure is very less, raft type footing with four columns is preferred.**

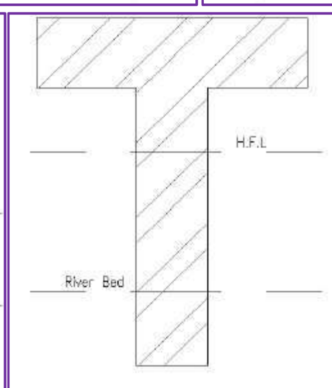
4.2 **Normally, the foundations are designed as open cast type. However, for river/creek crossing sections, pile foundation are also designed and constructed. The foundations for small towers in good soil are chimney and pyramid type. However, if the soil bearing capacity is poor or in case the loadings of the structure are higher, the step type or undercut type foundations are designed and constructed. Some of the popular shapes and types of footings are shown below.**



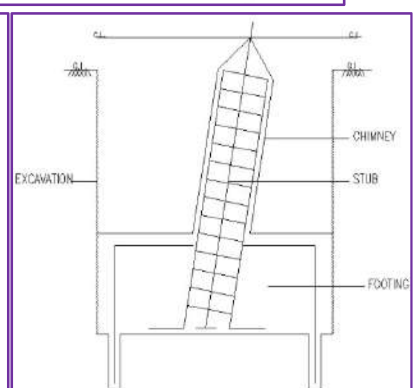




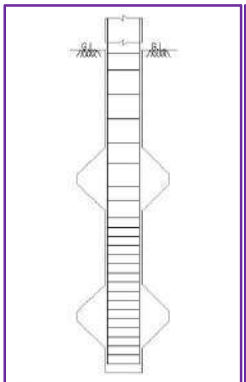
(10) Well type Foundation for Submerged & Sandy Soils & River Bed



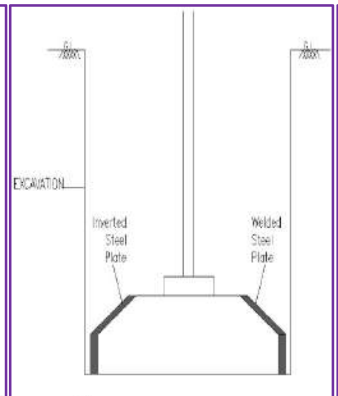
(11) Special Pile type R.C.C Foundation in Flowing River



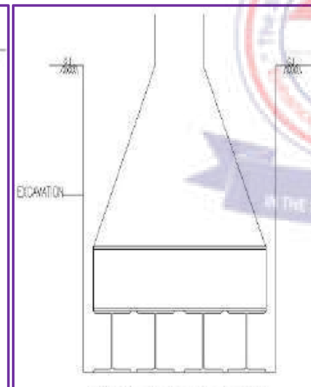
(6) Anchor rod type P.C.C Foundation for Hard rock Type



(7) Auger type or under reamend type Foundation for Clay Soil

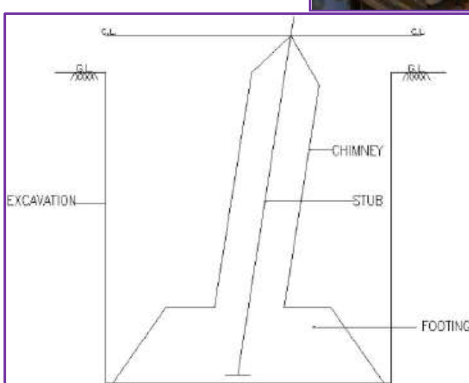


(8) Steel Plate Type Foundation for Normal Soil

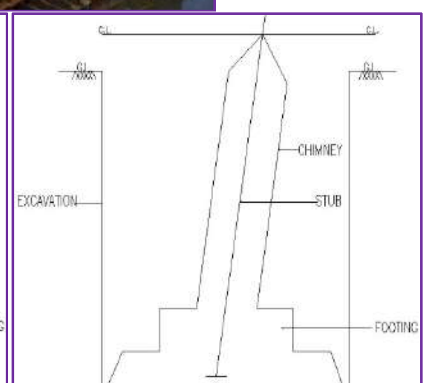


(9) Grillage type Foundation for Normal Cohesive Soils

Grillage



(4) Spread Footing type(Chamfered) R.C.C foundation



(5) Spread Footing (Chamfered) Step type R.C.C Foundation for Submerged Soil

4.3 **Between 1988 & 1992 Gujarat Electricity Board (Now GETCO) conducted a research program on tower foundations. The author spear headed the R&D project. Pull-Out tests were conducted to find out the reaction offered by the soil while balancing the uplift loads of the tower (Tension). Tests were carried out on all types of soils & combinations thereof. The results were very encouraging. Some of the recommendations and methodology for pullout tests have been included in the CBIP manual on transmission lines.**

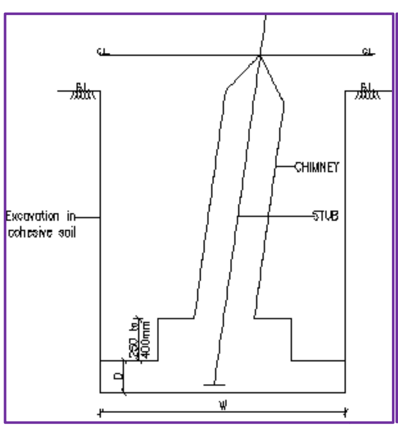
PULLOUTTESTIN PROGRESS

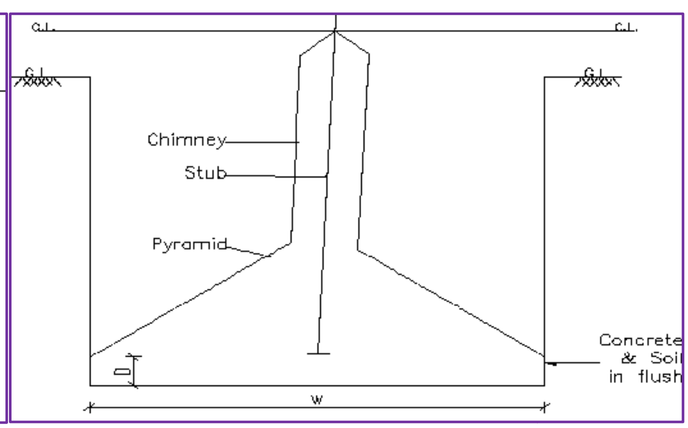
4.4 Few of such design philosophies are described in the following paragraphs. The purchaser and the contractors can adopt them on mutual agreement after taking into account the site situation and the merits/demerits of such foundation.

4.5 FOUNDATIONSINCOHESIVESOILSWITHOUTWORKING MARGIN ALL AROUND (FOR THE PLACEMENT OF FORM BOX).

4.5.1 Normally, the transmission line tower or switchyard structure foundations are cast providing 150 mm clearance all around for ease in placement and removal of form box and also placement of reinforcement. Even though the practice is very old and still in vogue, there are some disadvantages of this practice. If the tower erection work and stringing work have to be done immediately after the foundation work, stability of the foundation may pose a problem. Many a times, back filling done by the erection contractor is not up to the mark and chances of foundation uprooting are high.

4.5.2 The cohesive soil offers skin friction to the concrete which ranges from 0.2 kg/cm² to 0.4 kg/cm² depending upon the quantum of silt, clay and sedimentation. The schematic drawing of such foundation is given below.(Fig. 1a)Shows step type, spread footing foundation without working margin. (Fig. 1b) Shows the friction & pyramid type footing without working margin.

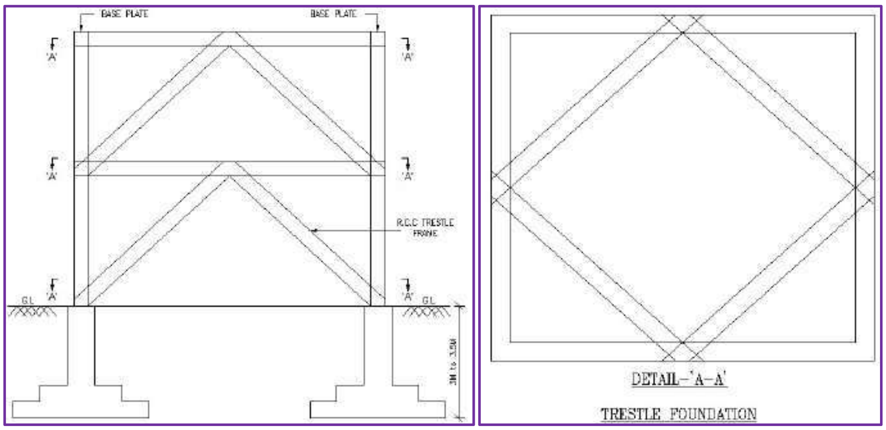




4.5.3 In above figures 1(a) & (b) let us consider d=300mm, W=2000mm and value of skin friction as 0.2 kg/cm². the anchorage due to the friction between the concrete & soil alone will work out to 30 x 200 x 4 x 0.2= 4800kg. This is substantial and need to be exploited as this anchorage is available immediately after the casting of foundation. The layer of soil ‘d’ which is in contact with concrete need to be saturated before pouring of concrete. In case of RCC, the cover can be increased from 50 mm to 75 mm. Such foundations are economical, as the friction adds to the available anchorage without much increase in concrete quantity and do not need form boxes.

4.5.4 TRESTLE FOUNDATIONS

At the locations where sufficient space is not available for spotting a broad base tower (like Himalayan Region),negative tower body extension with vertical shaped trestles can be erected as shown below.



Cost of construction of Trestle is less compared to pile foundation. Trestle are useful in following cases

- Creek, estuaries & riverbanks where water is not flowing
- In urban & industrial area having limited space and vehicular movement

4.5.5 FoundationsOnUn-NaturalSedimentations

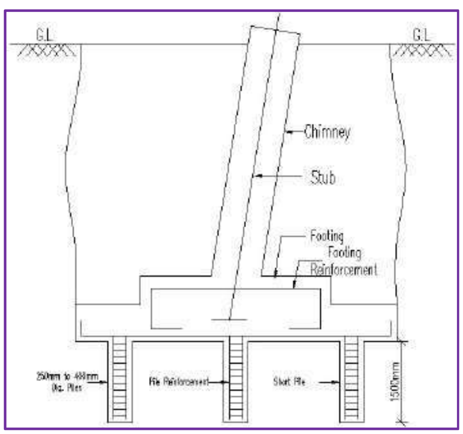
In many cases it becomes mandatory to take the line through un- natural sedimentation/strata for foundation. This includes garbage dumping, backfilled soils, mountains of overburden (from mines, confined locations in hydropower station and fly-ash dumping ponds). In such cases, either based on the soil investigation or on the basis of safe assumption of soil/strata parameter, special foundations can be designed on mutual agreement between the purchaser and the contractor.

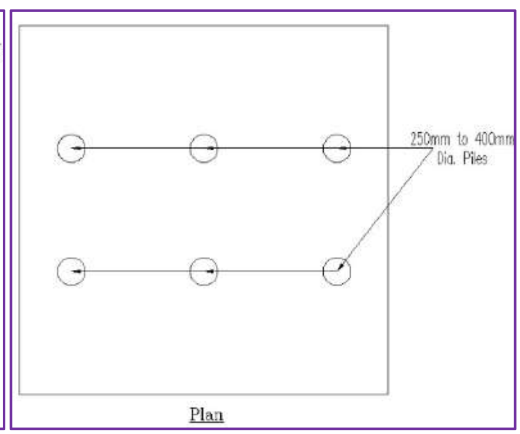
FOUNDATION IN FLY ASH

4.5.6 RAFT/SPREAD FOOTING CUM SHORT PILE FOUNDATIONS

In expansive soils, particularly the black cotton soil, the bearing capacity is poor. The raft/spread footing–cum–short pile foundations are found to be very useful.

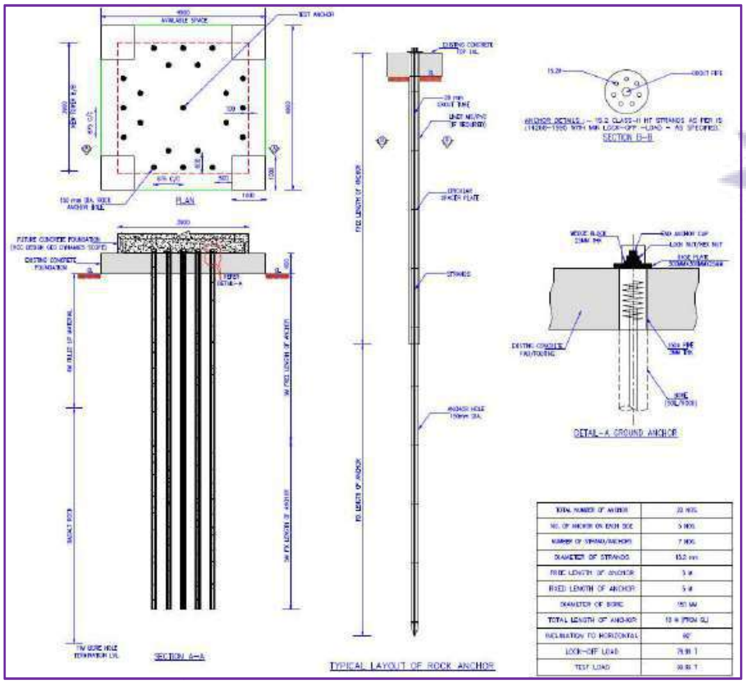
In this type, the normal type of open cast foundation is designed to a required depth (say 1.5M to 3.5M) with a short pile of say 1 M to 1.5M below the footing/raft. The number of piles per pit to be cast-in-situ will depend upon the quantum of compression and tension on the leg of the tower. The reinforcement of the short pile is connected to the reinforcement of main foundation for uniform anchorage.





This type of design may also be found useful for the foundations on backfilled soil. While the regular footing can rest on the back filled soil the pile can be cast in the parent soil.

Modern practice of providing rock anchors is to drill the holes in the hard rock and then insert HT steel cable as per IS 14268-1995. Master Flow 718 cementitious grout is then poured in the drilled holes. Thereafter the HT steel cable is tensioned by means of nut & bolt arrangement. The design is based on the skin friction between grout and concrete.

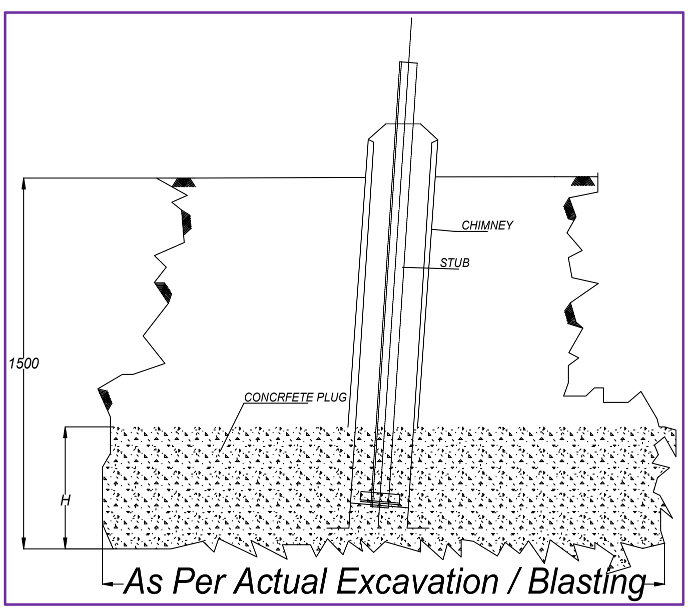


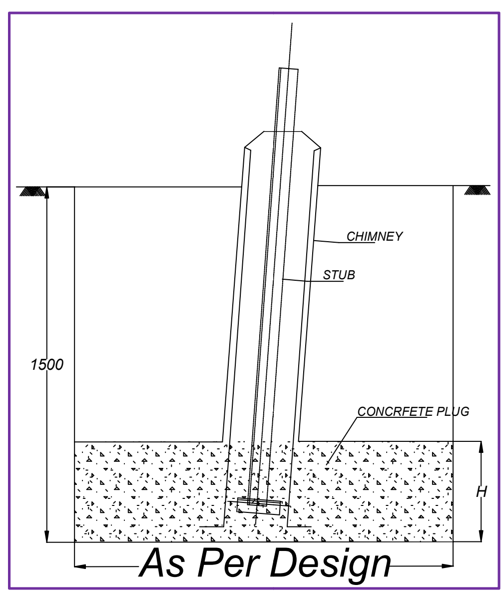
Rock anchor arrangement

4.5.7 FOUNDATION IN HARD ROCK WITHOUT ROCK ANCHORS

Block type foundations in hard rock without any rock anchors or working margin around the footing is one of the fast, economical as well as a reliable way of founding tower in the hard rock.

In such strata foundation is done by blasting the rock. The upward resistance (anchorage) is obtained through a skin friction between concrete and the rock. The condition is that while blasting if the dimensions given in the design are increased, the entire width of the blasted pit shall be filled with concrete upto the design depth of foundation.

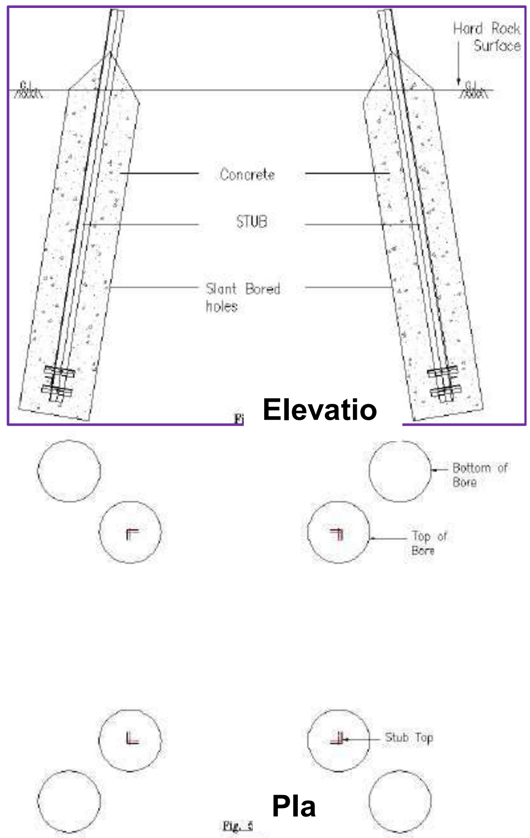




In absence of rock anchors, it will be desirable to have a design of foundation with minimum excavation/blasting of 1500 mm. This will avert a situation of founding the tower on an isolated boulder.

4.5.8 STUB TYPE ROCK ANCHOR FOUNDATIONS

In addition to the open cast hard rock foundations described above, it is also possible to use the stub of the tower as a rock anchor. In this method, the drilling of the rock is done in the hard rock with slopes of actual tower. It is a fact that the tower legs have slopes in X & Y directions. The boring of the rock shall also be done in the same slope. The diameter of the bore will be 150mm more than the stub size. This type of arrangement can be easily adopted for towers up to 220kV.



Elevatio

Pla

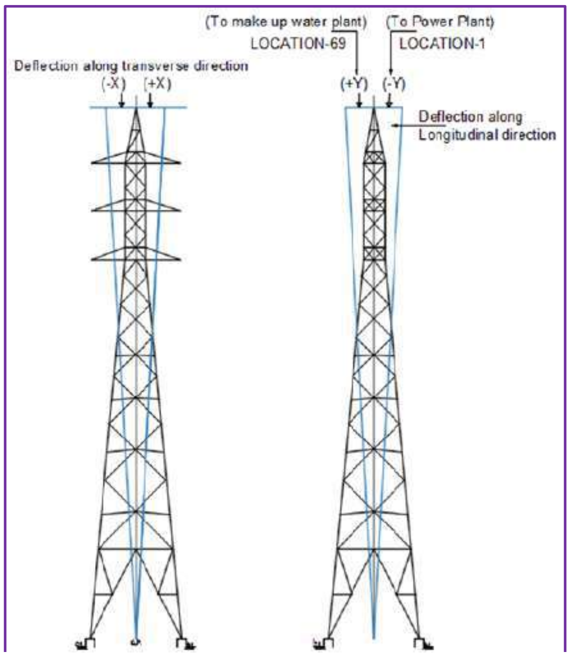
5. NON-DESTRUCTIVE CONDITION MONITORING OF TRANSMISSION LINE, TOWERS & FOUNDATIONS

5.1 Availability of transmission lines is gathering great importance in the regulatory regime. The utilities (Government & Private) are now focusing on the process of condition monitoring of old lines. Condition monitoring includes the following

- **Verticality measurements of tower in transverse & longitudinal direction**
- **Sag & Ground clearance measurement**
- **Galvanizing thickness test**

- Verification of condition of foundations which includes rebound hammer test, ultra-pulse velocity test, carbonation test etc...
- Core cutting & compressive strength evaluation is best method to ascertain quality of concrete

5.1.1. **While the tower is being erected, the crew members generally ensure that the tower is truly vertical. The permissible deviation in verticality is 1 in 360. This deviation is in transverse and longitudinal directions. This is indicated below.**



Transverse Face   Longitudinal Face

5.1.2. **Loss of verticality happens due to error in foundation work, erection work or stringing work. The atmospheric effect like wind pressures and temperature are also responsible for loss of geometry. The assessment of deflection in transverse and longitudinal direction can be done using Total Station (equipment used for surveying). Use of Drone can also be done to measure the deflection. Sag & Ground Clearance Measurement can also be done using Total Station or Drone.**

Total Station positioning for transverse deflection **Sag and Ground Clearance Measurement**

5.1.3. **Over a period of time there are chances of loss of thickness of galvanizing on the tower parts. As per the standard minimum thickness of Zinc coating is 85 micron. Random checking of thickness can be done using Elcometer.**

5.1.4. **The condition of foundation concrete can be done by rebound hammer as well as Ultra Pulse Velocity (UPV) test. In rebound hammer test the spring loaded rebound hammer is held at 900 to the surface whose hardness is to be tested. A spring loaded plunger is released and time taken to rebound is measured. Longer the time poor is the concrete and shorter the time good is the concrete. The results are compared with the standard values. The UPV test involves passing an electrical signal through the mass of the concrete by holding transducers on opposite sides of the concrete surface. If there are voids in the concrete time taken for the pulse to travel will be more and vice–a–versa. The following table is indicative of the standards.**

(As per IS 13311 (Part I) 1992)

Sr. No.	**U.P.V. (kM/sec)**	**Quality of Concrete for Direct Method**
1	Above 4.5	Excellent
2	3.5 to 4.5	Good
3	3.0 to 3.5	Medium
4	Below 3km/sec.	Doubtful

UPV Test

Rebound Hammer Test

5.1.5. **If the results of UPV and Rebound Hammer Test are much doubtful it becomes necessary to resort to core cutting in different sections of the concrete. The core extracted from the concrete are than subjected to compressive strength and are compared with the strength specified in the contract (i.e. M20, M15, etc.). Even this test can be performed at the construction stage for ensuring the quality of work.**

Core cutting work is completed

Removal of Core from the slab

Samples of core cutting

5.1.6. **In many cases the quality of concrete work is not maintained while casting foundation. This results into catastrophic failure of tower along with foundation. If this happens it becomes necessary to access the condition of foundation in various sections of the transmission line. After providing stay wires at appropriate height of the tower, the foundations of tower are opened by excavating leg-by-leg. The poor concrete work is removed and new concrete work is done. In some cases, capping of existing foundation is done to minimize outage on the line. Additional cleats to the stub are also provided in many cases.**

Provision of Stay Wire Excavation of Chimney

Level Verification Chimney Hacking

Provision of additional Cleats Concrete Pouring

Capping / Recasting

5.1.7. In Ahmedabad city the existing 66kV line is upgraded to 132kV. The line which was carrying 260Amp. with ACSR dog conductor is now carrying 1100Amp. with ACCC conductor. The portion of the tower below bottom cross-arm was retained and rest of it was designed for 132kV. Foundations were also validated and or modified for increase in tower loadings.

5.1.8. In north Mumbai (Mira-Bhayandar) the existing 220kV 600 tower with 11.6M base width was required to be converted into narrow base tower for allowing road widening by civic authorities. A narrow base tower with 4M X 4M base width was erected within the tower and the existingbroad base tower was dismantled. The shutdown of only 3 days was required.

Construction of narrow base tower within existing broad base tower

5.1.9. In Teesta lower IV HEP one take off tower for crossing the tail race was required to be constructed. The profile required 93M tall tower with base width of 8M X 8M. The foundation was to be made on existing flood protection wall with a width of 16M. The design was done to marginalize the deflection.

93M tall tower with base of 8M X 8M

5.1.10. **In Shimla, Himachal Pradesh 13M stool was required on the existing 132kV tower for obtaining adequate clearance above a residential building. Since, the matter was sub-judice, clearance was provided as per Indian Electricity Rules. The tower structure and the foundation were revalidated for the increase in load.**

132kV tower with stool

6. CONCLUSION

6.1 **Transmission line design, construction and maintenance are a very challenging task in the power sector. The case studies presented above indicate that various challenges can be taken up for reliability of the transmission lines.**

6.2 **Many times, the existing tower and section of transmission line need condition monitoring and special modifications. Such assignment needs careful study for achieving ultimate goal.**

#######

Design & Construction of Srinagar -Leh Transmission Line in High Altitude, Extreme Weather, Snow-Bound Avalanche Prone Areas

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SUMMARY

India is a vast country with varied geography & topography having wide range of weather conditions across different parts. Ladakh, a region of Jammu and Kashmir (J&K) state in the Northern part of India is geographically and climatically a peculiar region. It is located at an altitude ranging between 2400 m and 4500 m above mean sea level with rugged topography having steep slopes. The ground access to the region is cut off every winter due to avalanche activities along the roads. The Ladakh region is presently not connected to Indian power grid and for meeting the electricity demand, the region is dependent upon local small hydro and DG generation.

Power Grid Corporation of India Ltd (POWERGRID), a Govt. of India Enterprise & the Central Transmission Utility of the country is responsible for planning and coordination of inter-State transmission system and implements transmission system for evacuation of central sector projects & various Independent Power Producers (IPPs) and grid strengthening schemes across India. POWERGRID presently owns & operates approx. 135,000 ckt kms of transmission lines in the country forming National Grid.

As an endeavour to provide electrical connectivity to Ladakh region, POWERGRID has taken up construction of 220 kV transmission line from Srinagar (Alusteng) to Leh via Kargil, Drass and Khaslti. The transmission line is approx. 350 kms long passing through difficult mountainous terrain having high altitude and extreme climatic conditions (heavy winds, snow & temperature going below - 45°C). The line traverses through two major mountain ranges (viz. Great Himalayas & Zanskar) encountering some of the high altitude passes (viz. Zozi-la -3529m & Fatu-la – 4049 m) and heavy snow & avalanche prone areas (Gagangir, Zozi-la, Gumri, with more than 5m standing snow). The transmission line also passes through high security, military zones close to LOC with Pakistan. The construction of the line is in progress.

Appropriate selection of transmission line components, design parameters & developing detailed designs has been as challenging as construction of transmission line.

The line route was selected using satellite imagery. Due to in accebility in some places along the route, digital terrain modelling & fly through techniques have been used to identify most suitable route.

Spécial features have been considered in design of conducators, OPGW, toners and fondations, insulators & hardwares. As the line passes through the highest wind zone of the country (basic wind speed of 55 m/sec) and heavy snow zone areas, towers has been designed for the high wind speed & ice loading (25 mm radial ice deposition on conductor and earthwire). Tower geometry has been configured for additional electrical clearances due to high altitude and cross arm of towers have been specially designed and staggered to take care of conductor galloping. Special kind of steel for towers has been used to mitigiate the effect of low temperature. High strength conductor & OPGW has been considered instead of conventional conductors used in normal 220kV lines . In addition to this, high strength OPGW and double strength insulator strings with additional insulators have been considered.

All efforts has been made to select towers locations free of snow avalanches, despite, some locations between Minamarg and Zoji La are falling in snow avalanches prone area which may be subjected to impact of fast moving snow alongwith strong wind. Besides envisaged use of general avalanche protection control measures (such as snow rakes, deflecting and retarding structures), foundations of the towers which are to be constructed in these avalanches prone area are designed to take care of snow impact loading alongwith creeping and gliding of snowpack. Special type of chimneys of about 10 m height are designed for these towers to withstand the avalanche load and to provide sufficient height to cables above ground level to avoid avalanche impact. To protect the high raised chimney foundation from snow glide and snow avalanches forces, tie beams at two intermediate levels have been provided. These tie beams have been securely tied with chimney with sufficient reinforcement anchorage to make a perfect monolithic structure.

The paper covers in detail, salient design aspects and special design features of the under construction 220 kV Srinagar-Leh transmission line in high altitude, extreme weather, snow bound areas including analysis & design of foundations for lattice transmission towers in avalanche prone areas.

KEYWORDS

Avalanche-Hilly-Transmission Line-Snow

1. INTRODUCTION

India is a vast country with varied geography & topography having wide range of weather conditions across different parts. Ladakh, a region of Jammu and Kashmir (J&K) state in the Northern part of India is geographically and climatically a peculiar region ,located at an altitude between 2400 m and 4500 m above M.S.L . The topography attracts a lots of tourists during the summer season. The ground access to most part of the region is cut off every winter due to heavy snowfall and avalanche activities along the roads. The state share its boundaries with two neighbouring hostile countries (China and Pakistan).

2. BACKGROUND

The Ladakh region is presently not connected to Indian power grid because of which the following factors advocates its connection:

1. The region is dependent upon local **small hydro and DG generation**.
2. The present installed generation is only about **26 MW**,
   - Diesel generating unit (12MW)
   - Micro hydel units (14MW).
3. During winter seasons the power demand is **more** due to
   - Heating loads
   - Hydro units being run of river produce very low power at –25 deg C (due to freezing of water)
4. The power supply is limited to **3-4 hours**
5. Due to power shortage the small scale/cottage industries/ tourism have not been developed.
6. Being an area of **defense establishment / strategic importance** reliable power supply arrangement is very important.

POWERGRID has taken up the construction of 220 kV transmission line from Srinagar (Alusteng) to Leh via Kargil, Drass and Khaslti to connect Ladakh region to Indian power grid.

3. SRINAGAR - LEH TRANSMISSION SYSTEM

As an endeavour to provide electrical connectivity to Ladakh region, POWERGRID has taken up construction of 220 kV transmission line from Srinagar (Alusteng) to Leh via Kargil, Drass and Khaslti having transmission line length of approx. 350 kms .It traverses through difficult mountainous terrain having high altitude, extreme climatic conditions (heavy winds, snow & temperature going below -45°C), major mountain ranges encountering some of the high altitude passes and heavy snow & avalanche prone areas, high security, military zones close to LOC with Pakistan.

Transmission line	220 kV Single Circuit approx. **350 kms** long
Substations	220/66 kV GIS at Drass, Kargil, Khalsti & Leh.
Interconnection System	66 kV Interconnection Lines & Substation Bays at Drass, Kargil, Khalsti & Leh

Table 1. Components of Srinagar – Leh transmission system

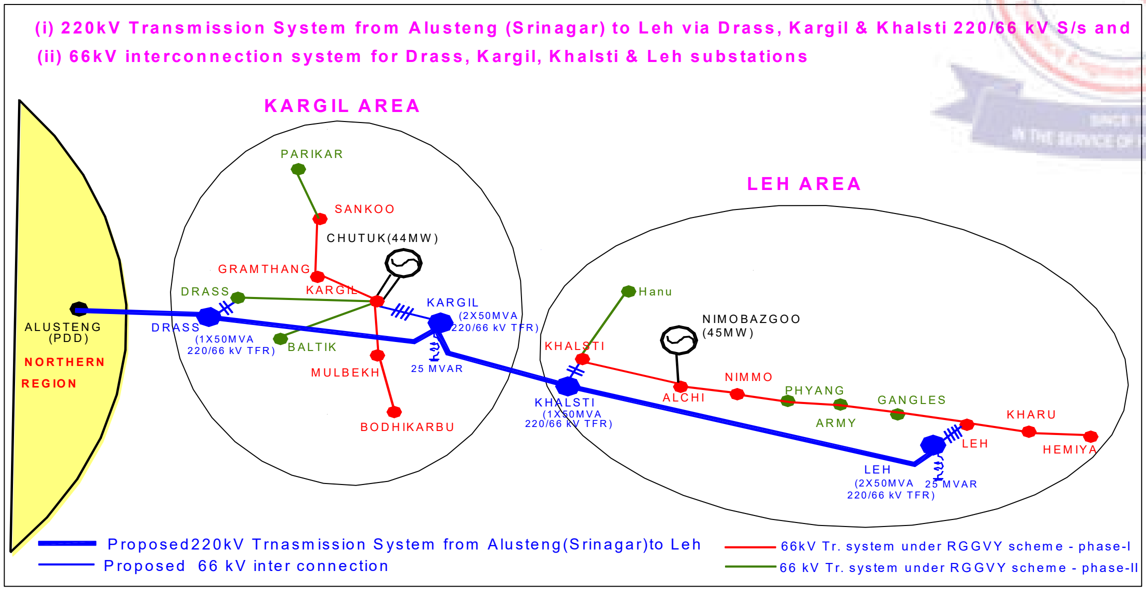

Fig 1. Srinagar – Leh transmission system Map

It caters to the power deficient regions (Ladakh, Leh, Drass and Kargil) of Jammu and Kashmir State.

4. ROUTE OF 220 KV S/C LINE WITH HEAVY SNOW

The line route was selected using satellite imagery. Due to inaccebility in some places along the route, digital terrain modelling & fly through techniques have been used to identify most suitable route. Snow avalanche is a major problem for this line apart from high wind pressure, low temperature, high seismic activity, heavy snow accumulation and high altitude.Portions of line passes through heavy avalanche zones. Despite of efforts, many towers came under avalanche funnel zone Prone to get impacted by avalanche forces.

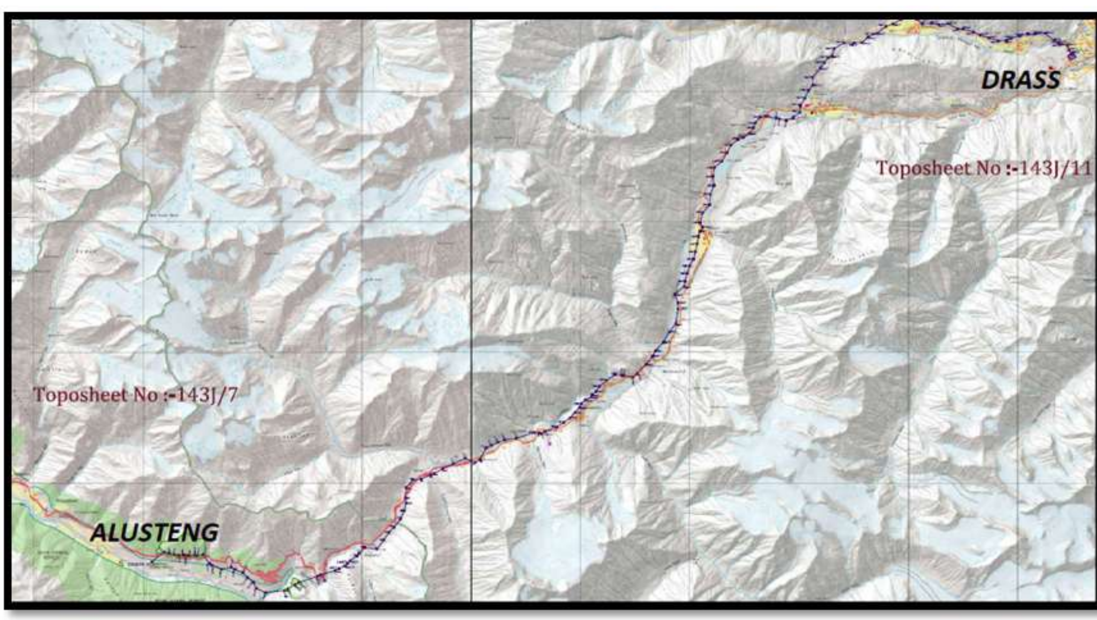

Fig 2. Route Map of 220 kV S/C line with heavy snow

5. SPECIAL DESIGN FEATURES

Special features have been considered in design of conductors, OPGW, towers and foundations, insulators & hardwares.

5.1 TOWER

As the line passes through the highest wind zone of the country (basic wind speed of 55 m/sec)[1] and heavy snow zone areas, towers has been designed for the high wind speed & ice loading (25 mm radial ice deposition on conductor and earth wire). Tower geometry has been configured for additional electrical clearances [2] due to high altitude and cross arm of towers have been specially designed and staggered [2] to take care of conductor galloping. Special kind of steel [3] for towers has been used to mitigate the effect of low temperature. High strength conductor & OPGW has been considered instead of conventional conductors used in normal 220kV lines. In addition to this, high strength OPGW and double strength insulator strings with additional insulators have been considered.

Tower Type	Weight Span (m)		Wind Span(m)	Base Width at Normal Tower Level(m)	Wind zone	Ground Clearance (m)	Radial Ice Thickness (mm)	Max Conductor Temp(degrees)
	NC (Max)/ (Min)	BWC (Max)/ (Min)						
220 kV S/C SINGLE ACSR DEER T.T. 'D'	2000/-2000	1200/-1200	500	9.00 x 9.00	6(55m/s)	7.7	25	85

Table 2. Design Parameters of 220 kV S/C Single ACSR DEER T.T. 'D'

Fig 3. 220 kV S/C SINGLE ACSR DEER T.T. 'D' with cross arm staggering

5.2 TOWER FOUNDATION

The foundation for avalanche prone area has some special features to take care of snow impact loading due avalanches which are stated below:

a) Its pedestals are straight as compared to the conventional tower foundations whose pedestals follow the slope of the leg connected to them. This has been done to avoid excessive excavation for the purpose of foundation casting. Moreover the pedestals are also kept circular in shape so as to reduce the effect of snow load on it as the shape factor is less as compared to rectangular or square column.

Fig 4. Special Foundation with Circular straight pedestals and tie beams

b) Instead of stub the tower leg is connected to the foundation by the anchor bolts and base plate.

c) Raised chimney of 9.5m and 6.5m height provided for sufficient height to cables above ground level to avoid avalanche impact

Fig 5. Raised Chimneys for increased clearance for conductors

(i) As the requirement for the raised chimney is quite high i.e. 9.5 m and 6.5 m due to area's vulnerability towards avalanche, therefore tie beams of four and three numbers respectively have been provided. It has the following purpose.

(ii) They are provided at different levels to increase inertial mass of the foundation.

(iii) They make all the four legs as one integral unit to resist the high avalanche impact.

(iv) They are securely tied with pedestal with sufficient reinforcement anchorage to make perfect monolithic structure and to provide effective restraint against avalanche impact

6. DESIGN ASPECTS

6.1 Modelling

Columns and tie beams were modeled in the STADD PRO as shown below. Only 9.5m RC analysis is shown below as 6.5mRC analysis is a subset of previous one.

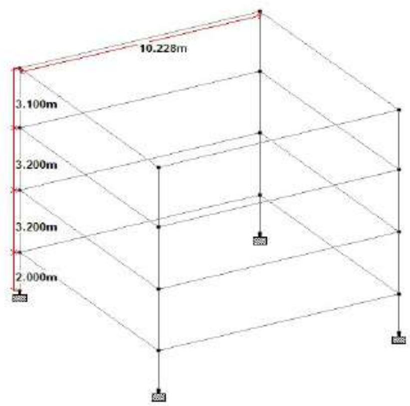

Fig 6. STADD model of column and tie beams for 9.5 m RC.

6.2 Loading

1) The following loads are considered for the analysis.
a) Dead Load- Self weight of the structure.
b) Live Load.
(i) Vertical Loads on beams due to deposited ice of 1.5 m thickness
1.50 x 0.40 = 0.60 t / Sq. m
[For thickness of snow = 1.50 m and Density of snow = 0.40 t cu.m]

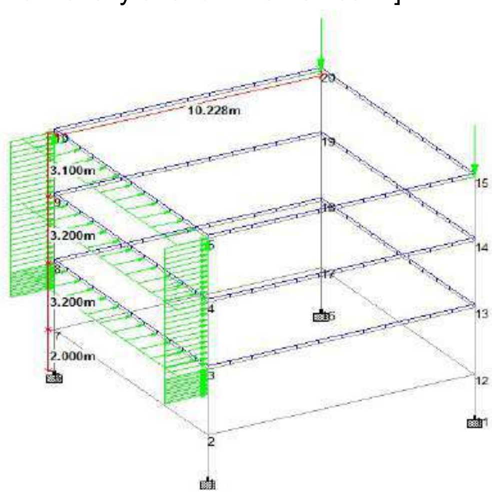

Fig 7. Vertical loads on beams

(ii) Horizontal loads due to avalanche pressure.

Loads have been applied in three directions i.e. Longitudinal, Transverse and Diagonal.
Horizontal load on beam and pedestal= 4.50 t /sq. m
[For density of avalanche debris = 0.45 t / cu.m and velocity of avalanche = 10 m / sec]

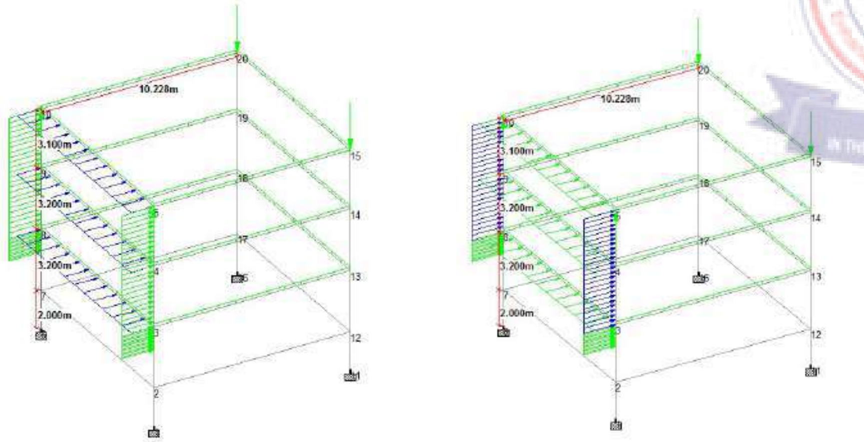

Fig 8. Horizontal loads on beams and pedestals in longitudinal and Transverse direction

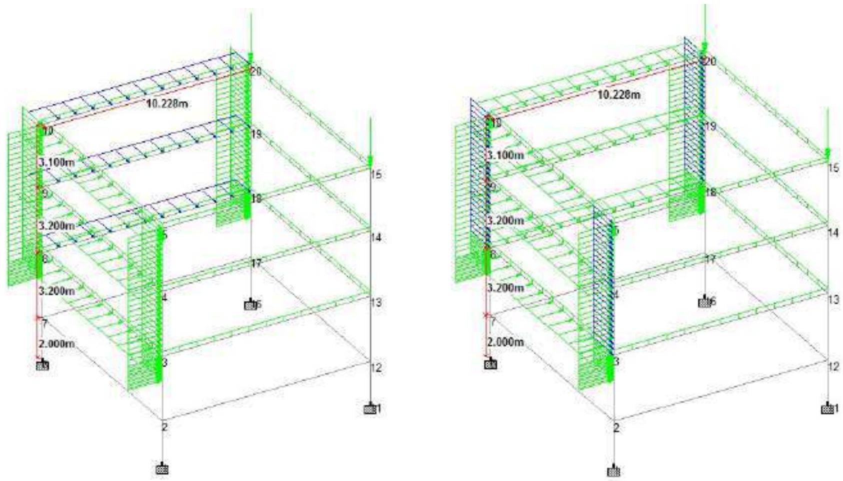

Fig 9. Horizontal loads on beams and pedestals in diagonal direction

(iii) Compression, uplift force and side thrust from the tower have been applied on the pedestals with a factor of safety of 1.1

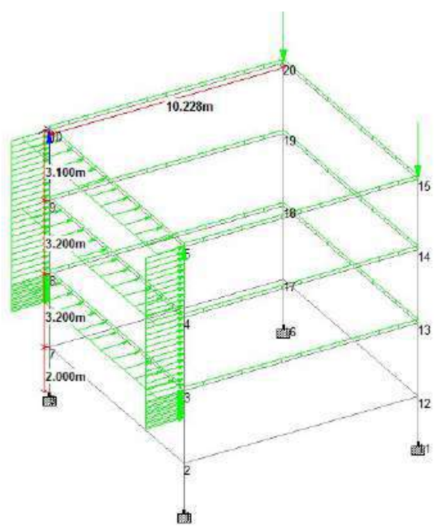

Fig 10. Uplift and compression loads pedestals in Vertical direction

6.3 ANALYSIS

The Modeling as well as the analysis has been done on STADD pro using stiffness matrix method. From the above analysis of the model Bending Moment, Shear Force and Axial Force Diagrams were derived. Some typical results are as follows:

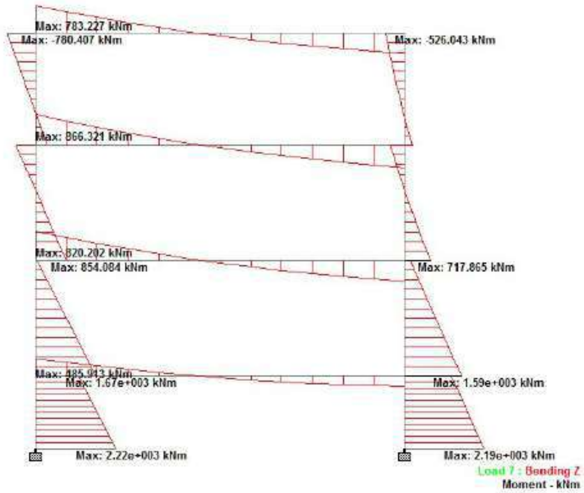

Fig 11. Bending Moment Diagram

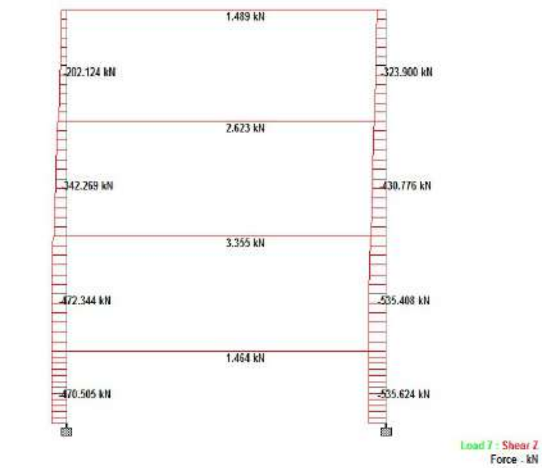

Fig 12. Shear Force Diagram

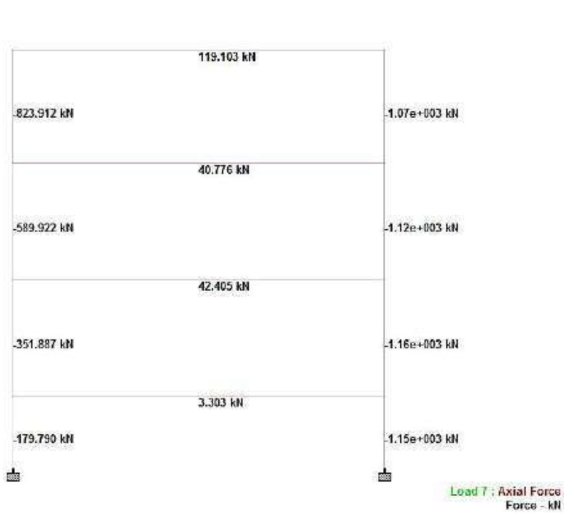

Fig 13. Axial Force Diagram

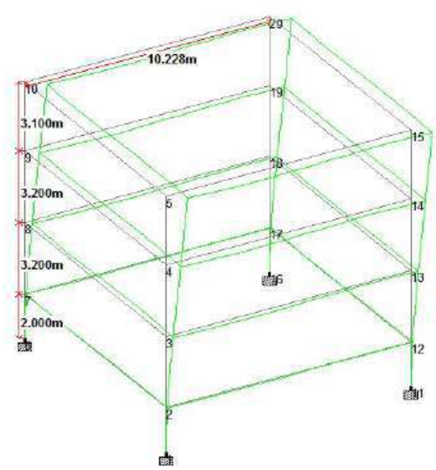

Fig 14.Deflection Diagram

6.4 FINALISED DESIGN

According to the analysis the forces were calculated. RCC design was commenced after taking the forces into account. In the design concrete M20 Nominal Mix1:1.5:3 (Cement: Sand: Aggregates) and Steel Fe500 is taken. RCC design done according to **IS 456:2000** [4].

Result: These are common for both 6.5m RC and 9.5m RC except in 6.5m RC there are only three tie beams whereas in 9.5m RC there are four of them.

Tie beam i) Size- 700mmX700mm
ii) Reinforcement- 20no. 32 Ø

Column i) Size-1200mm
ii) Reinforcement- 36 no. 32 Ø

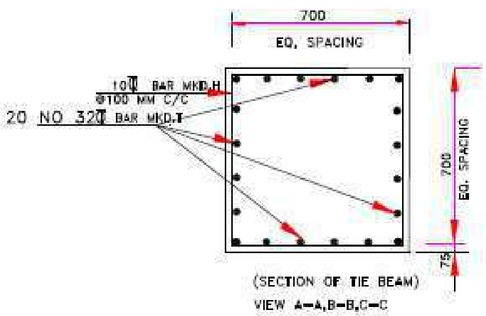

Fig 15. Typical Cross Section for Tie Beam

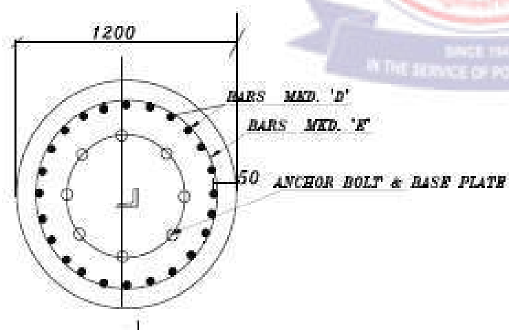

Fig 16.Typical Cross Section of Pedestal

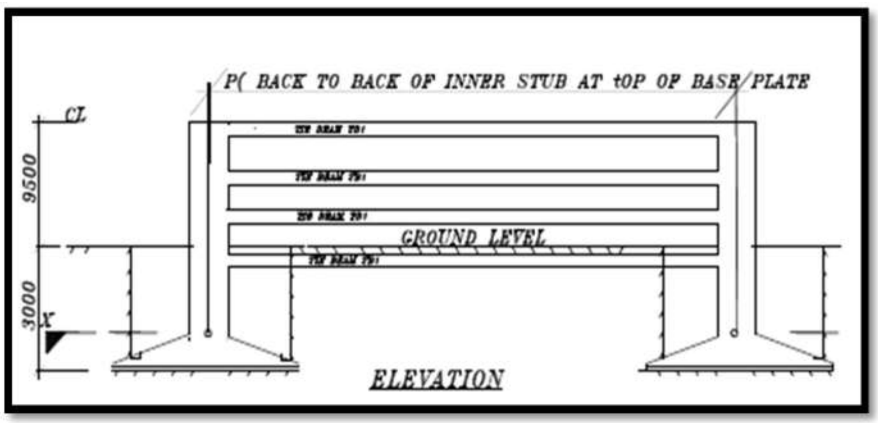

Fig 17.Typical Elevation of foundation showing tie beam arrangements

7. CONSTRUCTION CHALLENGES

As the region is located at an altitude ranging between 2400 m and 4500 m above mean sea level with rugged topography having steep slopes. The conditions are not conducive for the construction activities to take place. The following are the challenges faced during construction activities.:

(i) The ground access to the region is cut off every winter due to avalanche activities along the roads.

(ii) Extreme cold weather and high winds.

(iii) Short working period (July to October)

(iv) Unanticipated snowfall during the end of year

(v) Traversing difficulty due to snow.

(vi) Scorching sunlight at high altitude makes it difficult to see.

(vii) Approachability problem for the construction equipments

Fig 18.Snowfall during Construction **Fig 19. Traversing difficulty**

Fig 20.Difficult Approaches

8. CONCLUSION

Despite of severe challenges faced and short working period during construction of the line.

(i) Total of 1100 foundations were casted (out of which 14 were special foundations)

(ii) Erection of towers in a stretch of 350 km between Srinagar to Leh.

(iii) Stringing work completed.

(iv) Part of Srinagar-Leh line was commissioned.

(v) The experience of transmission line design and construction at high altitude and heavy snow

Areas was very useful .Therefore can be used as a benchmark to tackle similar problems (If occur) in future endeavors.

Fig 21.Reinforcement bar tying **Fig 22. Scaffolding Installation**

Fig 23. Casting of foundation **Fig 24. Erection of tower**

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[3] IS 2062: 2011 -Indian Standard -HOT ROLLED MEDIUM AND HIGH TENSILE STRUCTURAL STEEL — SPECIFICATION

[4] IS 456: 2000 -Indian Standard -PLAIN AND REINFORCED CONCRETE - CODE OF PRACTICE

Comparative Analysis of Transmission Line Towers and Transmission Line Poles, Including Eight-Legged Towers, Based on Key Structural and Operational Parameters

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Abstract

Transmission line supports are critical components in power transmission networks, influencing reliability, safety, cost, and environmental impact. While traditional four-legged lattice towers have dominated for decades, new configurations such as eight-legged lattice towers and tubular monopoles are gaining attention for their ability to handle compact right-of-way (ROW) corridors and multi-circuit lines. This paper provides a comprehensive comparison between four-legged lattice towers, eight-legged lattice towers (referencing the work of Shukla & Selvaraj, CPRI Bengaluru), and tubular monopoles based on structural, economic, and environmental parameters. Wind load deflection tests in Software indicate up to 28% reduction in top deflection for eight-legged towers compared to conventional four-legged ones. The study highlights the suitability of each structure type for varying terrain, voltage levels, and corridor constraints, offering insights for sustainable transmission infrastructure development.

Keywords

Transmission line structures; lattice towers; eight-legged towers; monopoles; right-of-way (ROW) optimization; wind loading; structural performance; environmental sustainability.

1. Introduction

Transmission lines serve as the backbone of the electrical grid, transmitting power across long distances from generation centers to load points. The mechanical reliability of these lines depends primarily on the design and performance of their supporting structures. Historically, four-legged lattice towers have been the preferred choice due to their cost-effectiveness, modularity, and ease of fabrication. However, as population density and environmental concerns increase, the demand for compact, visually less intrusive, and high-capacity structures has risen. Consequently, engineers are exploring eight-legged lattice towers and tubular monopoles as modern alternatives.

Shukla and Selvaraj (2019) conducted detailed analytical and experimental studies on eight-legged lattice towers at the Central Power Research Institute (CPRI), Bengaluru. Their results showed improved torsional stiffness, reduced sway, and compact base requirements, making these towers ideal for multi-circuit 220 kV and 400 kV applications. Meanwhile, tubular monopoles—though more expensive—offer faster erection, minimal land use, and a visually appealing design suitable for urban areas.

2. Classification of Transmission Line Support Structures

Transmission line supports can be classified based on geometry and structural behavior:

- **Four-Legged Lattice Towers**: Conventional truss structures made of bolted steel angles. They are efficient for long spans and heavy loads.

- **Eight-Legged Lattice Towers**: Modified truss configurations developed to carry multiple circuits with reduced base width, providing better lateral stability.
- **Tubular Monopoles**: Tapered steel or concrete poles designed as cantilever structures, offering aesthetic appeal and minimal ROW usage.

Each structure type is further categorized into suspension, angle, and terminal types depending on the line's geometry and functional requirements.

3. Design Considerations and Analytical Modeling

The structural design of transmission line supports in India follows IS 802 (Part 1/Sec 1):2015, *"Use of Structural Steel in Overhead Transmission Line Towers – Code of Practice"*, together with IS 5613 (Part 2/Sec 1):1985 for installation, and IEC 60826 for reliability criteria.

3.1 Design Loads

As per Clause 9 of IS 802 (Part 1/Sec 1):2015, the primary design loads considered for transmission line towers are:

- Dead load (DL): Self-weight of the tower, conductors, earth wires, and fittings.
- Wind load (WL): Pressure acting on the exposed area of members, insulators, conductors, and earth wires.
- Conductor and Earth Wire Tension Loads: Resulting from line deviation angles and broken wire conditions.
- Longitudinal Load (LL): Due to unequal span tensions or during stringing and maintenance.
- Seismic load (EL): Considered in high seismic zones per IS 1893 (when applicable).

The design wind pressure (p) at any height *z* above ground level is given by:

$$p=0.6V_z^2$$

where
p = design wind pressure (N/m²) and
Vz = design wind speed (m/s) at height *z*, obtained after applying the necessary terrain, height, and topography factors as per Clauses 9.2–9.5 of IS 802 (Part 1/Sec 1):2015.

Eight-legged lattice towers generally exhibit greater lateral stiffness and reduced sway due to their wider base geometry and triangulated configuration. Conversely, monopoles or tubular pole structures depend primarily on section modulus and material strength to resist lateral loads, and their slenderness and overall stability require careful verification in accordance with IS 802 (Part 2) and relevant structural steel design standards (e.g., IS 800:2007). Stability checks against local and global buckling are therefore critical for such pole structures.

4. Comparative Study Based on Key Parameters

A summary comparison of major performance parameters among the three structure types is presented in Table 1.

Parameter	Four-Legged Lattice Tower	Eight-Legged Lattice Tower	Transmission Line Pole (Monopole)
Structural Configuration	Truss with four legs forming square/rectangular base	Octagonal/rectangular truss with eight legs (Shukla & Selvaraj, CPRI)	Single tapered tubular shaft
Material Usage	Moderate, economical steel angles	Slightly higher than 4-leg but lower than monopole	High-grade thick wall steel; heavier sections
Wind Performance	Low drag due to open truss	Improved stiffness with comparable drag	Higher drag; large bending moments
Deflection under 50 m/s Wind	≈ 250 mm	≈ 180 mm	≈ 400 mm
Foundation	Four isolated footings	Eight pad or combined raft	Single large raft or pile
Erection &	Moderate; bolted	Complex; more	Quick crane

Maintenance	**joints**	**members**	**erection; fewer joints**
Aesthetic Appeal	**Industrial lattice**	**Compact truss**	**Sleek modern appearance**
Cost (Relative)	**1.0**	**1.2**	**1.6**
Expected Life (years)	**50+**	**55+**	**40–45**

Note: Values are indicative based on analytical models and field studies at CPRI, Bengaluru.

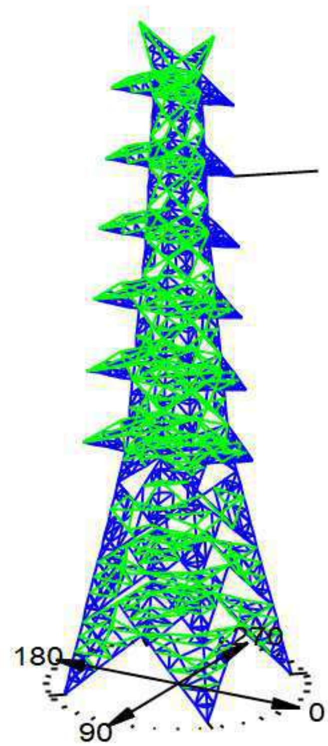
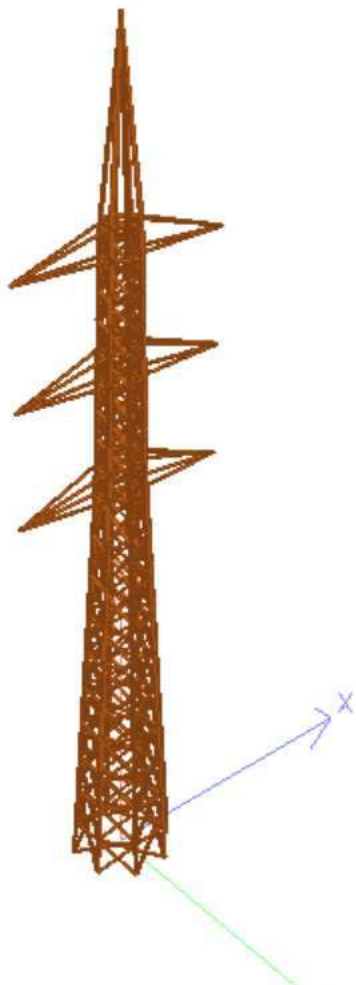


Fig. 1.-Typical Four-Legged Lattice Tower



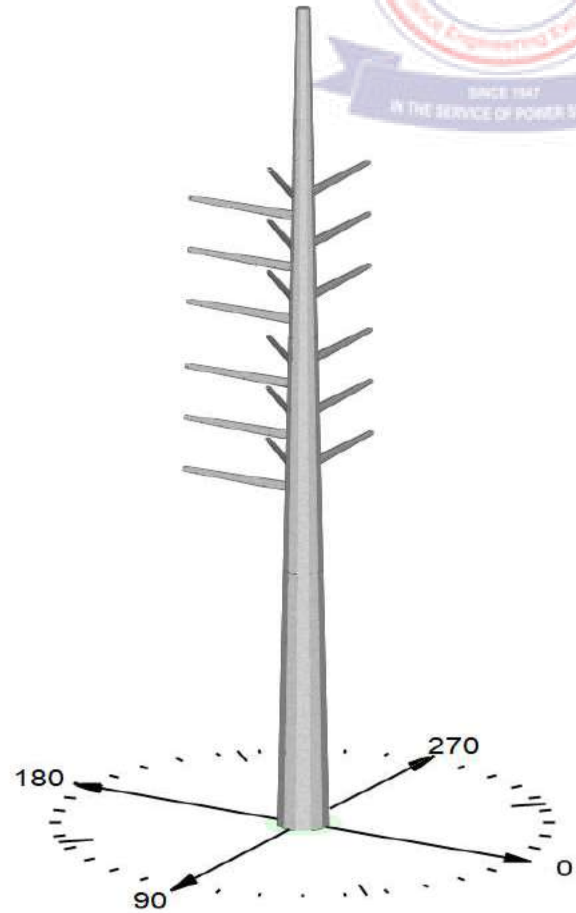


Fig. 2. Eight-Legged Lattice Tower

Fig. 3.Tubular Monopole Structure (Transmission Line Pole)

5. Discussion and Field Experience

Experimental field studies at CPRI indicated that the eight-legged tower exhibited approximately 20–30% lower top deflection under equivalent wind load compared to the conventional four-legged tower. This improvement is attributed to enhanced lateral stiffness and reduced effective slenderness of members. Fabrication challenges include increased joint complexity, but the overall stability gain justifies the cost increment.

In monopoles, deflection increases significantly with height due to cantilever behavior. Vibration monitoring revealed that damping ratios in monopoles are lower than lattice towers, necessitating tuned mass dampers or helical strakes in windy regions.

6. Cost–Benefit and Sustainability Analysis

The economic comparison shows that while monopoles have higher upfront costs, their ease of installation and reduced land requirements can offset these expenses in urban projects. Eight-legged lattice towers balance cost, performance, and land use effectively, making them suitable for semi-urban corridors and hilly terrain.

From a sustainability perspective, lattice towers have a lower carbon footprint due to the reuse of steel members and recyclability. Monopoles, being monolithic, are harder to recycle but offer minimal land disturbance. A life-cycle cost (LCC) assessment indicates the following relative performance:
- Four-legged: Baseline cost factor 1.0, maintenance cost moderate.
- Eight-legged: 1.15× fabrication cost, ~25% reduction in ROW cost.
- Monopole: 1.6× fabrication cost, ~40% ROW savings but higher material cost.

7. Conclusion and Future Scope

The comparative analysis demonstrates that each transmission line structure type has distinct advantages:
- **Four-legged lattice towers** remain the most economical and versatile for standard spans.
- **Eight-legged towers** provide improved stiffness, reduced deflection, and are ideal for multi-circuit lines in limited ROW conditions.
- **Monopoles** are best suited for urban and environmentally sensitive zones due to their compact footprint.

Future developments may explore hybrid lattice-tubular configurations, high-strength weathering steels, and advanced foundation systems to further optimize transmission line structures for future grid expansion.

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#######

Condition Assessment and Life Extension of Transmission Tower Stubs Using Advanced NDT and Retrofitting Techniques

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1. Abstract

The reliability of high-voltage transmission networks critically depends on the structural integrity of tower stubs and foundations. These vital components ensure the safe transfer of mechanical loads from towers to the ground and maintain overall system stability. However, exposure to aggressive environments, soil chemistry, corrosion, and ageing significantly reduces their service life. Traditional inspection methods are intrusive and often damage the structure, prompting a shift towards Non-Destructive Testing (NDT) techniques. This paper reviews advanced NDT methods — including Ultrasonic Testing (UT), Ground Penetrating Radar (GPR), Half-Cell Potential (HCP) measurements, Magnetic Flux Leakage (MFL), and visual inspection — for evaluating the in-situ condition of tower stubs and foundations. Field investigations shall be carried out across coastal, industrial, and arid zones to evaluate the environmental influences on structural deterioration. Based on the anticipated findings, the study will propose a comprehensive set of remedial and strengthening measures — including protective coatings, FRP wrapping, and micro-piling — to enhance and extend the service life of existing transmission tower structures.

2. Introduction

Transmission line towers form the backbone of modern power transmission systems, carrying critical loads across vast geographical regions. The structural safety and operational reliability of these towers depend heavily on the soundness of their stubs and foundations — elements that transfer axial, lateral, and uplift forces into the ground. However, these structural components are susceptible to degradation over time due to environmental exposure, corrosion, chemical attack, settlement, and dynamic loading.

Traditional condition assessment methods often involve excavation, dismantling, or partial destruction of the structure, which can disrupt service and lead to costly downtime. Non- Destructive Testing (NDT) techniques offer a superior alternative, enabling engineers toassess the internal condition of steel and concrete components without compromising serviceability. By integrating NDT into preventive maintenance programs, utilities can detect deterioration early, plan remedial measures efficiently, and significantly extend the lifespan of transmission infrastructure.

3. Objectives of the Study

The primary objectives of this study are as follows:

- To review and evaluate suitable NDT techniques for in-situ assessment of tower stubs and foundations.
- To analyse environmental influences on deterioration across diverse site conditions — coastal, industrial, and arid.
- Toproposeintegratedinspectionmethodologiesandlife-extensionstrategies.
- Todevelopaframeworkforremedialactionsandretrofittingapproachesfor deteriorated structures.

4. Overview of Non-Destructive Testing(NDT)Techniques

NDT techniques allow for accurate, non-invasive evaluation of structural condition. Key methods applicable to transmission tower stubs and foundations are summarized below.

Ultrasonic Testing(UT)

UT uses high-frequency sound waves to detect internal flaws and measure steel thickness loss due to corrosion. Portable ultrasonic thickness gauges enable precise measurement of residual section thickness.

- Advantages: Quantitative thickness data, detection of hidden cracks and weld defects.
- Limitations: Requires surface preparation and proper coupling for accurate results. UT is governed by standards such as ASTM E114 and IS 13311 (Part 1).

Ground Penetrating Radar(GPR)

GPR uses electromagnetic waves to detect subsurface anomalies like voids, cracks, buried foundations, or soil separation beneath pile caps. It is valuable for mapping foundation geometry and assessing soil–structure interaction.

- Advantages:Non-intrusive,rapidscanning,and3Dsubsurfaceimaging.
- Limitations: Accuracy depends on soil conductivity and moisture content.

Half-Cell Potential (HCP)Measurement

HCP is an electrochemical method used to assess corrosion activity in embedded steel. It measures the potential difference between reinforcement and a reference electrode.

- Interpretation:
  - Potential>−200mV→<10%probabilityofcorrosion
  - −200mVto−350mV→Uncertain corrosionprobability(~50%)
  - <

−350 mV → > 90 % probability of active corrosion HCP is standardised underASTM C876 and IS 516 (Part 5/Sec 2).

Magnetic Flux Leakage(MFL)

MFL detects corrosion and metal loss in steel members. A magnetizing field is induced in the steel, and leakage flux indicates regions of cross-sectional loss.

- Advantages: Detects hidden corrosion and pitting, even under coatings.
- Limitations: Requires specialized sensors and calibration.

Visual Inspection and Drone-Based Surveys

Visual inspection remains the first step in condition assessment. Rusting, cracking, misalignment, and coating deterioration can be identified visually. Drones equipped with high- resolution cameras allow close-range inspections in inaccessible locations, improving safety and efficiency.

5. Methodology

The study's methodology combines literature review, field inspections, and application of NDT techniques across representative sites. Three major environmental zones can be considered:

- Coastal Zone :High chloride and moisture levels, leading to rapid corrosion.
- Industrial Zone :Polluted, chemically aggressive soils causing void formation and leaching.
- Arid Zone: The rmal fluctuations, abrasive winds, and low humidity causing micro- cracking and coating loss.

Considering environmental zones, NDT techniques — UT, GPR, HCP, and MFL — can employed to assess stub and foundation conditions. Results can be correlated with visual inspections and verified through selective intrusive tests(core sampling, limited excavation).

6. Results and Discussion

Corrosion Detection and Thickness Loss

UT measurements revealed significant variation across regions. Coastal stubs exhibited 15– 25 % steel thickness reduction, whereas industrial and arid zones showed average losses below 10 %. The correlation between ultrasonic readings and visual corrosion showed strong, validating UT as a reliable diagnostic tool.

Subsurface Condition Assessment

GPR scans identified voids beneath 18 % of foundations in industrial environments, primarily due to chemical leaching and inadequate drainage. Coastal sites showed high signal attenuation — indicating moisture ingress — whereas arid zones revealed relatively stable subsurface profiles.

Electro chemical Activity

HCP results showed potential values between −400 mV and −500 mV in several coastal structures, confirming active corrosion. Industrial regions showed moderate corrosion potential (−300 mV to −350 mV), while arid sites exhibited minimal electrochemical activity.

Comparative Analysis of NDT Techniques

Each NDT technique offers unique insights:

- UT provides quantitative section loss data.
- GPR identifies voids, soil separation, and buried anomalies.
- HCP detects early- stage corrosion before visible signs appear.
- MFL locate spitting and hidden corrosion in buried members.

A combined NDT approach delivers a holistic structural health assessment.

7. Remedial Measures and Strengthening Techniques

Once deterioration has been detected through NDT methods, it is essential to implement timely remedial and strengthening actions to restore structural integrity and extend the service life of tower stubs and foundations. Strategies can be classified into preventive, corrective, and advanced retrofitting measures.

Preventive Measures

Preventive interventions aimto slow down or stop deterioration before it reaches critical levels.

- Protective Coatings and Paint Systems: Application of zinc-rich epoxy primers, polyurethane coatings, or advanced fluoro polymer paints protects steel from corrosion. Hot-dip galvanization remains one of the most effective long-term solutions.
- Cathodic Protection (CP): Installing sacrificial anodes (zinc or magnesium) or using impressed current systems can effectively control electrochemical corrosion, especially in chloride-rich coastal areas.

- Waterproofing and Drainage: Improving drainage around tower bases and applying water-repellent sealants to concrete surfaces reduces water ingress and chloride transport.
- Soil Improvement: Chemical stabilization or compaction grouting around the foundation reduces void formation and improves load transfer.

Corrective Repair Measures

When moderate deterioration is observed, corrective actions are necessary to restore structural performance.

- Stub Replacement or Welding: Severely corroded stub sections can be cut and replaced using new galvanized steel, with proper welding and protective coating.
- Concrete Jacketing: Reinforced concrete or polymer-modified mortar jackets can restore the cross-section of deteriorated foundations, improving strength and durability.
- Grouting and Void Filling: Non-shrink cementitious grouts are used to fill voids beneath foundations detected by GPR. Epoxy-based grouts are preferred where chemical resistance is needed.
- Re-alkalisation and Electrochemical Chloride Extraction: These techniques can re-passivate steel surfaces embedded in concrete, reducing corrosion potential without demolition.

Advanced Strengthening and Retrofitting Techniques

For ageing infrastructure or severe deterioration, advanced methods provide enhanced load capacity, durability, and resilience.

a) FRP Wrapping

Fiber Reinforced Polymer(FRP)wraps—made of carbon, glass, or aramid fibers—are applied externally to steel stubs or concrete sections.

- Advantages: Light weight, corrosion-resistant, rapid installation.
- Applications: Stub strengthening, crack confinement, and improving axial and flexural capacity.
- Codes: Refer to ACI440.2RandIS15988:2013forFRPapplications.

b) Micro-Piling and Under pinning

Micro-piles (150–300 mm diameter) are installed adjacent to existing foundations to transfer loads to deeper, competent strata.

- Advantages: Minimal vibration, suitable for constrained sites, improves load-bearing capacity.
- Applications: Used in cases of soil settlement, erosion, or foundation failure.
- Codes:IS2911(Part4):2013–DesignandConstructionofMicroPiles.

c) Hybrid Retrofitting Techniques

Hybridsystemscombinemultiplemethods—suchasconcretejacketingwithFRPconfinement or underpinning with grouting — to provide a synergistic effect.

- Use Case: Towers in coastal and industrial zones with simultaneous corrosion, settlement, and structural weakening.

d) Use of Chemical Inhibitors

Corrosion inhibitors can be added to concrete repair mortars or injected near stubs to slow electro chemical reactions.

- Example: Amino alcohol-based inhibitors for mapassive layer on the steel surface, reducing corrosion rates by up to 70%.

8. Recommendations

Based on the findings and field experience, the following recommendations are proposed for utilities and maintenance engineers:

1. **Integrate NDT into Routine Maintenance: Schedule periodic NDT inspections every 3–5 years, with increased frequency in coastal or industrial zones.**
2. **Establish Condition Rating Systems: Develop standardized grading(e.g.,Good, Moderate, Severe) based on NDT results to priorities interventions.**
3. **Adopt Predictive Maintenance Models: Use digital monitoring systems, IoT sensors, and AI-based predictive algorithms for early detection of structural issues.**
4. **Ensure Quality of Remedial Materials: Use IS/ASTM-compliant coatings, grouts, and FRP materials to ensure durability.**
5. **Training and Capacity Building: Train field engineers and maintenance teams in advanced NDT interpretation and retrofitting techniques.**
6. **Document Maintenance History: Maintain detailed inspection and repair logs to inform future asset management decisions.**

8.Conclusion

1. **Non-Destructive Testing has become an indispensable tool for assessing the condition of transmission tower stubs and foundations. It allows for accurate, cost-effective, and non-intrusive evaluation of structural integrity, enabling timely interventions and reducing the risk of catastrophic failure. Field studies reveal that environmental conditions significantly influence degradation mechanisms — coastal zones accelerate corrosion, industrial areas induce chemical attack, and arid zones cause mechanical fatigue.**

2. **By integrating NDT findings with preventive, corrective, and advanced retrofitting techniques such as FRP wrapping, micro-piling, cathodic protection, and hybrid systems, transmission infrastructure can achieve significant life extension. This holistic approach not only enhances safety and reliability but also optimises asset management and reduces lifecycle costs, ensuring a resilient and sustainable power transmission network.**

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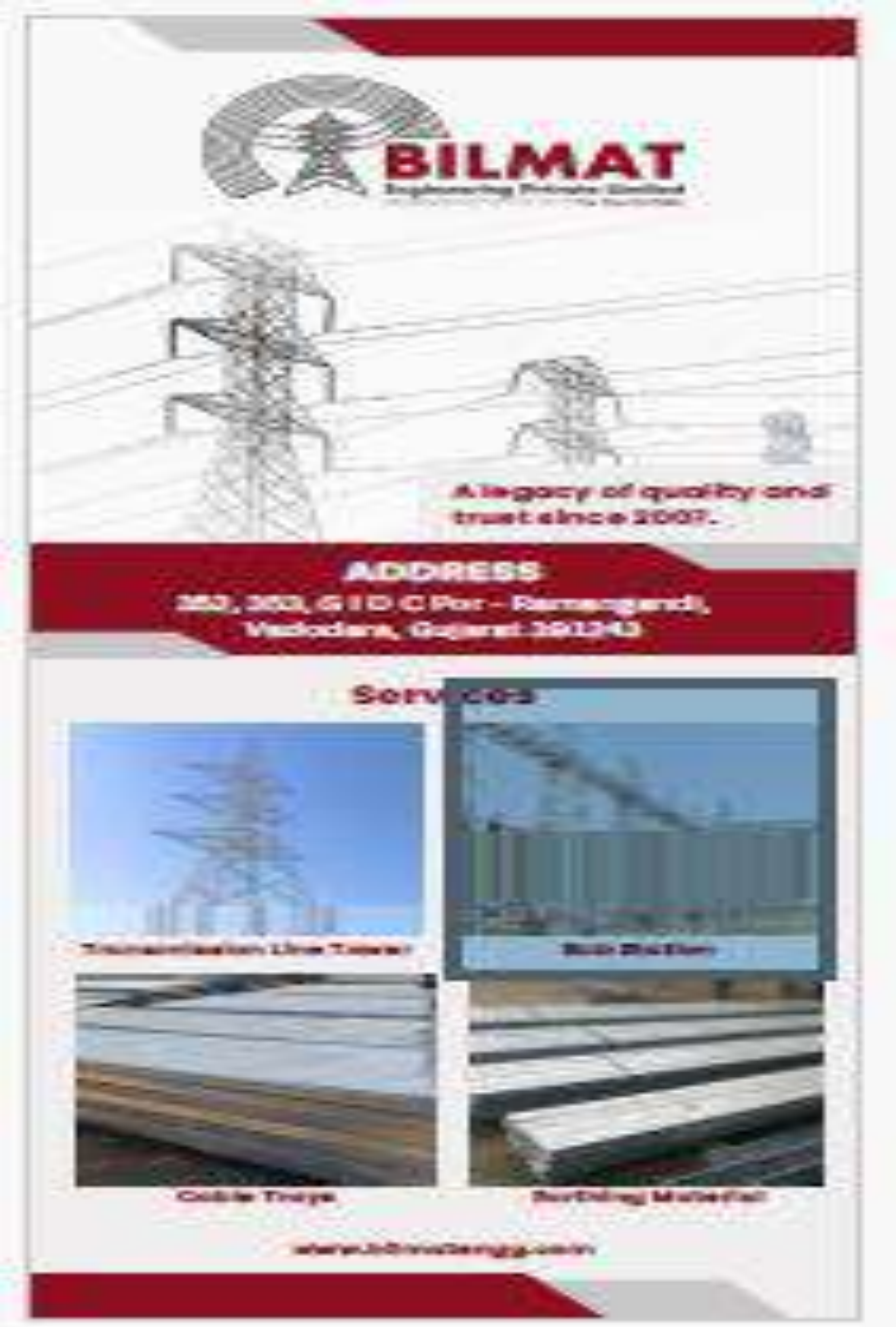
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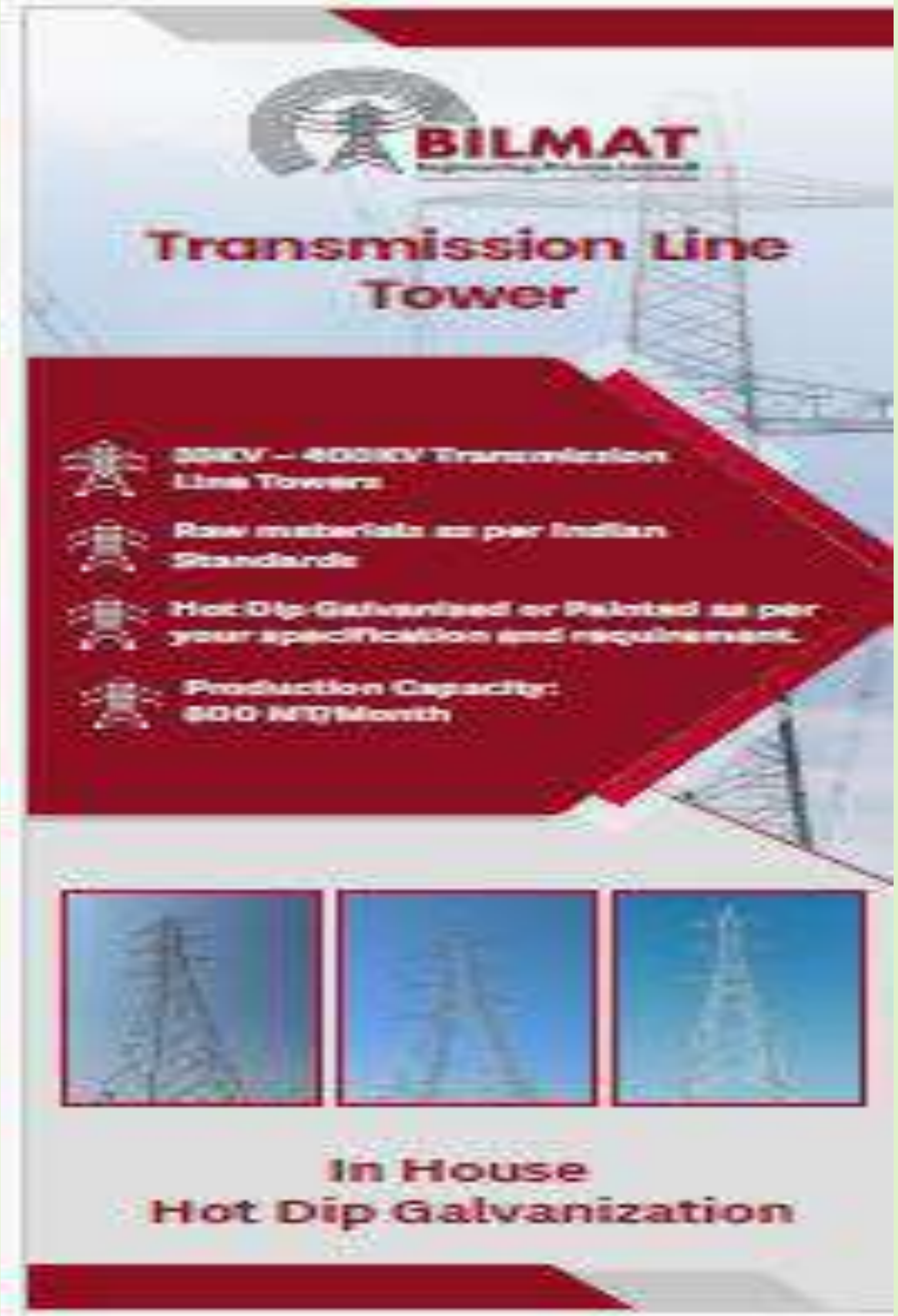
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- Prevents hazards like electrocution, equipment damage, and downtime.
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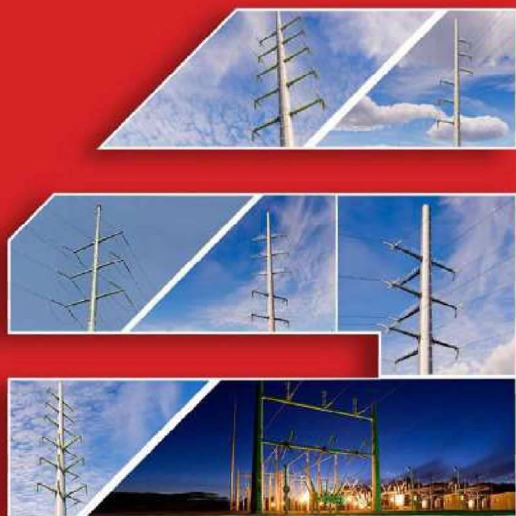

UTILITY POLES

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Leadership

Salasar is a company that has flourished under the deft guidance of its adept management team, whose track record of accomplishment is extensive and distinguished. Furthermore, the team's insightful vision for the company's future has been instrumental in charting a course for continued growth and success.

It is evident that the management team at Salasar is dedicated to upholding the company's values and principles, and is committed to ensuring that the company remains at the forefront of innovation and progress. Their unwavering commitment to excellence and their unwavering focus on achieving key objectives have been instrumental in the company's success to date, and bode well for its future prospects.

MD

Shashank Agarwal

Full-time Director

Shalabh Agarwal

The Salasar Story

In the year 2006, Salasar started out as a tower manufacturer with the vision of transforming the industry. Tower manufacturers rarely provided multiple solutions under one roof. Salasar sought to fill this gap by aspiring to become a **one-stop shop** for India's telecom giants by carrying out engineering, designing, procurement, fabrication, galvanization and EPC under one roof. Owing to our persistence, expertise, and capability to work wonders with steel, today we are no longer confined to towers and have expanded our range of products and services to encompass all the infrastructural needs of a rapidly developing nation.

Our Vision

To make a **substantial contribution towards the development of National Infrastructure** by providing technologically advanced solutions, and to play a critical role in making India the most preferred destination for the fulfilment of local & global Infrastructural needs.

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To be at the forefront of **developing technologically advanced Infrastructural solutions** for our customers around the world.

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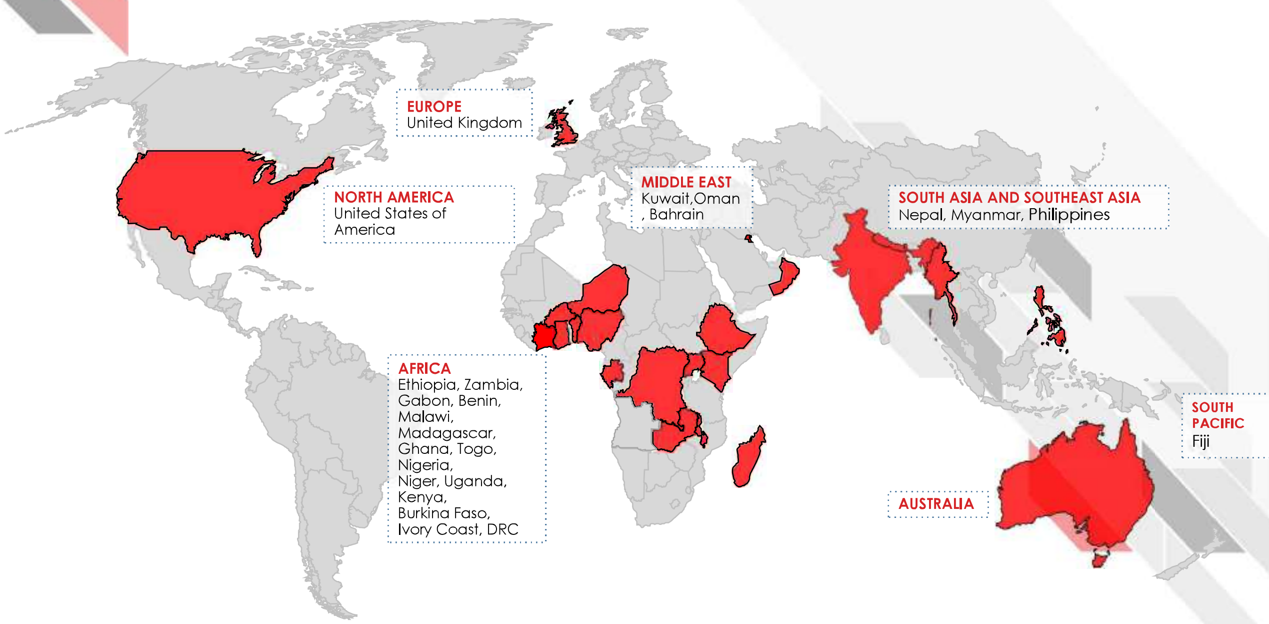

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  - Transmission (>66 kV)
  - Sub-Station Structures - 1 slide
- **Traction Mast (Metro/Railways)**
- **Telecom Tower / Pole**
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  - General Arrangement Drawings / SLD.
  - Assembly Drawings
  - Shop Drawings (Part/Piece Drawings)
- **Proto Inspection :**
  - Full Scale Test Towers / poles
  - Innovative products
- **Site Activities / Guidance / Support**
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UTILITY POLES - Where Poles

- ❑ CYCLONE/COASTAL REGION
- ❑ URBAN AREAS WHERE SPACE IS LIMITED
- ❑ METRO/FLYOVER/RIVER CROSSINGS
- ❑ MEDIAN/FOOT-PATH/SERVICE ROADS
- ❑ HILLY/VALLEY REGION
- ❑ UP-GRADATION OF RATING WITHOUT LONG SHUTDOWN (ERS)

Where Poles

CYCLONE/COASTAL REGION : As coastal regions are more likely to experience cyclones than other regions, poles may be a better option than a traditional tower.

Traditional tower transmission lines (colored red) are prone to breaking in extreme weather

The monopole transmission line withstood strong rain and cyclonic wind.

Images are for visual representation only

Where Poles

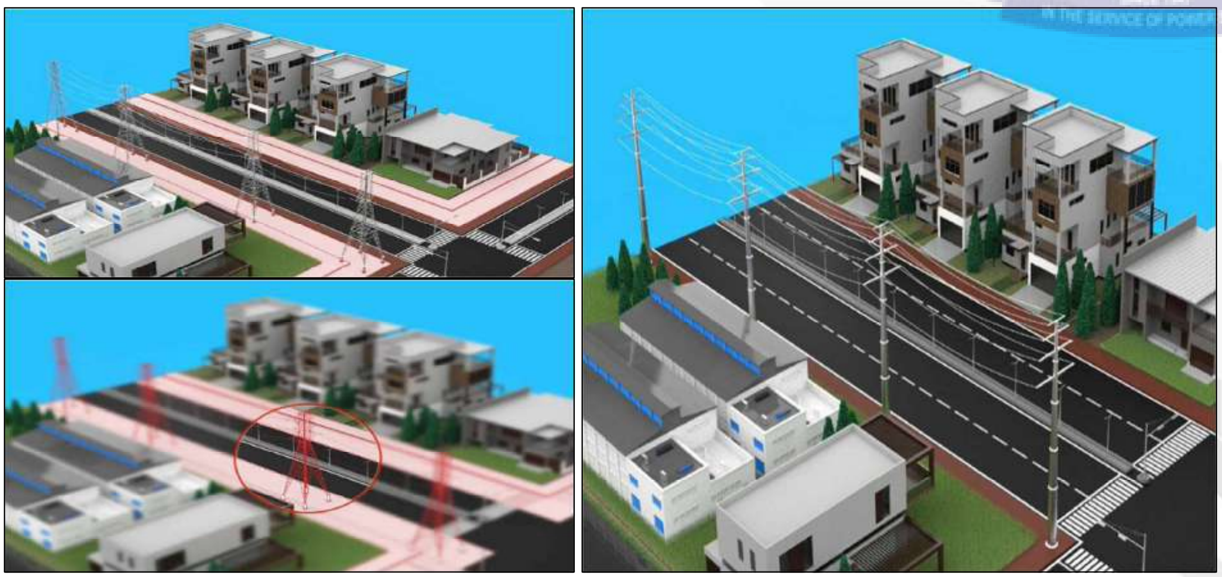
URBAN AREAS : We are currently constrained by space due to the increased construction of infrastructure in urban areas; consequently, poles are more likely to replace traditional towers since they require more land area.

NOTE : When space is really limited, direct embedded monopoles are employed. By using these types of poles, we may save some additional room in the foundation area by avoiding the need for massive foundation columns.

Images are for visual representation only

Where Poles

MEDIAN/FOOT-PATH/SERVICE ROADS : If we employ poles over towers, narrow medians, walkways, or service roads cannot prevent us from spreading power widely.



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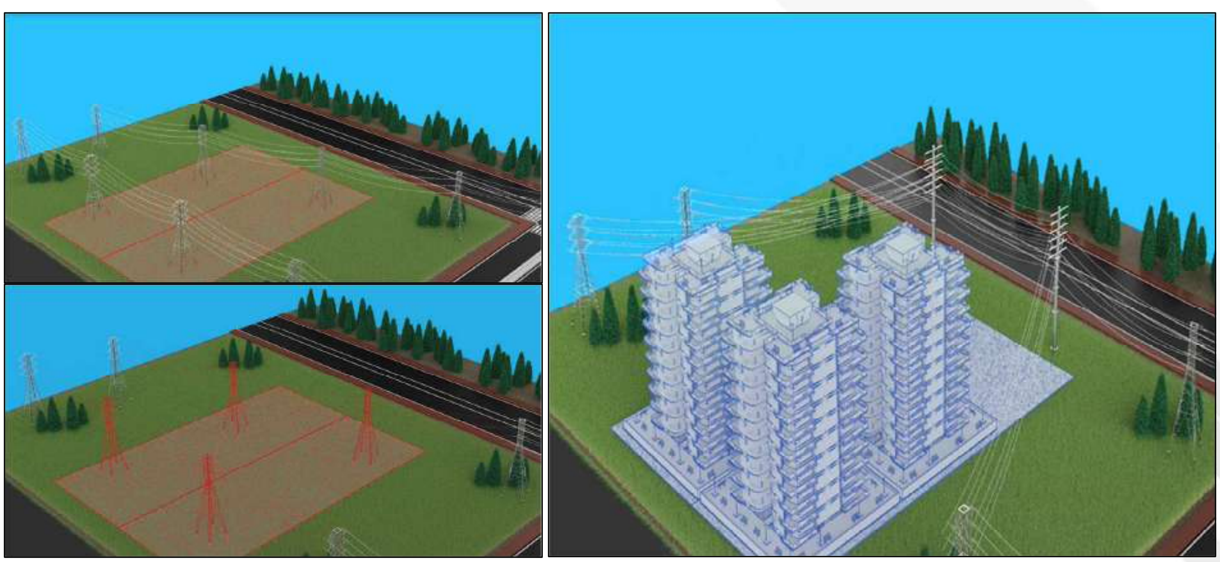

Where Poles

METRO/FLYOVER/RIVER CROSSINGS : Sometimes a flyover(can be a metro flyover) or a river crossing may be in the path of our transmission line; in that case, the height of the conductors must be increased. In that situation, a pole may be far simpler and less expensive to erect than a tower.

Where Poles

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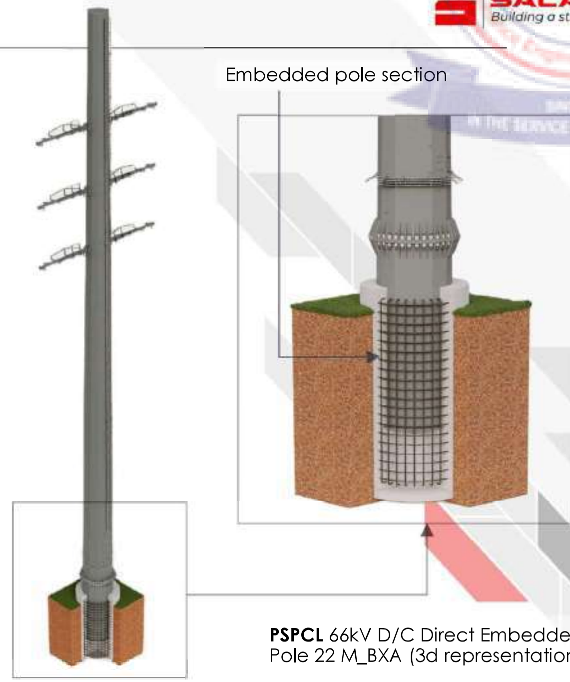
Structure

DIRECT EMBEDDED TYPE POLE

- Embedded type foundation is suitable where space is very limited and can be managed with small spans
- This type of foundation can be suggested for distribution, sub-transmission & transmission poles
- Depth of embedment of the pole for the purpose of foundation should not be less than one-sixth of the total length of the pole above ground level



PSPCL 66kV D/C Direct Embedded Pole 22 M_BXA (3d representation)

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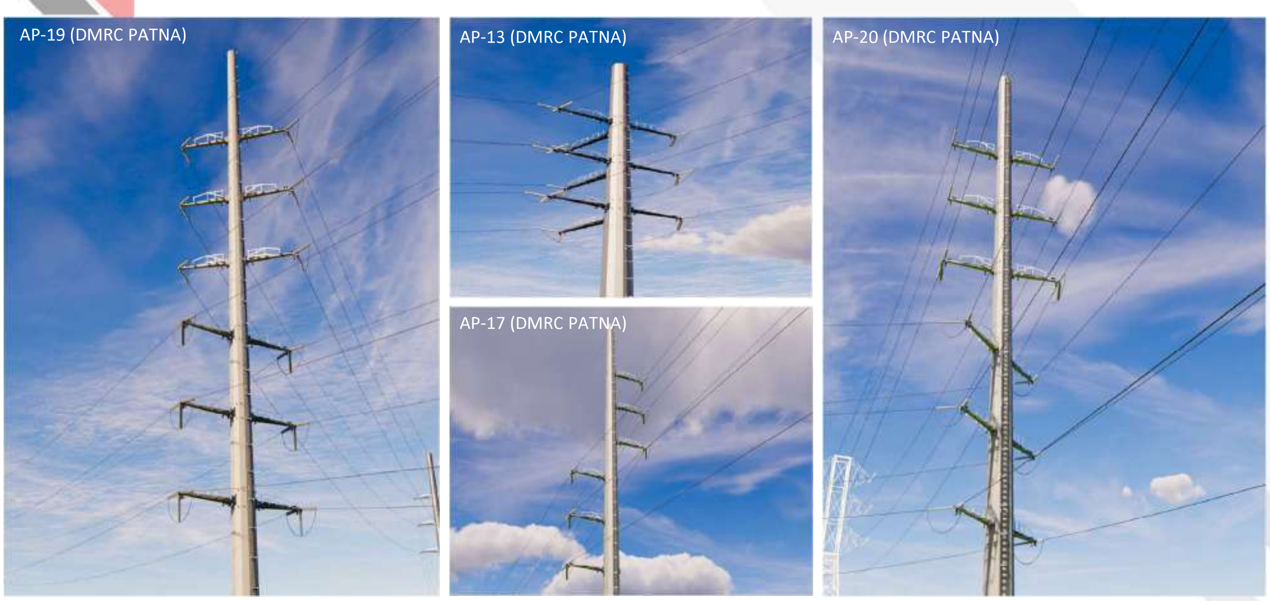
Different Types Of Poles

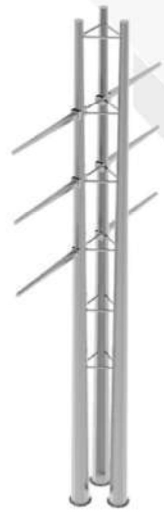


Structures

Different Types Of Poles


MONOPOLE

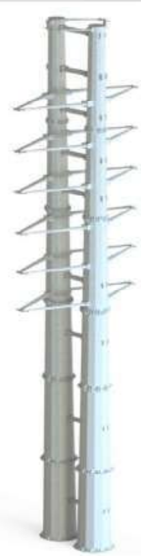

DUAL POLE


TRIPLE POLE


FOUR POLE

Types Of Dual-Poles

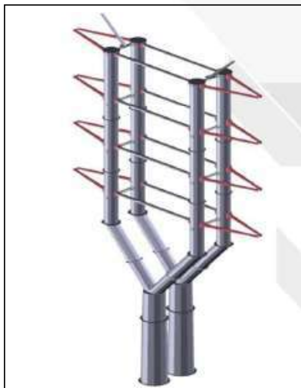

TRANSVERSE DUAL POLE


INLINE DUAL POLE M/C

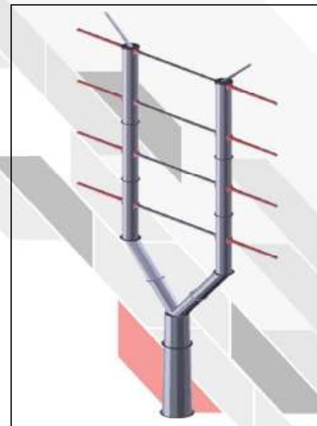

INLINE DUAL POLE D/C

Y -Type Pole Structures

Y-POLE S/C

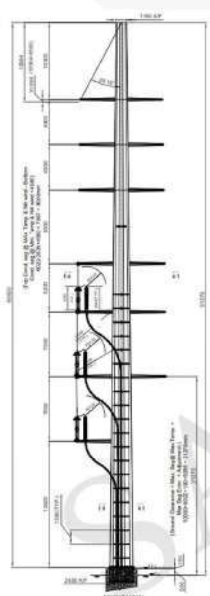


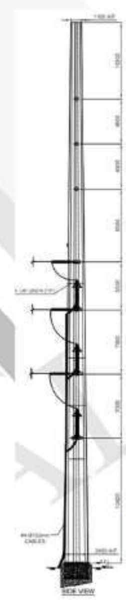
DUAL Y-POLE M/C



Y-POLE M/C

220 kV MC Pole with Single Circuit CT





220 kV MC Pole (Bolts Inside of Pole Shaft

220 kV "MCPB" MULTI CIRCUIT POLE
- Pole Height - 53.52 m
- Bottom Shaft Dia – 1.5 m

Y -Type Pole Structures

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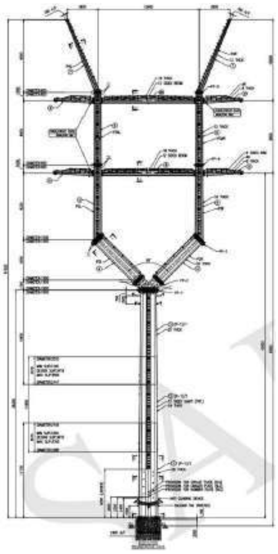
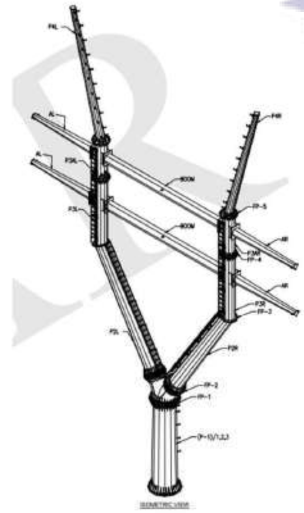
Building a stronger future

400 kV "Y – TYPE" DOUBLE CIRCUIT POLE
- Pole Height - 61.82 m
- Bottom Cross Arm Height - 45m

Y -Type Pole Structures





Sub-station Structure - 66kV, 132kV, 220kV & 400kV

Before electricity can reach the end user, it must pass through an assemblage of equipment called a Substation where the voltage is stepped up or stepped down to serve specific purposes.

Gantry Structure

Gantry structures are used for guiding the power conductor from dead-end tower near substation to the electrical equipment in a substation. This structure consist of a number of columns and girder beams, which depend on number of circuits of the line.

Manufacturing Process

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1 . RAW MATERIAL YARD

2 . PLASMA CUTTING

3 . CNC PRESS BRAKE

4 . SAW WELDING

5 . INSIDE SEAM
WELDING ROBOT

6 . GALVANIZING

Distribution Pole (testing)

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Horizontal Testing

Salasar has world-class facilities and equipment for testing poles as per national and international standards. We recently tested 11 and 13-metre poles for the **Nepal Electricity Authority (NEA)**.

Recently Tested Poles

SALASAR
Building a stronger future

1 . Pole Type: PD (90 ^{o}) _35 M BXA

- Voltage : 132 kV
- No. of Circuits : Two (Double Circuit)
- Pole Height : 53.118 M
  Ground Line Reactions :
  - Bending Moment : 26,500 kNm
  - Resultant Shear : 1779 kN
  - Axial Force : 485 kN
- Client : M/s. Delhi Metro Rail Corporation(DMRC)
- End Client : M/s. Bihar State Power Transmission Company Limited (BSPTCL)

2 . Pole Type: PD (60 ^{o} -90 ^{o}) _34.20 M BXA

- Voltage : 220 kV
- No. of Circuits: Two (Double Circuit)
- Pole Height : 44.210 M
  Ground Line Reactions:
  - Bending Moment : 31,297 kNm
  - Resultant Shear : 870.59 kN
  - Axial Force : 631.64 kN
- Client : M/s. Delhi Metro Rail Corporation(DMRC)-Mumbai
- End Client : M/s. Tata Power Company (TPC)

3 . Pole Type: PDT90 (60 ^{o} -90 ^{o}) / DE (0 ^{o} -15 ^{o})_22M BXA

- Voltage : 400 kV
- No. of Circuits: Two (Double Circuit)
- Pole Height : 47.160 M
- Ground Line Reactions:
  - Bending Moment : 29,895 kNm
  - Resultant Shear : 990 kN
  - Axial Force : 533 kN
- Client : M/s. BNC Power project Ltd.
- End Client : M/s. Maharashtra State Electricity Transmission Company limited(MSETCL)

Recently Tested Poles

SALASAR
Building a stronger future

4 . Pole Type: PC(15 ^{o} -30 ^{o})_19M BXA

- Voltage : 220 kV
- No. of Circuits: Four (Multi Circuit)
- Pole Height : 54.04 M
- Ground Line Reactions :
  - Bending Moment : 25,524 kNm
  - Resultant Shear : 815 kN
  - Axial Force : 506 kN
- Consortium
  Partners : M/s. Aarvanss Buildwell And Infracon Llp (ABI)
  M/s. Salasar Techno Engineering Limited (STEL)
- End Client : M/s. Uttar Pradesh Power Transmission Corporation Limited (UPPTCL)

5 . Pole Type: PD (30 ^{o} -60 ^{o}) / DE (0 ^{o} -15 ^{o})_21M BXA

- Voltage : 220 kV
- No. of Circuits : Four (Multi Circuit)
- Pole Height : 56.03 M
- Ground Line Reactions :
  - Bending Moment : 42,870 kNm
  - Resultant Shear : 1271 kN
  - Axial Force : 677 kN
- Consortium
  Partners : M/s. Aarvanss Buildwell And Infracon Llp (ABI)
  M/s. Salasar Techno Engineering Limited (STEL)
- End Client : M/s. Uttar Pradesh Power Transmission Corporation Limited (UPPTCL)

6 . Pole Type: PB (15 ^{o} -30^{o}) _21M BXA

- Voltage : 132 kV
- No. of Circuits : Two (Double Circuit)
- Pole Height : 34.27 M
- Ground Line Reactions :
  - Bending Moment : 8988 kNm
  - Resultant Shear : 382 kN
  - Axial Force : 181 kN
- Consortium
  Partners : M/s. Aarvanss Buildwell And Infracon Llp (ABI)
  M/s. Salasar Techno Engineering Limited (STEL)
- End Client : M/s. Uttar Pradesh Power Transmission Corporation Limited (UPPTCL)

Recently Tested Poles

7 . Pole Type: PMT30 (15° -30°) _21M BXA

- Voltage : 132 kV
- No. of Circuits : Four (Multi Circuit)
- Pole Height : 48.44 M
- Ground Line Reactions :
  - Bending Moment : 23385 kNm
  - Resultant Shear : 7676 kN
  - Axial Force : 433 kN
- Consortium
  Partners : M/s. Aarvanss Buildwell And Infracon Llp (ABI)
  M/s. Salasar Techno Engineering Limited (STEL)
- End Client : M/s. Uttar Pradesh Power Transmission Corporation Limited (UPPTCL)

8 . Pole Type: PC (0° -30°)/ (45° -75°) _ 25M BXA

- Voltage : 132 kV
- No. of Circuits : Four (Multi Circuit)
- Pole Height : 54.64 M
- Ground Line Reactions :
  - Bending Moment : 33253 kNm
  - Resultant Shear : 1066 kN
  - Axial Force : 642.35 kN
- Client : M/s. Delhi Metro Rail Corporation(DMRC)
- End Client : M/s. Bihar State Power Transmission Company Limited (BSPTCL)

9 . Pole Type : PB 19 TENSION POLE

- Voltage : 132 kV
- No. of Circuits : Two (Double Circuit)
- Pole Height : 33.27 M
  Ground Line Reactions :
  - Bending Moment : 26,500 kNm
  - Resultant Shear : 1779 kN
  - Axial Force : 485 kN
- Client : M/s. Salasar Techno Engineering Limited (STEL)

Recently Tested Poles

10 . Pole Type: DPD (60° - 90°) _14.4M BXA

- Voltage : 220 kV
- No. of Circuits : DOUBLE (Double Circuit)
- Pole Height : 33.08 M
- Ground Line Reactions :
  - Bending Moment : 8,946 kNm
  - Resultant Shear : 456 kN
  - Axial Force : 204 kN
- Client : M/s. Canara Electricals & Cosultancy Services
- End Client : M/s. Karnataka Power transmission Co. Ltd

11 . Pole Type: MCPE (60° - 90°)/DECT_21.27M BXA

- Voltage : 220 kV
- No. of Circuits : MULTI (Multi Circuit)
- Pole Height : 60.92 M
- Ground Line Reactions :
  - Bending Moment : 37,987 kNm
  - Resultant Shear : 1,042 kN
  - Axial Force : 1,010 kN
- Client : M/s. Canara Electricals & Cosultancy Services
- End Client : M/s. Karnataka Power transmission Co. Ltd

12 . Pole Type: MCPB (0° - 15°)_18.27M BXA

- Voltage : 220 kV
- No. of Circuits : MULTI (Multi Circuit)
- Pole Height : 53.52 M
- Ground Line Reactions :
  - Bending Moment : 12,042 kNm
  - Resultant Shear : 366 kN
  - Axial Force : 390 kN
- Client : M/s. Canara Electricals & Cosultancy Services
- End Client : M/s. Karnataka Power transmission Co. Ltd

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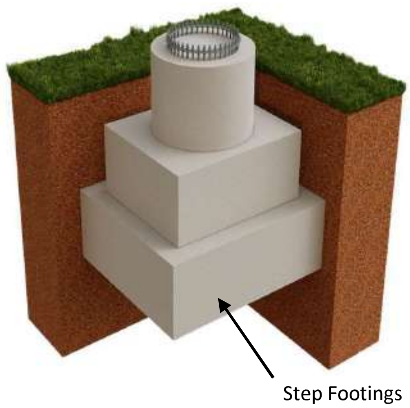
Building a stronger future

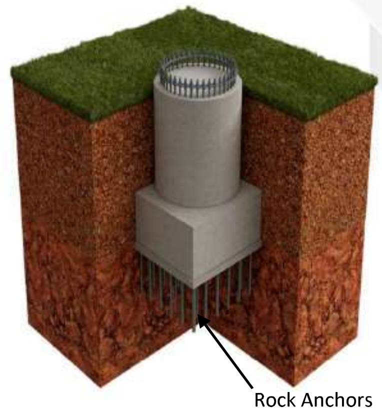
Foundation Types

STEPPED FOUNDATION



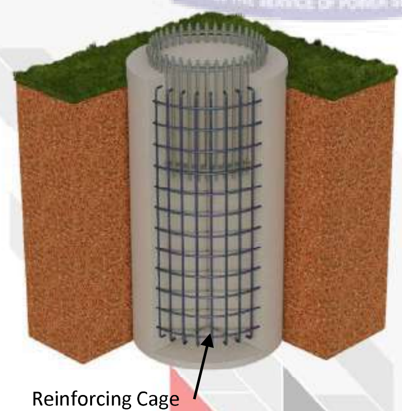
Type : Shallow Foundation
A stepped foundation is used in pole foundations to accommodate varying ground levels or uneven terrain. It involves constructing a series of steps or levels in the foundation to provide a stable and level base for the structure above.

HARD ROCK FOUNDATION



Type : Deep Foundation
Used in : BNC POWER PROJECT
Drilled Rock anchors in hard rock layer which are used to provide direct support to the structure or foundation.

CAISSON FOUNDATION

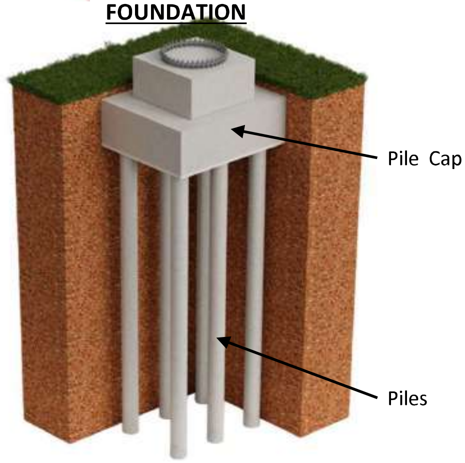


Type : Deep Foundation
Used in : JYOTI ENGINEERING WORKS
Caisson foundation are one of the types of Deep foundation which is popular for Monopole.

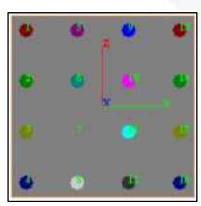
SALASAR
Building a stronger future

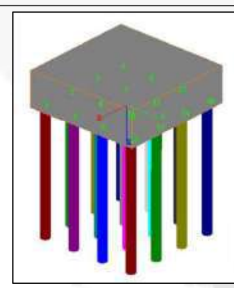
Foundation Types

PILE FOUNDATION

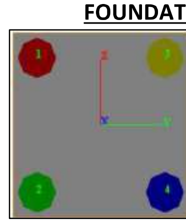


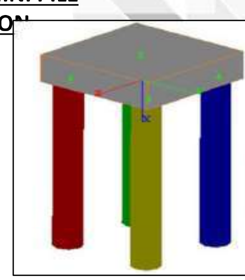
Used in : DMRC PATNA
Pile foundation is needed in areas where the structures constructed are large & heavy and the soil underlying is weak.





MICRO / MINI PILE FOUNDATION



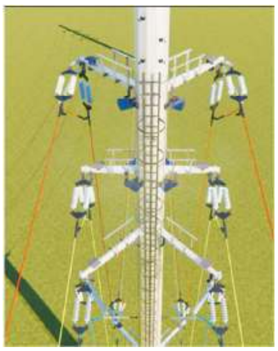


PILE FOUNDATION

CONCEPTUAL DESIGN SOLUTIONS

- 3D Model Preparation:

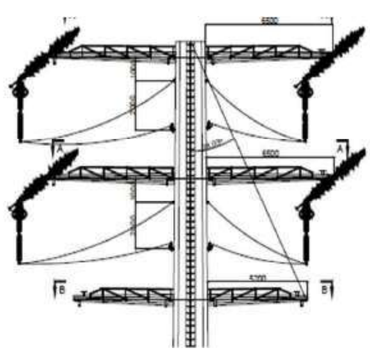
  - 3D model can be prepared in order to understand complex route and conductor stringing from one pole to the other by maintaining electrical clearances. Electrical clearance is very important in utility products.



DESIGN SOLUTIONS (Latest Development)

- **Pole with short peak**

  - This Pole is proposed in such a location where there is height restriction by the airport authority, we tried different options but not able to provide solution with the traditional aspect of clearance requirement. So, we considered transmission Lightening Arrestor at cross arm tip in order to reduce peak height to maintain airport authority height restriction limit.




DESIGN SOLUTIONS (Latest Development)

- **Double Circuit Multi-Level Pole**
  - This Pole is proposed in such a location where there is high ground clearance required in order to maintain sufficient clearance from conveyor belt which is proposed under the line.

Our Top Clients

Any Questions

Next-Generation Reconductoring: Higher Capacity, Same Corridor

Mr. S. K. Jana,
Sr. Vice President – Quality, Research & Product Application Engineering
(Conductors Division), APAR Industries Limited

Powering Progress With Smart Infrastructure

As global energy demand continues to grow and the pattern of generation shifts toward renewables, transmission systems face unprecedented stress. Existing overhead lines are being pushed to their limits—capacity constraints, increased losses, and sag issues are becoming more frequent. Building new transmission corridors is often time-consuming, costly, and environmentally challenging.

Reconductoring, using next-generation **High-Temperature Low-Sag (HTLS)** and **High-Performance Conductors (HPC)**, offers a powerful alternative: upgrading existing infrastructure to boost capacity and reliability**—without building new lines.**

Why Reconductoring Is the Future

Reconductoring empowers utilities to increase line capacity, enhance reliability, and extend asset life—using the same corridor. The benefits are compelling:

I. **Time Efficiency:** Projects can be completed in just **8–10 months**, compared to 5–10 years for new lines.
II. **Space Efficiency:** Utilizes existing Right-of-Way (ROW); no new land acquisition or tree cutting.
III. **Capital Efficiency:** Costs **less than 40%** of constructing new transmission lines.
IV. **Sustainability:** Reuses existing infrastructure, reducing environmental impact and carbon footprint.

Transform your lines, not your landscape

Transmission lines and sub-station capacity addition by 2031-32

Transmission System Type / Voltage Class	Unit	At the end of 2021-22 (31.03.2022)	Likely addition during 2022-27	Likely at the end of 2026-27 (31.03.2027)	Likely addition during 2027-32	Likely at the end of 2031-32 (31.03.2032)
Transmission lines						
(a) HVDC (± 320 kV/ 500 kV/800 kV Bipole)	ckm	19,375	80	19,455	15,432	34,887
(b) 765 kV	ckm	51,023	36,558	87,581	27,138	1,14,719
(c) 400 kV	ckm	1,93,978	34,618	2,28,596	20,989	2,49,585
(d) 230/220 kV	ckm	1,92,340	43,431	2,35,771	13,228	2,48,999

From Conventional to High-Performance: The HTLS Evolution

Traditional conductors such as ACSR were designed for moderate loads and temperatures (~85°C). Modern grids demand conductors that can operate safely up to **200–250°C** with minimal sag. This has led to the evolution of advanced conductor technologies such as **ACSS, ACCC®, INVAR (STACIR), GAP (GZTACSR), and SUPER-ZAD™**—each engineered for specific performance advantages.

HTLS Conductor Advantages:

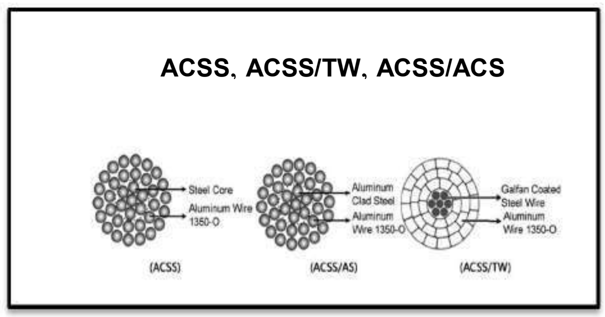
Parameter	Conventional Conductor (ACSR)	HTLS/HPC Conductor
Operating Temperature	Up to 85°C	Up to 250°C
Sag at High Temp	High	Very Low
Current Capacity	Limited	Significantly Higher
Strength-to-Weight Ratio	Moderate	High
Environmental Impact	Larger ROW, high losses	Lower ROW, reduced losses
Lifecycle Cost	Higher due to maintenance	Lower due to efficiency

HTLS conductors combine **higher ampacity**, **lower sag**, and **improved reliability**—making them ideal for modern, high-demand transmission networks.

Unlocking Grid Potential – Reconductoring the Smart Way with HTLS

1. ACSS (Aluminium Conductor Steel Supported)

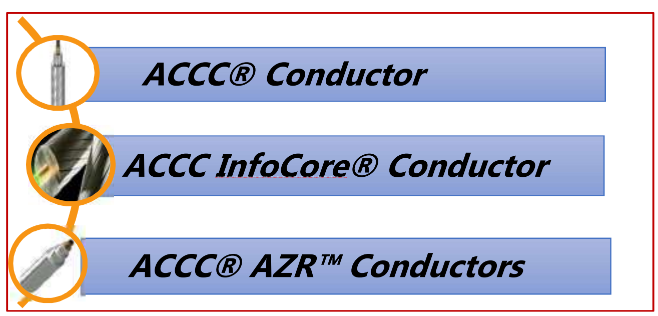
Designed for temperatures up to **250°C**, ACSS conductors use **annealed aluminium** and **ultra-high-strength steel cores**, allowing the steel to bear mechanical loads while minimizing sag. Improved conductivity (63% IACS) and self-damping characteristics enhance long-term performance.



2. ACCC® Aluminium Conductor Composite Core (ACCC®) – Redefining Reliability

They have lighter weight, Higher strength and higher current carrying capacity with lower electrical losses and superior corrosion resistance which gives this conductor wide acceptance in transmission corridor. Core made of composite material (glass fiber & carbon fiber matrix) – **High Strength & Ultra High Strength.**

Lowest sag among the HTLS category due to lowest coefficient of thermal expansion and higher strength to weight ratio. Can be operated up-to **180°C** & maximum emergency temperature up to 200°C. Composite core as strength member permits higher tensioning during installation.

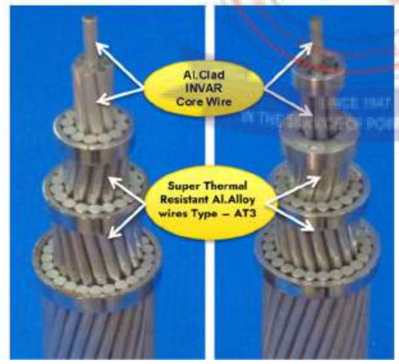


Variants include:

- **ACCC® INFOCORE™:** Built-in infrared inspection capability for real-time integrity verification.
- **ACCC® AZR™:** Aluminium-Zirconium alloy conductors engineered for cold climates, excelling in ice and wind conditions.
- **ACCC® ULS:** Ultra-Low Sag variant ensuring superior performance at 180–200°C.

3. SUPER THERMAL RESISTANT ALUMINUM ALLOY CONDUCTOR, ALUMINUM CLAD INVAR REINFORCED (STACIR & STACIR/TW)

High Temperature Thermal Resistant Aluminium Alloy Conductor: These are high ampacity conductors with inner core composed of Aluminum clad Invar Steel & outer layer composed of Super Thermal Resistant Aluminum alloy with round or trapezoidal shaped wires. Aluminum strands are made of thermal resistant aluminum alloy (with Zirconium) and Core is made up of alloy **NiFe** steel –Nickel having low thermal coefficient of expansion. After transition temperature all load transferred to the core and hence lower sag compared to ACSR after transition temperature.



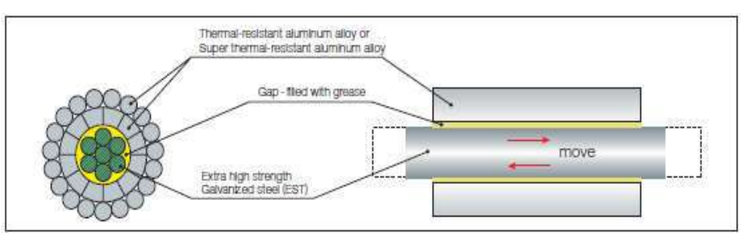
- ❖ These can operate up to **210-230°C**
- ❖ Comparatively high cost due to special Invar alloy.
- ❖ Handling & stringing similar to conventional ACSR
- ❖ For uprating lines, no modifications or reinforcement is required to the existing towers

4. GAP (GZTACSR) Conductors

Gap-type aluminum conductor steel reinforced (GZTACSR) uses heat-resistant aluminum over a steel core. A small annular Gap is maintained between steel core and the first layer of aluminum alloy strands. The gap between the first layer trapezoidal shaped aluminum strands and the steel core is filled with high thermal resistant grease to avoid friction between steel and inner layer of aluminium. The thermal resistant grease gives it a better corrosion resistance and improves overall thermal performance.

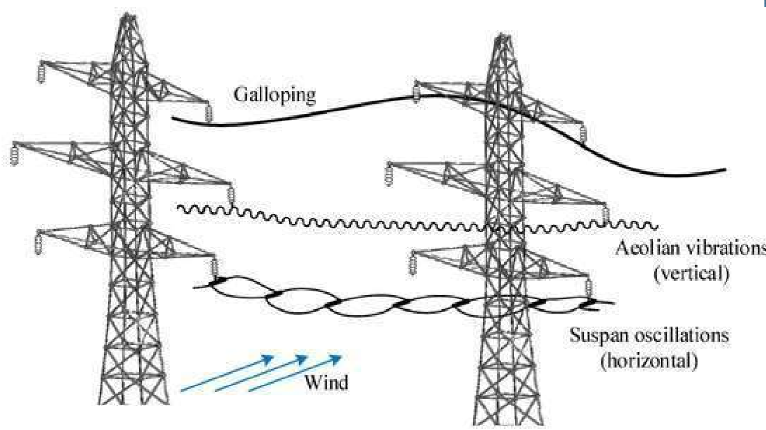
- ❖ No modification or reinforcement required for existing towers, Hence **Ideal for Re-conductoring Projects.**
- ❖ Can be deployed in Existing Structures or can **reduce strain on structures**, increasing life expectancy of conductor.
- ❖ **Double the current-carrying capacity** for the same size of conductor.
- ❖ At the time of sagging, all tension is applied to the steel core by a special stringing method. As a result, the thermal expansion is that of steel core, **Lower Thermal Expansion** of Steel Core maintains small sag at high temperature.
- ❖ Maintaining the mechanical strength of the conductor at higher operating temperature up to 210°C.
- ❖ Low Sag at high temperatures and Low thermal knee point
- ❖ All the Tension is applied independently on the core to have the knee-point at the installation temperature
- ❖ In case of re-conductoring of Transmission line Special type of compression dead end assembly is used during installation of Gap- Type conductor and rest other accessories will remain same.
- ❖ A very cost-effective solution for enhancing the power transfer capacity of existing lines

Smart Conductors for Extreme Conditions – Powering the Snow Zone



Frozen & Fierce – The Transmission Battle Against Nature

In challenging environments—snow, wind, or heat—next-generation conductors ensure consistent, reliable power. **ACCC® AZR™** and **SUPER-ZAD™** conductors exhibit **exceptional performance** in sub-zero climates, with **enhanced tensile strength** and **aerodynamic stability** that prevent galloping and breakage.



- **Ice Loading**: Ice accumulation increases weight and tension, leading to sag and breakage, especially in cold regions.
- **Wind-Induced Problems**: Wind-induced phenomena like Aeolian vibration and galloping can cause mechanical fatigue and failure in traditional conductors.
- **Mechanical Stress**: Transmission lines are subjected to severe mechanical stress from high winds, ice, and fluctuating temperatures, threatening the integrity of the system

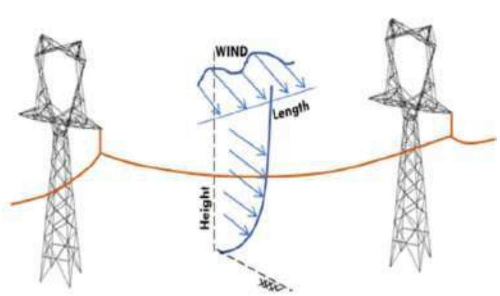
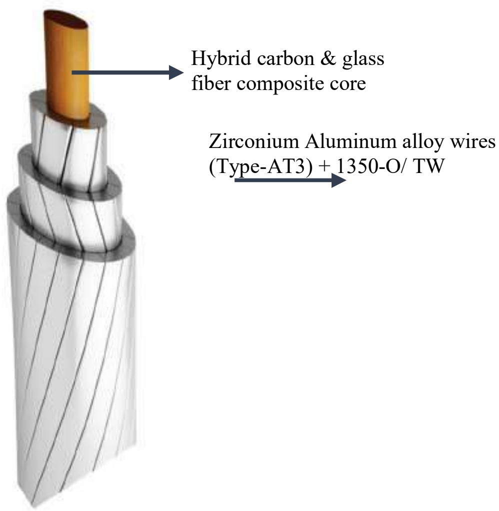


Figure 3 - Wind Loads on Transmission Lines

Reliable Power, Even When the Grid Freezes – ACCC® AZR™ Conductor

ACCC® AZR™ Composite Core Conductors: The ACCC® AZR Conductor leverages an **Aluminium - Zirconium alloy ULS Conductor** designs produce with high temperature resistant AT3 aluminium alloy meeting IEC 62004 OR ASTM B941 Specification. Few design also contain layer of AL0/1350-0 (fully annealed) aluminium. The ideal lightweight, super-efficient conductor capable of breaking the ice load burden.

- ❖ Core made of composite material (glass fiber & carbon fiber matrix) – High Strength & Ultra High Strength.
- ❖ The ACCC AT3+ Soft ULS design is 35% to 40% stronger than the comparable ACSR.
- ❖ Lowest sag among the HTLS category due to lowest coefficient of thermal expansion and higher strength to weight ratio.
- ❖ Superior behaviour in ice and snow climates due to combination dual alloy AT3 (Alloy) & 1350 –O (Full annealed) and ULS Core (9.53 mm Or 10.54 mm).
- ❖ The added strength and increased tensile modulus mitigates conductor sag under heavy wind or ice loads, or very long spans.

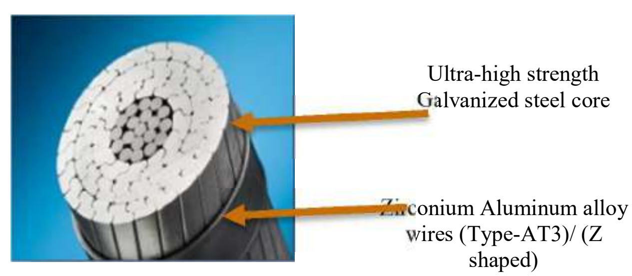


- ❖ Can be operated -15°C to 180°C & maximum emergency temperature up to 200°C

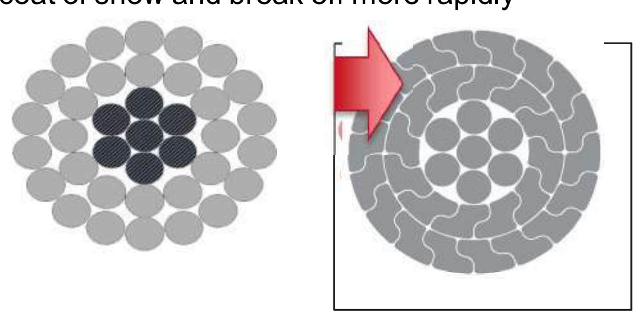
Precision under Pressure – SUPER-ZAD™ for Snow Zone Reliability

SUPER-ZAD Aluminium alloy Galvanized Steel Reinforced (Z shaped) Core: These are (HTLS) Conductors with excellent electrical characteristics, excellent sag tension characteristics and superior corrosion resistance to that of ACSR.

- ❖ Core made of S3A Galvanized steel.
- ❖ Reduced drag coefficient (Aerodynamic Drag).
- ❖ Superior behaviour in ice and snow climates.
- ❖ Can be operated -15°C to 180°C & maximum emergency temperature up to 200°C



- ❖ SUPER-ZAD conductors have high torsional coefficient, with snow deposit the conductor can resist the twisting force.
- ❖ SUPER-ZAD have comparatively smaller coat of snow and break off more rapidly than on a traditional conductor
- ❖ The Z Shaped wire interlocked with smooth surface conductor which is aerodynamically Superior to those of traditional stranded conductors with round wires.



IEC 62219

Untangling the Twist: Understanding Twisted Pair Conductors

These conductors are composed of two identical bare conductors twisted together which gives the conductor a spiral shape (TP= Twisted Pair or VR2= Vibration Resistant Twin). This spiral shape disrupts the wind forces that cause conductor vibration. Which allows the conductor to protect against the effect of Aeolian vibration and ice galloping to which many transmission and distribution lines are exposed.

- This spiral shape together with less torsional stiffness and varying bending stiffness also reduce conductor galloping due to combined ice and wind.
- The component conductors are twisted about themselves with a complete twist for all sizes as per ASTM Standards. The twist length are derived and designed based on the conductor diameter.
- Used in overhead transmission line in high wind terrain and High Ice & Snow region, High altitude.
- Low torsional stiffness, allowing flexibility under stress.
- Supports higher line tension, reducing sag and allowing longer spans.

APAR Laboratory (Testing & Research Centre): Major Test Facilities

- Apar laboratory is equipped with state-of-the-art test equipment's and facilities complying international standards approved by Govt. of India ISO/IEC17025 NABL, thus providing accurate and reliable results.

Software supported Axial Impact - **Very limited test set-up worldwide for testing of overhead transmission line HTLS conductor.**

Sheaves Test

Dilatometer for CLE Test

High Temperature Endurance & Creep

Surface Roughness Tester

Torsional Ductility Test Setup

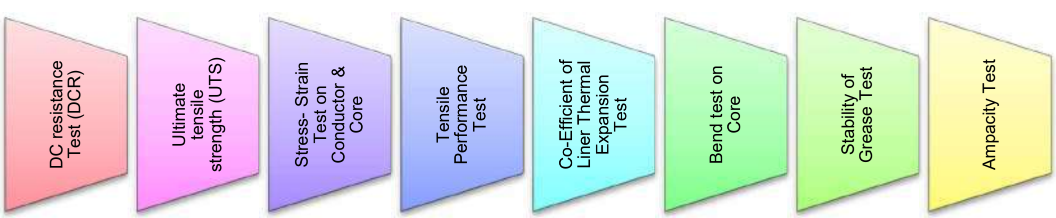
Bending Test on Carbon Fiber Core

Core Penetrometer for grease.

Constant Temperature Bath for Oil separation test on grease.

Horizontal Tensile Testing Machine

The Computerized Horizontal Tensile Test Bed with a 750 kN capacity is designed for comprehensive conductor testing at both room and elevated temperatures, featuring automated tension loading control. Equipped with highly sophisticated laser sensors, it provides precise displacement measurements along with multi-channel acquisition of load, displacement, and temperature data.



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Empowering Paschim Gujarat's farmers with 24x7 reliable power through 11 kV MVCC upgrades—**boosting productivity and rural**

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Safety Must & Quality First

Value Proposition

Built in last 12 months		Building for the future
PMO monitoring for all projects Use of ERS in re-conductoring -	Execution Efficiency	Use of Drones to expedite the execution Use of AI tool to monitor and predict
Restructured team with more focus of CFT – Execution Review. Project specific verticals – HTLS, OPGW, MVCC	People	Hiring right talent (Subject Matter Experts); Fostering culture of excellence, customer centricity by building trust & imbibing humility, empathy, inclusiveness
New customer added – Madhya Pradesh	Market (New)	**EPC in International Market** (Short term – evaluate entry barriers, Europe
New line with HTLS - Uttar Pradesh OPGW - 96F in Maharashtra &	Offering	**EHV (UG) Turnkey Solution** (Short term – Product Testing, work on tender
Pre-bid Survey & Bid review process Sticky/Overdue debtors review	Process	GFI, Overaged debtors, Unbilled & collection
Push for - MVCC, 96F Stakeholder Management (External)	BD & Policy Advocacy	National Reconductoring plan (Policy) Advocacy for Minimum Local Content 144F, coated conductor, HALL & OPPC

Overcoming Cable Installation Challenges in MV, HV, and EHV Transmission Systems: A Practical Approach to Friction Management and Project Optimization Using Polywater® Technologies

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Abstract— The transition to underground transmission systems for medium-voltage (6.6–35 kV), high-voltage (66–220 kV), and extra-high-voltage (above 220 kV) cables presents critical mechanical challenges that directly impact project economics, delivery, quality and system reliability. This paper presents a comprehensive analysis based on Polywater® Corporation's extensive work on coefficient of friction (COF) database, developed from over 40 years of laboratory testing and field validation across thousands of cable installations worldwide. Through analysis of real-world installations, including the ground breaking Pearl Harbour submarine-to-land cable project (1600meters pulls of 46 kV XLPE cables), we demonstrate that advanced polymer-based lubricants can reduce COF from typical dry values of 0.35–0.50 to 0.10–0.15, resulting in 40– 45% tension reduction. Field measurements using Polywater's Pull-Planner™ software show excellent correlation with predicted values, with back-calculated COF often exceeding design assumptions (0.12 actual versus 0.14 predicted). Economic analysis reveals that optimised friction management enables single-pull lengths exceeding 1,200 meters, reducing joint bay & splicing requirements by 50–75% and achieving 12– 18% savings in total project costs. This paper provides actionable guidance based on validated field data, establishing best practices for the development of underground transmission infrastructure.

Keywords—Underground transmission, coefficient of friction (COF), Polywater® lubricants, Pull-Planner™ software, capstan equation, sidewall bearing pressure (SWBP), cable pulling tension, XLPE cables, HDPE ducts, polymer lubrication, friction table testing, weight correction factor (WCF), cable jamming probability.

I. INTRODUCTION

The global shift toward underground transmission infrastructure has accelerated dramatically, driven by urbanization, environmental considerations, and system reliability requirements. This transition introduces unprecedented mechanical challenges during cable installation, directly impacting project viability. The physics of cable pulling, first formalized by F.H. Buller (1949) and expanded by R.C. Rifenburg (1953), remains fundamental to modern installation design. However, contemporary applications demand a sophisticated understanding of friction mechanics and advanced material technologies.

Polywater® Corporation has pioneered the science of cable-pulling friction measurement for over 4 decades, developing the world's most comprehensive database of coefficient of friction (COF) values. This database, derived from thousands of laboratory tests using the Polywater Friction Table methodology and validated through field installations globally, provides the foundation for accurate tension prediction. The COF in cable pulling depends on multiple factors: cable jacket material (PE, XLPE, PVC), conduit type (HDPE, PVC, RCC), surface conditions, temperature, and critically, the lubricant chemistry.

Consider a representative 220 kV XLPE cable installation: with a 1,600 mm² conductor, 130 mm overall diameter, and 21 kg/m weight, pulled through 200 mm HDPE duct. Under dry conditions with COF = 0.35, the tension at 600 meters reaches 3,200 kgf, approaching the manufacturer's limits. However, application of Polywater® NN lubricant reduces COF to 0.12, limiting tension to 1,800 kgf—a 44% reduction that enables extended pull lengths and eliminates intermediate joint bays.

The sidewall bearing pressure (SWBP = T/R) represents another critical constraint. Industry standards typically limit SWBP to 300–500 lbs/ft (4.5–7.5 kN/m) for power cables, though fibre-optic installations may tolerate up to 720 lbs/ft (10.7 kN/m) with appropriate bend-radius control. Polywater's research demonstrates that COF decreases under high sidewall pressure—a counterintuitive finding that improves the feasibility of installing complex routes.

I. THE SCIENCE OF FRICTION IN CABLE PULLING

A. Coefficient of Friction Fundamentals

The coefficient of friction (COF) is defined as the ratio of the force required to move one surface over another to the normal force between them. In cable pulling, this dimensionless parameter becomes the critical variable determining installation feasibility. Polywater's research identifies COF as a dynamic factor encompassing multiple field conditions, termed the "effective coefficient of friction."

For straight conduit sections, tension accumulates according to: $T_{out} = T_{in} + W \times L \times (\mu \times \cos(\alpha) + \sin(\alpha))$, where W is cable weight per unit length, L is segment length, μ is COF, and α is inclination angle. At bends, the capstan equation governs: $T_{out} = T_{in} \times e^{\mu\theta}$, where θ is the bend angle in radians. For a 90-degree bend with μ = 0.35, the multiplication factor equals 1.60; with effective lubrication reducing μ to 0.12, this factor decreases to

1.17—a critical difference in multi-bend installations.

B. Polywater Friction Table Testing Protocol

Polywater developed the industry-standard Friction Table test method to measure COF under conditions mimicking field installations. The Polywater Friction Table provides reliable, research-based coefficients of friction (COF) for various combinations of cable jackets and conduit materials under both dry and lubricated conditions. Developed through extensive laboratory and field testing, it serves as an essential reference for engineers and installers to accurately estimate pulling tensions and sidewall pressures during cable installation. By using data from the Polywater Friction Table, planners can optimize lubricant selection, improve installation efficiency, and ensure cable integrity— ultimately contributing to safer, smoother, and more cost-effective cable installations.

II. ADVANCED LUBRICATION TECHNOLOGY

A. Polymer-Based Friction Reduction Mechanisms

Polywater® lubricants employ high-molecular-weight polymers suspended in aqueous carriers, creating boundary lubrication layers that dramatically reduce friction. The polymers align under shear stress, forming organised structures that facilitate sliding motion. Primary friction reduction occurs through hydrodynamic film formation, with secondary effects from polymer adsorption onto surface asperities. The viscoelastic properties dissipate energy, dampening stick-slip behaviour that causes cable jacket damage.

Temperature-Dependent Performance

Temperature significantly impacts friction behaviour. Polywater winter-grade lubricants (Type WNN) incorporate antifreeze solutions enabling operation to -30°C (-20°F). As temperatures drop below freezing, lubricants thicken but continue to perform, maintaining a low COF. Laboratory testing shows COF variation of ±15% across typical installation temperatures. Field data confirms that prelubrication remains effective for weeks, with COF staying low after drying at accelerated temperatures.

TABLE I

POLYWATER® MEASURED COEFFICIENT OF FRICTION VALUES

Cable Jacket	Conduit Type	Dry COF	Polywater® NN	Reduction %
XLPE	HDPE Clean	0.35	0.10	71%
XLPE	PVC Clean	0.40	0.13	68%
PE	HDPE Clean	0.32	0.09	72%
MDPE	PVC Clean	0.38	0.12	68%
PVC	HDPE Dusty	0.45	0.15	67%
EPR	RCC Rough	0.55	0.20	64%

III. PULL-PLANNER™ SOFTWARE AND TENSION PREDICTION

A. Software Capabilities and Database

The Polywater Pull-Planner™ Version 5.0 is the industry's most sophisticated cable-pulling analysis tool, incorporating the world's largest COF database. The software performs sequential calculations using established pulling equations, providing segment-by-segment analysis of tension and sidewall pressure. Key capabilities include: accommodation of variable friction conditions, roller effects, and push/pull devices; weight correction factor (WCF) calculations for multiple cable configurations; jamming probability assessment for three-cable pulls; and lubricant quantity optimisation based on conduit volume calculations.

The software's COF database encompasses thousands of cable jacket and conduit combinations, with differentiation between unlubricated and lubricated conditions using various Polywater formulations. Field validation through back-calculation of actual tensions enables continuous refinement of the database. Users can develop custom COF databases based on their specific installations, creating organisation-specific knowledge bases for future projects.

B. Multi-Cable Installations and Weight Correction

For multiple cable installations, the weight correction factor (WCF) accounts for increased normal force as cables ride up the conduit wall. The WCF equals the ratio of normal force to gravitational force, ranging from 1.0 for single cables to 1.4 for cradled three-cable configurations. The Pull-Planner automatically calculates WCF based on the cable arrangement, transitioning from a cradled to a triangular configuration at $D/d \leq 2.5$ (48% fill). In bend calculations, WCF appears as an exponent, increasing tension by 5–15% for typical multi-cable pulls.

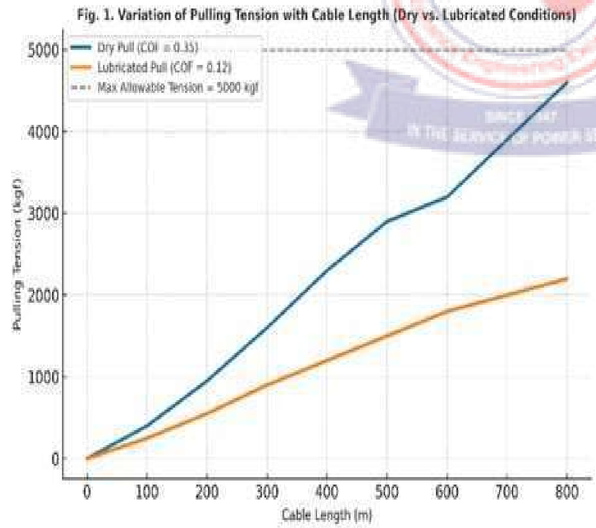

Fig. 1. Pulling tension versus cable length showing exponential growth in dry conditions (COF = 0.35) compared to linear progression with Polywater® lubrication (COF = 0.12).

IV. FIELD VALIDATION AND CASE STUDIES

A. Pearl Harbour Submarine Cable Installation

The Hawaiian Electric Company (HECO) Pearl Harbour project represents a landmark achievement in cable installation, requiring two circuits (six cable runs) pulled under Pearl Harbour to Ford Island—nearly one mile submarine crossing. Each 46 kV XLPE cable featured a 1,750 kcmil copper conductor, a OD 3.04-inch (77 mm) diameter, a 11.35 kg/m weight, and was installed through a 6-inch (152 mm) SDR-11 HDPE pipe over 1,615 m. Reel weight over 20 ton.

American Electric, the installation contractor, utilised Pull-Planner extensively during pre-planning. With assumed zero back tension and diligent lubrication, approximately 600 gallons (2,270 litres) of Polywater lubricant were specified. From October 2005 to February 2006, 24 successful pulls were completed under Pearl Harbour, delivering power ahead of schedule for the Ford Island redevelopment, supporting 2 million annual visitors.

Actual pull tensions turned out to be less than 3200Kg, with an occasional spike above 3600 kgs

MDPE Cable Pull Validation Study

Field Validation: 503-Meter PVC Conduit Installation

A contractor pulled MDPE-jacketed cable (5.2-inch/132 mm OD) through 8-inch (200 mm) PVC conduit over 1,649 feet (503 m). Route configuration: 3° uphill grade for 1,020 feet (311 m), 45° bend with 100-foot (30 m) radius, 4° downhill for the final 550 feet (152 m). Total cable weight: 35,000 lbs (15,876 kg).

Results: Using COF = 0.14, Pull-Planner predicted 5,157 lbf (22.9 kN) tension. Actual measured tension: 4,100 lbf (18.2 kN), back-calculating to COF = 0.12. The 20% better-than-predicted performance validates conservative design assumptions and demonstrates achievable field performance with proper lubrication.

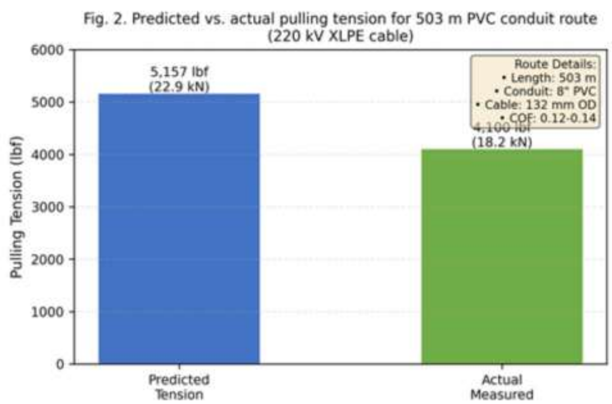

Fig. 2. Field validation showing predicted versus actual pulling tension, demonstrating Pull-Planner accuracy and conservative COF assumptions.

V. LUBRICATION APPLICATION METHODOLOGIES

A. Lubricant Quantity Optimisation

Polywater's recommended lubricant quantity is Q = 0.0015 × L × D (litres), where L is the pull length in meters and D is the conduit inner diameter in mm. This formula, validated across thousands of installations, ensures complete coating of conduit interior and cable exterior. Adjustment factors include: 1.5× for dirty or rough conduits, 1.3× for high conduit fill (>40%), 1.2× for multiple bends, and 1.4× for elevated temperatures.

B. Application Techniques and Equipment

Effective lubrication requires systematic application to ensure coverage at friction points. Methods include: manual application to the cable surface during feeding, pump systems (Polywater LP-D5) for continuous flow, Front End Pack™ bags for prelubrication ahead of the cable, and spray collars at the conduit entrance. Prelubrication using mandrels or spreader devices

proves particularly effective for long pulls, with COF remaining low weeks after application.

Critical application points include: conduit entrance (100% of recommended quantity), intermediate vaults at 500-meter intervals (25% refresh), and before major bends (spot application). For submarine or vertical installations, specialised gel formulations with enhanced adhesion prevent lubricant migration while maintaining low friction.

VI. ADVANCED INSTALLATION CONSIDERATIONS

A. Horizontal Directional Drilling Applications

Modern horizontal directional drilling (HDD) creates large-radius bends that require modification to traditional Rifenburg equations. When cable weight exceeds the vertical component of the pulling force, cables drop to the conduit bottom rather than riding the inside of bends. Pull-Planner accommodates these conditions by treating large-radius bends as sloped straight sections when the weight-to-tension ratio exceeds critical values, thereby improving prediction accuracy for HDD installations.

B. Pull Direction Optimisation

Pull direction significantly impacts total tension, particularly with asymmetric bend placement. Pull-Planner analysis reveals differences of 20–30% in tension between directions for identical routes. Pulling through bends first typically reduces overall tension by minimising the cable weight subjected to bend multiplication factors. For routes with elevation changes, the software evaluates whether gravitational assistance outweighs the effects of bend placement.

VII. ECONOMIC ANALYSIS AND PROJECT OPTIMISATION

Comprehensive economic analysis reveals multiple benefit streams from optimised friction management. Direct savings include: joint bay reduction (50–75% fewer splices at $150,000–$300,000 each), decreased cable reserves (5–10% reduction through longer pulls), lower equipment requirements (smaller winches, fewer setups), and reduced installation time (30–40% schedule compression).

TABLE II
PROJECT ECONOMIC IMPACT ANALYSIS

Installation Method	**Max Pull Length**	**Joints/3km**	**Cost Index**
Traditional (Dry)	600 m	4	100
Standard Lubricant	850 m	3	92
Polywater® NN	1,200 m	2	85
Optimised System*	1,500+ m	1	82

**Optimized System: Polywater® NN + Pull-Planner design + prelubrication*

VIII. CONCLUSION

Four decades of friction research and field validation by Polywater Corporation have established definitive methodologies for optimising underground cable installation. The extensive COF database, encompassing thousands of cable-conduit-lubricant combinations, enables accurate tension prediction through Pull-Planner software. Field measurements consistently validate or exceed design assumptions, with actual COF often 10–20% better than predicted values.

Advanced polymer lubricants reduce friction by 65– 75%, enabling pull lengths of up to 1,500 meters for optimised systems. This dramatic improvement transforms project economics: joint bays decrease from 4 per 3 km to 1–2, installation schedules compress by 30–40%, and total project costs reduce by 12–18%. Beyond immediate savings, controlled installation tensions enhance long-term reliability, with failure rates 60–80% lower for cables installed below 60% of tension limits.

Future developments focus on integrating real-time monitoring, with distributed fibre sensing providing continuous measurements of tension, temperature, and strain. Machine learning algorithms will optimise pulling parameters based on accumulated field data, further improving installation efficiency. As underground infrastructure expands globally, these validated technologies ensure reliable, economical power delivery for urban development.

IX. ACKNOWLEDGMENT

The authors acknowledge Polywater Corporation's research team for providing access to the comprehensive friction database and Pull-Planner software. Special recognition to American Electric and Hawaiian Electric Company for sharing data on the Pearl Harbour project. We thank field engineers worldwide for their contributions of installation data for validation studies. The continuous support from cable manufacturers and utilities in advancing installation science is gratefully acknowledged.

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#######

"INTEGRATION OF ADVANCED TECHNOLOGIES FOR HOTLINE MAINTENANCE AND PREDICTIVE FAULT MANAGEMENT IN HIGH-VOLTAGE TRANSMISSION LINES"

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Abstract

In electrical engineering, live-line working, also known as hotline maintenance, is the maintenance of electrical equipment, often operating at high voltage, while the equipment is energized. The ever-increasing demand for electric energy necessitates higher reliability in the transmission and distribution (T&D) of electrical energy. The in-creasing complexity of transmission networks, interregional/interstate ties transporting a huge quantum of power and less redundancy in the transmission system have rendered shutdowns of transmission lines/substations almost impossible. Therefore, preventive maintenance deploying the live-line maintenance technique seems to be the best solution for power T&D utilities.

The reliability and continuity of power supply in high-voltage transmission networks heavily depend on effective maintenance practices. Hotline maintenance, also known as live-line maintenance, enables utilities to perform inspection, testing, and repair of transmission lines **without power interruption**, ensuring grid stability and minimizing outages. This paper discusses modern tools, equipment, and predictive technologies used for hotline maintenance, highlighting products such as **SBB Make Emergency Restoration System (ERS)**, **Positron Make Partial Discharge (PID) Diagnostic Instrument**, **RITZ Hotline Tools**, **TEREX Aerial Insulated Work Platform**, **Hotline Washing Unit**, and **SAFEGRID Predictive Fault Monitoring System**.

I. Introduction

While the use of live-line maintenance tools is sometimes considered a recent development in the electrical power industry, forerunners of modern live-line tools made their appearance as far back as 1913. These initial tools were homemade, crude, and bulky; however, they sparked the development of our present efficient and refined tools.

In India Having a large amount of old aging transmission system life & aging equipment results in higher probabilities of failure, higher maintenance cost & higher replacement cost. Aging equipment will have to be replaced; this replacement should be planned in coordination with capacity additions. Extra and ultra-high voltage transmission lines have been developed worldwide and are successfully being operated in developed nations. Recent trends in Indian transmission scenario are progressing towards establishing 765 KV lines to strengthen its transmission infrastructure. Massive expansion of inter-state transmission system is under way to cater to the transmission requirement of new generation projects.

These techniques allow maintenance personnel to perform critical operations on energized lines up to 765 kV and beyond, without service interruptions. The maintenance of line conductors, line insulators, structural, parts etc. without de-energizing the line and with live line is called live line maintenance.

<u>The activities in live-line maintenance include:</u>

- Repair of conductor of overhead line or overhead bus bars, overhead earthing wire.
- Inspection from close distance.
- Inspection/repairs/replacements of Insulators.
- Live line washing of insulators.

The rest of the paper is organized as follows. II. Experimental Methods of Live Line Maintenance III. Advanced Equipment and Systems for Hotline Maintenance IV. Conclusion.

II. Methods of Live Line Maintenance

In general, there are three methods of live-line working which help workers avoid the considerable hazards of live line working. In various ways, they all serve to prevent current flowing from the live equipment through the worker. There are two basic Live Line methodologies for High Voltage (HV) work, which in industry terminology are called „Hot stick" and Bare-hand" methods: Using hot-stick methods, direct human contact with live components is avoided. Line workers use tools fastened to insulated fiber glass poles to carry out the work, and always keep themselves at a safe distance from the live components

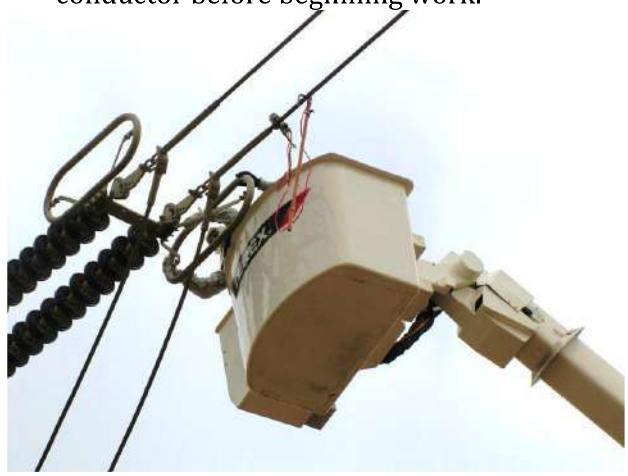
A. Hot Stick (Insulated Tool) Method:

- **Principle:** The worker remains at **earth potential** (grounded) and uses long, insulated tools (hot sticks), typically made of fiberglass-reinforced plastic (FRP), to perform tasks on the energized conductor.

- **Application:** Suitable for a wide range of voltages. Tasks include insulator replacement, line hardware tightening, and conductor repair. It maintains maximum distance between the worker and the energized component, providing an essential layer of safety.

B. Bare hand (Potential) Method:

- **Principle:** The worker is brought up to the **same electrical potential** as the energized conductor. This is achieved by wearing a **conductive suit** made of 25 per cent microscopic stainless steel and 75 per cent Nomex is used (based on the Faraday Cage principle) and bonding the suit to the conductor before beginning work.



- **Application:** Primarily used for very high voltage (EHV/UHV) lines, as it allows for more dexterous and complex work than the hot-stick method. The worker works directly on the line hardware after being equipotentialized. Access is typically via an insulated aerial work platform or insulated ladder.

C. Insulated Glove (Rubber Glove) Method:

- **Principle:** The worker is positioned at **earth potential** but works closer to the conductor using **insulating gloves** and sleeves for protection.
- **Application:** Generally limited to lower voltages (up to ~ 69 kV), where phase-to-ground and phase-to-phase distances are shorter. It offers more dexterity than the hot-stick method for minor repairs.

Table 1. Osha Standards For Safe Working

Voltage range phase to phase in kV	Meters	FEETS
46.1 - 72.5	0.91	3
72.6 – 121	1.02	3.4
138 – 145	1.07	3.6
161 – 169	1.12	3.8
230 – 242	1.52	5
345 – 362	2.13	7
500 – 552	3.35	11

III. Advanced Equipment and Systems for Hotline Maintenance

Modern hotline maintenance relies on advanced, certified equipment to ensure safety, efficiency, and predictive capabilities.

A. SBB Emergency Restoration System (ERS)

The SBB Emergency Restoration System is a modular, lightweight, high-strength **aluminum tower system** designed for rapid response to transmission line failures.

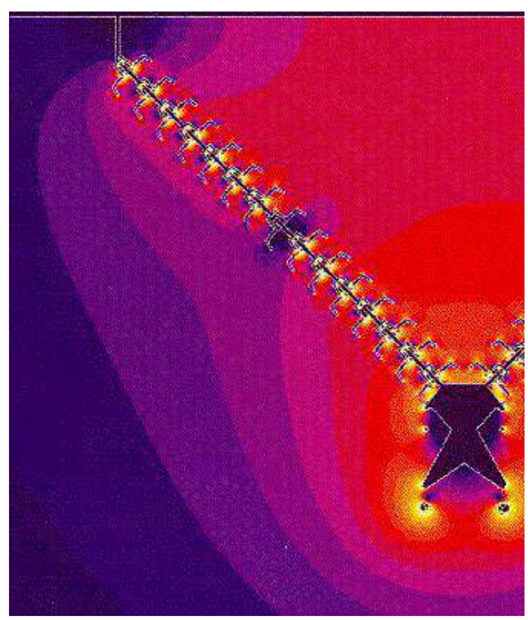
- **Core Application: Temporary Bypass and Rapid Restoration**. In the event of catastrophic tower failure (due to extreme weather, accident, or natural disaster), the SBB ERS towers can be quickly erected, often within hours, to bypass the damaged section.

- **Hotline Maintenance Application:** ERS is crucial for **temporary line support** during planned maintenance or upgrades. Conductors can be temporarily moved to the ERS structures, allowing the permanent tower to be rebuilt, reinforced, or foundations repaired **without de-energizing the line**. The modular design facilitates transport and assembly in remote or difficult-to-access terrain.

B. Positron PID Instrument

The Positron **P**unctured **I**nsulator **D**etector (**PID**) is a specialized diagnostic instrument for assessing the condition of energized insulators.

- **Principle:** The PID is a **non-contact E-field (Electric Field) detector**. It measures the electrical field distribution along the insulator string. A defective (punctured or cracked) insulator disk will have a significantly altered electric field gradient compared to a healthy one.

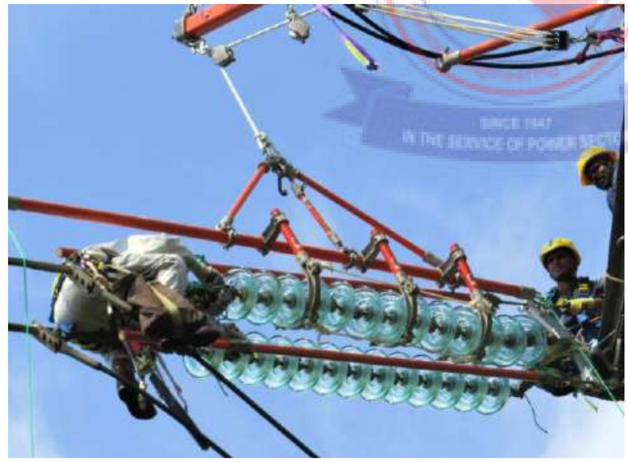


- **Hotline Application:** It is typically mounted on a hot stick and used by live-line crews to **diagnose faulty insulators** on suspension strings or post insulators while the line is **fully energized**. This allows for the precise identification of failed units, enabling targeted insulator replacement before a flashover occurs. Its method is superior to traditional line-of-sight (corona, infrared) or simple voltage-drop tests as it reliably detects conductive defects, including early-stage faults.

C. RITZ Hotline Tools

RITZ, a pioneer in the field, provides an extensive portfolio of certified live-line tools, primarily based on the hot stick method.

- **Key Products:** The foundation is the **RITZGLAS®** fiberglass reinforced plastic (FRP) insulating tube, known for high dielectric and mechanical strength.
- **Tools:** The range includes clamp sticks, disconnect sticks, rope sticks, tie sticks, telescopic hot sticks, and conductor support tools (e.g., roller links, strain carriers).
- **Application:** These tools are used for **manipulating conductors and hardware** from a safe distance, including:
- Replacing insulator strings (using strain carriers and rigging).
- Tightening clamps and hardware.
- Applying or removing temporary grounding devices.
- Operating disconnect switches.



D. TEREX Insulated Aerial Work Platform (AWP)

Insulated Aerial Devices, such as the TEREX Hi-Ranger™ models, are essential for bringing line workers into the working space on medium and high-voltage transmission lines.

- **Design & Safety:** These platforms feature a **multi-section fiberglass boom** and an insulated bucket (work platform) designed with upper and lower boom insulating inserts. They are certified to withstand the working voltage, allowing workers to perform barehand or hot-stick work safely.

- **Hotline Application:** They provide **elevated, maneuverable access** to the conductor for crews performing complex tasks like:

  - ✓ Barehand work at conductor potential.
  - ✓ Close-proximity hot-stick work.
  - ✓ Inspecting and repairing line hardware.
  - ✓ They are mounted on robust chassis, sometimes with off-road capabilities, to reach remote tower locations.

E. Hot Line Washing Unit

Contamination of insulator surfaces (due to salt, industrial pollution, dust, etc.) can lead to excessive leakage current, eventually causing a flashover and line trip. Hot line washing addresses this without an outage.

- **Principle:** A **high-pressure stream of de-ionized or de-mineralized (DM) water** is sprayed onto the energized insulators. The water's **high resistivity** (low conductivity, typically <200 µmhos/cm) and the non-continuous nature of the high-pressure jet (atomization) prevent a conductive path for leakage current to the ground.

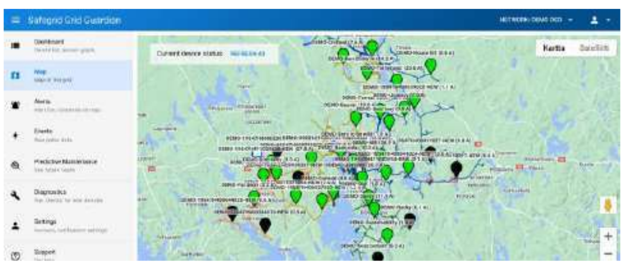
- **Hotline Application:** Used to **restore the dielectric strength** of contaminated insulators while the line remains in service, preventing costly forced outages and equipment damage due to flashovers. Specialized washing units ensure precise control of water pressure and purity.

F. SAFEGRID Products for Fault Prevention and Prediction

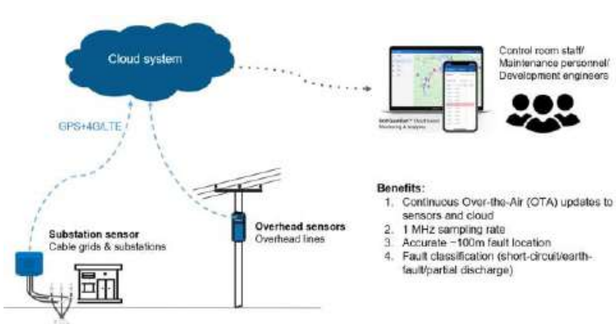
SAFEGRID's **Intelligent Grid System®** (IGS) shifts grid maintenance from reactive to a data-driven, **Predictive Maintenance** strategy.

- **Components:** The system utilizes wireless, high-frequency sensors (e.g., **Grayhawk®** for overhead lines) and the cloud-based **GridGuardian®** analytics software.

- **Fault Prediction/Prevention:**
    - ✓ **Detection:** The sensors monitor high-frequency transient signals associated with potential faults (e.g., partial discharges, micro-arcing from loose hardware, or conductor defects).
    - ✓ **Location & Prediction:** The GridGuardian® platform uses these transient measurements and GPS time-synchronization to **pinpoint the exact location of anomalies** with high accuracy. Proprietary algorithms classify events, allowing utilities to identify precursors to failure—such as early-stage insulation breakdown—well before a catastrophic fault occurs.



- **Application in Hotline Context:** By providing **accurate, real-time location and type of pre-fault conditions**, SAFEGRID enables utility teams to dispatch hotline crews for surgical, planned maintenance (e.g., replacing a specific degrading insulator or tightening a hot spot) while the line is live. This **minimizes unplanned outages** and optimizes the expensive deployment of specialized hotline crews.



IV. Conclusion

Hotline maintenance is an indispensable practice for modern power systems, directly supporting high reliability and optimal asset utilization. The integration of advanced equipment—from the rapid bypass capabilities of **SBB ERS** to the sophisticated diagnostic precision of **Positron PID**, the safe distance handling provided by **RITZ Tools**, the access flexibility of **TEREX AWP**, and the preventive measure of **Hot Line Washing**—enhances operational efficiency. Furthermore, the implementation of **SAFEGRID's** predictive fault detection technology marks a significant evolution, allowing maintenance programs to transition from time-based routines to condition-based, data-driven, live-line interventions, further strengthening the resilience of high-voltage transmission networks.

Innovative Practices and Proven Technologies for Enhancing Safety, Reliability and Efficiency in Overhead Transmission Systems – A Ramelex Perspective

Author:

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Abstract

The transformation of India's power sector is being driven by the combined forces of renewable energy integration, grid digitalization, and the modernization of aged transmission infrastructure. With growing environmental constraints and reliability expectations, the transmission industry must embrace innovations that ensure operational resilience, safety, and efficiency.

This paper presents the pioneering contributions of **Ramelex Pvt. Ltd.**, a techno-spiritual engineering company that has developed several patented and field-validated technologies—including **Compression-Type Crimping Connectors (Patent No. 315715)**, **Stub Strengthening Technique (Patent No. 297450)**, and **Universal Saver Clamp Assembly (Patent No. 414905 & 452911-001)**. These innovations, coupled with advanced predictive maintenance and sustainability initiatives, are redefining India's overhead transmission landscape by enhancing network reliability, reducing losses, and minimizing outage duration.

Keywords: Transmission Line Reliability, HTLS, Monopole, Stub Strengthening, Compression Connector, Saver Clamp Assembly, ERS, Techno-Spiritual Engineering, AMC, Sustainability.

I. Introduction

India's transmission network—spanning over 4,00,000 CKM—forms the backbone of its energy economy. As renewable integration intensifies and power demand surges, maintaining grid stability has become increasingly complex.

Ramelex Pvt. Ltd., established in 1990 and headquartered in Pune, has emerged as a leader in **power transmission and distribution infrastructure** through a unique approach termed *Techno-Spiritual Engineering*. The company blends technological innovation with ethical, eco-sensitive design philosophies to deliver sustainable value.

With **ISO 9001:2015** certification, **ZED Gold rating**, a **DSIR-recognized R&D Centre (RRDC)**, and **NABL-accredited Testing & Research Institute (RTRI)**, Ramelex operates across more than 15 states executing EPC, O&M, and manufacturing projects for major utilities such as **MSETCL, PGCIL, JSW, Adani, HPSEBL, and RRVPNL**.

DIAGNOSTIC SERVICES

- Thorough Line Patrolling
- IR Thermography
- Tower Footing Earth Resistance
- Punctured Insulator Detection
- Contact Resistance Measurement
- Corona Detection

MAINTENANCE SERVICES

- Hot Line Maintenance
- Hot/Cold Line Washing
- Insulator Sting Replacement
- Tower Stub Strengthening
- Maintenance of EHV Lines & S/S
- Providing & Fixing Power Connectors
- RTV Coating on Insulators

MANUFACTURING

- Compression Type Power Connectors
- Tension, Suspension & IPS Tube H/W
- Hydraulic Crimping Machines & Cutters
- Hot Line Washer Tested at CPRI
- Defence Components
- Automobile Components

TURNKEY PROJECTS

- Replacement of Conductors by HTLS
- EPC Contracts of Substation
- EPC Contracts of EHV/HT/LT Lines
- Augmentation of Substation

TESTING SERVICES (RTRI)

- Electrical (Temperature Rise, Heating Cycle, Magnetic Power Loss, Resistance Testing)
- Mechanical (Tensile, UTS, Hardness, Coating Thickness, Mechanical Properties and Vibration Damper Testing)
- Chemical (Spectro - Chemical Composition Testing)

RESEARCH AND DEVELOPMENT

- DSIR (Department of Scientific and Industrial Research, Govt. of India) registered in-house R&D Unit

PAINTING SERVICES

- Polyurethane Surface Coating on all types of surfaces

II. The Changing Grid Landscape

The transmission grid is undergoing structural and operational transformation:

- **Renewable Energy Integration:** The shift towards 500 GW of renewable capacity necessitates flexible, high-ampacity transmission systems.
- **ROW & Urban Space Constraints:** Dense industrial corridors demand compact alternatives to lattice towers.
- **Aging Infrastructure:** Corrosion, stub failure, and joint degradation threaten long-term reliability.
- **Climate Stress:** Cyclones, floods, and extreme heat demand resilient hardware and rapid restoration.

- **Digitalization:** Predictive maintenance and data-driven asset management are redefining O&M strategies.

These challenges call for **multi-disciplinary innovation**—combining mechanical design, materials science, and digital analytics—areas where Ramelex's field experience provides actionable insights.

III. Methodology and Design Philosophy

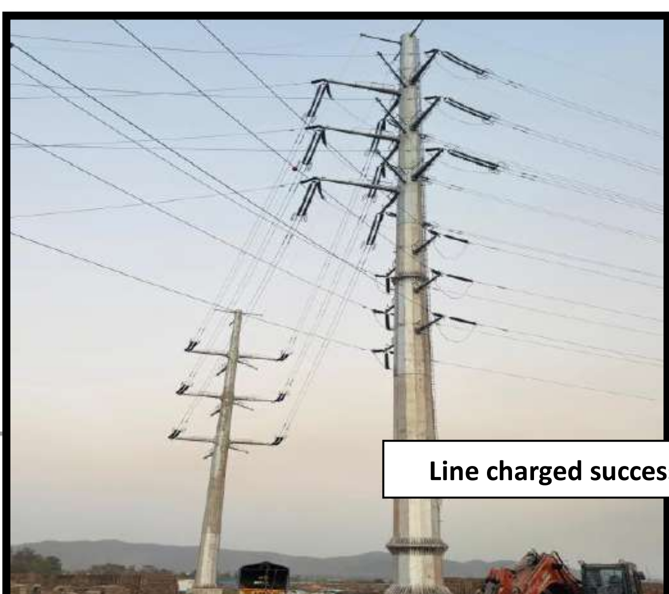
Ramelex's R&D follows a **Techno-Spiritual methodology** consisting of four iterative stages:

1. **Problem Identification** – Field data analysis from O&M projects identifies recurrent technical failures (e.g., hotspots, stub corrosion).
2. **Spiritual-Ethical Design** – Concepts are developed with *WECARE* values: **Welfare, Ethics, Compassion, Accountability, Respect, and Excellence.**
3. **Scientific Validation** – Laboratory validation through RTRI (NABL) and CPRI.
4. **Field Deployment & Feedback Loop** – Continuous improvement based on field observations and predictive performance metrics.

IV. Proven Practices and Technological Innovations

A. Monopole Technology

Problem: Conventional lattice towers require large ROW and have high erection time.
Innovation: High-strength galvanized monopoles offering **60 % less footprint** and **30 % faster erection**.
Case Study: JSW Dolvi 220/400 kV industrial corridor, executed ahead of schedule despite spatial constraints, validated the efficiency of monopole systems in urban zones.



Line charged successfully on 29th April 2025

B. High-Temperature Low-Sag (HTLS) Conductor & Hardware Deployment

Ramelex Pvt. Ltd. is a **pioneer in Bus Strengthening and Uprating Services of OHTL** utilizing **ACSS-type High-Temperature Low-Sag (HTLS) conductors** and manufacturing of compatible hardware. These advanced uprating solutions enhance current-carrying capacity, minimize line losses, and extend the operational life of existing bus systems and OHTL — ensuring improved reliability, efficiency, and long-term grid stability for Extra High Voltage (EHV) substations/TL.

Objective: Double the transmission capacity without new corridors.
Approach: Manufacturing and EPC execution of HTLS hardware compatible with ACSS/ACCR conductors.
Impact: Enhanced ampacity, reduced line losses, and improved mechanical strength across projects for MSETCL, HPSEBL, and TSSPDCL.

220kV Nagothan-Warkal TL (JSW) – HTLS Reconductoring Work

RPL HTLS Hardware for Substations/TL

C. Compression-Type Crimping Technology (Patent No. 315715)

Ramelex Pvt. Ltd. has been a **pioneer in India** in the **manufacturing of Compression-Type Transmission Line and Substation Clamps & Connectors**, including **HTLS-compatible hardware**, since **15 January 1995**.

These **patented products** are designed for superior mechanical strength and electrical efficiency, ensuring homogeneous, corrosion-resistant joints across Extra High Voltage (EHV) and High Voltage (HV) systems. Over the decades, Ramelex has established itself as a **trusted indigenous manufacturer**, supporting numerous national grid modernization and HTLS upgradation projects with field-proven reliability and performance excellence.

Issue: Bolted connectors often fail due to thermal hotspots, vibration, and corrosion.
Solution: Ramelex's patented compression joint technology forms a **homogeneous, air-tight and corrosion-resistant bond**.
Performance Metrics:

- Tensile Strength = 1,990 kgf (> 18× IS limit of 110 kgf).
- Resistance Reduction ≈ 30 % @ Chandrapur CPRI trials.
- Passed all short-circuit and temperature-rise tests at CPRI and RTRI.
  Outcomes: Zero bimetallic corrosion, improved current flow, ROI < 1 month.
  Recognition: Adopted by MSETCL, MSEDCL and MPPKVCL.

RPL Compression Type Hardware & Crimping Services

D. Tower Stub Strengthening (Patent No. 297450)

Ramelex Pvt. Ltd. has developed a **unique and patented Tower Stub Strengthening System**, a pioneering innovation introduced in **1996**. Over the past **27 years of continuous field application**, this technology has demonstrated exceptional reliability — with **no failures or deterioration reported to date**.

The system enables **structural rehabilitation of corroded or weakened stubs without shutdown**, effectively restoring tower integrity, extending service life by over **25 years**, and ensuring network safety at a fraction of re-towering costs. Its long-term performance record stands as a benchmark in India's transmission infrastructure maintenance domain.

Challenge: Corroded tower stubs reduce foundation strength, risking collapse.
Innovation: A **shutdown-free reinforcement technique** using sleeve encapsulation and epoxy protection.
Impact: Restores original load capacity, extends tower life by 25 years, and achieves 80 % cost savings over re-towering.


Rectification of Corroded Tower Stub using RPL Patented Stub Strengthening Technology

E. India/US Patented RPL Universal Saver Clamp Assembly (Patent No. 414905) & (Patent No. 452911-001)

Purpose: Prevent conductor snapping in case of joint or clamp failure.
Mechanism: Secondary holding assembly maintaining conductor continuity under fault stress.
Validation: CPRI and RTRI tested for conductor dia. 28mm to 32mm up to 765 kV & for single,

twin, quad & hexa configurations; field proven at 220 kV and installed on 220 kV, 400 kV, and 765 kV levels in MSETCL and PGCIL networks.
Impact: Zero conductor snapping post installation; improved grid safety index.

Universal Dead End Saver Clamp Assembly suitable for conductor dia. 28mm to 32mm upto 765 kV

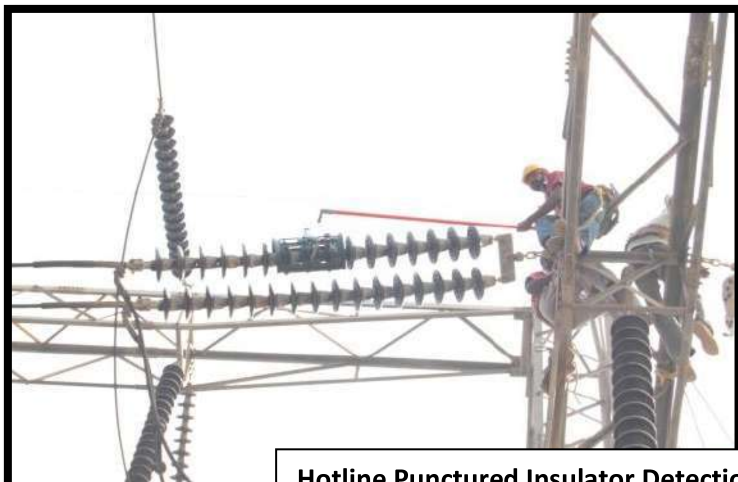
Universal Midspan Joint Saver Clamp Assembly suitable for conductor dia. 28mm to 32mm upto 765 kV

F. Ramelex – Pioneering Live-Line & Diagnostic Technologies in India

Predictive diagnostics using corona cameras, thermography, and partial discharge analysis.
Result: > 99.6 % network availability and reduced outage costs.
Capability: Hotline-trained teams by RITZ, Brazil and CPRI.

- **Hotline Washing of Overhead Transmission Lines (OHTL):**
  Ramelex Pvt. Ltd. introduced India's first **self-powered, vehicle-mounted washer pump system** for energized transmission line cleaning. This groundbreaking service was launched on **14 January 2003**, marking the beginning of live-line washing in the nation's power sector.
- **Live-Line Maintenance Technologies:**
  Pioneered and operationalized in India by Ramelex on **14 January 2003**, enabling maintenance of Extra High Voltage (EHV) lines **without shutdown**, thereby ensuring uninterrupted power transmission and enhanced network reliability.
- **Live-Line OPGW Replacement for 500 kV HVDC Systems:**
  Ramelex Pvt. Ltd. pioneered **live-line replacement of Optical Ground Wire (OPGW)** for **500 kV HVDC transmission systems** in India, introducing this advanced technology in **2022**. The method enables OPGW upgradation **without shutdown**, ensuring uninterrupted communication and grid reliability.
- **Comprehensive EHV Transmission Line Patrolling:**
  Ramelex established a systematic **thorough-patrolling methodology** for EHV transmission lines on **12 June 2006**, integrating visual inspection, mechanical verification, and predictive diagnostic tools.
- **Partial Discharge (PID) Detection Technology:**
  Introduced and commissioned by Ramelex in India on **20 December 2007**, this innovation enables early detection of insulation defects and corona discharges under live-line conditions, significantly improving preventive maintenance practices.
- **Coronagraphy Imaging Technology:**
  Technology inception and field deployment by Ramelex on **20 March 2009**, facilitating **non-contact detection of corona activity** and arcing points on energized equipment, enhancing the overall safety and reliability of high-voltage assets.
- **Infrared (IR) Thermography:**
  Implementation of **P65 Thermal Cameras with 7° telephoto lenses**, capable of diagnosing hotspots and connection defects up to **765 kV systems**. This technology was introduced by Ramelex on **20 March 2009**, setting new benchmarks in precision thermal diagnostics for transmission infrastructure.

Hotline Insulator Washing Services



Hotline Punctured Insulator Detection & Hotline Insulator Replacement

India's first **self-powered, vehicle-mounted washer pump system by RPL**

RPL Hotline Maintenance Services

G. AMC Model for Network Reliability

A 5-year data-driven AMC program covering > 2,800 km of EHV lines.
Deliverables: Monthly health-index reporting and predictive analytics.
AMC operations reduced joint-failure incidents by 70 %, enabling faster restoration and improved reliability.

Restoration work of Collapsed Transmission Towers for RVPNL

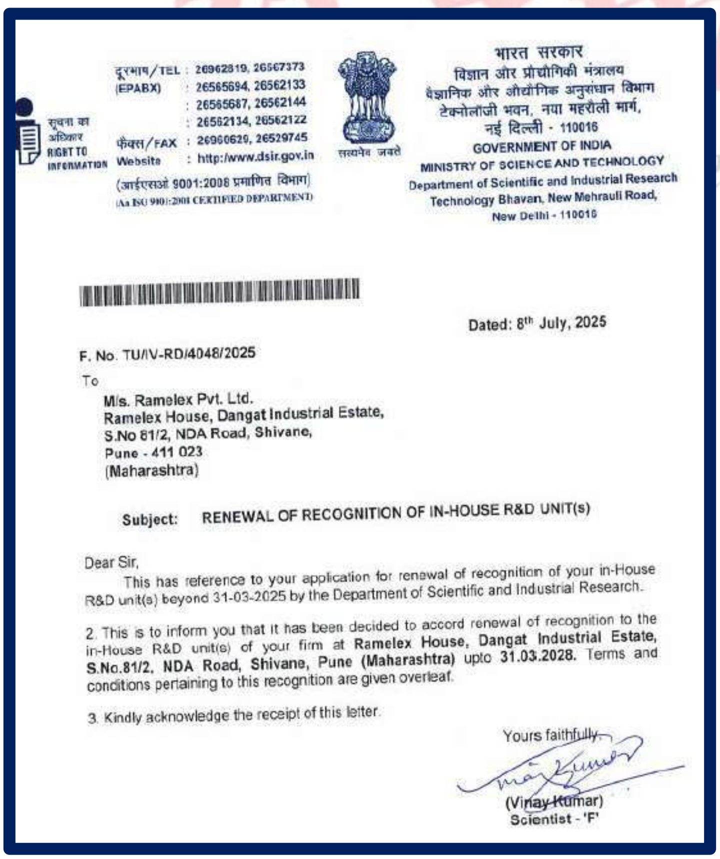
H. R&D and Testing Infrastructure

➢ RPL R&D Division (RRDC)

The **Ramelex Research & Development Centre (RRDC)** is a **DSIR-recognized innovation hub** dedicated to the design and development of advanced transmission line hardware and reliability solutions. The division focuses on **indigenous technology development**, patent-driven engineering, and **Make-in-India initiatives** for EHV and UHV systems. Its innovations—including Stub Strengthening, Saver Clamp Assemblies, and Compression Connectors—have transformed grid safety and efficiency across India's power network.

➢ RTRI – Ramelex Testing & Research Institute

The **Ramelex Testing & Research Institute (RTRI)** is a **NABL-accredited laboratory** conforming to **ISO/IEC 17025:2005** standards. It provides comprehensive **electrical, mechanical, and chemical testing** of transmission hardware and conductors. RTRI supports utilities and manufacturers by ensuring compliance, validation, and performance assurance through advanced testing infrastructure and certified experts.



दूरभाष/TEL : 26962819, 26567373
(EPABX) : 26565694, 26562133
: 26565687, 26562144
: 26562134, 26562122
फैक्स/FAX : 26960629, 26529745
Website : http:/www.dsir.gov.in
(आईएसओ 9001:2008 प्रमाणित विभाग)
(An ISO 9001:2008 CERTIFIED DEPARTMENT)

सूचना का अधिकार RIGHT TO INFORMATION

सत्यमेव जयते

भारत सरकार
विज्ञान और प्रौद्योगिकी मंत्रालय
वैज्ञानिक और औद्योगिक अनुसंधान विभाग
टेक्नोलॉजी भवन, नया महरौली मार्ग,
नई दिल्ली - 110016
GOVERNMENT OF INDIA
MINISTRY OF SCIENCE AND TECHNOLOGY
Department of Scientific and Industrial Research
Technology Bhavan, New Mehrauli Road,
New Delhi - 110016

Dated: 8th July, 2025

F. No. TU/IV-RD/4048/2025

To
M/s. Ramelex Pvt. Ltd.
Ramelex House, Dangat Industrial Estate,
S.No 81/2, NDA Road, Shivane,
Pune - 411 023
(Maharashtra)

Subject: RENEWAL OF RECOGNITION OF IN-HOUSE R&D UNIT(s)

Dear Sir,

This has reference to your application for renewal of recognition of your in-House R&D unit(s) beyond 31-03-2025 by the Department of Scientific and Industrial Research.

2. This is to inform you that it has been decided to accord renewal of recognition to the in-House R&D unit(s) of your firm at **Ramelex House, Dangat Industrial Estate, S.No.81/2, NDA Road, Shivane, Pune (Maharashtra)** upto **31.03.2028.** Terms and conditions pertaining to this recognition are given overleaf.

3. Kindly acknowledge the receipt of this letter.

Yours faithfully,

(Vinay Kumar)
Scientist - 'F'

National Accreditation Board for Testing and Calibration Laboratories

NABL

CERTIFICATE OF ACCREDITATION

RAMELEX TESTING AND RESEARCH INSTITUTE

has been assessed and accredited in accordance with the standard

ISO/IEC 17025:2017

"General Requirements for the Competence of Testing & Calibration Laboratories"

for its facilities at

S. NO. 81/4A, P. NO. 1759, DANGAT INDUSTRIAL ESTATE, NDA ROAD, PUNE, MAHARASHTRA, INDIA

in the field of

TESTING

Certificate Number: TC-15780

Issue Date: 28/03/2025 Valid Until: 27/03/2029

This certificate remains valid for the Scope of Accreditation as specified in the annexure subject to continued satisfactory compliance to the above standard & the relevant requirements of NABL.
(To see the scope of accreditation of this laboratory, you may also visit NABL website www.nabl-india.org)

Name of Legal Entity: Ramelex Private Limited

Signed for and on behalf of NABL

Anita Rani
Director

N. Venkateswaran
Chief Executive Officer

I. Emergency Restoration Systems (ERS)

Design: Modular, lightweight aluminum structures adaptable for 132 kV to 400 kV.
Performance: Mechanically stable under high wind and seismic conditions.
Benefits: Rapid restoration post disaster, minimal outage losses, reusability.

RPL Emergency Restoration Services for MSETCL and MRVCL

V. Sustainability and Techno-Spiritual Responsibility

Ramelex integrates sustainability at multiple levels:

- **Green Manufacturing:** Solar rooftops, low-carbon processes.
- **Eco-Friendly Packaging:** 100 % recyclable material.
- **Water Management:** Rainwater harvesting and groundwater recharge.
- **Afforestation:** 25,000 + teak trees on 200 acres.
- **Community Empowerment:** *Vedant Public School* and industrial awareness programs promoting WASH, ISO, ZED, and Green Initiatives.

Green Manufacturing & Sustainable Packaging

Rainwater Harvesting/Afforestation & Community Empowerment

Industrial Awareness Programmes at RPL Auditorium

VI. Awards and Recognitions

- **CII Industrial Innovation Award 2022** – Saver Clamp Assembly
- **MCCIA G.S. Parkhe Award 2020** – Innovative Practices
- **Adani Transmission Safety Award 2022–23**
- **Human Asset Excellence Award 2019–20**
- **ZED Gold, NABL, and DSIR Certifications**

AWARDS:

MCCIA GS PARKHE INNOVATION AWARD 2020 for Saver Clamp Assembly

CII INDUSTRIAL INNOVATION AWARD - 2022 for Saver Clamp Assembly

ADANI TRANSMISSION ANNUAL SAFETY AWARD 2022-23

YOUNG ACHEIVER 2025 (Awarded to CEO-RPL R&D)

Human Asset Management Excellence Award 2019-2020

Appreciation for Contribution to Defence

GHR AWARD – Innovative Practices in Energy Saving

CERTIFICATIONS:


सूक्ष्म, लघु और मध्यम उद्यम मंत्रालय
MINISTRY OF
MICRO, SMALL & MEDIUM ENTERPRISES

CERTIFICATE

MSME Zed GOLD

ZED GOLD

under MSME Sustainable (ZED) Certification Scheme
awarded to

M/S RAMELEX PRIVATE LIMITED

Flat No:- Survey No. 82/4, Building:- Near Vidyut Control Pvt Ltd., Road/Street:- Off NDA Road, Village/Town:- Shivane, Block:- , City:- Pune, PUNE, MAHARASHTRA-411023

27-Manufacture of electrical equipment

UDYAM-MH-26-0027385

RSJ INSPECTION SERVICE LTD


QUALITY COUNCIL OF INDIA

TÜVRheinland
Precisely Right.

WASH

Workplace Assessment for Safety and Hygiene (WASH)

A Scheme by Quality Council of India

Organization Name

M/s. RAMELEX PRIVATE LIMITED

Organization Address

S.No.: 82/4, Dangat Industrial Estate, NDA Road, Shivane, Pune-411023

Date of Assessment

31/07/2020

This Certificate of Assessment is an assertion of the fact that this organization has exhibited intent & commitment towards ensuring safety and hygiene at the workplace. The assessment is to assist in the preparedness of this organisation on the 15 key elements of WASH Standard and does not imply certification of compliance, as practice of these elements is a continuous process. The outcome of this assessment is annexed with this certificate along with opportunities of improvement, if any, and is governed by the disclaimer given at the end of this assessment report.

Date of Issue: 31/07/2020 Place: Ahmedabad, India

Assessment Agency: TUV RHEINLAND INDIA PRIVATE LIMITED

WASHQCIAA630/001

Assessment Report No.

Authorized Signatory
(WASH Assessment Agency)

VII. Conclusion

Through patented technologies and techno-spiritual engineering, Ramelex demonstrates India's capacity for self-reliant innovation in power transmission.
Its solutions have proven to enhance safety, extend asset life, reduce losses, and foster sustainable development across the national grid.

The future of transmission engineering lies in *responsible innovation*—a synergy of design intelligence, ethical practice, and environmental stewardship.
Ramelex's patented technologies and field-driven methodologies represent a **replicable model** for achieving India's **Atmanirbhar Bharat** goals in the power sector.

By bridging R&D, manufacturing, and sustainability through techno-spiritual engineering, Ramelex continues to deliver reliability, safety, and efficiency for India's grid of tomorrow.

VIII. References

1. CPRI Test Reports (2018–2024)
2. DSIR Recognition – RRDC Ramelex Pvt Ltd
3. NABL Accreditation – RTRI Pune
4. Project Reports – JSW Dolvi, MSETCL HTLS lines, RRVPNL AMC
5. Patent No. 297450 – Stub Strengthening
6. Patent No. 315715 – Compression-Type Connectors
7. Patent No. 414905 & 452911-001 – Saver Clamp Assembly

*****

Engineering Safety and Reliability:

CSIR-SERC's Pioneering Role in India's Power Infrastructure

Dr. R.P. Rokade & Dr. R. Balagopal
Senior Principal Scientist
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Mobile: 9444931723
CSIR-Structural Engineering Research Centre,
Chennai - 600113

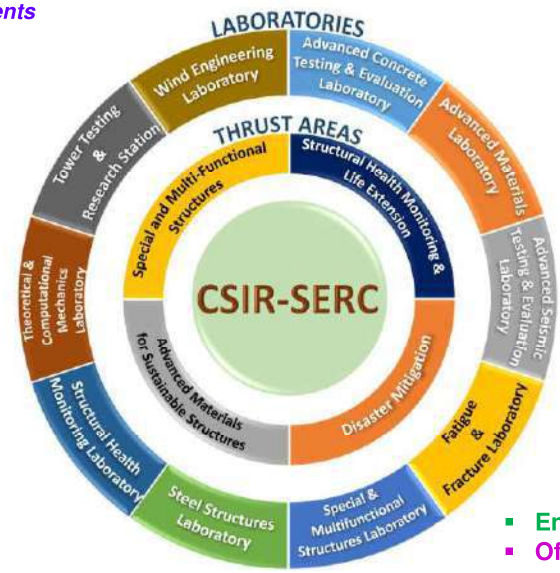
CSIR-Structural Engineering Research Centre (CSIR-SERC)

A premier R&D Institution under CSIR pursuing advanced and high quality Research in Structural Engineering augmented with

- State-of-the-art Unique Facilities for Struct. Testing & Evaluation
- Computational Facilities

Thrust Areas & Laboratories

CSIR-SERC has built up excellent facilities and expertise for the analysis, testing and design of structures and structural components



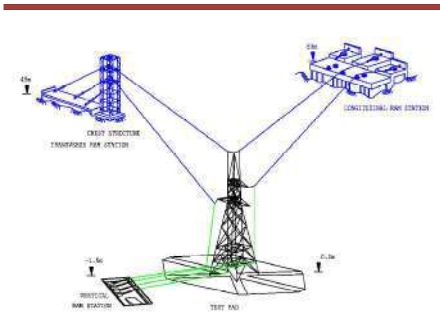
EXPERTISE

- Computational Structural Mechanics
- Bridge Engineering
- Fatigue & Fracture
- Health Assessment Using Guided Wave Propagation
- Nano Mechanics & Engineering
- Risk & Reliability
- Shock & Vibration
- Steel Structures
- Structural Concrete Engineering
- Structural Dynamics & Engineering
- Structural Health Monitoring
- Sustainable Materials and Composites
- Wind Engineering

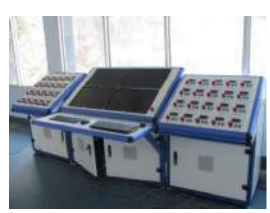
- **Energy Infrastructure**
- **Offshore Structures**

27-10-2025 3

Tower Testing and Research Station (CSIR-SERC)







27-10-2025 4

Failures Observed during Prototype Tests

Prototype Tower Failure Videos

Transmission Line Towers Testing

S/C Tower 72.95 m
M/s Tehran Reg. Elec. Co.

Heaviest 78 Ton and Longest Cross Arm 46 m M/s Tehran Reg. Elec. Co.

Highest D/C Tower 80 m
M/s Inter Chile

Communication Tower Testing

80 m MW Tower

60 m High Schifflerized MW Tower

GFRP Hollow Circular Tube MW Tower

GFRP Angle MW Tower

GFRP-Steel Hybrid MW Tower

Testing of Monopole Structures

CFRP Isolator for ISRO

Spun Concrte MW Pole

30 m High Lighting Mast

400 kV D/C Suspension Pole

132 kV D/C Angle Pole

Testing of Insulators

Triple Tension Glass Insulator

Y-Type Porcelain Insulator

Post Insulator

Quad Tension Composite Insulator

Double-V Porcelain Insulator

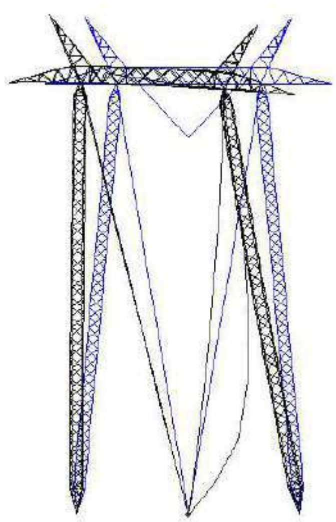
Studies on Cold-Formed Steel Sections for TL Towers

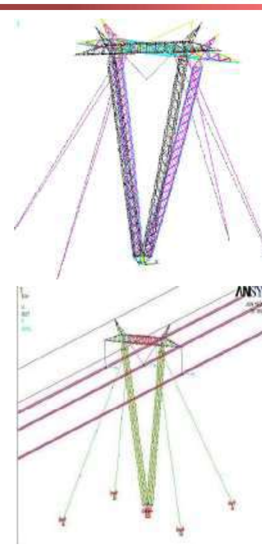
Cold Formed Steel
Hybrid Tower

Cold-Formed Steel
Lipped Angle Connections

Cold-Formed Steel
Lipped Angle Panel

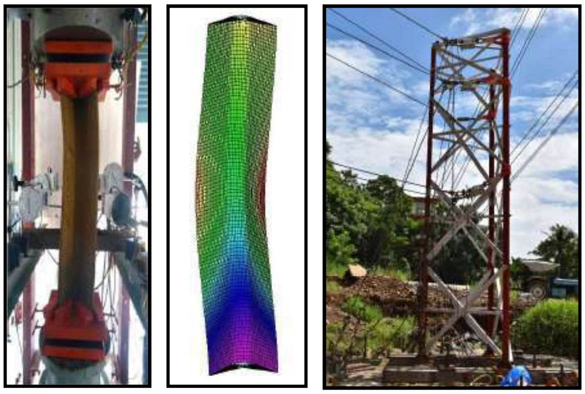
Studies on Guy Tower Structures





400 KV and 800 KV S/C Portal and 'V' Type Guyed Towers
Testing & Analysis for First Time in India

60° and Schifflerized Angle Sections for Triang. Config.



60° Steel Angle Sections

Schifflerized Angle Sections

Pultruded GFRP Angle Sections for TL/MW Towers

Refurbishment Techniques of TL/MW Towers

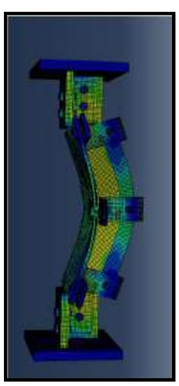






27-10-2025 15

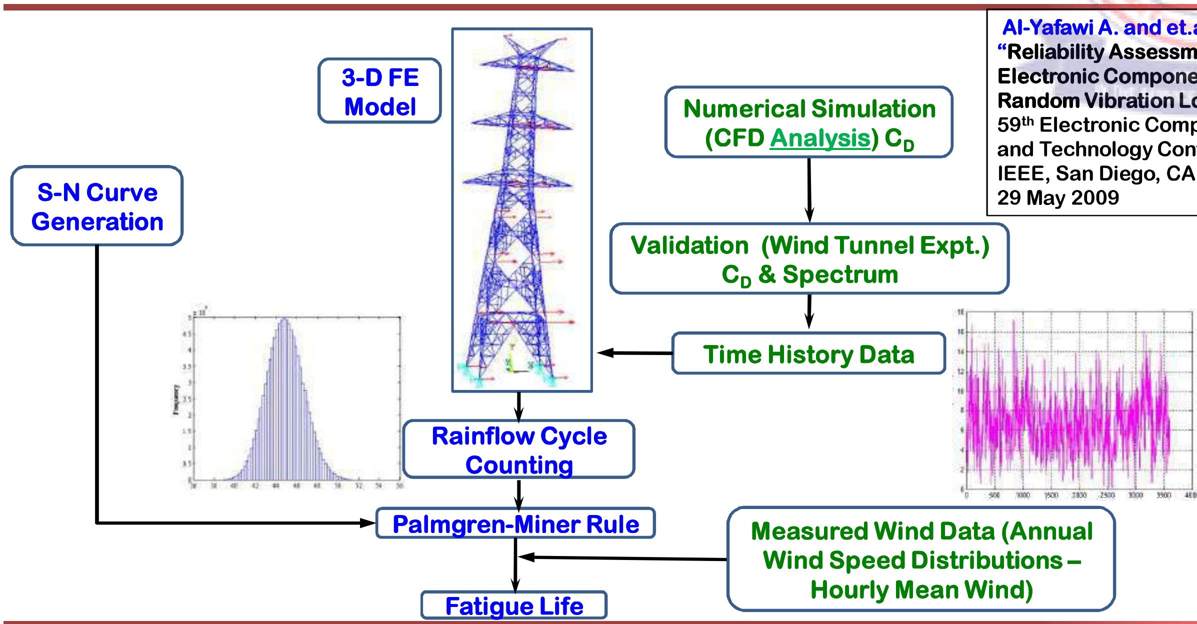
Retrofitting of TL Towers

27-10-2025 16

Fatigue Damage Assessment of TL Towers under W.L.

Al-Yafawi A. and et.al. (2009), "Reliability Assessment of Electronic Components under Random Vibration Loading", 59th Electronic Components and Technology Conference, IEEE, San Diego, CA, USA 26-29 May 2009



Sustainable and Reliable Steel Lattice Structures

- Behaviour of High Strength Steel (HSS) members under axial loads
- Component level behaviour of High Strength Steel (HSS) structural connections
- *Reliability Based Design of Transmission Line Towers*
- Progressive collapse analysis of Transmission Line Towers

RBD - Literature Test Database

Sr. No.	Literature	Year	Number of single angle column specimen tested				
			Equal Flange Angle Section			Unequal Flange Angle Section	
			Leg Member	Bracing Member	Cross-Arm Lower Member	Leg Member	Bracing Member
1	Stang et al.	1917	87	79	-	-	4
2	Minoru et al.	1965	10	-	-	-	-
3	Mangat et al.	1969	6	-	-	-	-
4	Kitipornchai et al.	1986	7	-	-	6	-
5	Al-Sayed et al.	1989	8	-	-	4	-
6	Bathon et al.	1992	-	31	-	-	44
7	Adluri et al.	1996	26	-	-	-	-
8	Adluri et al.	1996a	4	-	-	30	-
9	Haider et al.	1996	-	104	-	-	93
10	Shani et al.	1998	-	16	-	31	-
11	Cao et al.	2010	-	48	-	-	-
12	Jyoti et al.	2015	-	18	-	-	-
13	Jyoti et al.	2017	-	18	-	-	-
14	Kettler et al.	2019	-	27	-	-	-
15	Zulin Huang et al.	2021	378	182	135	-	-
		Σ	**526**	**523**	**135**	**71**	**141**
Total Data Points in Literature Test-Dbase			**1396**				

27-10-2025

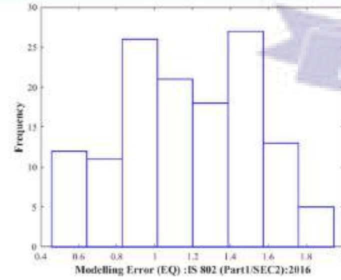
RBD - Test Database – Statistics

Transmission Line Tower Member	Loading Condition	Specimen Nos.	Mean	Std. Dev.	Skewness	Kurtosis	CoV
Leg Member $\lambda \leq 120$	Concentrically loaded on both ends	**429**	1.109	0.167	2.086	12.910	0.150
Leg Member $120 \leq \lambda < 150$		**54**	1.218	0.354	0.515	1.986	0.291
Bracing/Diagonal Member $\lambda \leq 120$	Eccentrically loaded on both ends	**367**	0.926	0.295	1.425	7.456	0.319
Bracing/Diagonal Member $120 \leq \lambda < 200$		**218**	1.056	0.278	1.514	9.800	0.263
Cross-Arm Lower Member $\lambda \leq 120$	Concentrically loaded on one end and eccentrically loaded on other end	**75**	1.029	0.153	0.491	0.475	0.148
Cross-Arm Lower Member $120 \leq \lambda < 150$		**15**	1.115	0.180	1.200	1.442	0.161
Test Data Points not considered in statstical study		**238**	**as either (b/t) > $(b/t)_{lim}$ or λ > maximum λ**				
Total No. of Specimens considered in Test Data Base for Compression Members		**1396**					

27-10-2025

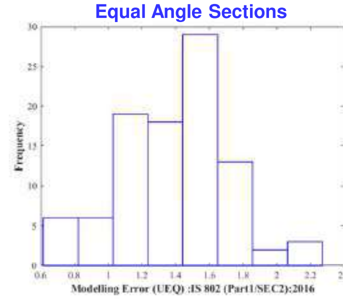
RBD - Details of Tension Test Database – Literature

Sr. No.	Literature	Year	No. of Single and Double Angle Members Tested	
			Equal Angle Section	Unequal Angle Section
1	McKibben et al	1906	-	27
2	Epstein et al.	1992	12	26
3	Wu et al.	1993	8	16
4	Kulak et al.	1997	19	5
5	Orbison et al.	1999	-	3
6	Geethu et al.	2014	9	-
7	Agrawal et al.	2018	4	-
8	Kshirsagar et al.	2018	6	-
9	Bernatowska et al.	2018	8	-
10	Dhanuskar et al.	2020	12	-
11	Jiang et al.	2020	-	5
12	Bernatowska et al.	2021	16	-
13	Barcewicz et al.	2021	18	-
14	Chandrakar et al.	2023	9	12
15	Nagasato et al.	2023	14	-
		Σ	135	94
Total Data Points for Test Database			229	



μ = 1.1728
σ = 0.3558
Sk = -0.0669
Ku = 2.1347
COV = 0.3034

Equal Angle Sections



μ = 1.3868
σ = 0.3428
Sk = 0.0421
Ku = 3.0717
COV = 0.2472

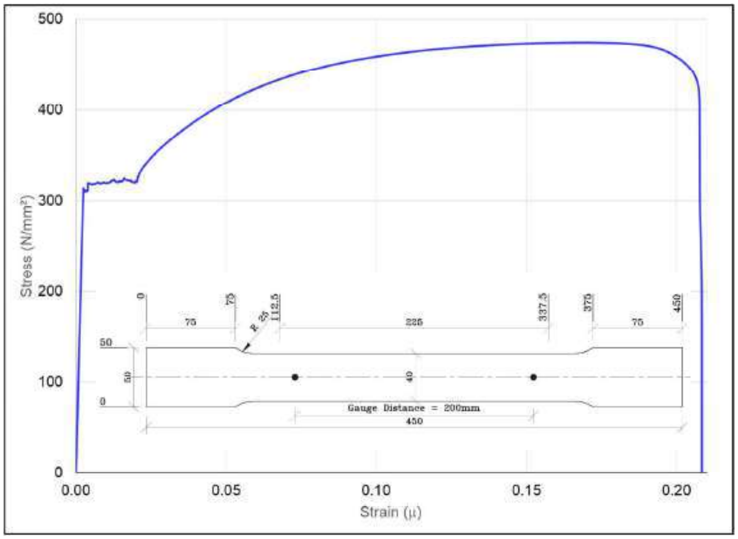
Unequal Angle Sections

Single Angle Section - Material Characteristics

Tension Coupon Test (ASTM E8) – Test Setup

Tested Tension Coupon Test Specimen

Single Angle Section - Material Characteristics



Stress-Strain Curve (SPC-3)

Tension Coupon Test Results

Specimen	Yield Strength (N/mm^2)	Ultimate Strength (N/mm^2)	Modulus of Elasticity (N/mm^2)	% Elongation
SPC-2	322.974	479.005	1.746E+05	18.49
SPC-3	319.906	473.557	1.825E+05	20.80
SPC-4	314.396	479.706	1.778E+05	20.90
Mean	**319.092**	**477.423**	**1.78E+05**	**20.06**

TL Tower Cross Arm Lower Member – Buckling Test

Test Specimen Section and Material Properties

Angle Section	Area - A (mm^2)	Radius of Gyration - r_{vv} (mm)	Mild Steel			Based on Coupon Test			Bolt Nos. on Concentric Load End	Bolt Nos. on Framing Eccentricity End
			F_y (N/mm^2)	C_c	E (N/mm^2)	F_{yT} (N/mm^2)	C_{cT}	ET (N/mm^2)		
L60x60x4	471	11.8	250	125.7	2.00E+05	319.092	111.230	1.78E+05	4 Nos. (2 on each flange)	4 Nos. on Connected Flange
L75x75x6	866	14.6	250	125.7	2.00E+05	319.092	111.230	1.78E+05		

L 60 x 60 x 4
L = 40, 60, 80 & 100

L 75 x 75 x 6
L = 40, 60, 80, 100, 120 & 130

TL Tower Cross Arm Lower Member – Buckling Test

Test Setup

TL Tower Cross Arm Lower Member – Buckling Test

L 60 x 60 x 4

L 75 x 75 x 6

λ = 40 60 80 100

λ = 40 60 80 100

TL Tower Cross Arm Lower Member – Buckling Test

Experimental Investigation on Single Angle Member – TL Tower Cross-Arm Lower Member

Sr. No.	Section	Specimen No.	Specimen Designation	c/c Length (mm)	λ	IS 802(Part1/ Sec2) : 2016 λ_E	IS 802(Part1/ Sec2) : 2016 Capacity (kN)	Test Load (kN)	Average Test Load (kN)	M.E.	Remarks
1	L 60x60x4	1	S1A					121.528			
2	L 60x60x4	2	S1B	472	40	60	128.427	115.000	115.426	0.899	
3	L 60x60x4	3	S1C					109.751			
4	L 60x60x4	1	S2A					102.312			
5	L 60x60x4	2	S2B	708	60	75	116.127	107.772	105.042	0.905	Local plate buckling at framing eccentricity end
6	L 60x60x4	3	S2C								
7	L 60x60x4	1	S3A					116.825			
8	L 60x60x4	2	S3B	944	80	90	101.094	123.085	113.918	1.127	
9	L 60x60x4	3	S3C					101.843			
10	L 60x60x4	1	S4A					103.724			
11	L 60x60x4	2	S4B	1180	100	105	83.328	112.239	108.986	1.308	
12	L 60x60x4	3	S4C					110.994			

TL Tower Cross Arm Lower Member – Buckling Test

Experimental Investigation on Single Angle Member – TL Tower Cross-Arm Lower Member

Sr. No.	Section	Specimen No.	Specimen Designation	c/c Length (mm)	λ	IS 802(Part1/ Sec2) : 2016 λ_E	IS 802(Part1/ Sec2) : 2016 Capacity (kN)	Test Load (kN)	Average Test Load (kN)	M.E.	Remarks
13	L 75x75x6	1	S5A					203.152			
14	L 75x75x6	2	S5B	584	40	60	236.130	210.720	205.394	0.870	Local plate buckling at framing eccentricity end
15	L 75x75x6	3	S5C					202.309			
16	L 75x75x6	1	S6A					190.823			
17	L 75x75x6	2	S6B	876	60	75	213.516		200.180	0.938	
18	L 75x75x6	3	S6C					209.536			
19	L 75x75x6	1	S7A					177.573			
20	L 75x75x6	2	S7B	1168	80	90	185.876	205.303	191.066	1.028	Flexural Buckling
21	L 75x75x6	3	S7C					190.321			
22	L 75x75x6	1	S8A					204.940			
23	L 75x75x6	2	S8B	1460	100	105	153.211	179.407	183.998	1.201	Flexural Buckling
24	L 75x75x6	3	S8C					167.646			

Observations

- Test database for TL tower members tested in compression e.g. Leg, Bracing and Cross-arm lower members is created for 1396 data points from literature.
- The stastics of Modelling Error (M.E.) for TL tower members tested in compression indicate that the M.E. is around 5-10% except for leg members in elastic buckling it is 20% with respect to IS 802 (Part 1/Sec 2): 2016.
- From the tension coupon test it is observed that the average variation for M.S. Angle sections procured is 27.6% for yield strength, 16.4% for tensile strength, 10.9% for modulus of elasticity and 12.8% for % elongation.
- Experimental investigations on x-arm lower member suggested 10-12% variation in buckling capacity for λ=40 to 80 whereas for λ=100, it is 30% for L60x60x4 and 20% for L75x75x6
- It is also observed that the failure mode for L60x60x4 is in local plate buckling at eccentric end connection, irrespective of λ whereas for L75x75x6, it is local plate buckling at eccentric end connection for λ 40 & 60 and flexural buckling mode for λ 80 & 100.

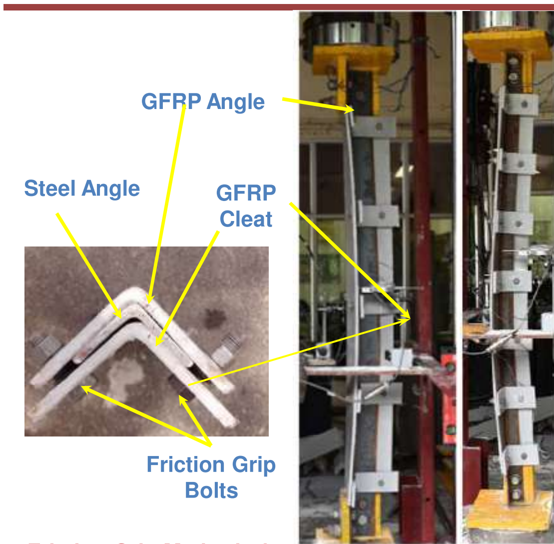
27-10-2025 29

Prototype Testing of Retrofitted of TL Towers

Studies on Friction Grip Method of Strengthening using GFRP Angle and Cleat for 220 Kv D/C TL Tower

27-10-2025 30

Retrofitting of TL Towers



Friction Grip Method of strengthening with GFRP Angle and Cleat

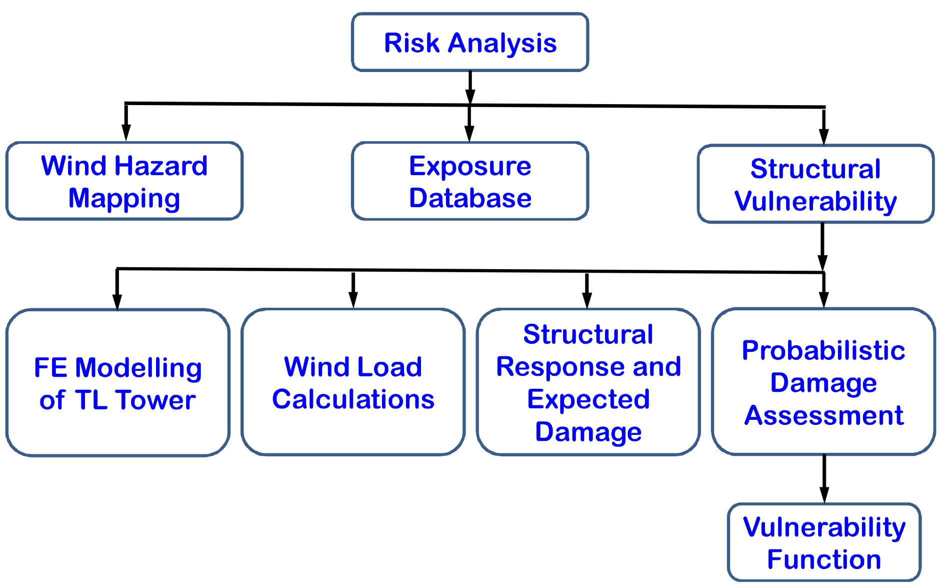
Leg Member   Bracing Member

Element Level Studies

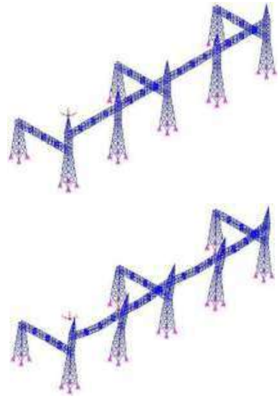
Observations:

- The element/component-level studies, incorporating the proposed strengthening techniques for the concentrically loaded leg and eccentrically loaded bracing members, showed an increase in compression capacity of up to 20% and 54%, respectively.
- In the case study tower without any strengthening, the structure sustained 95% of the design load under reliability load conditions, with failure occurring due to buckling of the bottommost panel's leg member.
- After applying the proposed strengthening techniques, the failure load for the case study tower increased to 135%, and a change in the failure pattern was observed. In this enhanced scenario, failure of the leg member occurred in the third panel, resulting from the tearing failure of the GFRP angle sections, followed by the subsequent buckling of the leg member.

Prob. Risk Assessment of TL Towers under High W.C.

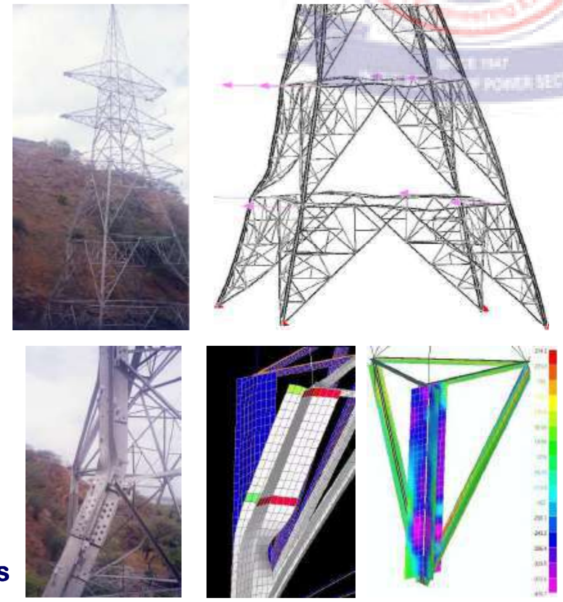


Failure Investigations



400 kV Sub-Station Structure

Research on Compound Members



Technology Development

Emergency Retrieval System (ERS) for Transmission Lines

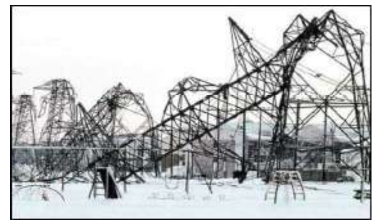
TL Tower Failures during Extreme Events

Collapse of Transmission Towers during Haiti Earthquake

Tower Collapse in flood-hit eastern Terai, India

Electric tower damage during Amphan Cyclone

Rainfall induced landslide at Pingguang stream in Taiwan

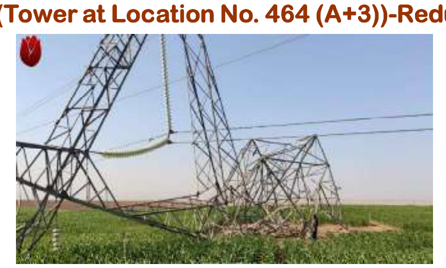


Great Ice Storm of 1998, US & Canada

TL Tower Failures during Extreme Events

765 kV S/C Meerut-Greater Noida TL on 13.06.2016 (Tower at Location No. 464 (A+3))-Redundant member missing

Dumper-Crashes-into-Tower, Gurgaon Sector 65-66



ISIS blows up Kirkuk-Erbil Electricity TL, Iraq

Missing Redundant Members observed during PILOT Audit

Cost Benefit Analysis & CEA Regulations/NEP on ERS

Sl. No.	Particulars	Restoration on ERS	Restoration by conventional method
1	Average power Flow	500 MW	500 MW
2	Generation loss/ day	=12,000,000 Units	12,000,000 Units
3	Restoration time	12 days	40 days
4	Total generation loss	144,000,000 Units	480,000,000 Units
5	Rate/ Unit	Rs. 2.00	Rs. 2.00
6	Total loss	Rs.28,80,00,000	Rs. 96,00,00,000
7	Savings by restoration on ERS	Rs.67,20,00,000/-	Source – M/s PGCIL

- Every transmission licensee shall have an arrangement for restoration of transmission lines of at least 220 kV and above through the use of ERS
- The primary criterion for deciding number of ERS to be arranged by a transmission utility has to be the length of transmission line (Circuit kms - Ckm)
- For any transmission utility, 1 - set of ERS have to be planned to cater failure of towers for TL lengths up to 5000 Ckm.
- Accordingly, 2 - sets of ERS have to be planned for TL lengths of about 5000 to 10,000 Ckm and 3 - sets for > 10,000 Ckm and so on.
- The transmission Utility with line length less than 500 ckm (of 400kV lines) have given option that either to procure ERS or have agreement with other transmission utilities for providing ERS on mutually agreed terms, when need arises

ERS Development at CSIR-SERC

R&D Focus

Development of indigenous technology to produce cost-effective ERS suitable for 33 kV to 800 kV TL Systems – A "Make in India" and "Atmanirbhar Bharat" initiative

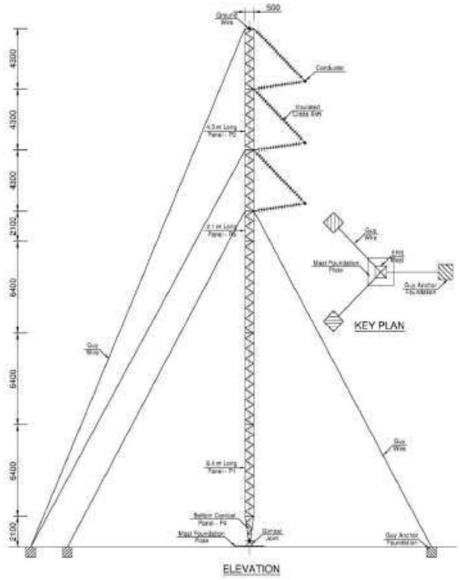
Objectives

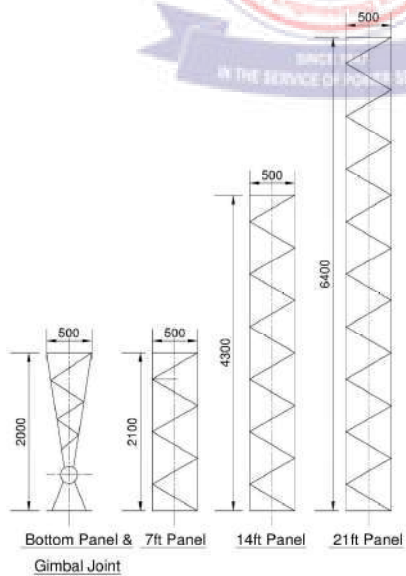
- Design and development of modular ERS using lightweight materials
- Development of easy to construct foundation and connection systems for the modules and accessories
- Guidelines for site specific ERS

Important Parameters Unique to the Development

- Easy to plan and use
- Suitable for industrial production
- Compact system yet economically affordable
- Made of light weight material easy to transport
- Modular in nature easy to construct/assemble
- Flexible enough to develop various configurations for single or double circuit transmission lines
- Scalable system can be used for 33 to 800 kV transmission lines

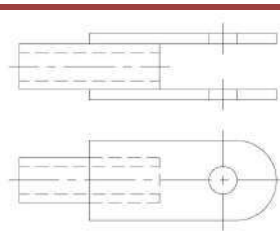
Conceptualization of ERS & It's Modules



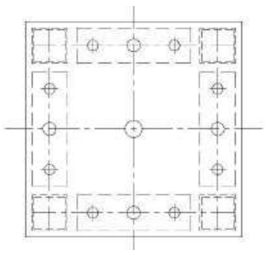


132 kV S/C TL Tower | **Equivalent ERS Mast** | **ERS Modules**

Conceptualization of Connections & Foundations

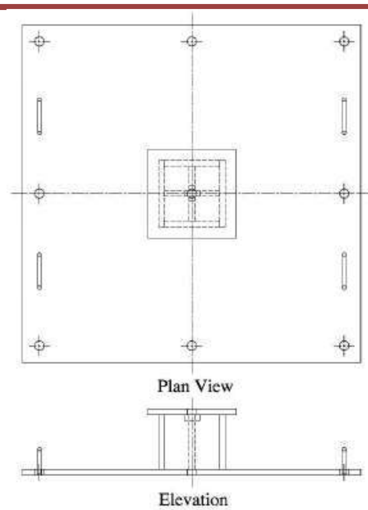


a) For Anchor End



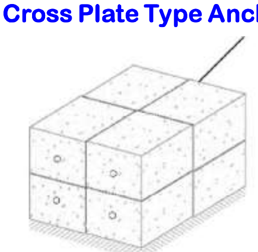
b) For ERS Mast

Guy Wire Connection Plates



a) For ERS Mast

b) Cross Plate Type Anchor



c) Dead Weight Anchoring System For Guy Wires

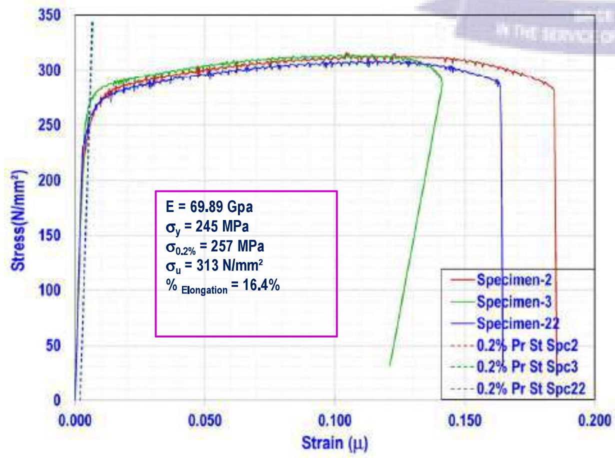
Foundation System

Material Modelling

Coupon Test Set-up

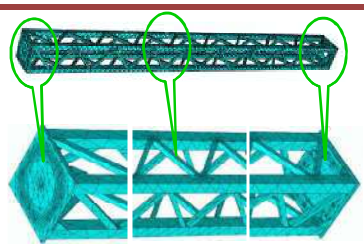
Coupon Specimen Failure Pattern

Material Testing (ASTM B557M)

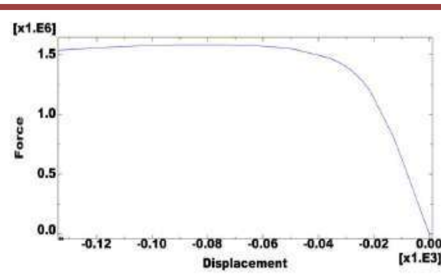


Stress-Strain Curve Al. Alloy 6061 T6 (Properties ASTM 308/B308M-10)

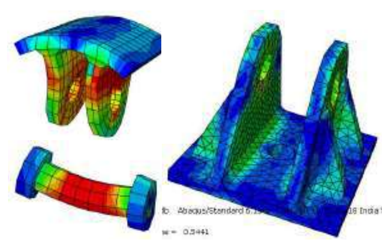
Analysis and Design of ERS Modules and Accessories



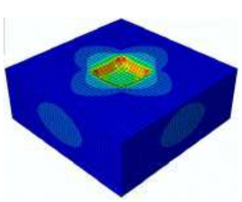
FE Model – 6.4 m ERS Module



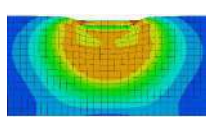
Force Vs Displacement Plot



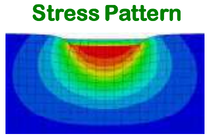
Gimble Joint FE Model



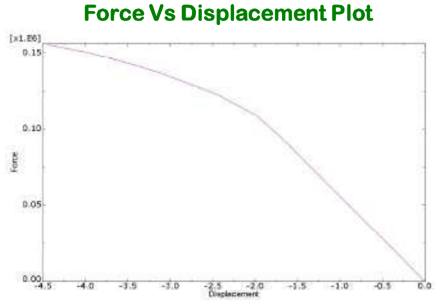
FE Model – ERS Mast Foundation



Stress Pattern



Displacement Pattern



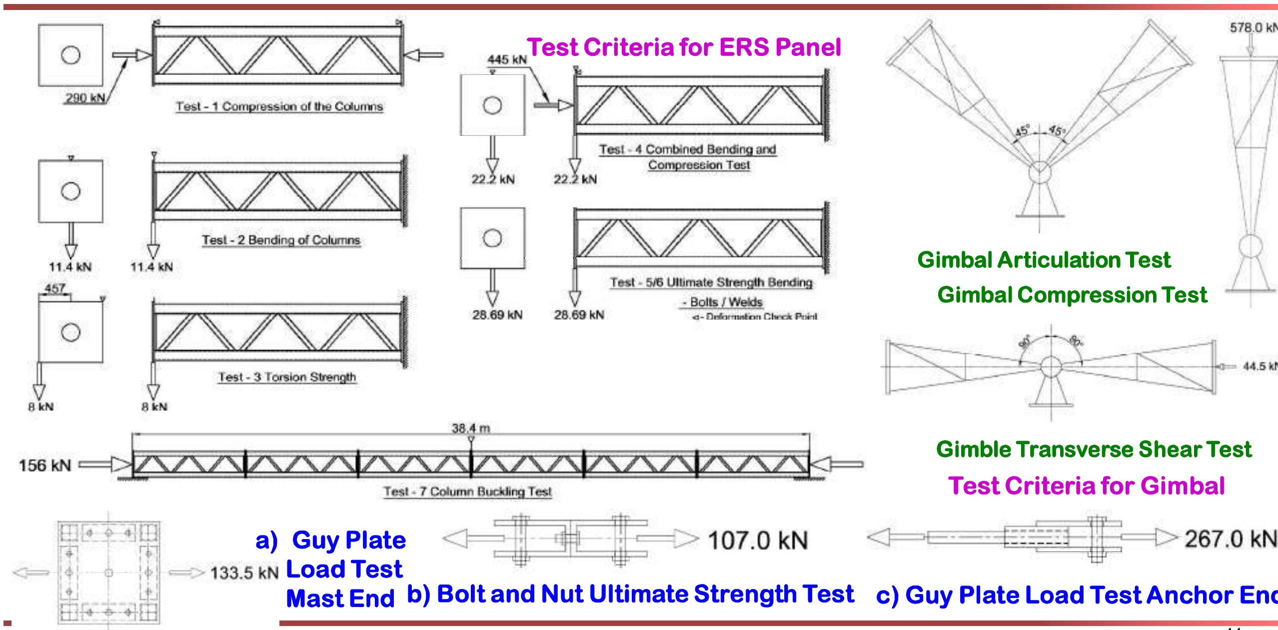
Force Vs Displacement Plot

Gimble Joint Assembly

Fabrication of ERS Modules and Accessories

Fabrication Jig, ERS Panels and Test Rig Fabrication in Progress

Qualification Tests as per IEEE Standard



Qualification Tests on ERS Modules as per IEEE Std.


Test Rig for Qualification Tests on ERS Panels

Compression Test

Buckling Test

Bending Test

Compression & Bending Test

Torsion Test

Qualification Tests on Gimbal and Accessories as per IEEE Standard

a) Compression Test

b) Transverse/Shear Test

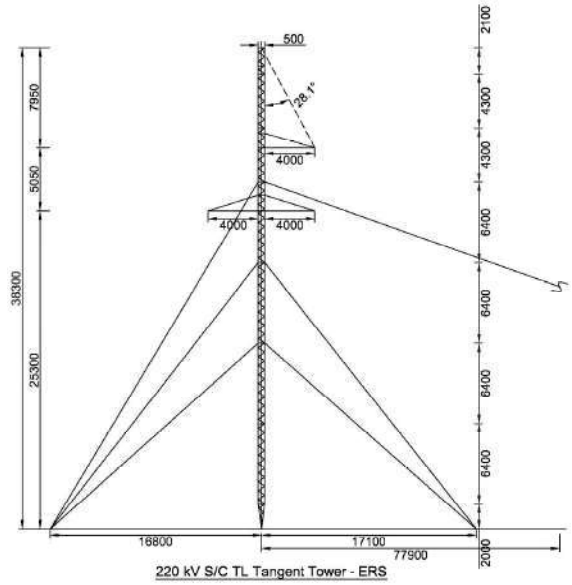
Tests on Gimble Joint and Bottom Panel

Component Level Experiment on Gimble Joint



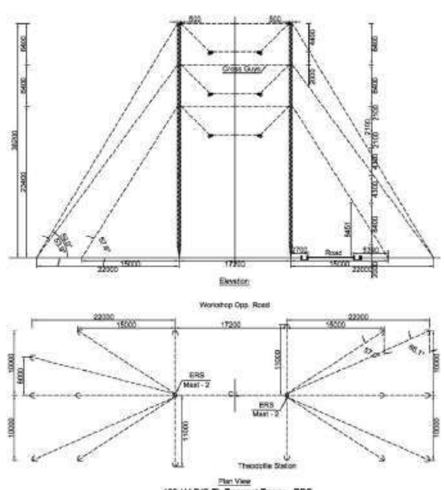
Tests on other accessories

Prototype Test on ERS Equivalent to 220 kV TL Tower



ERS Equivalent for 220 kV S/C TL Tower **ERS Test Set-up** **Deformed Shape of ERS**

Demo ERS Eqv. to 400 kV D/C Suspension TL Tower



Actual Tower **Schematic of Eqv. ERS Structure** **ERS Structure** **Mast Foundation**

Guy Wire Anchor Foundation

Stakeholders Connect, Technology Commercialization

Patents:

Temporary support structural system for power lines – India, USA, Canada

Two Pin Gimbal Joint – India

Technology Transfer:

M/s Advait Infratech Ltd., Ahmedabad, Gujarat

M/s Hi-Tech Systems & Services Ltd., Kolkata

M/s IAC Electricals Pvt. Ltd., Kolkata

27-10-2025 **Industry Meet on ERS** 49

Emergency Retrieval System (ERS) for Power Lines

About Technology

- Natural Disasters or manmade sabotages cause collapse of Transmission Line (TL) towers due to which the power transmission will be interrupted. This causes heavy monetary losses to the power utilities as well as loss of service to the consumers.
- Permanent restoration of tower/s may take several weeks
- Emergency Retrieval System (ERS) is the temporary system of modular guyed masts made up of light weight material. It is used to support the TL's at failed tower locations, thus creates a bye-pass so that the power transmission can be resumed within 2-3 days as compared to several weeks of time
- Forms of ERS are available in the western countries are patented technologies and their procurement costs are huge. Hence, CSIR-SERC has developed an indigenous technology to produce the cost-effective ERS suitable for 33 kV to 800 kV TL Systems – A "Make in India" as well as "Atmanirbhar Bharat" initiative

Features/Highlights/USP

- Indigenous system, 40% cost, Import substitution, Flexible for customization, Easy and quick to erect, Immediate power restoration

27-10-2025 50

Emergency Retrieval System (ERS) for Power Lines

Technical Details :

Temporary support structural system for power lines, in the form of guyed masts made up of light weight modules with easy to connect connection system, supported on two pin gimbal joint and easy to construct foundation system which is constructed in short duration (2-3 days).

Applications:

In the event of transmission line tower failure, ERS is used to support the power lines temporarily for restoring power transmission by creating by-pass corridor so that the permanent restoration can take place

Linkage to GoI Missions/initiatives :

- Atmanirbhar Bharat

Potential Stakeholders :

Power Transmission Utilities in India and Abroad

Technology Readiness level/transfer status :

- TRL 9
- Tech. transferred to –
  - M/s Advait Infratech Ltd., Ahmedabad
  - M/s Hi-Tech Systems & Services Ltd., Kolkata &
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ERS for 220 kV S/C Tower

ERS for 400 kV D/C Tower

CSIR-SERC

Thank You …

Importance of Earthing and Lightning Protection System in Transmission Line

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Abstract—

The dependability and operational continuity of electrical transmission networks are significantly influenced by the effectiveness of their earthing and lightning protection systems. Transmission lines are frequently exposed to lightning strikes, switching surges, and transient faults, leading to insulation breakdowns, equipment damage, and service interruptions. An efficient earthing and lightning protection system ensures the safe dissipation of fault and lightning currents into the ground, maintains system voltage stability, and safeguards both equipment and personnel. This paper presents the importance, design parameters, and performance requirements of earthing and lightning protection systems in transmission lines. Reference has been made to relevant international standards such as IEEE Std 80-2013, and IEC 62305 series.

Keywords—

Earthing system, lightning protection, tower footing resistance (TFR), transmission line, surge protection, shielding angle, equipotential bonding, grounding electrode.

I. INTRODUCTION

Electric power transmission lines are the backbone of electrical power systems. These lines traverse diverse terrains and are exposed to varying climatic and soil conditions, making them highly vulnerable to lightning strokes and switching surges. Studies show that nearly **70% of line outages** in high-voltage networks are related to lightning activities.

Earthing and lightning protection systems play a critical role in ensuring the stability and reliability of power transmission networks. An earthing system provides a low-resistance path for fault current to flow safely into the earth, while the lightning protection system intercepts, conducts, and dissipates the high-energy lightning current. Together, these systems protect equipment, maintain service continuity, and ensure safety to both operating personnel and the general public.

II. ROLE OF EARTHING SYSTEM IN TRANSMISSION LINE

The **earthing system** (also known as the grounding system) serves multiple essential functions in a transmission network.

A. Safety of Personnel

During fault or lightning events, dangerous potential differences (step and touch voltages) can occur around the tower base. Proper earthing maintains the potential difference within safe limits as per IEEE Std 80.

B. Equipment Protection

Effective earthing prevents excessive voltage stress on insulation, reducing the risk of flashovers and equipment failure.

C. System Stability

It ensures all metallic structures remain at a uniform potential, providing a stable reference for the system neutral and facilitating the correct operation of protection relays.

D. Reduction in Tower Footing Resistance

A lower **Tower Footing Resistance (TFR)** helps in quick dissipation of lightning and fault currents. Ideally, the TFR should be **below 10 ohms** for 132 kV and above transmission lines as per field experience and standard guidelines.

III. LIGHTNING PROTECTION SYSTEM FOR TRANSMISSION LINES

The **lightning protection system (LPS)** minimizes the possibility of direct lightning-induced flashovers by safely intercepting and discharging lightning currents.

A. Shield Wire (Ground Wire)

A shield wire is installed at the top of transmission towers to intercept lightning strokes before they strike phase conductors. The **shielding angle** is a critical design parameter and is typically kept within **20°–30°** for EHV lines.

B. Surge Arresters

Surge arresters are employed at substations and selected tower locations to limit overvoltages caused by direct or induced lightning strokes. They provide an alternate discharge path and protect line insulation.

C. Equipotential Bonding

Bonding ensures that all metallic parts, including tower steel, earth wires, and electrodes, remain at the same potential. This reduces step and touch voltages and improves lightning current dissipation.

D. Down Conductors and Ground Electrodes

Lightning current flows from the air termination system to ground through down conductors and grounding electrodes. Proper sizing, material selection (Cu or Cu-bonded steel), and corrosion resistance are essential for reliability.

IV. TOWER FOOTING RESISTANCE (TFR) AND ITS SIGNIFICANCE

The **Tower Footing Resistance (TFR)** is the resistance offered by the earth connection of the transmission tower.

- **High TFR** results in increased potential rise during lightning discharge, causing flashovers between tower and phase conductors.
- **Low TFR (<10 Ω)** improves lightning performance by reducing the tower potential rise and back-flashover probability.
- **Factors affecting TFR:**
    1. Soil resistivity (ρ)
    2. Electrode type and depth
    3. Soil moisture content
    4. Number of parallel electrodes
    5. Ground enhancement materials (e.g., bentonite, carbon-based compounds)

V. DESIGN CONSIDERATIONS

The design of earthing and lightning protection systems is governed by several international standards.

A. Soil Resistivity Measurement

Performed using the **Wenner four-pin method** (as per IEEE Std 81) to determine the resistivity profile and select the appropriate earthing electrode system.

B. Electrode Configuration

- **Rod Electrode:** Suitable for loamy or clay soil.
- **Pipe Electrode:** Used in moist or semi-rocky areas.
- **Plate Electrode:** For limited space conditions.

- **Mesh/Multi-Rod System:** Used in rocky or high-resistivity soil.

C. Step and Touch Voltage Analysis

As per IEEE Std 80-2013, the design must ensure the following safety criteria:

D. Lightning Shielding Design

The shielding angle or **rolling sphere method** (as per IEC 62305-3) is used to ensure proper protection of conductors.

E. Ground Enhancement Materials

Grounding compounds such as bentonite, graphite, or carbon-based ETPGEL can be used to lower soil resistivity and improve electrode performance.

VI. PERFORMANCE EVALUATION

To verify the system's effectiveness, **Earth Resistance Measurement (ERM)** and **Tower Footing Resistance Testing** are performed periodically.

- With-grid measurements typically show values below **1 ohm**, while isolated tower earthing should achieve **below 10 ohms**.
- Regular inspection ensures no corrosion, joint looseness, or electrode degradation.

VII. STANDARDS AND CODES OF PRACTICE

Major references for design and implementation include:

Standard	Title / Description
IEEE Std 80-2013	Guide for Safety in AC Substation Grounding
IEEE Std 81-2012	Guide for Measuring Earth Resistivity and Ground Impedance
IEC 62305 (Part 1–4)	Protection Against Lightning
IS 3043:2018	Indian Code of Practice for Earthing
IEEE Std 1243-1997	Guide for Improving Lightning Performance of Transmission Lines

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VIII. DISCUSSION

Integration of advanced earthing techniques such as **ETP Make Earthing Mesh Electrodes** and **maintenance-free grounding systems** significantly improve the overall performance of transmission lines in high-resistivity areas.
Simulation tools such as **CDEGS** or **ETAP** can be used for accurate soil modeling and to evaluate lightning surge behavior. Field results have shown up to **40–60% reduction in lightning outages** with properly optimized TFR and shield wire design.

IX. CONCLUSION

Earthing and lightning protection systems are essential for reliable and safe operation of high-voltage transmission lines. Proper design, based on soil conditions, tower geometry, and lightning risk assessment, ensures effective current dissipation and prevents damage. By maintaining tower footing resistance below standard limits and following IEC/IEEE guidelines, the risk of flashovers, outages, and equipment failure can be minimized. Periodic testing, maintenance, and the adoption of advanced grounding technologies are key to ensuring long-term system reliability.

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SEISMIC-RESILIENT FOUNDATION SYSTEMS FOR TRANSMISSION LINE TOWERS IN LIQUEFIABLE SOILS

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Abstract

Transmission line towers form the backbone of a reliable power transmission network. In seismic Zone V and liquefaction-prone areas, foundation design is the most critical factor influencing their safety and service life. This paper presents a detailed framework for designing seismic-resilient foundations by integrating geotechnical characterization, dynamic soil–structure interaction, and ground improvement technologies. Special attention is given to the behavior of saturated sandy soils under cyclic loading, design philosophies for raft–pile hybrid systems, and the application of modern ground improvement and monitoring methods. Field experiences and code-based guidelines are synthesized to present practical recommendations for resilient transmission infrastructure.

1. Introduction

India's ambitious renewable-energy evacuation plan of 500 GW by 2030 demands thousands of kilometers of new transmission corridors. Many of these traverse geotechnically complex areas such as river valleys, coastal belts, and seismic belts of the Himalayas and northeast. Tower collapse incidents in past earthquakes—Bhuj 2001, Nepal 2015, and Sikkim 2011—have emphasized that failures often originate from foundation distress rather than structural or electrical faults. Traditional pad or chimney foundations perform well in firm soils, but in saturated sandy or alluvial deposits they lose bearing strength during shaking due to pore-pressure buildup. A holistic design approach is therefore essential—one that unites soil mechanics, seismic analysis, and construction practice into a single integrated process.

2. Seismic and Geotechnical Challenges

Seismic ground motion generates both inertial forces from the tower mass and kinematic effects from soil deformation. In liquefiable soils, cyclic shear stresses lead to a temporary loss of effective stress, causing rapid settlement, lateral spreading, or uplift. Foundations in such conditions face loss of bearing capacity, tilt, lateral spreading, uplift, and dynamic amplification where flexible soils magnify tower vibration response. The magnitude of these effects depends on PGA, soil density, saturation, and duration of shaking. Hence, seismic-resilient design requires both geotechnical and structural engineers to work in tandem from project inception.

3. Soil Characterization and Liquefaction Analysis

A comprehensive geotechnical investigation program is the first step. Boreholes are drilled up to refusal or 20–30 m depth, and in-situ tests such as SPT, CPT, and MASW are conducted. Laboratory tests determine cohesion, friction angle, and compressibility. Liquefaction assessment is carried out using CSR–CRR method per IS 1893 (Part 1): 2016. Layers with factor of safety against liquefaction less than 1.0 are treated as liquefiable. High groundwater table and saline conditions accelerate corrosion of tower stubs and reinforcement. Design concrete should meet IS 456 severe exposure requirements with low permeability and adequate cover.

4. Dynamic Soil–Structure Interaction

During earthquakes, the tower–foundation–soil system behaves as a coupled dynamic entity. The stiffness of the foundation and the damping capacity of the soil significantly influence the response. p–y curve analysis represents nonlinear soil resistance versus lateral displacement, k–θ model relates rotation to applied moment, and finite-element modeling allows parametric studies of pile groups under cyclic loading. Ensuring compatibility between soil flexibility and tower stiffness helps prevent resonance and reduces base shear.

5. Design Philosophy for Seismic Foundations

A seismic-resilient foundation is one that can sustain earthquake forces without losing strength or stability, while maintaining the overall functionality of the transmission tower. In simple terms, the foundation must support, stabilize, and protect the tower even when the ground beneath it vibrates, shifts, or temporarily loses strength due to liquefaction or cyclic loading.

5.1 Objectives of Seismic Foundation Design

The main goals of designing a foundation for seismic safety are:

1. **Stability:** The tower should not overturn or slide during an earthquake.
2. **Strength:** The foundation and soil should safely resist combined loads (dead + wind + seismic).
3. **Serviceability:** Any settlement, tilt, or deformation must remain within tolerable limits to prevent conductor clearance violations.
4. **Ductility:** The foundation and reinforcement should have sufficient deformation capacity without brittle failure.
5. **Resilience:** After an earthquake, the structure should remain functional or require only minor repairs.

5.2 Load Combinations for Seismic Design

According to **IS 1893 (Part 1): 2016**, seismic loads must be combined with other service loads. Typical combinations for transmission tower foundations are:

- **1.0 (DL + WL + EL)** – for overall stability.
- **1.2 (DL + EL ± WL)** – for strength design.
- **0.9 DL ± 1.5 EL** – for extreme earthquake condition.
  where:
  DL = Dead load (self-weight + tower + equipment),
  WL = Wind load,
  EL = Earthquake load.

These loads act simultaneously in vertical, horizontal, and rotational directions and must be applied at the base of the tower in the structural analysis.

5.3 Types of Foundations for Seismic Regions

(a) Deep Bored Pile Foundation

- Used when competent strata lie below liquefiable or weak layers.
- Piles act as vertical columns transferring loads to deeper, stiffer soil or rock.
- Design considerations:
  - Embed piles beyond liquefiable layer by at least 3 × diameter.
  - Check for combined axial and bending stresses per **IS 2911 (Part 1/2)**.
  - Perform group action analysis using **p–y** and **t–z** curves.

(b) Hybrid Raft–Pile Foundation

- Combines the advantages of both shallow (raft) and deep (pile) systems.
- The raft distributes the load uniformly, while short piles control uplift and tilt.
- Ideal where SBC = 10–20 t/m².
- Cost-effective and preferred in moderate seismic zones.

(c) Monopile or Large-Diameter Pile

- Used for single-mast or pole-type towers and coastal or river-crossing lines.
- High bending stiffness makes them suitable for resisting large lateral loads.
- Require detailed finite-element analysis (e.g., PLAXIS 3D) for lateral soil–structure interaction.

(d) Well Foundation

- Common for river crossings and heavy lattice towers.
- Heavy mass provides seismic stability through inertia and friction.
- Should be designed against overturning and scouring as per IRC 45 and IS 3955.

5.4 Analysis of Soil–Structure Interaction (SSI)

During an earthquake, both **soil** and **foundation** move, and their interaction controls the overall response. This is modeled by:

- **p–y curves:** Represent lateral soil resistance vs. pile deflection.
- **t–z curves:** Represent skin friction vs. pile displacement.
- **k–θ relationship:** Represents rotational stiffness at pile head.

Modern software such as **PLAXIS 2D/3D**, **STAAD Foundation Advanced**, and **OpenSees** simulate nonlinear SSI behavior.
Students should remember:
"The more flexible the soil, the larger the movement; the stiffer the soil, the higher the transmitted force."

5.5 Ductile Detailing and Reinforcement Design

Under seismic loading, plastic hinges may form at pile heads or raft junctions.
To prevent brittle failure:

- Provide **extra stirrups** and **anchorage length** near pile caps and raft joints.
- Maintain minimum **reinforcement ratio (ρ)** as per **IS 456 and IS 13920**.
- Use **Fe 500D** or **Fe 550D** ductile steel for reinforcement.
- Provide **shear keys or dowels** at raft–pile interface for load transfer.

5.6 Liquefaction and Uplift Mitigation

Liquefaction leads to temporary loss of soil strength, reducing pile friction and bearing capacity. Countermeasures include:

- **Stone columns or gravel drains** to dissipate pore water pressure.
- **Encasing pile heads with concrete collars** to resist uplift.
- **Providing tie beams** between tower legs to redistribute forces.
- **Hybrid raft–pile systems** that can maintain partial bearing even if the upper layer liquefies.

6. Ground Improvement and Hybrid Systems

The primary objective of ground improvement for transmission-tower foundations is to enhance bearing capacity, reduce settlement, mitigate liquefaction, and ensure uniform support under cyclic and seismic loading. Selection of the improvement method depends on soil type, depth of weak strata, groundwater level, and project accessibility.

6.1 Stone Columns / Vibro-Replacement

Stone columns are formed by replacing weak soil with compacted granular material, creating vertical inclusions that act as drains and reinforcement.
Mechanism:

- Increase composite shear strength and stiffness of soil mass.
- Accelerate pore-pressure dissipation during cyclic shaking, reducing liquefaction risk.
- Function as vertical drains, lowering long-term settlements.

Applications: Loose sandy soils, soft to medium clayey deposits (up to 10–15 m). Design Considerations: Spacing typically 2.0–2.5 × diameter (D); area replacement ratio 10–25 % Codes: IS 15284 (Part 1): 2003 and PGCIL guidelines.

6.2 Vibro-Compaction

This method densifies granular soils by inserting a vibro-flot probe that rearranges soil particles into a denser configuration.
Mechanism: Reduction of void ratio → increase in relative density and shear strength.
Effective Depth: Up to 20 m in clean sand with fines < 10 %.
Advantages: Rapid installation and effective for large tower-base areas.
Limitations: Not suitable for cohesive or silty soils; requires water or air flushing.
6.3 Dynamic Compaction Dynamic compaction involves repeatedly dropping a heavy weight (10–30
tons) from 10–20 m height to densify shallow granular soils.
Benefits: Economical for open terrains like solar-park corridors.
Depth of Improvement: 5–8 m.
Cautions: Causes surface vibration—careful near existing structures.
Typical Energy: 1000–3000 kN·m/m² per pattern.

6.4 Soil Mixing and Grouting For fine-grained soils or very high groundwater, in-situ soil mixing or cement grouting is adopted.

Jet grouting uses high-pressure jets (300 bar) to mix cement slurry and soil, creating soil-cement columns (0.8–1.2 m diameter).

Permeation grouting injects low-viscosity grout into voids.

Deep Soil Mixing (DSM) mechanically blends cement binder using augers.

Advantages: Strength gain up to 1500 kPa, ideal for uplift resistance.

Codes: IS 15284 (Part 4), ASTM D8065.

6.5 Preloading and Vertical DrainsIn cohesive soils, preloading with prefabricated vertical drains (PVDs) expedites consolidation. A temporary surcharge equal to 1.2–1.5 × design load is applied until 90 % settlement occurs. This reduces post-construction settlement by > 80 %.

6.6 Hybrid Raft–Pile Foundations Hybrid systems combine shallow and deep load transfer mechanisms.

Concept: The raft distributes vertical loads and provides confinement, while short piles resist uplift and differential settlement.

Advantages:

- Reduces pile length by 30–50 %.
- Enhances redundancy—load redistributes if one pile weakens.
- Minimizes differential settlement under multi-leg lattice towers.

Design Notes: Typical pile spacing 3 × diameter; raft thickness 1.0–1.5 m; reinforcement as per IS 456 & IS 2911.

6.7 Ground Improvement with Reinforcement Mats

In seismic or soft clay regions, geosynthetic reinforcement mats placed below the foundation reduce settlement and distribute loads.

- Acts as tensioned membrane supporting uniform load transfer.
- Reduces foundation thickness by 10–20 %.
- Compatible with shallow and hybrid systems.

6.8 Quality Assurance and Monitoring

- Conduct post-treatment CPT and SPT to verify density (N > 25).
- Install piezometers for pore-pressure monitoring.
- Check compaction using sand-cone or nuclear tests.
- Maintain QA/QC documentation as per IS 1892 and PGCIL.

6.9 Comparative Summary

Method	Effective Soil	Depth (m)	Liquefaction Control	Cost	Remarks
Stone Columns	Soft clay / sand	5–15	Excellent	Moderate	Proven, economical
Vibro-Compaction	Clean sand	5–20	Excellent	Moderate-High	Fast, open sites
Dynamic Compaction	Sand / gravel	3–8	Good	Low	Avoid near structures
Jet Grouting	Silt / clay	5–20	Very good	High	For small zones
Hybrid Raft–Pile	Mixed	5–12	Excellent	Moderate	Ideal for Zone V
Geogrid Reinforcement	Clay / mixed	2–4	Moderate	Low	Reduces raft thickness

6.10 Design Integration and Sustainability

Combining hybrid foundations with improved soil ensures both safety and cost efficiency. Using low-carbon binders (slag/fly ash) aligns with sustainability. Reuse of excavated soil and solar-powered dewatering pumps enhance environmental performance.

7. Case Study: Coastal Tower Failure and Remedial Measures

A 220 kV double-circuit lattice tower in coastal Andhra Pradesh experienced progressive tilting after Cyclone Phailin (2013). Investigations revealed scour and liquefied silty sand beneath shallow pad footings. Remedial actions included micro-piles, riprap apron, geotextile, and epoxy-coated reinforcement. Post-retrofit monitoring showed negligible tilt, highlighting the need for integrated seismic and hydraulic design.

7. Recommended Design Workflow for Zone V Sites

1. Pre-Design Phase: Collect seismic zoning, PGA, and historical liquefaction data.
2. Geotechnical Investigation: Conduct SPT/CPT to non-liquefiable strata.
3. Liquefaction Analysis: Calculate CSR–CRR and map liquefiable layers.
4. Preliminary Design: Select foundation concept.
5. Structural Modeling: Evaluate tower–foundation interaction.
6. Seismic Verification: Apply IS 1893 load combinations.
7. Durability Design: Include corrosion protection.
8. Construction QA/QC: Perform integrity and cube tests.
9. Operation & Maintenance: Routine survey of tilt/settlement.

8. Emerging Technologies for Resilient Foundations

FRP wrapping of tower stubs and pile heads offers corrosion-resistant confinement. MEMS-based sensors enable real-time health monitoring. AI-based models predict distress and optimize foundation design. Digital twin simulations integrate geotechnical and structural data for virtual testing before construction.

9. Conclusions and Future Scope

Transmission line tower foundations in seismic and liquefiable environments require an integrated approach. A seismic foundation design should not rely solely on strength but also on **ductility, redundancy, and soil behavior awareness**. Students must appreciate that earthquake resistance is achieved not by making the structure unyielding, but by **allowing controlled movement** without collapse. Integration of geotechnical investigation, soil–structure interaction modeling, ductile detailing, and field testing ensures that tower foundations remain **safe, serviceable, and durable** even in the most adverse seismic events.

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#######

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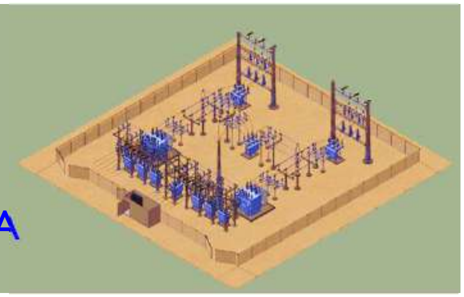
1

DISASTER MITIGATION EXPERIENCE ON TRANSMISSION SYSTEM

PRESENTATION

TAKALKAR POWER ENGINEERS & CONSULTANTS PVT. LTD., VADODARA



1-Nov-25

2

INTRODUCTION

- **Like all the establishments and structures, the transmission lines and the sub-stations also suffer Disaster. Some time they are catastrophic.**
- **Disaster can be man-made, accidental or natural. The mitigation will depend upon the gravity of the disaster and consequent damage to power system.**
- **Some case studies related to experience of Disaster mitigation are given here under**

3

CASE STUDIES AND DESCRIPTION

- **CONTAINING DIFFERENT**
- **CASE-STUDIES WITH**
- **DESCRIPTION & FIGURES**

1-Nov-25

4

CASE 1:

DAMAGE TO VAITARNA RIVER CROSSING TOWER

July 2014 Maharashtra (boiser-borivali line)

1-Nov-25

5

DESCRIPTION: DAMAGE TO VAITARNA RIVER CROSSING TOWER

- During a heavy down pour in Maharashtra, in July 2014 a contributory to river Vaitarna caused heavy scouring to one of the legs of the 220kV D/C special river crossing tower location number 147 of Boiser–Borivali line.
- The special tower was crippled, due to long river crossing span followed by full anchor spans on either side.
- The line was carrying around 200MW from Dahanu/Boiser Power Stations and had to be shutdown.
- The special tower on the other side of the river as well as the anchor towers on either sides were not affected.
- The proper temporary rigging of the damaged special tower and additional Anchoring provided.

1-Nov-25

6

DESCRIPTION: DAMAGE TO VAITARNA RIVER CROSSING TOWER

- The sand bags were provided to cover the damaged foundation of one leg and also provide a temporary coffer to divert the contributory away from the tower.
- The line was charged within 24 hours of mishap.
- Erection of new special tower 30 nit away from the damaged tower was done after monsoon and the line was slightly diverted.
- Thus, the mitigation saved the utility from the great revenue loss.

1-Nov-25

7

DESCRIPTION: DAMAGE TO VAITARNA RIVER CROSSING TOWER

Figure 1

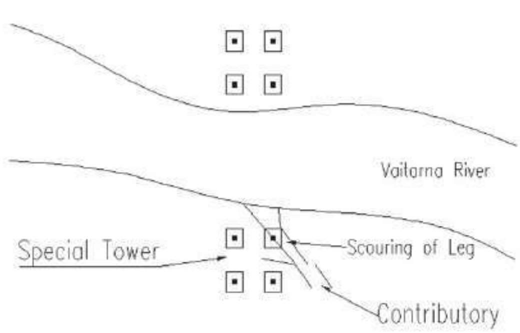
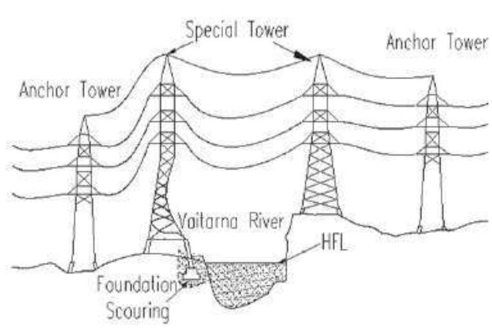


Figure 2



1-Nov-25

8

DESCRIPTION:
DAMAGE TO VAITARNA RIVER CROSSING TOWER



1-Nov-25

9

DAMAGE TO VAITARNA RIVER CROSSING TOWER (ON-SITE PHOTOS)



1-Nov-25

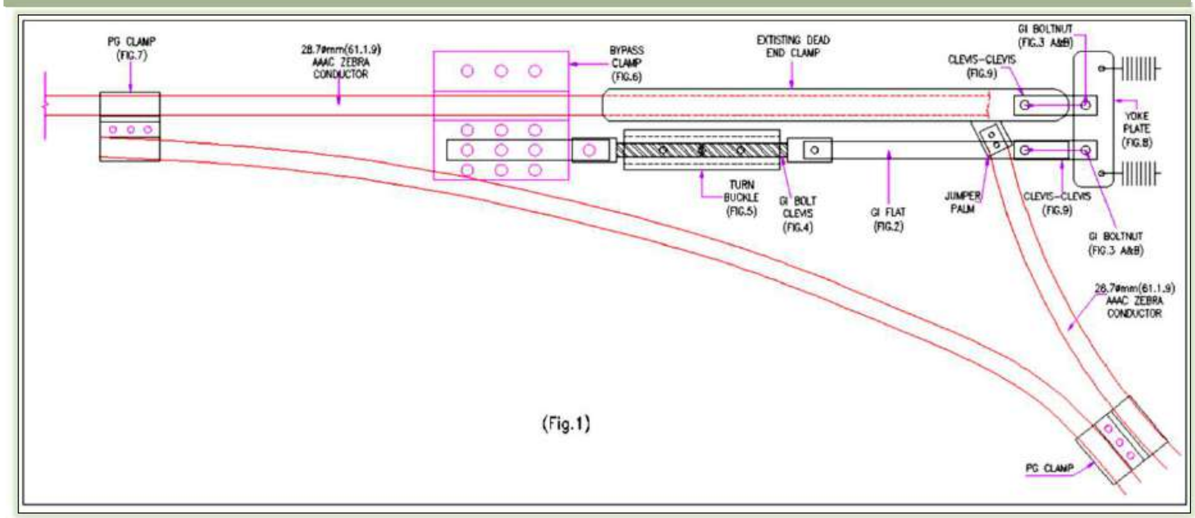
10

CONDUCTOR FALLING ON ELECTRIFIED RAILWAY TRACK

11th November, 2017

11

SNAPPING OF 220KV CONDUCTOR & FALLING ON ELECTRIFIED RAILWAY TRACK



(Fig.1)

12

CASE 2 : SNAPPING OF 220KV CONDUCTOR & FALLING ON ELECTRIFIED RAILWAY TRACK

- A 220kV line conductor snapped from the dead end clamp and fell on the railway track near Mumbai and railway track between Dahanu & Mumbai Central remained closed for couple of hours.
- the AAAC Zebra conductor was strung some 25 years before and improper crimping of AAAC conductor in the dead end clamp coupled with oxidation due to the vicinity of the sea, had developed hot spot within the clamp.
- On the day of occurrence, the temperature and load flow were also high. This caused local heating and shearing of the Aluminum dead end clamp (tube).
- It was gathered that the line had suffered from similar issues in past.so, a permanent solution to avoid the catastrophe, was needed.

1-Nov-25

13

CASE 2 : SNAPPING OF 220KV CONDUCTOR & FALLING ON ELECTRIFIED RAILWAY TRACK

- Author decided to design a by-pass assembly clamp for each dead end tower for each circuit and each phase. In case of snapping of AAAC conductor from the Aluminum dead end clamp (pipe),
- the by-pass assembly will retain the conductor and the power flow may not be affected. The fixing of by-pass assembly was required to be done in HOTLINE condition and therefore the design of the clamp needed precision.
- There has been no incidence of snapping of conductor thereafter. As a matter of fact, the utility has made a policy to provide such by-pass assemblies on all the vulnerable sections of network.

1-Nov-25

14

CASE 3: FAILURE OF VERY TALL NARMADA RIVER CROSSING TOWER

- Many years back, a special tower with the height of 100 metres, collapsed on the south side of Narmada River in Vadodara district of Gujarat.
- The failure occurred due to whirl wind (tornedo) engulfing the tall tower.
- The 220kV D/C line was catering 350MW from south Gujarat to the central Gujarat.
- It took almost one year to restore the line, as in those days sophisticated equipment and machineries were not available.
- The existing towers had Eiffel type construction and the investigation lead to the conclusion that it was not suitable for whirl wind action.so, the simple barrel type tower used as new tower.

15

CASE 3: FAILURE OF VERY TALL NARMADA RIVER CROSSING TOWER

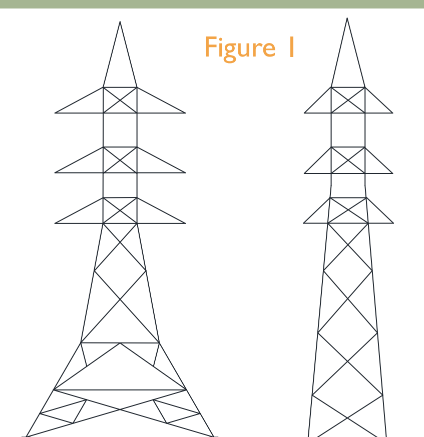


Figure 1

EIFFEL TYPE BARREL TYPE

- After a passage of six years, the north side tower collapsed under similar type of whirl wind. It took no time to investigate and conclude that Eiffel type construction of tower is not suitable for the location.
- Again, this tower was also replaced by simple barrel type tower. This time the line remained out for 6 months.
- After replacement of both the towers (South & North) on the Narmada Riverbank with conventional design, there has been no failure for more than 3 decades.

16

1982 Saurashtra Region

1-Nov-25

17

DESCRIPTION: CYCLONE DISASTER

State of Gujarat is always under the threat of cyclonic storms.

During 1982, In Saurashtra region one of such storms thrashed, while the 220kV network was recently established in the region.

Which of Six 220kV transmission lines faced the fury of the cyclone and towers crippled badly on different sections through which a 180 kms/hr cyclone had hit the area. Luckily, the foundations were intact.

In those days EPC contracting system and Emergency Restoration System (ERS) were not in vogue.

Therefore, the utility had to co-ordinate with various suppliers of line material and the erection agencies and The reputed contractors of transmission line construction were required to mobilize their work force and to restore the lines on war footing.

There was heavy loss of human lives and livestock and the restoration team had to face a threat of epidemic, due to cyclone and heavy rain.

The PLCC was not working as major 220 kV system was affected. This caused retardation but still the team worked day and night and restored the system within 8 days partially. Entire system was through within 30 days.

1-Nov-25

18

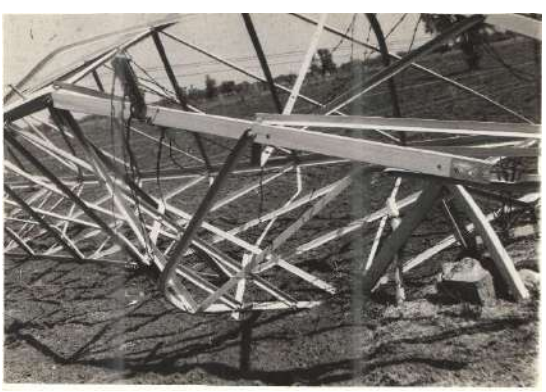
DESCRIPTION: CYCLONE DISASTER

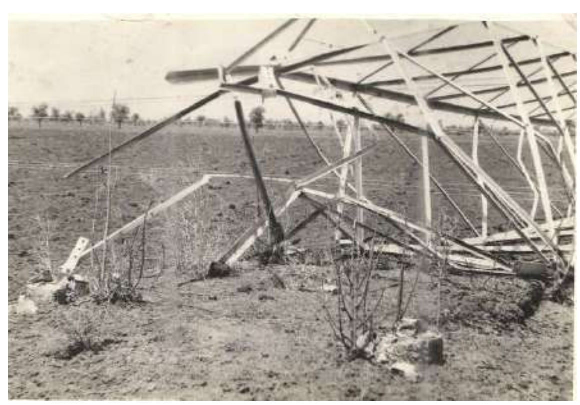
- In 1976 a cyclonic storm hit the north Saurashtra and Kutchh region having the wind velocity was more than 150 km/hr.
- The only 132kV line connecting the region of Kutchh to the main parts of Gujarat, collapsed bringing darkness to the region.
- The bottle neck was the Surjbari creek crossing and all the towers in this section of the line collapsed.
- A temporary line on the bridge piers was erected with brackets and power was made available in a record time of 100 hours.
- As a long term measure, it was decided to strengthen the power network in Kutchh region by establishing 220 kV line from North Gujarat directly to Kutchh, bypassing the creek portion.

1-Nov-25

19

TOWERS AFFECTED DUE TO CYCLONE DISASTER





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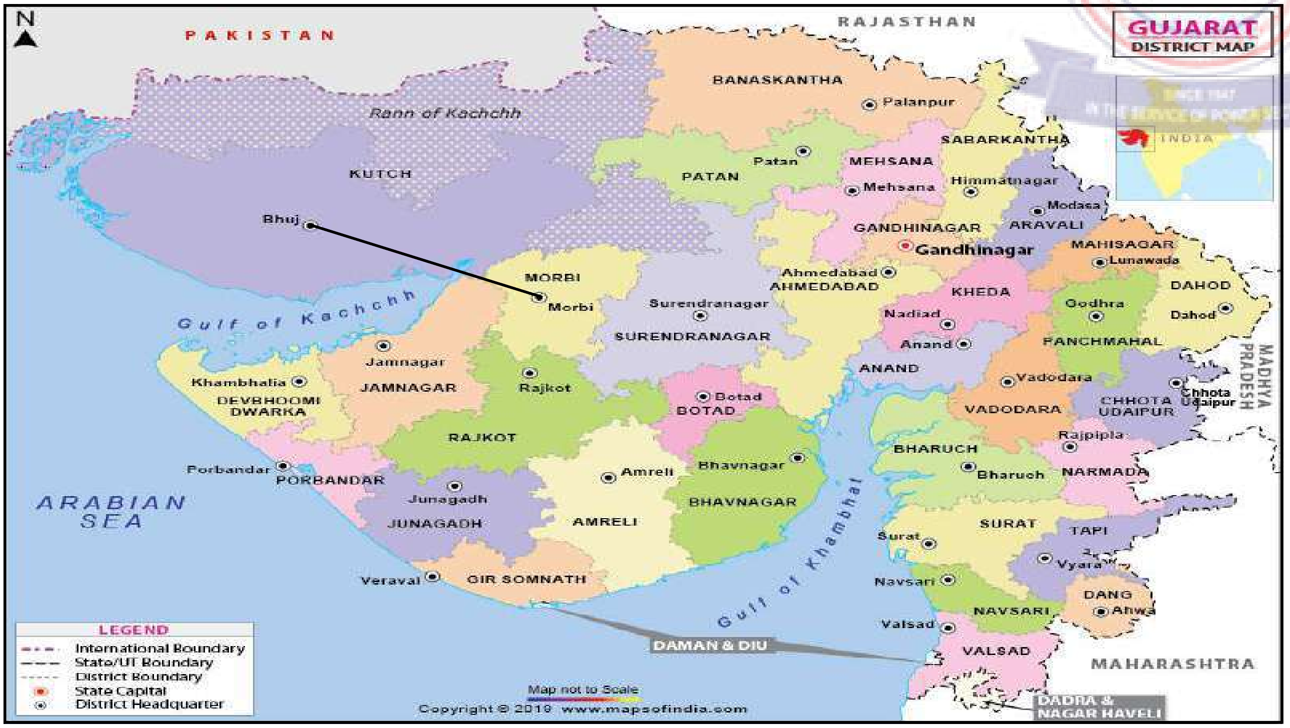
20



21

- **26th January, 2001**
- **Kutchh ,Gujarat**

1-Nov-25

22

DESCRIPTION: EARTHQUAKE IN KUTCHH

- On 26th January 2001 a devastating Earthquake of 7.7 moment magnitude ravaged the Kutch and part of Saurashtra Region of Gujarat state.
- Around 20,000 human lives were lost due to the collapse of buildings and dwellings and the entire town of Bhachau in Kutch was reduced to rubbles.
- The state power utility also lost 100 employees in the disaster.
- The transformers jumped the support rail and the control rooms were shattered, even the public communication system was also rendered useless due to extensive damage to the establishments & non availability of power.

DESCRIPTION: EARTHQUAKE IN KUTCHH

- Immediately a team of engineers was rushed to Kutch region for taking the stock of what had happened but due to extensive damage to the roads & bridges, the team could reach only next day early morning.
- The team of engineers from H.Q. which reached next morning, connected two 24 volt vehicle batteries in series and put the PLCC in operation in Anjar.

DESCRIPTION: EARTHQUAKE IN KUTCHH

1-Nov-25

25

DESCRIPTION: EARTHQUAKE IN KUTCHH

- Clear picture of the devastating earthquake emerged only after the official reached to Anjar and observed damage along the route.
- About 70 sub–stations in the region were rendered infunct due to toppling of transformers and the region of Kutchh has good agriculture potential in patches.
- Due to failure of power, Rabi crop started suffering.

1-Nov-25

26

DESCRIPTION: EARTHQUAKE IN KUTCHH

- The entire region of Kutchh and part of Saurashtra was divided into various groups headed by very senior engineers.
- The toppled transformers were placed again on the rail. The damaged bushings were replaced, oil was filtered, and they were put into service.
- Due to damage to control room and aftershocks, it was decided to construct temporary control rooms under tin sheds and plinths and all power cables and control cables were routed through new control panels and supply was made through.

1-Nov-25

27

EARTHQUAKE IN KUTCHH (RE-INSTALLATION OF TRANSFORMER AND TEMPORARY SHED)

1-Nov-25

28

EARTHQUAKE IN KUTCHH DAMAGED CONTROL ROOM

1-Nov-25

29

DESCRIPTION: EARTHQUAKE IN KUTCHH

- Fortunately, there was no damage to switchyard structures and other equipment including switchgears.
- Fortunately, all the transmission lines were unaffected, even the 220kV towers near the epicenter were also not affected.
- This helped in quick restoration after transformer refurbishment.
- **The power was restored in 56 hours**.
- All the important towns and hospitals were given priority. The complete power system of the Kutchh region was restored **in 30 days** with temporary control rooms.

1-Nov-25

30

DESCRIPTION: EARTHQUAKE IN KUTCHH

Engineers of Vadodara for Relief Work

- The engineers and work force from PGCIL, MSEB etc. were also requested to join the rescue operations. This helped in quicker restoration.
- Even the team of the Society of Power Engineers (I), Vadodara headed by the author also adopted two 66kV S/S for restoration and completed the work within one week.

1-Nov-25

31

- **1979**
- **Morbi, Gujarat**

1-Nov-25

32

PHOTOS OF DISASTER CAUSED BY BREACH OF MACHHU DAM

1-Nov-25

33

DESCRIPTION: BREACH OF MACHHU DAM

In 1979 monsoon there was heavy flood in River Machhu and there was a heavy breach in the earthen dam.

The entire town of Morbi in north Saurashtra was ravaged.

The sub–stations in and around Morbi were also flooded.

1-Nov-25

34

DESCRIPTION: BREACH OF MACHHU DAM

The power system in Morbi town and surrounding areas was completely disrupted, due to large scale carcasses on the roads and streets and heavy layers of mud, it became difficult for the rescue teams to take up restoration work.

Team of personnel comprising senior engineers, technicians, workers were rushed to the spot by the state's power utility.

Teams were formed to speed up the work. The contractors also responded to the call of the power utility and mobilized their work force.

In addition to the sub-stations, the 66kV, 11kV and 415 volt distribution network also suffered a lot. The restoration of power took 6 days. The entire power system took more than a month to come to normalcy.

1-Nov-25

35

BREACH OF MACHHU DAM

1-Nov-25

36

PHOTOS OF DISASTER CAUSED BY BREACH OF MACHHU DAM

1-Nov-25

37

BREACH OF MACHHU DAM: (FLOODING IN THE SUBSTATION PHOTOS)

1-Nov-25

38

DISASTER MANAGEMENT PLANS AND OTHER CALAMITIES

1-Nov-25

39

DISASTER MANAGEMENT PLANS :

- The state has a full-fledged disaster management department which is equipped with all necessary infrastructure to deal with the calamities.
- The advance information and warning system along with good communication network, has resulted into better mitigation of the disaster.
- In recent past due to readiness., many disasters were handled by the utility in much better way.
- This has resulted into reduction in loss of lines and properties.
- The state of Gujarat has suffered from devastating floods and cyclones many times and there is lot to present but for the constraint of space & time those case studies are not included here.

1-Nov-25

40

CONCLUSION

- Natural and man-made disasters can have a distressing impact on small businesses as well as Power grid and its equipments, which is why it's critical to have a disaster management strategy in place.
- The natural calamities inflict lot of disruption of power and causes huge loss of revenue and suffering to population.
- The co–ordinated efforts bring quicker relief to the devastated region.

1-Nov-25

41

Thank you

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1-Nov-25

42

Construction Monitoring and Inspection of Transmission Line using Drones

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Abstract

Transmission line (TL) infrastructure demands continuous monitoring to ensure operational integrity, safety, and timely project execution. Traditional inspection methods—manual walkdowns, tower climbing, and helicopter surveys—are labor—intensive, hazardous, and often yield incomplete data. A convolutional neural network (CNN) deployed on an embedded Jetson TX2 platform detects and localizes TL components from drone video, while server-side algorithms identify defects such as arc traces, corrosion, and broken insulators. The system's bar-line GIS interface enables intuitive progress tracking, spatial linkage, and critical path visualization. Results demonstrate improved inspection accuracy, reduced manual effort, and enhanced safety. The proposed framework offers a scalable, intelligent solution for modernizing TL construction and maintenance workflows.

This paper intends to present an integrated drone-based framework for construction monitoring and defect detection framework that leverages GIS dashboards, thermal and ultraviolet imaging, and deep learning techniques for real-time analysis, etc.

Key Words: Traditional inspection, manual walkdowns, drone-based monitoring, defect detection, GIS dashboards, CNN

1. Introduction

1.1 Legacy Challenges and Market Drivers and present market Motivation Transmission line (TL) projects require continuous monitoring to ensure safety, schedule adherence, and structural integrity. Traditional inspection methods are slow, risky, and often incomplete.

1.2 Technological Shift Toward Drones & Automation Drones (UAVs), GIS dashboards, and AI-based analytics offer safer, faster, and more precise alternatives for TL monitoring and fault detection.

Fig. Drone Thermal Images

1.3 Drone deployment improves inspection accuracy, reduces manual effort, and enhances safety across all phases of TL construction and maintenance.

1.4 In the dynamic landscape of UAVs, or drones, extending their operational range and flight time is evolutionary. The types of drone charging stations are ***Fixed Ground Stations,*** **Mobile Charging Units,** ***Wireless Charging Pads****, etc.* The Paper does not cover UAV charging stations. [1] refer.

2. Drone-Enabled Monitoring Framework

2.1 Progress Tracking via Drone Flyovers

Drones capture high-resolution imagery of tower foundations, erection stages, and conductor stringing. GIS dashboards visualize planned vs. actual progress.

2.2 GIS Dashboard Integration Bar-line logic links activities to spatial assets.

Color-coded bars indicate status, and critical path visualization supports delay management.

2.3 Pre-Commissioning and Final Checks

Thermal and UV sensors detect hotspots, corona discharges, and vegetation encroachments. Data is archived in the digital twin for compliance and energization readiness.

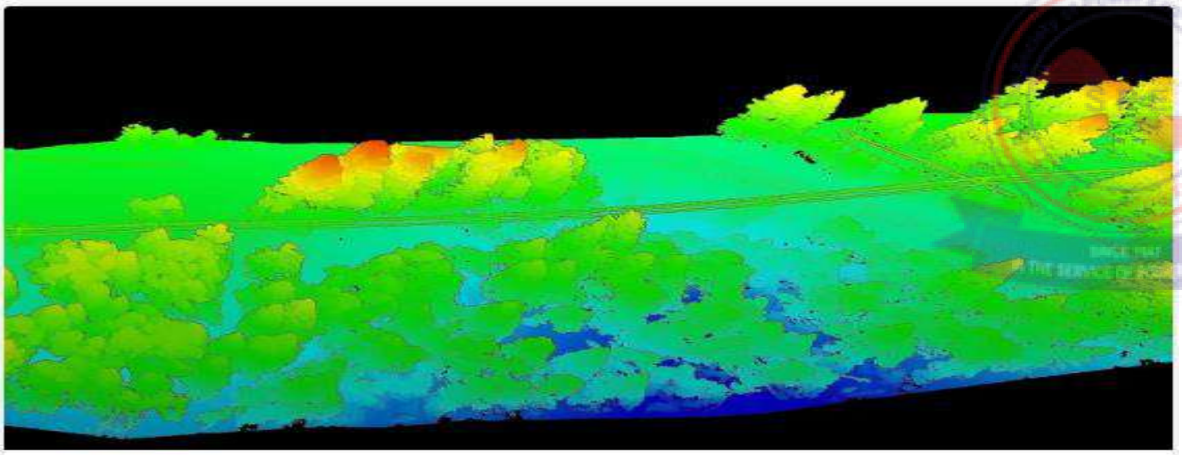

Fig. Drone LiDAR for Vegetation Management

3. Automated Defect Detection deploying Convolutional Neural Network (CNN)

3.1 CNN Architecture and Component Detection

CNNs deployed on Jetson TX2 detect insulators, connectors, and conductors from drone video. The system is robust against clutter, occlusion, and lighting variability.

3.2 Server-Side Analysis and Drone-Centric Strategy Cropped images

Images are analyzed for arc traces, corrosion, broken sheds, and fading color.

Drones serve as mobile platforms for post-storm assessments, thermal/UV imaging, and automated object classification.

3.3 Operational Advantages

Drone-based inspection improves safety, efficiency, and data quality. All imagery is georeferenced and archived for traceability and predictive maintenance.

3.4. Visual Documentation and Results

4. Convolutional Neural Network (CNN)-Based Detection Framework [2]

CNNs are a class of deep, feed-forward artificial neural networks widely used in image processing due to their robustness and adaptability. CNNs employ variant-sized sliding filters that are updated during training, enabling translation and scale invariance—ideal for detecting features across diverse visual contexts. Most CNN architectures conclude with fully connected layers that aggregate convolutional features to generate final classifications.

4.1 System Architecture (Fig. 1) Illustrates acquisition, embedded processing, and server-side defect analysis.

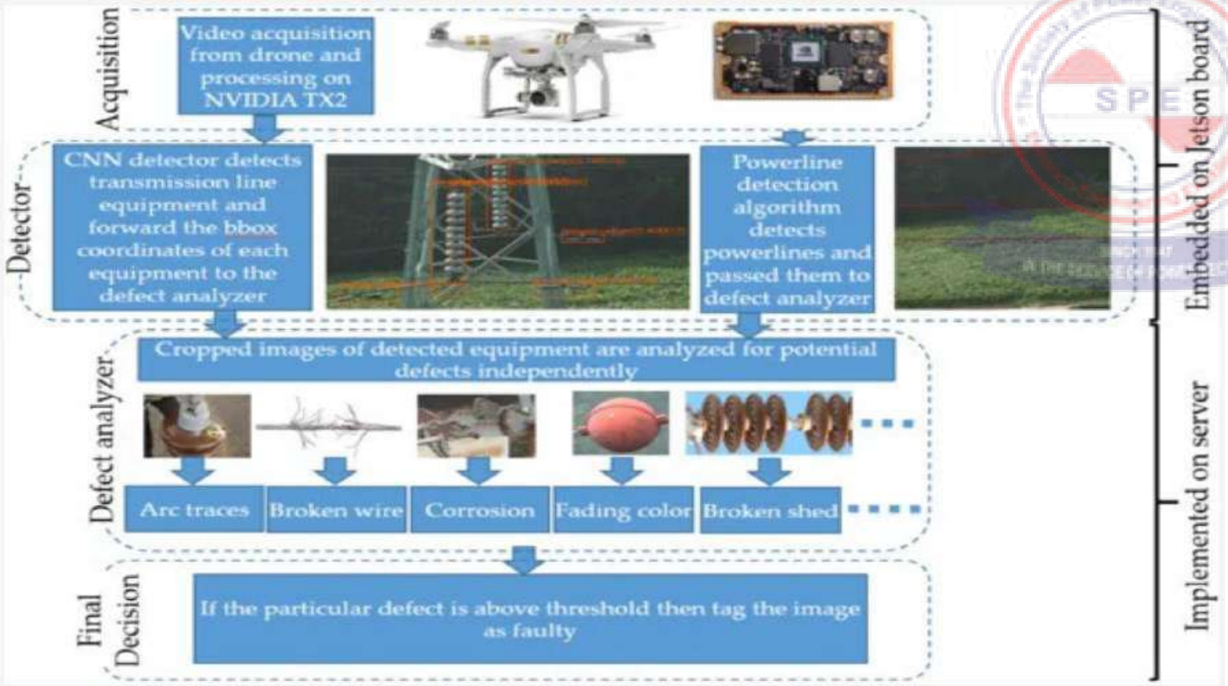

Fig.1: Overall System Diagram

4.2 Component Views (Figs. 2–6) Includes aerial corridor views, close-ups of insulators and connectors, thermal scans, and UV corona detection.

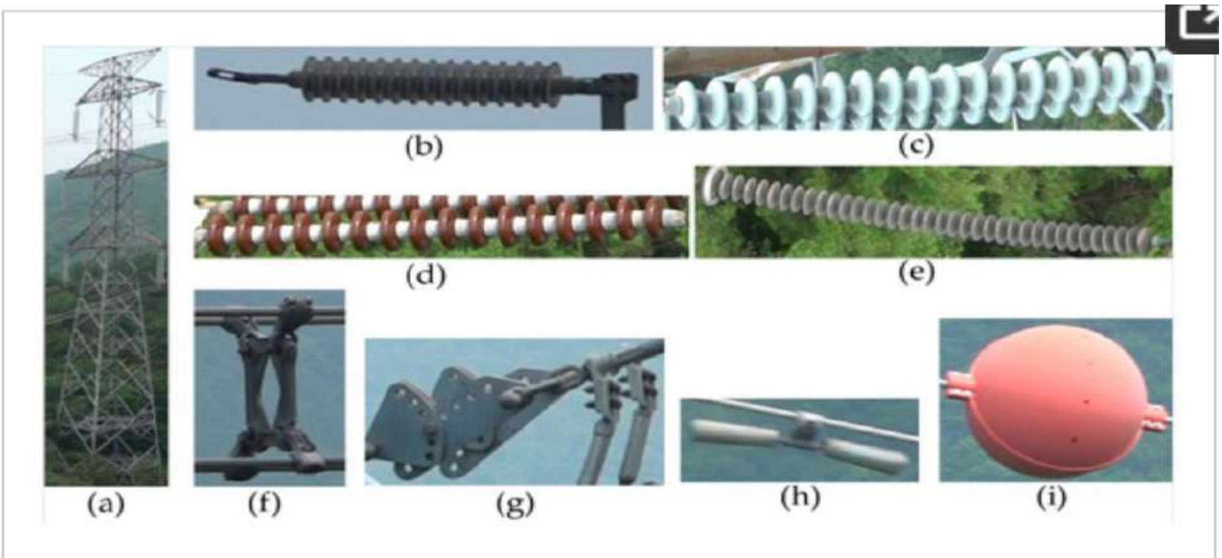

Figure 2. Various types of transmission line components that can be detected by the proposed system. (**a**) Transmission tower; (**b**) lightning arrester (LA); (**c**) suspension-type—white porcelain insulator; (**d**) suspension type red porcelain insulator; (**e**) polymer insulator; (**f**) spacer; (**g**) sag adjuster with bolted tension clamp; (**h**) vibration damper; and (**i**) balisor.

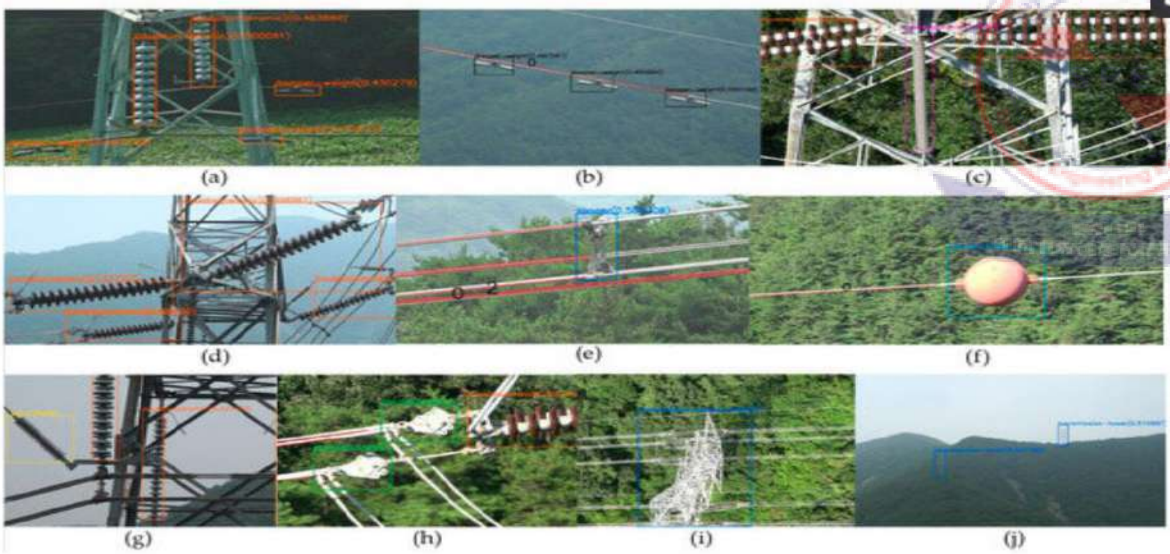

Fig 3 . Detection results of the different types of electrical components, (**a**,**b**) PorSTI-W and damper weights, (**c**,**d**) PorSTI-R and PolSTI, (**e**) spacer, (**f**) balisor, (**g**) LA and PorSTI-W, (**h**) sag adjusters and PorSTI-R, and (**i**,**j**) transmission towers, by the trained transmission line components detector. Each component appears with a random orientation, view point, lighting conditions, shapes, colors, and scales, yet it is detected by the CNN-based detector robustly.

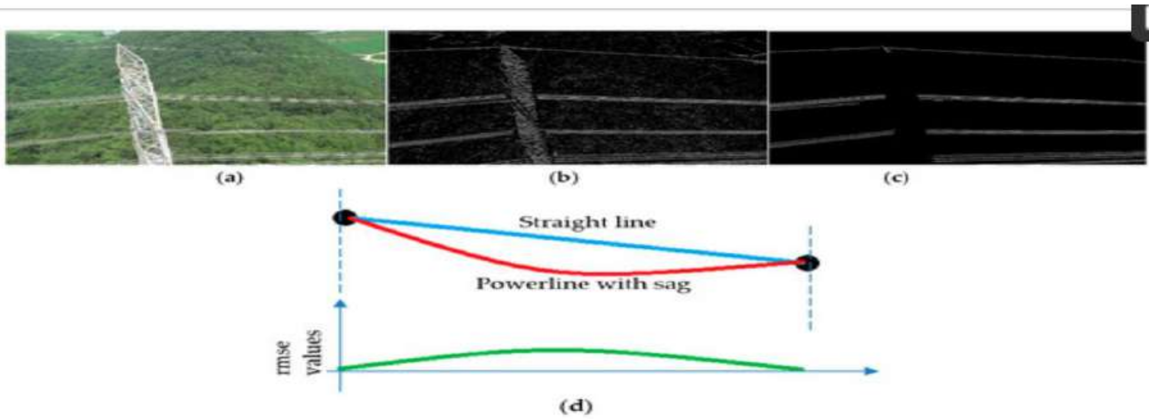

Figure 4. (**a**) Aerial view of the transmission tower with power line. (**b**) The edge equivalent is very noisy due to the presence of trees and cluttered objects in the background. (**c**) The use of custom shaped Sobel kernel helps in removing the noise. (**d**) Imaginary straight blue line connecting the endpoints of the power line (red) having a sag. Green curve

Figure 5. Power line detection results. The proposed power line detection algorithm shows robustness against cluttered background and different lighting conditions Detected power lines are marked in red and labelled with ID numbers.

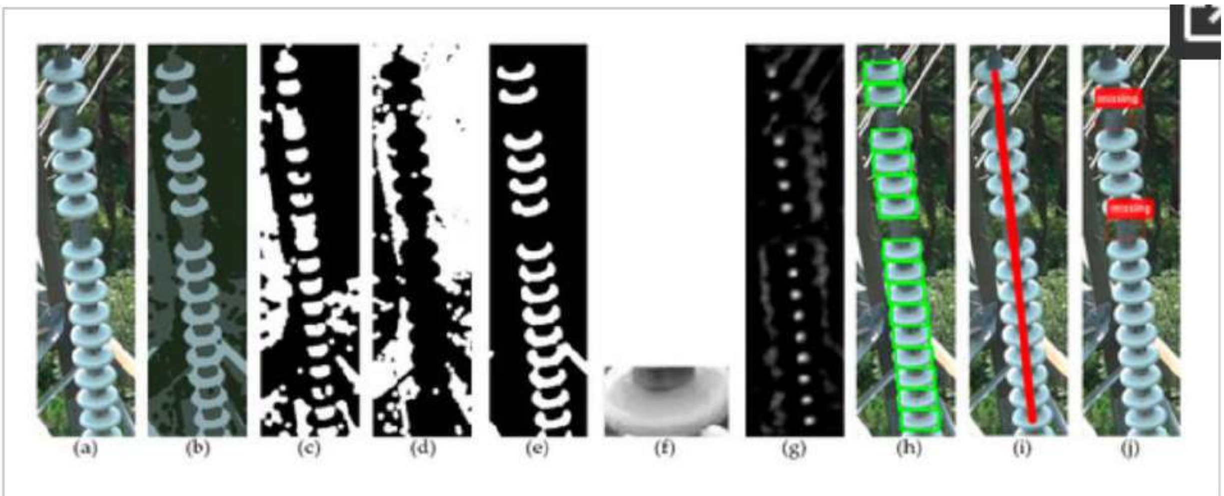

Figure 5. Steps of the broken shed detection. (**a**) Detected insulator image from CNN-based detector, (**b**) output of color clustering based segmentation, (**c**–**e**) segmentation masks of the three clusters, (**f**) candidate template after connected component analysis and max voting for finding most repeating pattern, (**g**) activation map of the template matching, (**h**) results of template matching, (**i**) fitting the centers of the template matching result to a straight line, and (**j**) final detected defect.

[2] for more details

5. Other Uses of Drone

5.1 Drones using LIDAR Sensor are used to measure clearances over roads and ground is a standard and highly accurate method for inspecting and maintaining transmission lines. The technology is faster, safer, and more precise than traditional ground surveys or manned aerial inspections.

5.2 Process of data capturing, data processing and analysis is explained below.

I. **LiDAR data capture:** A LiDAR scanner is attached to an unmanned aerial vehicle (UAV) or drone. As the drone flies along the transmission line corridor, the LiDAR sensor emits millions of laser pulses per second. These pulses strike objects like the power lines, terrain, vegetation, and roads, and then reflect back to the sensor.

II. Point cloud generation: By measuring the time it takes for each laser pulse to return, the system can calculate the precise distance to every object in the flight path. This data is used to generate a highly dense and accurate 3D "point cloud" that digitally maps the entire transmission corridor and surrounding environment.

III. **Data processing:** Specialized software filters the raw point cloud data. It can separate the different elements, identifying and classifying points that belong to:

- The power lines and tower structures.
- Natural ground elevation.
- Obstacles such as trees, buildings, and roads, Railway track etc.

IV. **Clearance measurement and analysis:** Once the data is processed, the software can automatically measure the vertical and horizontal clearance distances between the power lines and all other objects. This allows utility companies to:

- Pinpoint exact locations where ground or road clearances are below regulatory standards.
- Detect dangerously encroaching vegetation, even identifying tree crowns that are too close to the wires.
- Generate reports and visualizations that detail any clearance anomalies.

V. Advantages over traditional methods

- **Enhanced safety:** Drones eliminate the need for human inspectors to physically access dangerous or hard-to-reach areas, such as rugged terrain, tall towers, or locations near high-voltage lines.

- **Increased efficiency:** A LiDAR drone can survey long sections of a transmission line corridor in a fraction of the time it would take a ground crew. This speed allows for more frequent and comprehensive inspections.

- **Superior accuracy:** The precision of LiDAR technology allows for millimeter-level accuracy in distance measurements, which is far more reliable than visual assessments. This prevents measurement errors that can lead to costly and time-consuming rework.

- **Penetration capabilities:** Unlike standard photography, LiDAR can penetrate through gaps in vegetation to map the ground beneath trees and dense foliage, providing a complete and unobstructed view of the entire corridor.

VI. Specific applications for ground and road clearance

- **Right-of-Way (ROW) management:** Utility companies use LiDAR drone data to monitor and manage vegetation growth in the ROW. By identifying specific areas where trees are approaching the minimum safe distance, they can perform targeted trimming instead of broad, untargeted clearing.

- **Regulatory compliance:** For power lines crossing roads, railways, and other infrastructure, LiDAR provides verifiable proof that minimum clearance standards are being met. This is critical for regulatory approvals and for mitigating legal risks.
- **Sag analysis:** The data can be used to precisely measure the sag, or downward curve, of the power lines. By monitoring changes in sag over time, utilities can determine the effects of temperature, wind, and load on the lines and ensure they never drop below the minimum clearance to the ground or a road.

5.3 **3D modeling for asset management:** The 3D point cloud data can be used to build a complete digital model of the transmission line network. This model becomes a powerful asset management tool, allowing engineers to simulate conditions, analyze terrain, and plan maintenance and upgrades with greater accuracy.

5.4 Drone can also be used for hastening the construction process.

I. In hilly terrain, railway crossing etc. the drone can pick up a rope from 1 side and carry to other side (of valley river, etc.) and after rope riches to other end sling wires can be pulled through the rope and thereafter construction activity like transferring the material, tools / tackles etc. can be done by the use of sling wires. Sometimes temporary ropeway can also be made after the initial use of drone.

II. For crossing railway, road, bridges and existing power lines if outage or a traffic block is not available or is available for a very shot duration, drone can facilitate carrying of rope, sling wires and other material. Thus, providing scaffolding and other stay arrangements can be eliminated.

5.5 Drone can also be used for maintenance of transmission lines

I. Drones can be used for close observation of insulators, hotspot, missing tower members, missing nut bolts, damaged conductor, insulators / GSS Earthwire / OPEGW / Deflection of tower, Sag & Ground clearance measurement etc.

 

II. Drone can be very useful when there is damage to the transmission line or part thereof. During the calamities also drone can hasten the restoration work.

6. Operational Impact and Future Scope

6.1 Efficiency and Safety Gains Automated workflows reduce inspection time and eliminate hazardous manual tasks.

6.2 Scalability and Integration Potential Supports predictive maintenance, compliance tracking, and integration with enterprise platforms.

6.3 Future Enhancements Next steps include AI model refinement, cross-platform data fusion, and expansion to other utility sectors.

Key Takeaways

1. **Drone technology enhances safety and efficiency**
2. **GIS dashboards enable real-time progress tracking**
3. **Deep learning improves fault detection**
4. **Thermal and UV imaging strengthen**
5. **Utilities to develop Automated Defect Detection via CNN**

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Deflection of Transmission Line Poles under Wind Loads Across Indian Wind Zones: A PLS-POLE Based Approach

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Abstract

This paper presents a study on the deflection of 12-sided tapered steel transmission line poles under varying wind loads across Indian wind zones. A 20-metre, two-section pole with a 0.375 m slip joint (per ASCE 48-11, Clause 6.4.1) is analyzed. Analytical cantilever beam calculations and PLS-POLE finite-element simulations are conducted to assess tip deflection under various wind zones. Results show the influence of slip-joint flexibility on top deflection and validate PLS-POLE as a reliable design tool for serviceability and structural checks.

1. Introduction

Transmission line poles are essential structural elements subjected to environmental and mechanical loads. Wind load often governs the design, especially for tall and slender poles. The performance of poles depends on geometry, material properties, height, and types of connections. IS 875 (Part 3) defines wind loads for India, while ASCE 48-11 and IS 802 provide structural design guidance of the transmission line poles. Finite element tools like PLS-POLE allow detailed analysis of geometric and boundary nonlinearities, including slip joints.

2. Codes, Standards, and Software

Design follows IS 875 (Part 3) for wind loads and IS 802 for steel transmission line structures. PLS-POLE (Bentley Systems) enables finite element modelling of poles with slip joints, foundation flexibility, and nonlinear behavior. Slip joints are represented via overlap length and partial rotational stiffness, not as a detailed mesh, per ASCE 48-11 guidance.

3. Methodology

A 20-metre, 12-sided tapered steel pole consisting of two sections joined through a 0.375 m slip-fit connection (ASCE 48-11 Clause 6.4.1) is analyzed. Bottom section: 10 m high, base diameter 500 mm tapering to 400 mm at the joint. Top section: 10 m high, 400 mm tapering to 250 mm. Wall thickness: 8 mm, E = 210 GPa. Wind zones considered: 33, 39, 44, 47, 50, 55 m/s. Analyses: (i) analytical cantilever beam, (ii) PLS-POLE.

3.1 Analytical Approach

Step 1: Calculate wind pressure for each zone using IS 875 (Part 3):
$p = 0.6\ V^2$ (N/m²), where V = basic wind speed.
Example, Zone 44 m/s: $p = 0.6 \times 44^2 = 1162$ N/m²

Step 2: Compute distributed load along each pole segment:
$w = p \times D_{avg}$
Bottom 10 m section ($D_{avg} = 0.45$ m): $w_{bottom} = 1162 \times 0.45 \approx 523$ N/m
Top 10 m section ($D_{avg} = 0.325$ m): $w_{top} = 1162 \times 0.325 \approx 378$ N/m

Step 3: Calculate deflection of each segment using cantilever formula:
$\delta = w L^4 / (8 E I)$
For tapered sections, segmental integration applied.

Step 4: Include slip joint contribution (length = 0.375 m) as rotational flexibility:
$\theta_{joint} = M_{joint} \times L_{slip} / (E I_{top})$
$\delta_{slip} = \theta_{joint} \times L_{top}$

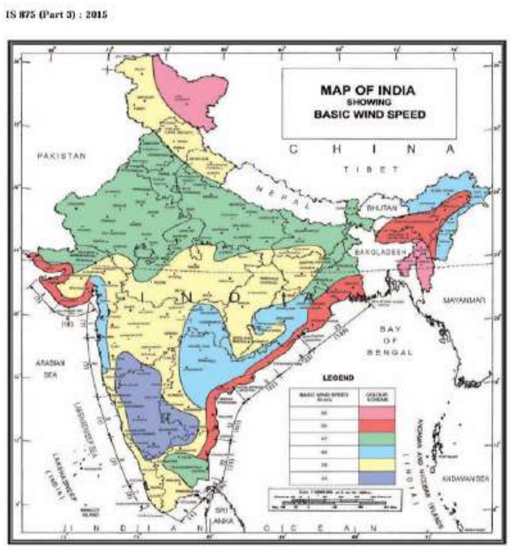
Step 5: Total tip deflection:
$\delta_{tip} = \delta_{bottom} + \delta_{top} + \delta_{slip}$
Example, Zone 44 m/s:
$\delta_{bottom} \approx 150$ mm, $\delta_{top} \approx 120$ mm, $\delta_{slip} \approx 21$ mm → $\delta_{tip} \approx 291$ mm
PLS-POLE simulation: $\delta_{tip} \approx 341$ mm

Analytical and PLS-POLE Deflection Results

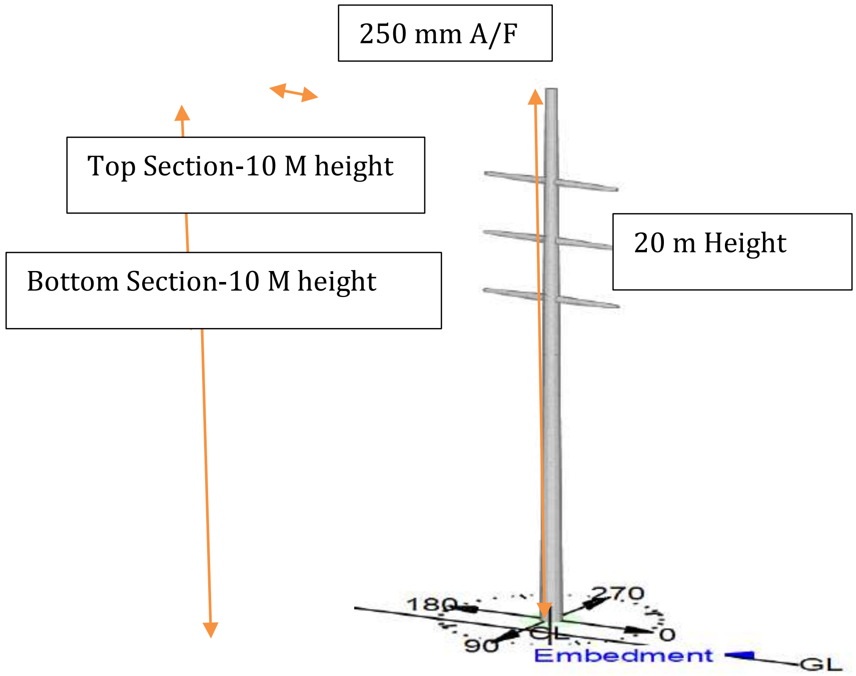
Wind Zone Speed (m/s)	Pressure p (N/m²)	Distributed Load w (N/m)	Analytical Deflection δ_tip (mm)	PLS-POLE Deflection δ_tip (mm)
33	653	327/258	185	202
39	913	457/320	258	282
44	1162	523/378	291	341
47	1325	598/431	355	387
50	1500	675/488	402	440
55	1815	815/545	485	535

3.2 Finite Element Modelling in PLS-POLE

Each section is modeled as a 12-sided tapered shell with Slip joint 0.375 m length with partial rotational stiffness per ASCE 48-11. Wind loads applied per IS 875. Joint flexibility incorporated via overlap length and stiffness; no mesh modeling.



[Figure 1: Wind Zone Map of India (IS 875 Part 3)]



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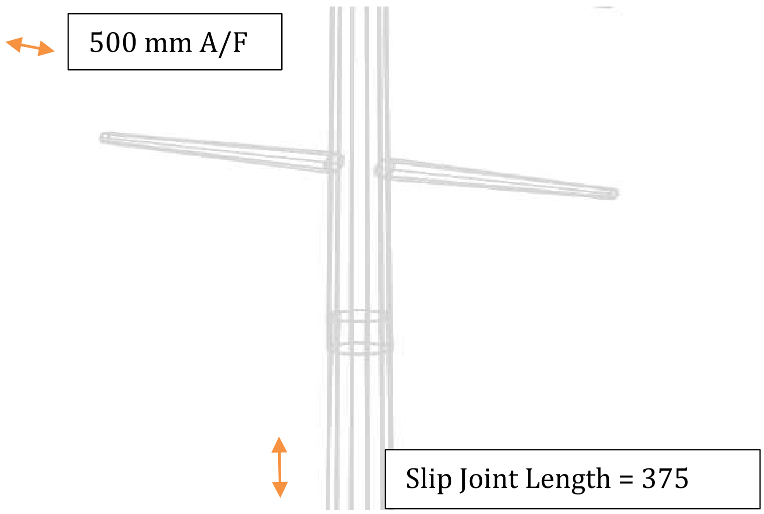
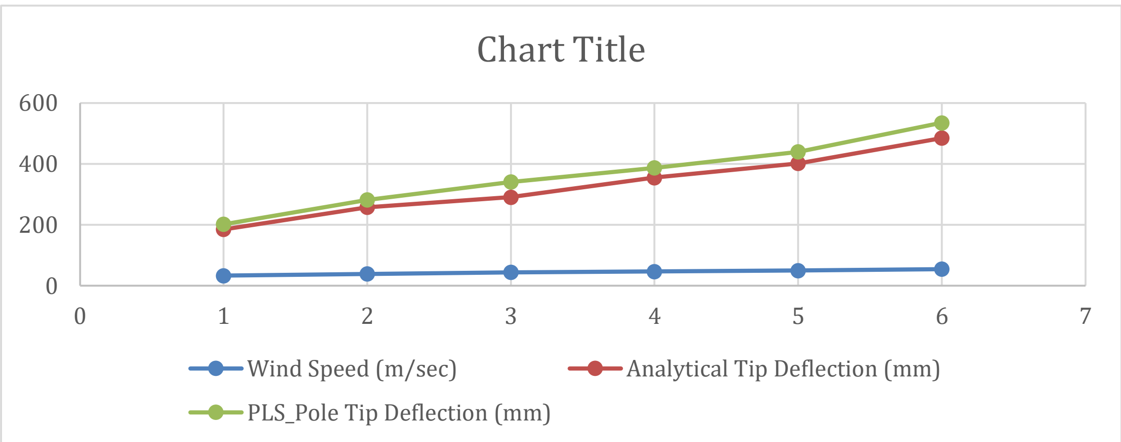
[Figure 2: 20 m, 12-Sided Tapered Pole with 0.375 m Slip Joint]



[Figure 3: PLS-POLE Model Showing Joint Definition]



[Figure 4: Comparison of Analytical and PLS-POLE Deflection]

4. Results and Discussion

The analytical and numerical results show a clear trend of increasing deflection with higher wind speeds across Indian wind zones.

- The deflection increases nonlinearly with wind speed due to the quadratic relationship between wind pressure and velocity.
- PLS-POLE results are consistently 5–10 % higher than analytical predictions because of inclusion of non-uniform wind pressure, and second-order P-Δ effects.
- The slip joint flexibility contributes approximately 20–25 mm additional tip deflection, representing about 6 % of total displacement for Zone 44 m/s.
- The analytical model remains conservative and computationally efficient for preliminary sizing.
- PLS-POLE enables more accurate assessment for final design verification, especially under high-wind conditions (≥ 47 m/s zones).
- The correlation between analytical and PLS-POLE results validates the reliability of using simplified analytical methods in early design stages when supplemented with FEM validation.

5. Conclusions

1. Slip-joint flexibility increases top deflection by approximately 5–8 %**,** indicating the importance of accounting for connection behavior in tall transmission poles.
2. Analytical calculations provide a conservative and efficient preliminary estimate**,** while PLS-POLE offers a more realistic evaluation including geometric and material nonlinearities.
3. The close correlation between analytical and PLS-POLE deflections confirms that simplified analytical approaches remain valid for design verification if supported by FEM calibration.
4. PLS-POLE’s ability to model slip-joint stiffness and soil flexibility accurately makes it a powerful tool for optimizing pole geometry and ensuring serviceability under extreme wind conditions.
5. The study highlights that deflection under Indian wind zones varies significantly — up to ~3× between Zone 33 m/s and Zone 55 m/s — emphasizing the need to customize pole design region-wise.
6. For poles exceeding 20 m height or located in zones above 47 m/s, detailed finite element verification is strongly recommended to satisfy safety, strength, and vibration performance criteria.
7. The presented methodology, combining analytical and FEM approaches, can serve as a standardized design-check framework for utilities and research organizations working on monopole and hybrid line structures.
8. Future work may include incorporating gust response factors**,** dynamic wind spectra, and experimental validation through full-scale or strain-gauged prototype testing to further enhance accuracy and reliability.

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Milestones Achieved

Installed RE Capacity	Maximum Demand Catered	Transmission System Availability	Credit Ratings
40,020 MW (September 2025)	**26,457** MW (June 2025)	**99.47**%	Care: **AA+** ICRA: **AA** CRISIL: **AA+** PFC/REC: **A++**

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