Improvement of Reliability of JSP 220kV Transmission Line Network

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1. ACKNOWLEDGEMENT

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These past two months working on the 220kV transmission line reliability project at Jindal Steel and Power's Raigarh plant have been an unforgettable journey of learning and growth. The chance to collaborate with such a dedicated and professional team was instrumental. Their insights into the practical challenges and intrinsic details of real-world transmission line maintenance were invaluable. Witnessing their dedication and professionalism firsthand has instilled a strong work ethic in us.

The project itself presented unique opportunities to bridge the gap between theory and practice. Concepts learned in textbooks came alive as we analyzed real data and explored potential solutions for improving reliability. This hands-on experience has been far more impactful than any textbook could offer. We are incredibly grateful to Jindal Steel and Power for providing this exceptional opportunity. It has not only deepened our technical knowledge but also transformed our approach to work, fostering a commitment to excellence, meticulousness, and a collaborative spirit.

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2. COMPANY OVERVIEW

2.1 Jindal Steel & Power (JSP)

Jindal Steel & Power (JSP) is more than just an industrial giant; it's a beacon of India's progress, forging the nation's future through steel, mining, power, and infrastructure. With every beam and every megawatt, JSP is building the backbone of a self-reliant, thriving India.

At the heart of JSP’s mission is the belief that a nation's strength lies in its infrastructure. By producing world-class, cost-effective steel, JSP ensures that the pillars of progress are both sturdy and sustainable. Their innovative and efficient methods set them apart as one of the most forward-thinking steelmakers globally, constantly pushing the boundaries of what’s possible. JSP's influence stretches across continents, from the bustling heart of India to the vibrant lands of Africa and Australia.

Under the visionary leadership of Mr. Naveen Jindal, JSP has not only grown exponentially but has also remained steadfast in its commitment to the "Make in India" vision. The company’s diverse product range serves as a testament to its dedication to covering the entire steel value chain.

Key Figures

- **Steel Production Capacity**: 9.6 MTPA
- **Captive Power Capacity**: 1634 MW
- **Community Impact**: 10 million people benefited
- **Workforce**: Employees: Over 20,000 across three continents

JSP’s philosophy of nation-building through its core operations is more than just a mission; it’s a relentless pursuit of excellence. With a focus on innovation, capacity enhancement, and enriching lives, JSP is not just creating products but crafting the future, one project at a time.

2.2 Jindal Steel and Power, Raigarh

JSP Raigarh, a key part of Jindal Steel & Power (JSP), exemplifies the company's commitment to nation-building through steel production, power generation, and community development.

Steel Production:

- **Capacity**: 3.6 MTPA
- **Highlights**: High-quality, cost-effective steel through advanced technology and integration.

Power Generation:

- **Capacity**: 839MW
- **Contribution**: Supports plant operations and regional energy needs.

Community Impact:

- **Beneficiaries**: Over 1 million people
- **Focus**: Education, healthcare, and infrastructure through extensive CSR initiatives.

Environmental Stewardship:

- **Measures**: Advanced pollution control and sustainable practices
- **Impact**: Significant reduction in ecological footprint.

Leadership:

- **Vision**: Driven by Mr. Naveen Jindal's commitment to innovation, quality, and community welfare.

JSP Raigarh has various departments like RMH (Raw material Handling), Coal Washery, Sinter Plant, Blast Furnace, DRI (Direct Reduced Iron), SMS (Steel Making Shop), Plate mill, SPM (Special Profile Mill), Rail Mill, Power Plant, Cement Plant, Brick Plant and EPS (Electrical Power Systems).

3. INTRODUCTION

3.1 Importance of Reliability of Power Transmission

The steel industry is a cornerstone of modern civilization. Reliable access to electricity is an absolute necessity for steel production. Every stage of the steelmaking process, from raw material processing to finished product creation, relies heavily on electric arc furnaces, motors, and other equipment.

Power outages can have significant consequences, leading to:

- **Production disruptions**: Even brief outages can halt operations, causing delays in production schedules and impacting fulfillment commitments. Re-starting furnaces and other equipment after an outage can be a lengthy process.
- **Product quality issues**: Fluctuations in power supply can affect the quality of steel being produced, leading to potential product defects or inconsistencies.
- **Economic losses**: Production delays, scrap generated due to quality issues, and the cost of restarting equipment all contribute to significant financial losses for steel companies.

3.2 Problem Statement: Power Outages and Impact on Reliability

Despite its importance, steel production facilities like Jindal Steel and Power can be vulnerable to power outages caused by various factors. This project focuses on Jindal Steel and Power and the challenges it faces with power outages impacting the reliability of its 220kV transmission line network.

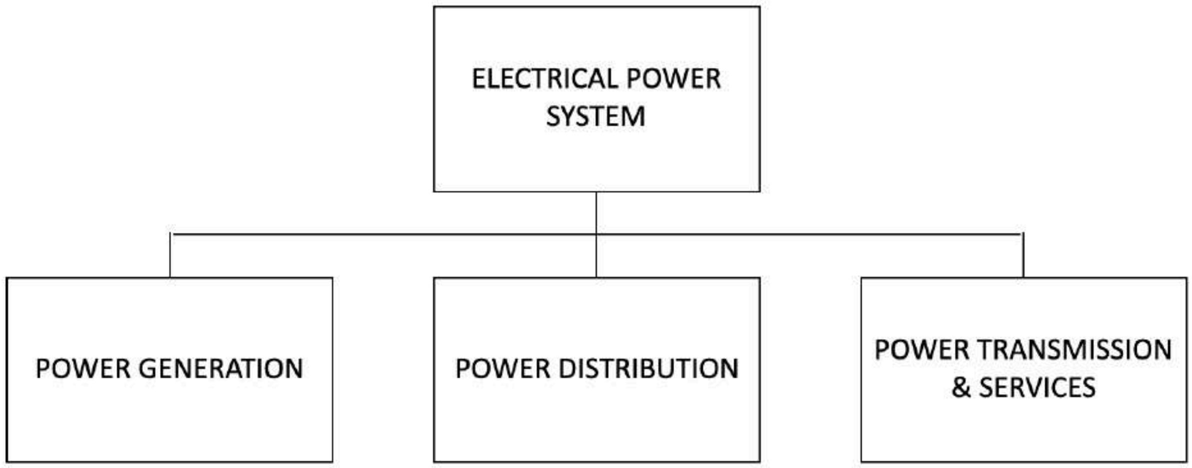
3.3 Project Objectives

This project aims to address the issue of power outages and improve the overall reliability of the 220kV transmission line network of Jindal Steel and Power. The specific objectives are:

- To identify the **root causes of power outages** affecting the transmission line network.
- To study the **measures to mitigate these outage causes** and enhance network resilience.
- To provide **recommendations for future enhancements** to further strengthen the reliability of the power supply for the steel making company.

3.4 Electrical Power System (EPS)

The Electrical Power Systems (EPS) department acts as the backbone of Jindal Steel and Power's Raigarh plant, guaranteeing a steady and efficient flow of electricity to power not only the plant's critical operations but also fulfilling the needs of the township's households. From maintaining critical equipment, transmission lines, towers,etc to implementing safety protocols, scheduled patrolling, etc and optimizing energy consumption, the EPS department plays a central role in keeping the wheels of steel production turning smoothly.



EPS broadly has three divisions, Power Generation, Power Distribution and Transmission and services.

Power Generation

Power generation is the process of converting various forms of primary energy into electrical power. It serves as the initial stage in the electricity supply chain, preceding transmission, distribution, and ultimately, delivery to end users. Power plants, also known as generating stations, utilize a diverse range of energy sources to drive electromechanical generators, the workhorses of electricity production. In JSP Raigarh, the main primary source of energy used is coal. The total power generation is around **839 MW**. The power requirement is met from

- Dongamauha Captive Power Plant (DCPP)
- Raigarh Captive Power Plant (RCPP)

The power generated here caters to the plant's vital operations like Blast Furnace, Sinter Plant, etc and also the household consumption of the township within the campus.

Power Distribution

Power distribution is the stage of delivering electrical energy from the bulk transmission system to individual consumers. It involves a network of interconnected equipment designed to efficiently step down the high voltage electricity from transmission lines to lower voltage levels for homes, businesses, and industrial facilities. There are four MRSS (Main Receiving Substation) in JSP Raigarh Plant.

- **MRSS-1** has JLDC (Jindal Load Dispatch Center) which monitors load dispatch to the various plants, which majorly include SMS-3, Blast Furnace-1, Rail Mill, DRI-1, BRPT, SAF. The voltage levels of 220 kV, 33 kV and 11 kV are available in MRSS-1.
- **MRSS-2** has voltage levels of 220 kV, 33 kV and 6.6 kV.

- **MRSS-3** has voltage levels of 220 kV, 11 kV, 6.6 kV and majorly caters to Sinter Plant, Blast Furnace, DRI-2.
- **MRSS-4** is located 28 km from Raigarh plant at OP Jindal Industrial Park at Punjipathra. It caters to the load demand of 43 consumers. The voltage levels available here are 220 kV, 33 kV and 11 kV.

Power Transmission

220 kV Power Transmission is used for high voltage for long distance power transmission. 220 kV transmission lines are the workhorses of bulk electricity delivery, forming the backbone of interconnected grids in many regions. 220 kV lines utilize tall towers with widely spaced conductors to minimize electrical discharge (corona) and maintain safety clearances.

The 220kV transmission lines have a length of around **76 km** in total, and fall under the category of **medium transmission lines**.

The 220kV transmission lines are mainly composed of 4 lines:

- **CSEB** (Chhattisgarh State Electricity Board) line, from CSEB to MRSS#1, of 4.5km
- **JSP** (Jindal Steel and Power) line, from MRSS#4 to JSP via NSPL (Nalwa Steel and Power Ltd.), of 24 km
- **JPL** (Jindal Power Limited) line, from MRSS#4 to JPL, of 21km
- **DCPP** (Dongamauha Captive Power Plant) line, from DCPP to MRSS#4, of 26km

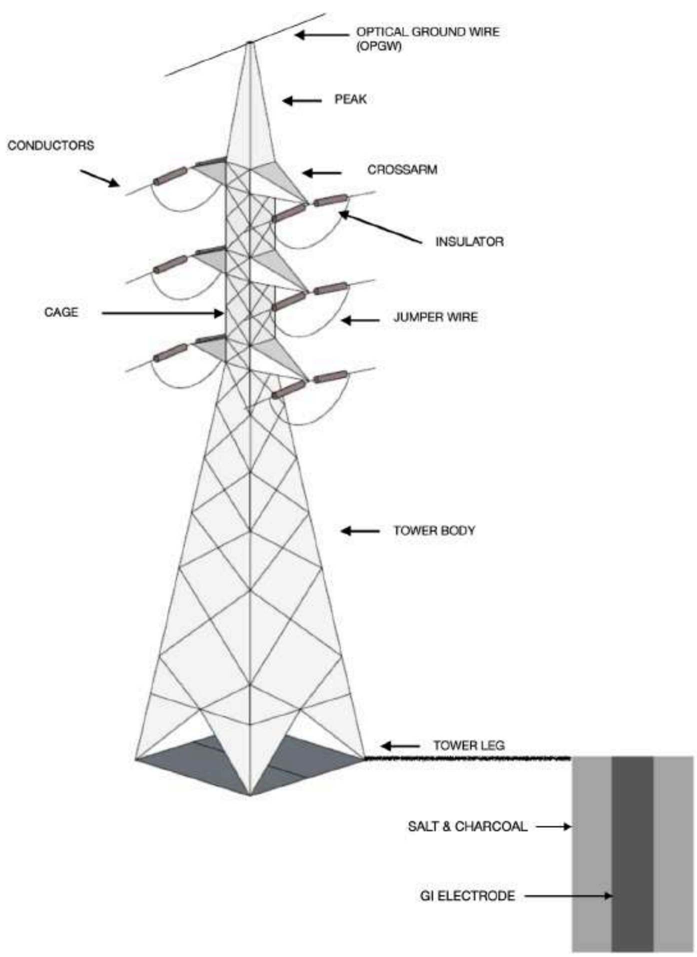
4. 220kV TRANSMISSION LINES

220 kV Power Transmission is used for high voltage for long distance power transmission. 220 kV transmission lines are the workhorses of bulk electricity delivery, forming the backbone of interconnected grids in many regions. They operate with alternating current voltage of 220,000 volts, though actual operation may be slightly higher to reduce losses. Substations play a crucial role in the 220 kV system.Substations house transformers that "step-up" the voltage from generation levels (around 11 kV) to 220 kV for transmission, and then "step-down" the voltage to lower distribution levels (33 kV, 11 kV) for delivery to industries and communities. The 220kV transmission lines network broadly consists of the **transmission line towers** and the **conductors**.

4.1 Transmission Line Towers

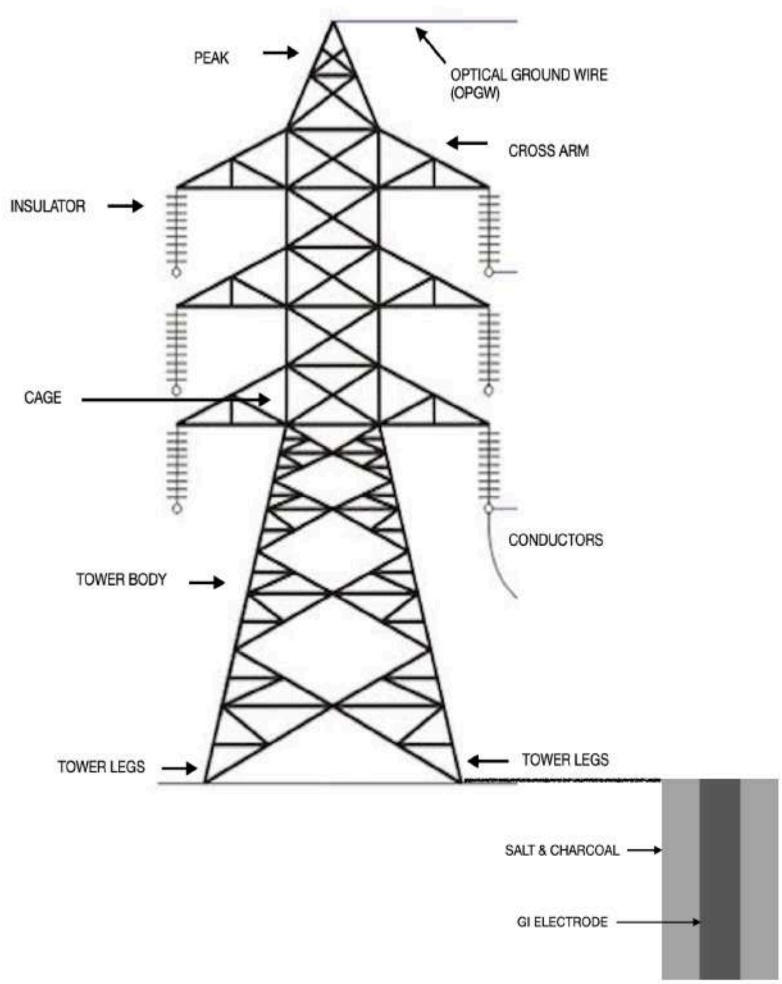
Transmission line towers are the tall lattice structures that support overhead power lines carrying electricity over long distances. Transmission line towers for 220kV transmission are broadly of two types, tension type and suspension type towers.

Tension Towers:



- **Function:** Primarily used for sharp turns (greater than 10-15 degrees) in the line path or at dead-end points where the line changes direction.
- **Design:**
  - Stronger and more robust structure compared to suspension towers.
  - Utilize guy wires or V-shaped braces to provide additional support against the tension forces from the conductors.
  - May have insulator strings on both sides of the tower to handle the tension in both directions.
- **Technical Specifications:**
  - Material: Typically steel lattice structures.
  - Height: Varies depending on line voltage and terrain, but generally taller than suspension towers for increased clearance.
  - Foundation: Requires stronger foundations due to the higher loads they support.
  - Cost: More expensive than suspension towers due to their complex design and construction.

<u>Suspension Towers:</u>



- **Function:** Used for straight sections of the line or for small angle deviations (up to 10-15 degrees).
- **Design:**
  - Simpler and lighter structure compared to tension towers.
  - Primarily rely on the vertical suspension of conductors from the crossarms to support the weight.
  - Insulator strings are typically suspended from the crossarms on one side of the tower.
- **Technical Specifications:**
  - Material: Typically steel lattice structures, although some may be made of wood or concrete.
  - Height: Can be shorter than tension towers as they handle less tension.
  - Foundation: Require less robust foundations compared to tension towers.
  - Cost: Less expensive than tension towers due to their simpler design and construction.

Parts of Transmission Towers:

- OPGW - Optical fiber cable integrated within the overhead ground wire for communication.
- Peak - Highest point on the transmission line profile.
- Cage - Grounding structure around disconnect switches for safety during maintenance.
- Cross Arms - Horizontal structures that hold insulators and conductors away from the tower body.
- Yoke Plate - Metal structure connecting the cross arm to the tower body.
- Insulators - Electrical isolators that prevent current flow from the conductor to the tower.
- Corona Ring - Ring-shaped device that reduces corona discharge around the conductor.
- Arcing Horn - Diverts fault current away from insulators and towards the grounding system.
- Dead Ends - Anchor points where the tension in the conductor is terminated.
- Vibration Damper - Device that reduces wind-induced conductor oscillation.
- Conductors - Electrical cables that carry electricity.
- Jumper Wires - A short connecting wire used connect two conductors of the transmission line
- Tower Body - Main vertical structure supporting the cross arms and conductors.
- Tower Legs - Individual vertical members that form the base of the tower.
- Tower Pedestal - Transition element between the tower legs and the foundation.
- Tower Foundation - Base structure that transfers the weight of the tower and conductors to the ground.
- Grounding System - A network of conductors that connects the OPGW via the tower structure to the earth to ensure safety.

4.2 Conductors used in Transmission Lines

Aluminium conductors of different types and sizes are used for drawing overhead lines, whether they are LT or HT lines. These include:

- **AAAC – All Aluminium Alloy Conductors:** These conductors are made out of high strength Aluminium- Magnesium-Silicon Alloy. These conductors are designed to get better strength to weight ratio and offer improved electrical properties, excellent sag-tension characteristics and superior corrosion resistance when compared with ACSR.

Advantages:

a. **Higher Strength:** AAAC conductors are composed of an aluminum alloy with additional elements like magnesium and silicon. This alloy offers significantly higher tensile strength compared to pure aluminum in AAC conductors.

b. **Improved Corrosion Resistance:** The specific alloying elements in AAAC conductors enhance their corrosion resistance compared to AAC.The combination of magnesium and silicon in AAAC conductors creates a synergistic effect. They not only contribute their own protective oxides but also modify the overall structure and properties of the oxide layer on the aluminium surface.

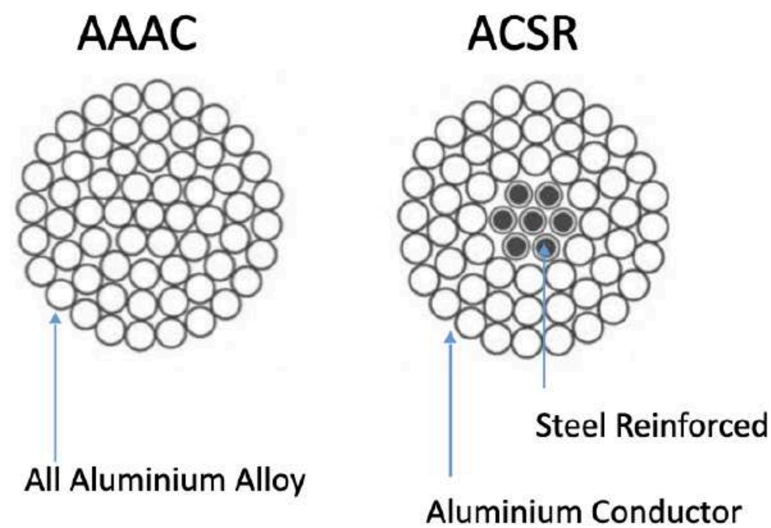
c. **Lower Cost:** Compared to copper conductors, AAAC conductors offer a cost-effective solution with good overall performance for many power transmission and distribution applications.

Disadvantages:

a. **Lower Conductivity:** Although AAAC offers some improvement over AAC, it still has lower electrical conductivity compared to copper. This can lead to higher I^2R losses resulting in energy loss.

b. **Brittle at Low Temperatures:** Similar to AAC, AAAC conductors can become more brittle at very low temperatures, increasing their susceptibility to breaking under high mechanical stress.

c. **More Complex Manufacturing:** The addition of alloying elements makes the manufacturing process of AAAC conductors slightly more complex compared to simple AAC conductors.



• **ACSR – Aluminium Conductor Steel Reinforced:** It is a type of high-capacity, high-strength stranded conductor typically used in overhead power lines. The outer strands are high-purity aluminium, chosen for its excellent conductivity, low weight and low cost. The center strand is of steel for additional strength to help support the weight of the conductor.

Advantages:

a. **High strength** to weight ratio: light weight due to Al but steel core gives high strength.

b. **Good conductivity and efficiency**: Al is a good conductor, thus less losses and high efficiency

Disadvantages:

a. **Galvanic corrosion**: steel core and aluminium strands can undergo galvanic corrosion reaction, which weakens the cables

b. **Lower flexibility**: Compared to some other conductors like AAAC (all aluminium alloy conductor) and AAC (all aluminium conductor) , its less flexible

c. **Not the most conductive**: Cu is better than Al for conduction. Cu is 1.6 to 1.7 times more conductivity than Al

Type 220kV Transmission Line Conductor based on dimensions

1) Dog – The conductor used from **33KV to 66KV** is called a dog conductor. Its current carrying capacity is up to **300A**. It consists of 6 strands of aluminium dia 4.72mm, and 7 strands of steel dia 1.57mm.

2) Panther – It is used from **66KV to 132KV**. In this, current can be given up to **480A**. It consists of 30 strands of aluminium dia 3.00mm, and 7 strands of steel dia 3.00 mm.

3) Zebra – Zebra conductor is used for **220kV**. In this, current can be given up to **735A**. Zebra conductor has 54 strands of aluminium dia 3.18mm and 7 strands of steel dia 3.18mm.

4) Moose – Used on **220kV or 440kV** lines, which can easily withstand current up to **800A**. It also has 54 aluminium dia 3.53mm and 7 steel strands dia 3.53 mm like the zebra conductor. But the size of strands is bigger.

The main conductors used for 220kV transmission lines in JSP Raigarh are **AAAC (All Aluminium Alloy Conductor) Moose** and **ACSR (Aluminum Conductor Steel Reinforced) Zebra.**

SIZE: DOG < PANTHER < ZEBRA < MOOSE

CONDUCTOR (ACSR)	VOLTAGE	CURRENT	STRANDS	COMPARATIVE SIZE
DOG	66KV	300A	6 Aluminium and 7 Steel strands	SMALL
PANTHER	132KV	480A	30 Aluminium and 7 Steel strands	MEDIUM
ZEBRA	220KV	735A	54 Aluminium and 7 Steel strands	LARGE
MOOSE	220-440KV	800A	54 Aluminium and 7 Steel strands	LARGEST

5. ANALYSIS OF POWER OUTAGES

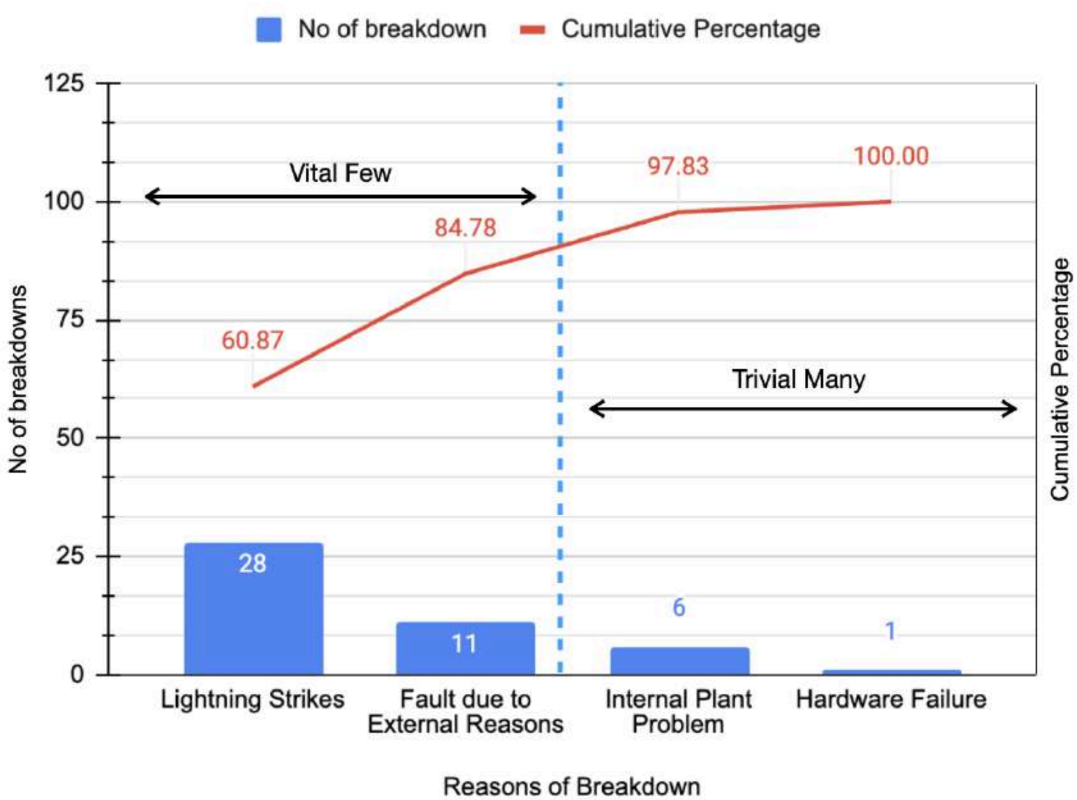
5.1 Data Collection and Methodologies

This section details the process of gathering and analyzing data on power outages affecting the 220kV transmission line network:

- **Data Sources**:
  1. **Protection relay logs** recording fault events and outage durations.
  2. **Maintenance records** documenting outage events and corrective actions.
  3. **Physical patrolling** fault location for cause of fault
- **Data Analysis Techniques**:
  1. Graphical analysis for **Pareto Chart** of reasons of power outage.
  2. Analysis of **faults due to lightning** over the last 6 years.
  3. **FishBone Diagram** for cause to consequence.

5.2 Graphical Representation and Analysis of the Findings

CASE STUDY #1: Pareto Analysis of number of breakdowns versus the reasons of breakdowns over the last 6 years (2018-19 to 2023-24)



Reasons of Breakdown	No of breakdown	Cumulative Percentage
Lightning Strikes	28	60.87
Fault due to External Reasons	11	84.78
Internal Plant Problem	6	97.83
Hardware Failure	1	100.00

NOTE: Fault due to external reasons include factors like fire on vegetation/trees, flying tree branch hit live lines, animal activities etc.

Observations:

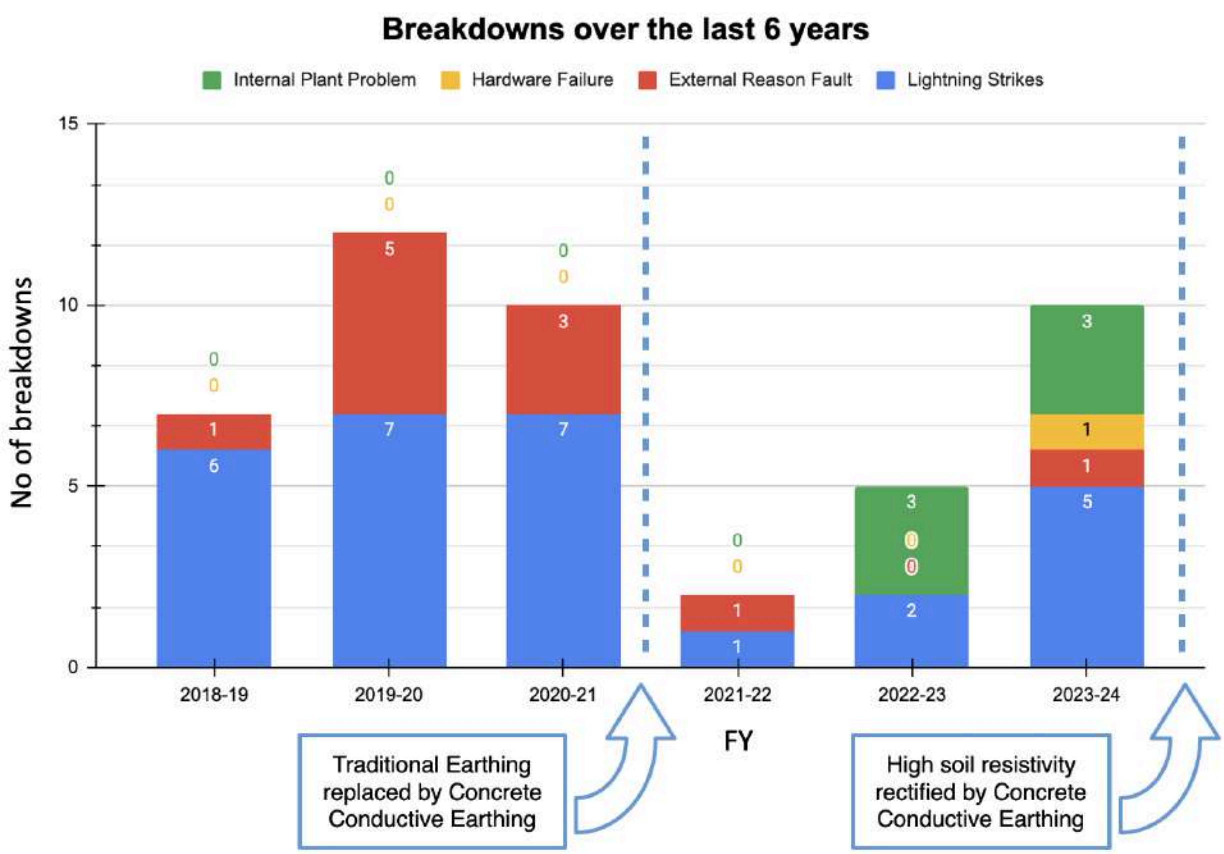
According to **Pareto Principle (80/20 rule)**, 80 % of the consequences come from 20 % of the causes.

- **Lightning strikes**: Lightning strikes have been identified as the most significant factor contributing to transmission line outages, responsible for over half (60.87%) of the 46 breakdowns experienced in the last six years. Implementing effective mitigation measures for lightning strikes has the potential to significantly reduce the overall breakdown rate.
- **Faults due to external reasons**: These include factors like vegetation fires, flying tree branches contacting energized conductors, and animal activity were identified as contributing to 11 outages (23.91% of total). This category represents the second most significant cause of outages, with a cumulative impact of 84.78%.
- **Internal Plant Problems**: These include internal plant problems which have caused 6 breakdowns, contributing to a share of 13.04%, with a cumulative impact of 97.83%.
- **Hardware failure**: This factor has occurred only once in the last 6 years. A deadend got damaged in the fiscal year 2023-24, contributing to 2.17%, with a cumulative impact of 100%.

  Aligned with the Pareto Principle (80/20 rule), the analysis indicates that approximately **80% of the transmission line outages** can be attributed to two primary causes: **lightning strikes and faults due to external reasons**.

CASE STUDY #2: Analysis of distribution of the different reasons of breakdown versus the fiscal year, over the last 6 years (2018-19 to 2023-24)

Year	Lightning Strikes	External Reason Fault	Hardware Failure	Internal Plant Problem
2018-19	6	1	0	0
2019-20	7	5	0	0
2020-21	7	3	0	0
2021-22	1	1	0	0
2022-23	2	0	0	3
2023-24	5	1	1	3



NOTE: Fault due to external reasons include factors like fire on vegetation/trees, flying tree branch hit live lines, animal activities etc.

Observations:

The following observations were made from the analysis of different reasons for breakdowns over the last 6 years, and analysis of the contribution of each reason on each year basis.

- **Observation#1**: The biggest contributor to breakdowns over the last 6 years, as also discussed earlier, is lightning strikes.
- **Observation#2**: Breakdowns due to lightning strikes went down drastically after 2020-21, from earlier causing 6 to 7 breakdowns every year, to reducing to 1 breakdown due to lightning strike in 2021-22 and 2 breakdowns in 2022-23.This reduction was a result of replacement of the traditional Earthing technique using salt and charcoal, by Marconite concrete conductive earthing technique, which significantly reduced the tower foot resistance (TFR) to 0.1 Ω m.
- **Observation#3**: In the fiscal year 2023-24, breakdowns due to lightning strikes went up again to 5, showing concerns with earthing systems, subsequent TFR testing showing high TFR in more than 50 towers. Marconite concrete conductive earthing being implemented for the same.
- **Observation#4**: The first 3 years have had contribution in the breakdowns due to faults due to external reasons, which went down drastically in the next three years, due to improvement and more effective implementation of Preventive Maintenance activities.
- **Observation#5**: Only one occurrence of hardware failure was seen in the fiscal year 2023-24, where deadend got damaged and led to breakdown

Aligned with the Pareto Principle (80/20 rule), the analysis indicates that approximately **80% of the transmission line outages** can be attributed to two primary causes: **lightning strikes and faults due to external reasons**. Breakdowns due to lightning strikes have been tackled by Earthing Maintenance practices. The second severe cause was faults due to external reasons like fire on vegetation/trees, flying tree branches hitting live lines, animal activities etc. were tackled by Preventive Maintenance activities.

5.3 Breakdown of Outage Causes

Findings of the power outages analysis of the last 6 years show that there are 5 main causes of faults that lead to line tripping, that in turn lead to power outages, and they are as follows:

• **Lightning strikes**:Lightning is the biggest challenge behind transmission line outages, causing over half of all failures in the past six years. This is especially true for long stretches of lines in open areas, where they become prime targets for strikes. The immense current surge from a direct hit can cause intense line insulation, causing flashovers and outages. Additionally, the heat can damage equipment, requiring repairs and extending downtime. A poorly designed grounding system further worsens the situation. If the grounding can't handle the current, it can damage equipment or create safety hazards by allowing high voltage to flow onto the towers themselves.

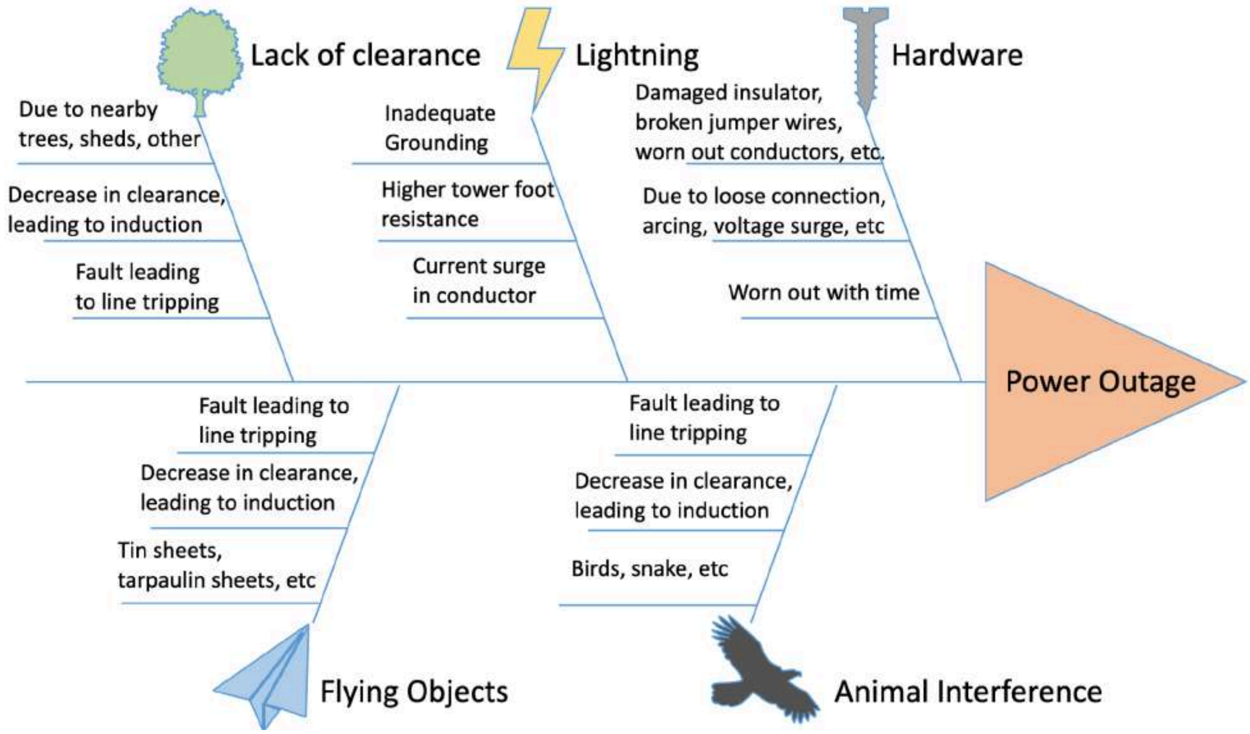


Fig: FishBone Diagram of causes of Power Outages

- **Damaged or Defective Hardware**: Maintaining top-notch hardware on 220kV transmission lines is essential for reliable power delivery. Even minor issues like loose connections, failing dead ends, or broken jumper wires can snowball into major problems. These issues can cause heat damage, arcing faults, conductor breakage, and outages. A proactive inspection and preventive maintenance program where tightening connections, inspecting hardware for wear, and ensuring proper functionality to prevent these problems and guarantee a more reliable flow of electricity is done.
- **Lack of Clearance**:Untamed trees, nearby structures built too close, insufficient line spacing, sagging lines, and even poorly maintained jumper wires can all lead to accidental contact, path for induction, short circuit, flashovers, or equipment damage. To ensure a reliable transmission network, vegetation management plans, enforced construction regulations, proper line spacing, maintaining ground clearance, and regular jumper wire inspections are all essential practices.
- **Animal Activities**: Animal activity can cause power outages on high-voltage lines. Birds' nests with conductive materials or snakes slithering on towers can create short circuits. Large birds near conductors risk causing outages too. Careful planning to discourage nesting and using insulation on key parts can significantly reduce these animal-related disruptions.
- **Flying Objects**: Strong winds can turn loose tarpaulins or metal sheets into airborne hazards, and can cause short circuits in a few ways. They might directly bridge the gap between live

wires, or come close enough to induce sparking (arcing) due to the high voltage. Both scenarios can damage equipment and trigger outages as the line automatically trips circuit breakers to isolate the fault.

Lightning strikes, insufficient clearance, damaged hardware, airborne objects, and even animal activity can all disrupt power flow. However, a **proactive Preventive Maintenance strategy** can significantly mitigate these risks.

6. PREVENTIVE MAINTENANCE STRATEGIES

The reliable delivery of electricity relies heavily on a robust 220kV transmission network. Various challenges threaten this network, including lightning strikes, overgrown vegetation, faulty hardware, airborne objects, and wildlife activity. Proactive preventive maintenance strategies can significantly reduce the risk of outages. These strategies include scheduled maintenance, regular inspections, earthing maintenance, right-of-way management, etc. all working together to ensure the network's integrity and minimize disruptions for consumers.

6.1 Preventive Maintenance Schedule

Ensuring the smooth operation of a 220kV transmission network hinges on a meticulously crafted preventive maintenance schedule, which outlines a series of activities performed throughout the year to identify and address potential problems before they snowball into outages.

- **Monthly Activities**: Patrols Take Center Stage: The cornerstone of the schedule is monthly **scheduled patrolling**, covering all 242 towers and the entire 220kV transmission line network. This visual inspection allows trained personnel to identify potential hazards like damaged hardware, loose objects, or signs of animal activity near the line. Earthing system integrity is also monitored during these patrols, and any minor issues can be rectified promptly.

  Right-of-way management is a crucial aspect of these patrols. Inspectors ensure proper clearance is maintained by identifying and addressing:
    - **Encroaching Trees and Structures**: Trees decreasing clearance are trimmed down..
    - **Metallic Dust and Dry Vegetation**: The presence of metallic dust particles on the line or tower corridor can potentially lead to short circuits. Dry vegetation near the line or towers increases the risk of wildfires and cause short circuit too throughout the airborne carbon particles, these these are cleared off from line and tower corridor
- **Annual Activities**: Hotline Maintenance, String Replacement & Punctured Insulation Detection:
- **Biennial Activities**: **Earthing maintenance** is done twice a year. It mainly has TFR (Tower Foot Resistance) testing and required corrective and preventive maintenance along with it.

6.2 Scheduled Patrolling

A reliable flow of electricity depends on constant monitoring of transmission lines. Imagine 242 towers safeguarding a 220kV network. Scheduled patrols, conducted by trained professionals, act as the watchful eyes, identifying potential threats before they cause outages. This proactive approach is the first line of defense in maintaining a smooth and efficient power delivery system.
A checklist is prepared for scheduled patrolling, which is duly followed. One such checklist is

shown as follows:

DATE:

220 kV JPL (TAMNAR) TO PUNJIPTRA S/S TRANSMISSION LINE

(Tower Schedule, Starting from JPL To Punjipatra)

PHYSICAL\VISUAL INSPECTION

Sl. No.	Location	Patrolling Done by	Tower No	New Tower No	Type of Tower	Span in meters	Number Plate	Missing Member	Arcing Horn/Vibration Damper CK1	CK2	Insulator Crack/Damage CK1	CK2	Conductor sag CK1	CK2	Bird Nest	Earthing	Earth wire	Painting	Chimney	Revetment Wall	Anti Climbing Devices	Tree Cutting	Step Bolt	Thermography
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									R,Y,B	R,Y,B	R,Y,B	R,Y,B	R,Y,B	R,Y,B										
			Gantry	Gantry	JPL Gantry																			
						190																		
1			1	JP1	NB 60+10																			
						127																		
2			2	JP2	NB 60+10																			
	Road					270																		
3			3	JP3	NB 60+10																			
	Nala					366																		
4			4	JP4	NB 0																			
	Nala					223																		
5			5	JP5	NB 60 + 5																			
	Road					200																		
6			6	JP6	NB 0+5																			
						260																		
7			7	JP7	NB 60+7.5																			
						280																		
8			8	JP8	NB 0 + 10																			
						200																		
9			9	JP9	NB 0																			
						220																		
10			10	JP10	NB 0 + 5																			
	Road					250																		
11			11	JP11	NB 0+10																			

Signature
(Site Supervisor)
F-01(7.1.501-141)/Issue-01, Date:15.04.2016

Signature
(Section Incharge)

Signature
(Section Head)

Fig: Scheduled Patrolling Checklist

The following checkpoints are checked in this checklist:

- **Number Plate**: Patrollers record each inspected tower's number to track their route and guarantee all 242 towers are covered on the 220kV line. This systematic approach minimizes the risk of missing any important component.
- **Missing Members**: Patrol personnel meticulously examine for missing members, such as steel angles or bracings, that could compromise the structural stability of the tower. Early identification of such deficiencies allows for timely repairs and mitigates the risk of potential tower failures that could disrupt power delivery.
- **Arcing horn/ Vibration damper:** Arcing horns protect equipment by diverting fault currents, and any damage or corrosion can hinder this function. Vibration dampers, on the other hand, minimize conductor sway caused by wind. Inspectors meticulously examine these components for signs of wear, cracks, or loose connections, ensuring they can effectively safeguard the transmission line from potential faults.
- **Cracked or damaged Insulator**: Inspecting insulators is a key part of this process. Made of high-resistance materials, these insulators prevent electricity from jumping from the energized conductors to the supporting towers. Cracks or damage can compromise this insulation, potentially causing leakage or flashovers that disrupt power. Trained personnel

meticulously examine insulators during patrols to ensure the continued safe and reliable operation of the transmission line.

- **Conductor Sag**: During scheduled patrols, a watchful eye is cast upon conductor sag, the dip between transmission line towers. Excessive sag can be caused by scorching temperatures, ice accumulation, or even the natural aging of the line.
- **Bird Nest:** The presence of nests poses a potential fire hazard if constructed from flammable materials. Additionally, large nests can increase the risk of flashovers (electrical arcing) if they bridge the gap between conductors.
- **Earthing**: Patrollers examine the earthing system, ensuring a secure connection between the tower and the earth.
- **OPGW:** Overhead Ground Wires (OPGW). The checklist ensures any damage or corrosion on the OPGW is documented. Early detection of such issues is crucial, as a compromised OPGW can hinder its ability to safely divert lightning strikes away from the power-carrying conductors, potentially leading to outages.
- **Painting**: Corrosion can be a silent threat, and timely identification of chipped or flaking paint allows for preventative maintenance.
- **Pedestal:** Inspectors examine these structures for signs of cracks, corrosion, or any movement that could compromise their stability.
- **Revetment Wall**: Revetment walls are structures that reinforce and stabilize the base of towers, often near water bodies or areas prone to erosion. Inspectors examine these walls for signs of damage, deterioration, cracks, leaning, or excessive vegetation growth.
- **Anti Climbing Devices:** Barbed wire around the tower base, deter unauthorized access that could pose a safety hazard.
- **Climbing Bolt:** These bolts serve as anchor points for lineman and beltman. Inspectors examine these bolts during patrols, ensuring they are secure, free from corrosion, and haven't suffered any damage.
- **Thermography**: Inspectors check for hotspots that indicate loose connections, overheating components, or potential equipment failure. Early detection through thermography allows for timely repairs and helps prevent unexpected outages that could disrupt power delivery.
- **Right of Way:** ROW ensures the designated clearance area around the transmission line is free of hazards. Inspectors check for encroaching elements like trees, overgrown vegetation, metallic dust, dry vegetation or even tall structures that could potentially cause contact with the conductors.

Scheduled patrolling can again be of two types:

1. Ground Patrolling: A Meticulous Close-Up Look

- **Method:** Trained personnel traverse the designated right-of-way on foot or using specialized vehicles.
- **Features:**
  - Offers a detailed inspection of towers, conductors, and surrounding infrastructure.
  - Allows for close-up examination of potential hazards like damaged hardware, loose connections, or signs of animal activity.
  - Enables right-of-way management by identifying encroaching vegetation or structures that require trimming or removal.

2. Aerial Patrolling: A Broader View from Above

- **Method:** Utilizes lineman and beltman going till crossarm of the tower or drones equipped with high-resolution cameras and other inspection tools.
- **Features:**
  - Provides a rapid and comprehensive overview of the entire transmission line corridor.
  - Offers a bird's-eye view for identifying potential issues like conductor sag, damaged insulators, or right-of-way encroachments that might be missed from the ground.
  - Covers large distances efficiently, making it ideal for long transmission lines.

6.3 Hotline Maintenance

One of the key elements of this preventive maintenance strategy is hotline maintenance. This specialized technique allows for inspections and repairs of 220kV transmission lines while they are still energized. This not only minimizes disruption to the power supply but also offers a unique opportunity to address potential issues before they escalate into outages. The following sections will delve deeper into the world of hotline maintenance, exploring the specific risks it mitigates and the procedures involved in this crucial practice.

6.3.1 Methods of hotline maintenance

Hotline work can be classified into the following categories:

- **Hot stick method**: In this method, the lineman is at ground potential working with hot sticks (live-line tools), keeping a safe distance from the line by using a conductive suit and hotline tools.

- **Bare hand method**: In this method, the linemen work at the same potential as the conductor, keeping safe clearance from the ground. For this, an insulated suit made of 25 per cent microscopic stainless steel and 75 per cent Nomex is used.
- **Combination of hot stick and bare hand methods**: This method is used to overcome the constraints in tower top geometry.
- **Insulating glove or rubber glove working**: Gloves protect the worker from exposure to the live part being worked upon, also referred to as the first point of contact. Insulating material such as blankets and line hose are employed in rubber glove working to protect the worker from exposure to a part at a different potential sometimes referred to as the second point of contact. Most utilities require work to be performed from an insulating platform to provide isolation from earth/ground potential, hence the term insulate and isolate.
- **Hotline washing**: Pressurised demineralised water with resistivity more than 30,000 ohms is used for the washing of insulators on line with the safe distance of 6.1 meters for 400 kV lines and 4.57 meters for 220 kV lines. A polyplastic nylon reinforced non-conductive hose is handled by the crew on the tower with proper earthing.
- **Insulated aerial work platform**: The insulated bucket truck used for live-line working is an extraordinary tool that is exceptionally safe and highly efficient to perform more tasks per day. Further, productivity and safety of a live-line crew will be increased manifold by using an aerial insulated platform.

6.3.2 Hotline operations in transmission lines and substations

Some hotline maintenance operations for 220kV lines, can be carried out are as follows:

- **Changing Insulators:** Over time, insulators (typically porcelain or composite) can become damaged due to aging, cracks, or contamination. Hotline maintenance allows for the safe replacement of these insulators with new ones that meet the required dielectric strength and flashover voltage ratings for a 220kV system.
- **Changing Hardware Components, Spacers and Dampers; Application of Repair Sleeves; Maintenance and Replacement of Mid-Span Joints:** Hardware components like **spacer dampers** and **stockbridge dampers** mitigate conductor vibration and aeolian oscillations. **Mid-span joints** connect conductor sections. Hotline maintenance allows for the inspection, cleaning, repair (using **heat-shrink repair sleeves** for minor damage on conductors), or replacement of these components as needed. Materials used for these components are chosen for their high strength, conductivity, and corrosion resistance.
- **Replacement/Repair of Damaged Sections of the Conductor:** Even the most robust conductors (typically Aluminum Conductor Steel Reinforced - ACSR) can be susceptible to damage from wind, lightning strikes, or hardware failures. Hotline maintenance

enables the identification and repair of minor conductor damage using **compression repair sleeves** or, in more severe cases, the replacement of the affected section with a new conductor segment of the same specifications.

- **Testing of Insulators (One Line Insulator Tester, Puncture Insulator Detector [PID]):** While visual inspection is crucial, hotline maintenance also allows for the use of specialized testing equipment like **one line testers** and **puncture insulator detectors (PIDs)**. These tools inject a high-frequency AC signal into the insulator and measure the leakage current. Deviations from normal readings can indicate internal cracks, flaws, or moisture ingress within the insulators, prompting proactive replacements before failures occur.
- **Tension String Replacement:** Tension strings, typically made of high-strength steel strands, are critical for maintaining proper conductor sag and preventing excessive movement during wind or ice loading. Hotline maintenance allows for the inspection and replacement of worn or damaged tension strings, ensuring the line maintains its optimal operating tension as specified by engineering design calculations.
- **Live-Line Washing:** Over time, dust, salt, and other contaminants can accumulate on insulators, reducing their surface resistivity and increasing the risk of flashovers. Live-line washing utilizes pressurized demineralized water (with a conductivity less than 1 microsiemens/cm) to safely clean these insulators while the line remains energized. The **pressure** used for washing can range from **0.7 MPa (100 psi) to 1.4 MPa (200 psi)**, depending on the severity of contamination and the specific washing tool design.
- **Jumper Online Tightening and Nut-Bolt Changing:** Jumpers, typically made of ACSR or similar conductors, are used to connect conductors or bypass equipment during outages. Hotline maintenance allows for the inspection and tightening of loose connections on jumpers using calibrated torque wrenches to ensure proper bolt tension and reliable electrical contact. Replacement of worn-out nuts and bolts might also be necessary. The specific bolt size, material, and required torque value depend on the jumper design and application.
- **Strengthening of Dead End Hardware:** Dead end hardware assemblies, typically a combination of clamps, wedges, and insulators, anchor the conductors at the ends of the line and at tower suspension points. Hotline maintenance allows for the inspection and, if necessary, the strengthening of this hardware using additional components or by replacing worn-out elements. The specific dead end hardware design and materials are chosen to withstand the maximum tension forces experienced by the conductor under various loading conditions.
- **Replacement of Arcing Horn and Corona Ring Hardware:** Arcing horns, typically made of metal rods, divert lightning strikes away from the insulators. Corona rings, often toroidal in shape, help mitigate corona discharge and associated power losses. Hotline maintenance allows for the inspection and replacement of damaged or worn-out arcing horns and corona rings, ensuring continued protection for the line. The design and

material selection for these components consider factors like lightning strike current expected and corona inception voltage of the conductor configuration.

6.3.3 Equipment for Hotline Maintenance

Personal Protective Equipment (PPE):

- **Insulated Gloves:**
    - Voltage Rating: Exceed 220kV AC for a safety margin. (e.g., Class 5 gloves rated for 75kV can be used for 220kV lines)
    - Material: High-voltage rubber or composite materials with flame retardant properties.
    - Standards: Compliant with **IS 13774 (1993)**
- **Conductive Suit:**
    - Voltage Rating: Match or exceed the voltage rating of the gloves.
    - Material: Flame-retardant fabric with insulating layers, often incorporating moisture management features. The fabric should comply with **IS 15656 (2009)** for flame retardancy. While no single IS code directly addresses conductive suits, the insulating layers can be evaluated based on principles outlined in **IS 3043 (Parts 1 & 2)**.
    - Composition: 25% microscopic stainless steel and 75% Nomex (or a similar blend that meets the performance criteria of the mentioned IS standards).
- **Face Shields**:
    - Material: High-impact resistant polycarbonate for protection against arcs, debris, and dust.

    - Standards: The visor material should comply with the requirements for "plastic visors" as outlined in **IS 8521 (Part 1): 1977** - Industrial safety face shields, Part 1: With plastic visor.
- **Grounding Equipment**:
    - Grounding Rods: Copper or steel rods with a minimum length of 1.8 meters (6 feet) for effective grounding.
    - Grounding Cables: Insulated cables with appropriate conductor size (based on fault current calculations) and secure connection points for linemen and grounding rods.
    - Standards: Compliant with **IS 2002 (2012):** Code of Practice for Earthing provides guidance on earthing systems.

<u>Hot Sticks and Tools:</u>

- **Hot Sticks**:
    - Material: Non-conductive fiberglass with high dielectric strength.
    - Length: Range from 2 meters (6.5 feet) to over 8 meters (26 feet) for various tasks and clearances required.
    - Voltage Rating: Exceed the line voltage for a safety margin. (e.g., 265kV rated hot sticks for 220kV lines)
    - Standards: Compliant with **IS 14281 (2002):** This standard specifies requirements for fiberglass reinforced plastic (FRP) rods and tubes used for general structural purposes.
- **Insulated Tools**:
    - Voltage Rating: Match or exceed the voltage rating of the gloves and hot sticks.
    - Tool Type: Include wrenches, screwdrivers, pliers, cutting tools, and others designed for specific maintenance tasks.
    - Material: High-voltage rated insulating materials covering the handles and operational areas of the tools.
    - Standards: Compliant with **IS 3386 (Parts 1 & 2)** should be used to cover the handles and operational areas of the tools.
- **Grappling Hooks and Hook Sticks**:
    - Material: Non-conductive fiberglass or composite materials with appropriate strength for handling energized components.
    - Design: Grappling hooks have mechanisms for securely snaring conductors or insulators, while hooksticks offer extended reach for manipulation.
    - Voltage Rating: Match or exceed the voltage rating of the hot sticks used.

<u>Inspection and Testing Equipment:</u>

- **High-Power Binoculars and Cameras**:

  - Binoculars: Magnification of 10x or higher for detailed inspection of conductors, insulators, and hardware from a safe distance.
  - Cameras: High-resolution zoom cameras with weatherproof enclosures for capturing clear images and videos of energized components.
  - Durability: Ruggedized construction to withstand harsh outdoor environments.
- **Infrared Thermography Gun**:
  - Wavelength Range: Optimized for detecting temperature variations within the range of potential anomalies on energized components (typically between 3 µm and 5 µm).
  - Resolution: High enough to pinpoint hot spots on conductors, connections, or equipment.
  - Durability: Waterproof and shockproof for use in outdoor environments.
- **Puncture Insulator Detectors (PIDs)**:
  - Functionality: Puncture Insulator Detectors (PIDs): Utilize partial discharge detection techniques to identify cracks or voids within the insulator.
  - Voltage Rating: Compatible with the voltage of the line being tested (220kV in this case).
  - Standards: Instruments might comply with relevant standards like IEEE Std 432 (Guide for Manual Methods for Measuring Partial Discharges in Electric Power Apparatus).
  - Positron Insulator Testers are used for PID

6.3.4 Challenges and Limitations: The Balancing Act of Hotline Maintenance

While offering significant advantages, hotline maintenance does present certain challenges and limitations:

- **Weather Dependence:** Favorable weather conditions are crucial for safe and effective hotline maintenance. Strong winds, rain, or even fog can hinder visibility and complicate the delicate procedures involved. Additionally, lightning strikes pose a significant safety risk, often necessitating the postponement of maintenance activities.
- **Specialized Skills and Equipment:** Hotline maintenance demands a highly skilled workforce with expertise in electrical systems and the ability to work safely near high voltage. Specialized insulated tools, protective gear, and high-resolution cameras are crucial for these complex tasks. While this specialized training and equipment contribute to the cost of hotline maintenance, they are essential for ensuring worker safety and successful completion of the job.
- **Cost Considerations:** Compared to traditional maintenance procedures that involve de-energizing the line, hotline maintenance can be more expensive. The training, specialized equipment, and potential need for additional safety measures can contribute to

higher costs. However, these costs must be weighed against the benefits of minimized downtime and improved long-term reliability of the transmission network

6.4 Punctured Insulation Detection (PID)

Punctured insulators, where internal flaws compromise their insulating ability, can lead to disruptive outages and equipment damage. To prevent such occurrences, utilities employ specialized techniques like Punctured Insulator Detectors (PIDs). These devices are used during annual hotline maintenance inspections to identify potential punctures within energized insulators, allowing for proactive replacements before they cause problems.

6.4.1 Insulators

Insulator strings are a crucial component in 220 kV transmission line towers. They act as electrical barriers, isolating the high-voltage conductors from the grounded metallic tower structure.

6.4.2 Types of Insulators

- **Based on Voltage level:**
  1. **Pin Type Insulators:** These are commonly used on 11 kV Lines. The pins for pin insulators shall have a stalk length of 135 mm, shank-length of 125 mm and minimum failing load of 2kN. They should be forged. The pin type insulator is secured to the cross-arm on the distribution pole. There is a groove on the upper end of the insulator for resting the conductor. The conductor passes through this groove and is bound by the annealed wire made of the same material as the conductor. Pin type insulators can be of one part, two parts or three parts type, depending upon the application voltage. For example, in an 11kV system, one part type insulators are used where the whole pin insulator is one single piece of properly shaped porcelain or glass.

Fig: i. Pin type ii. Shackle type

2. **Shackle Type Insulators:** The shackle insulators are used in low voltage distribution lines (LT lines). They are also called spool insulators. These insulators are used to isolate the live conductor from the pole and are mounted in every pole of the electrical line. These insulators can be mounted either in vertical or horizontal positions. .

3. **Disc Type Insulators:** In higher voltage, such as beyond 33kV, it becomes uneconomical to use a pin insulator as the size and weight of the insulator becomes more. Handling and replacing bigger sized single unit insulators is a difficult task. Suspension insulator was developed to overcome these difficulties. In a suspension insulator, the number of insulators are connected in a series to form a string and the line conductor is carried by the bottom most insulator. Disc insulators are normally used in 11kV lines for dead-end locations.

fig i. Disc type ii. Guy strain type

4. **Guy Strain Insulators:** These are only used for guy/stay wires. These are designed to work in mechanical tension or strain, as they are capable of withstanding the pull of a suspended electrical wire or cable. The guy strain insulators are used in overhead electrical lines. The strain insulator is inserted between the stay wire to isolate the lower

portion from electricity.

- **Based on type of material**
  There three main types of insulator discs used in transmission lines, along with their technical specifications:

<u>1. Porcelain Disc Insulators:</u>

- **Material:** Made from high-quality clay fired at high temperatures, resulting in a strong, hard, and electrically insulating material.
- **Technical Specifications:**
  - **Dielectric Constant:** Around 4.5 to 5.5 (a measure of a material's ability to store electrical energy)
  - **Dielectric Strength:** Approximately 20 to 40 kV/cm (kilovolts per centimeter) (ability to withstand electric field before breakdown)
  - **Mechanical Strength:** Tensile strength can range from 40 to 70 MPa (Megapascals) (ability to withstand pulling forces)
  - **Advantages:** Relatively low cost, mature technology with a long history of reliable performance.
  - **Disadvantages:** Heavy weight, susceptible to mechanical damage due to brittleness, can be affected by pollution (especially salt fog).

<u>2. Polymer Disc Insulators:</u>

- **Material:** Composed of fiberglass reinforced plastic (FRP) with a silicone rubber housing. The FRP core provides mechanical strength, while the silicone rubber sheds water and resists pollution buildup.
- **Technical Specifications:**
  - **Dielectric Constant:** Lower than porcelain, typically around 3 to 4
  - **Dielectric Strength:** Comparable to porcelain (around 20 to 40 kV/cm)

- **Mechanical Strength:** Can be higher than porcelain due to the FRP core
- **Advantages:** Lighter weight compared to porcelain, superior performance in polluted environments, less susceptible to mechanical damage.
- **Disadvantages:** Higher initial cost than porcelain, relatively new technology with less long-term performance data compared to porcelain.

3. Glass Disc Insulators:

- **Material:** Tempered glass with high mechanical strength and good electrical insulating properties.
- **Technical Specifications:**
  - **Dielectric Constant:** Around 4 to 5 (similar to porcelain)
  - **Dielectric Strength:** Can be slightly higher than porcelain (around 25 to 45 kV/cm)
  - **Mechanical Strength:** Higher than porcelain due to tempering process
  - **Advantages:** Lighter weight than porcelain, good mechanical strength, excellent insulator for high-voltage applications.
  - **Disadvantages:** More expensive than porcelain or polymer and brittle nature.

Comparative Analysis of Porcelain, Polymer, Glass Insulator

Feature	**Porcelain**	**Polymer (Composite)**	**Glass**
Material Composition	High-alumina ceramic	Fiberglass reinforced polymer (FRP) with epoxy resin	Soda-lime or borosilicate glass
Dielectric Strength (kV/cm)	40-70	20-40	10-20
Mechanical Strength (MPa)	40-70 (tensile)	150-200 (tensile)	40-70 (compressive)
Weight	Heavy	Light (around 70% lighter than porcelain)	Heavy (similar to porcelain)
Leakage Distance	Requires longer string length for same voltage rating	Can achieve same voltage rating with shorter string length	Requires longer string length than porcelain
Brittle vs. Ductile	Brittle - can shatter on impact	Ductile - can absorb some impact without breaking	Brittle - can shatter on impact
Weather Resistance	Good, but susceptible to moisture ingress over time	Excellent, highly resistant to moisture and pollution	Good, but more susceptible to thermal shock than porcelain
Operating Temperature Range	-40°C to +150°C	-40°C to +200°C	-70°C to +170°C
Cost	Relatively low initial cost	Higher initial cost than porcelain	Moderately high initial cost
Maintenance	Requires periodic cleaning and inspection for cracks	Requires minimal maintenance	Requires periodic cleaning and inspection for cracks
Environmental Impact	More energy-intensive to manufacture	More recyclable materials compared to porcelain	Requires specific disposal methods for glass
Applications	Widely used for transmission lines, especially in older installations	Increasingly popular for new transmission lines where weight is a concern	Less common due to lower mechanical strength and higher cost

6.4.3 Significance of Insulator Health in 220kV Systems:

In a 220kV transmission line, insulators play a critical role in maintaining safe and reliable power delivery. These high-voltage insulators act as a physical barrier, electrically isolating the energized conductors from grounded structures like towers. By preventing current leakage, they ensure the smooth flow of electricity at the intended voltage level.

Maintaining High Voltage Isolation:

- **Dielectric Strength:** Insulators are manufactured from materials with a high dielectric strength. This property signifies the material's ability to resist the passage of electrical current. For 220kV systems, insulators typically use porcelain or composite materials with a breakdown voltage limit of 11kV per disc of the insulator string.

  Thus, the number of discs desired in a string can be calculated as:

  Phase to phase voltage $= 220kV$
  Phase to neutral voltage $= 220kV/\sqrt{3}$
  $= 127.02kV$

  Now, we know that the critical breakdown voltage of each porcelain disc $= 11kV$

  Thus, the minimum number of porcelain discs required for $220kV$ transmission lines
  $= 127.02kV/11kV$
  $= 11.54$

  Therefore, **at least 12 porcelain insulator discs** must be present in each insulator string. Generally, **Jindal Steel and Power**, uses **13 to 14 porcelain discs** in each insulator string.

- **Creepage Distance:** The design of the insulator incorporates a long leakage path, often referred to as the creepage distance. This extended path makes it difficult for flashover to occur, where electricity jumps across the insulator surface due to contamination, moisture, or degradation.

  1. **Tension Tower**
     Creepage length of each porcelain insulator disc $= 170mm$
     Total number of porcelain disc used $= 14$
     Total creepage length of 14 porcelain insulator discs $= 14 \times 170mm$

$= 2380mm$

2. **Suspension Tower**
   Creepage length of each porcelain insulator disc $= 145mm$
   Total number of porcelain disc used = 13
   Total creepage length of 13 porcelain insulator discs $= 13 \times 145mm$
   $= 1885mm$

- **Mechanical Load Rating:** The design of the insulator takes into consideration the tension load of the conductors that it can bear, called the mechanical load rating.

  1. **Tension Towers**
     Mechanical Load Rating = $120kN$ (According to IS Code)
     Mechanical Load Rating = $160kN$ (Buffer taken by JSP)

  2. **Suspension Towers**
     Mechanical Load Rating = $90kN$ (According to IS Code)
     Mechanical Load Rating = $120kN$ (Buffer taken by JSP)

Different Types of Insulator Failures:

While flashovers are a significant concern, several other failure mechanisms can affect insulators:

- **Puncture Faults:** Internal cracks, voids, or manufacturing defects within the insulator can create a path for current to flow directly through it, leading to a puncture fault.
- **Aging and Weathering:** Over time, exposure to environmental factors like ultraviolet radiation, extreme temperatures, and pollution can degrade the insulator material, reducing its effectiveness.
- **Contamination:** Accumulation of dirt, salt deposits, or other contaminants on the insulator surface can decrease its insulating capability and increase the risk of flashovers.
- **Hardware Failure:** The metal parts connecting the insulator to the tower or conductor can corrode or loosen, compromising the overall integrity of the assembly.

By understanding the significance of insulator health and the potential consequences of failure, utilities can prioritize proactive maintenance strategies like hotline maintenance techniques to ensure the continued reliable operation of their 220kV transmission lines.

6.4.4 Working Principle of PID

A diagnostic tool that leverages the principles of electric field measurement for the evaluation of both porcelain and composite insulator health on energized transmission lines.

1. The Significance of the AC Electric Field:

Within an energized transmission line, the insulator string acts as a crucial dielectric barrier, isolating the high-voltage conductor from the grounded tower structure. The presence of an electric field is a fundamental consequence of this voltage differential. This **AC electric field** exhibits the strongest intensity near the conductor and progressively diminishes with increasing distance towards the grounded tower. Notably, the **magnitude of this electric field is directly proportional to the voltage** across the insulator string.

2. The Disruptive Effect of Punctures:

The integrity of the insulator string is compromised when a **puncture defect** develops within a disc or skirt. This defect essentially creates a **conductive path**, allowing a portion of the electric field to "leak" through the compromised area. This leakage phenomenon results in a **localized weakening** of the overall electric field intensity in the vicinity of the puncture.

3. Unveiling Defects Through Measurement:

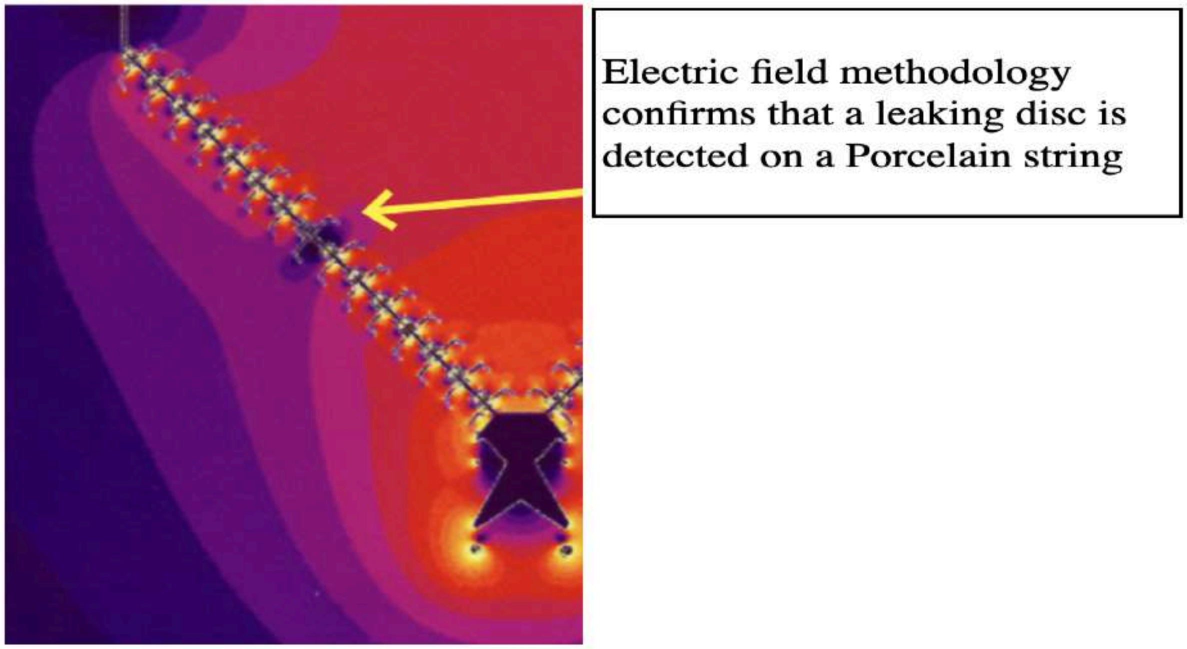
Positron's Insulator Tester employs a specialized sensor that meticulously measures variations in the **strength of the AC electric field** along the entire length of the insulator string. The testing process typically involves **sliding the tester** along the string, capturing measurements at designated points on each disc or skirt.

4. Identifying Punctures Based on Field Deviations:

A **healthy insulator** exhibits a **uniform** electric field distribution, characterized by a gradual weakening as it progresses away from the conductor. Conversely, the presence of a **puncture** manifests as a **distinct and localized drop** in the electric field strength at the precise location of the defect. This **abrupt decrease** serves as a telltale sign of a puncture within the insulator.

5. Data Acquisition and Analysis:

The Positron Insulator Tester likely incorporates a data logging function that captures the electric field measurements taken at each point on the insulator string. This acquired data can then be subjected to meticulous analysis to identify any significant drops in the field strength. Such reductions potentially signify the existence of punctures within the insulator material.



Advantages of the Electric Field Methodology:

This approach offers several compelling advantages over conventional inspection techniques:

- **Non-Destructive Evaluation:** This method allows for the assessment of insulator health on **energized lines**, eliminating the need for service outages.
- **Quantitative Data Acquisition:** By providing measurable data on the electric field distribution, this technique facilitates an **objective evaluation** of insulator health.
- **Early Detection Potential:** This method has the potential to detect **developing defects** before they evolve into catastrophic failures, thereby enhancing overall line reliability.

6.4.5 Step by Step Guide for Operation of Positron Insulator Tester

This section outlines the operational procedures for effectively utilizing Positron's Insulator Tester to assess the health of energized transmission line insulators. Following these steps ensures efficient data collection and facilitates informed decision-making regarding insulator maintenance.

1. Preparation and Equipment Activation:

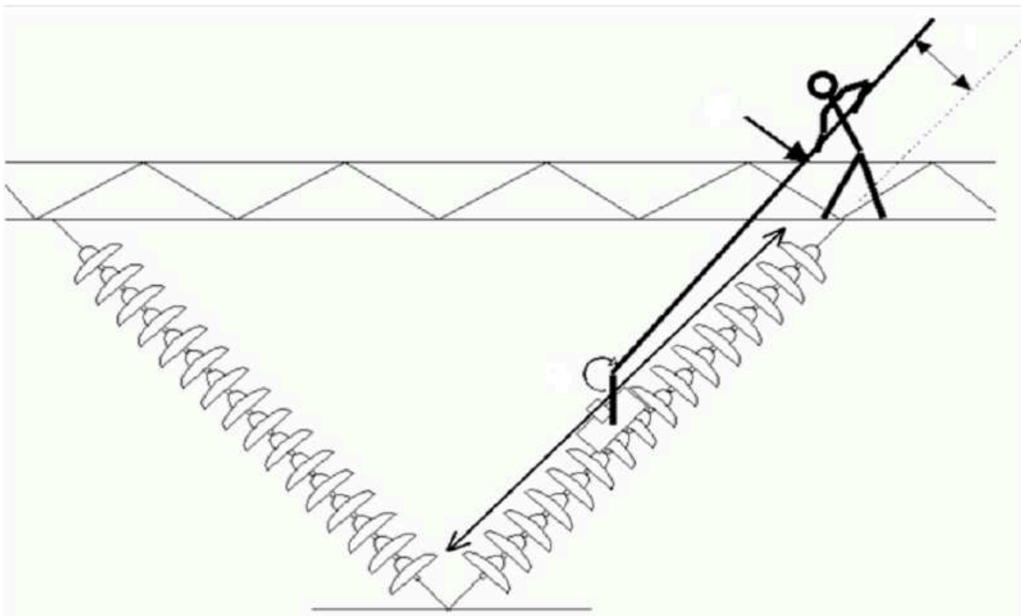
The operator should first position themselves at a safe working distance from the energized line. And press the designated push button on both the probe and logger.

2. Initial Probe Placement:

The next step involves carefully placing the tester on the insulator string a few positions below the grounded end. This ensures proper starting position for the subsequent data acquisition.

3. Calibration and Baseline Measurement:

With the probe positioned, the operator smoothly slides the tester back towards the beginning of the string. It's crucial to maintain a stationary position for at least 10 seconds at this point. A distinct long beeping sound will typically indicate successful calibration and baseline measurement.



4. Data Acquisition:

Following the calibration step, the operator systematically slides the tester along the insulator string towards the line end, ensuring it captures measurements at each disc or skirt. An audible buzzer sound usually accompanies each reading, providing confirmation of data acquisition. Upon reaching the line end, the tester is then slid back to the starting position, continuing to collect data at each insulator unit.

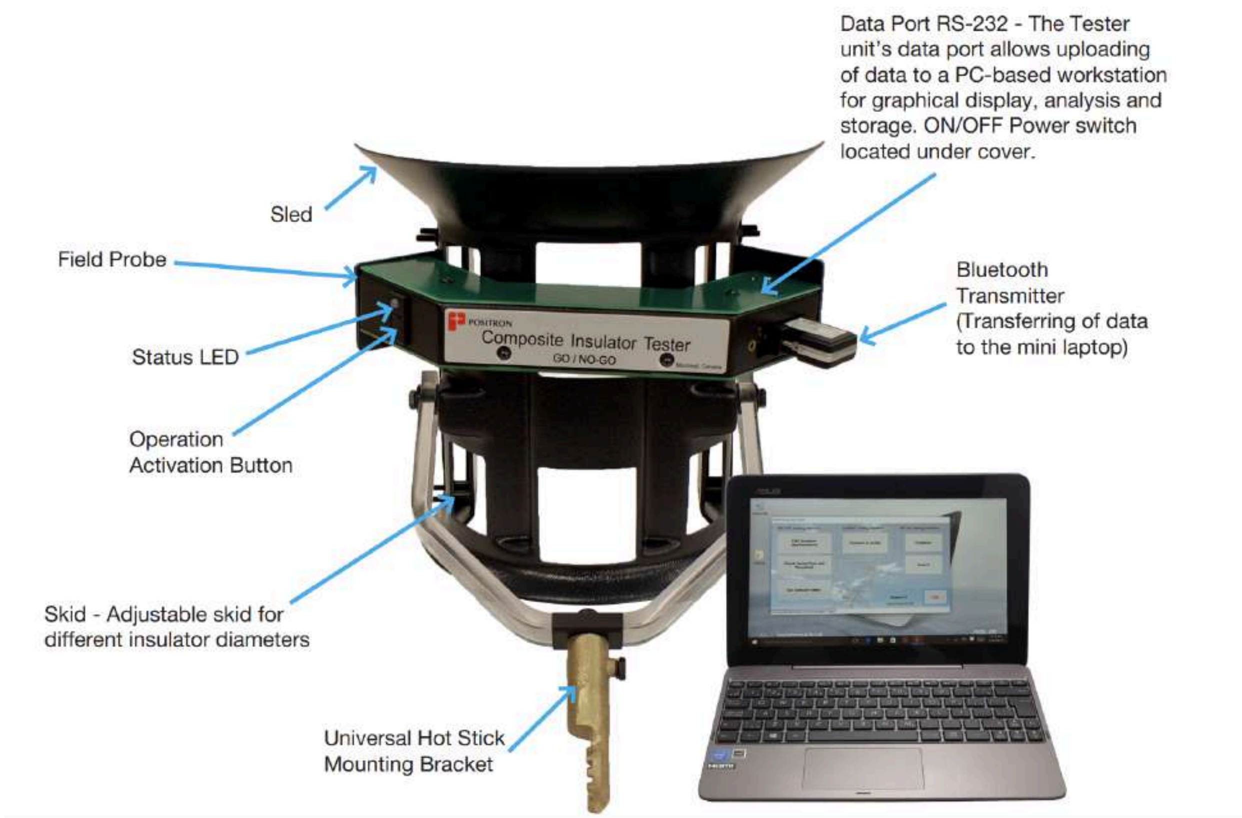
5. Data Storage and Test Completion:

Once the tester reaches the starting point again, a continuous sound will likely signify a successful scan of the entire string. The operator can then confirm data storage by pressing the designated button on the tester. This final step ensures the valuable information collected during the testing process is preserved for further analysis.

6.4.6 Technical Specification of Positron Insulator Tester

Positron Composite (Polymer) Insulator Tester
The Positron Insulator Tester offers a user-friendly and efficient solution for evaluating the health of composite and polymer NCI (Non-Ceramic Insulators) on energized transmission lines. Here's a breakdown of its key features:

- **Simple One-Button Operation:** Effortless to use, requiring only powering on the unit and sliding it along the insulator string.
- **Enhanced Safety:** Eliminates the need for direct electrical contact with potentially compromised insulators, minimizing risk.
- **Compatibility:** Designed specifically for testing polymer or composite NCI (Non-Ceramic Insulators).
- **Sled-Mounted Design:** Offers a stable platform for smooth gliding during testing (custom sled options available).
- **Ideal for Long Insulators:** Well-suited for insulator strings exceeding 10 skirts.
- **High Data Capacity:** Capable of capturing up to 15,000 readings during a single test.
- **Rechargeable Battery:** Provides convenient and portable operation.
- **Adjustable Skid:** Accommodates varying insulator diameters ranging from 4.3 inches to 6.7 inches (10.9 cm to 17 cm).
- **Optional GO/NO-GO Feature:** Provides a clear indication of insulator safety for live-line work (availability may vary).



Positron Porcelain Insulator Tester

The Positron Insulator Tester offers a user-friendly and safe solution for assessing the health of porcelain and glass insulators on energized transmission lines. Here's a breakdown of its key features for this specific application:

- **Simple One-Button Operation:** Effortless to use, requiring only powering on the unit and gliding it across the insulator discs.
- **Enhanced Safety:** Eliminates the need for direct electrical contact with potentially compromised insulators, minimizing risk during testing.
- **Compatibility:** Designed specifically for testing porcelain and glass insulators.
- **Sled-Mounted Design:** Offers a stable platform for smooth gliding during testing (custom sled options available).
- **Ideal for Longer Strings:** Well-suited for insulator strings with 4 discs or more.
- **High Data Capacity:** Capable of capturing up to 15,000 readings during a single test.
- **Rechargeable Battery:** Provides convenient and portable operation.
- **Adjustable Skid:** Accommodates varying insulator diameters ranging from 9 inches to 13 inches (22.9 cm to 33 cm).
- **Instantaneous Status Reporting:** Provides real-time feedback on insulator conditions, including identification of potential danger zones.

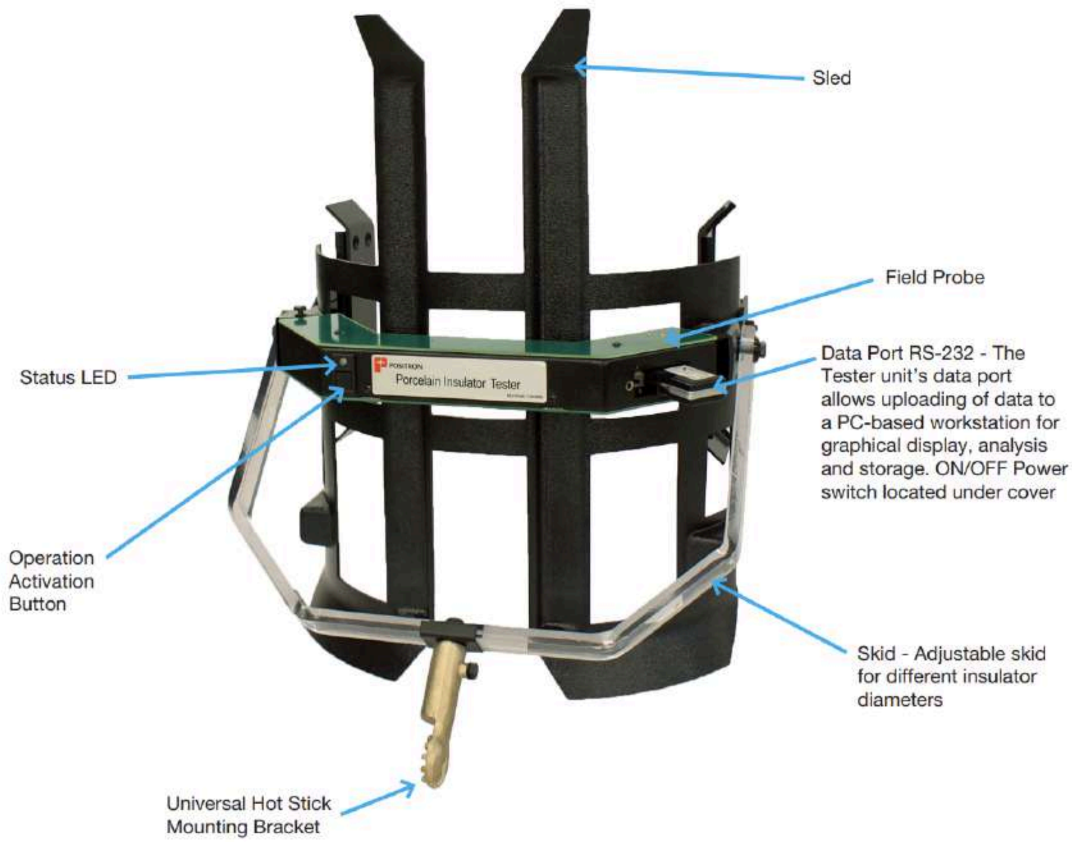


Fig: Positron Porcelain Insulator Tester

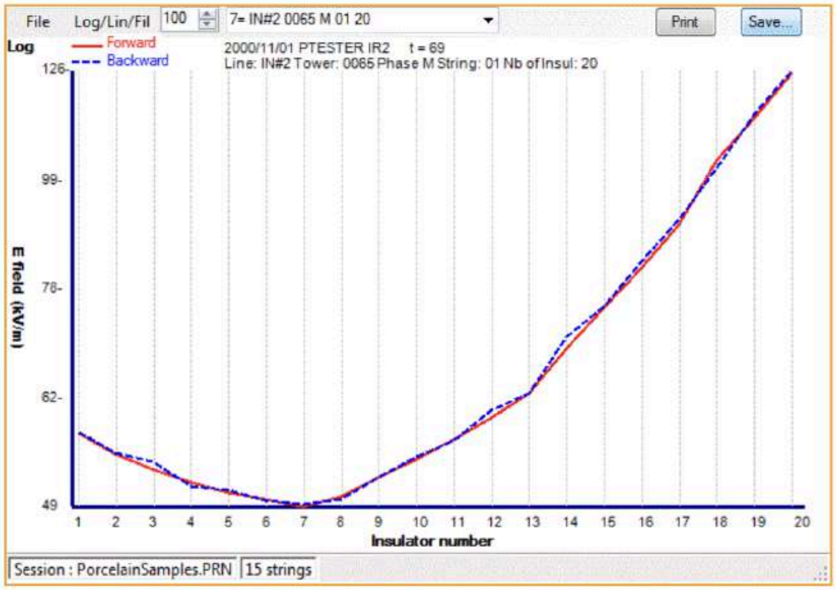
6.4.7 Interpreting Graphical Results

Case Study#1 Porcelain Insulator Tester Results: Healthy Insulators

1. Linear Graph

This linear graph indicates a healthy porcelain insulator string. The identical curves of the Forward (red) and Backward (blue) passes confirm the scanning integrity of insulator bells along the string.

2. Logarithmic Graph



The logarithmic (Log) scale amplifies the small variations in the lower portion of the curve of the E-field readings taken by the Insulator Tester enabling early detection of minor defects or low contamination.

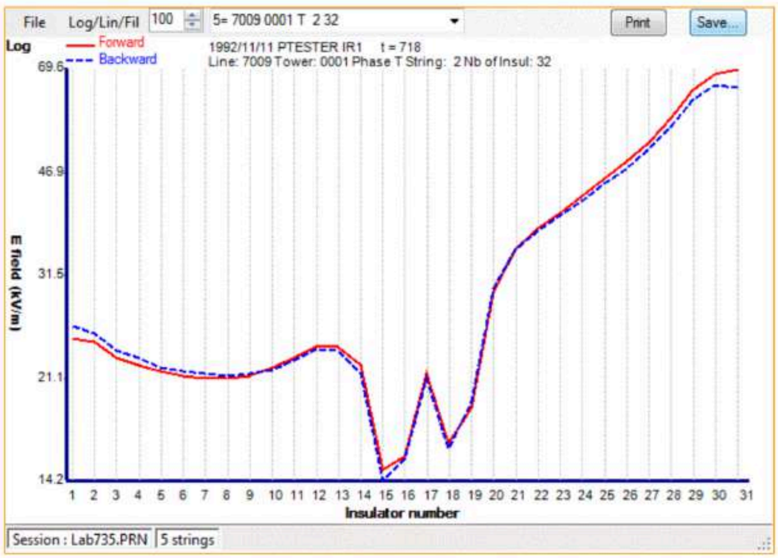
<u>**Case Study#2 Porcelain Insulator Tester Results: Unhealthy Insulators**</u>

1. Linear Graph

This linear (Lin) graph (Figure 20) indicates an unhealthy porcelain insulator string. The identical curves of the Forward (red) and Backward (blue) scans confirm where perforations or other defects exist in the porcelain insulator string being scanned. Compromised discs are shown as #'s 15, 16, 18 & 19

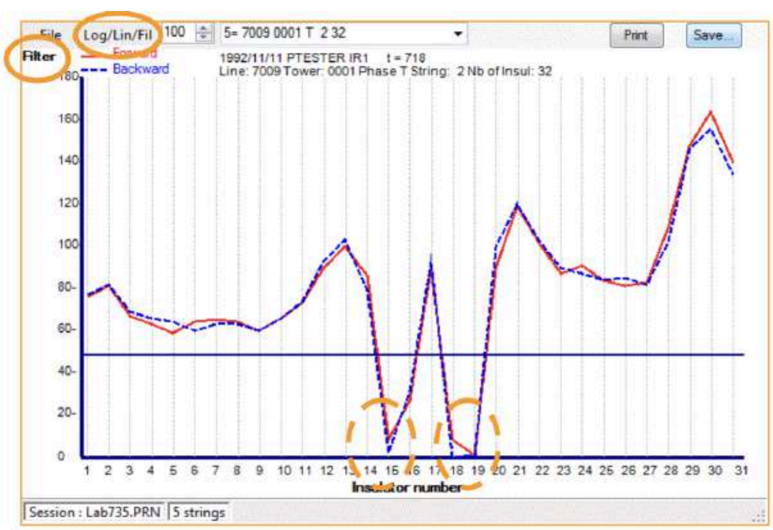
2. Logarithmic Graph

This Logarithmic graph amplifies the variations of the E field in the lower portion of the curve. The readings shown in the linear graph are represented in the logarithmic graph below so greater detail can be observed. Compromised discs are shown as #'s 15, 16, 18 & 19



3. Filter Graph

The Filter (Fil) setting uses a special digital filter algorithm to assist in the interpretation of the graph: Insulators under the blue line are punctured. Note: The vertical axis shows no unit in the Filter mode.



Badly compromised porcelain insulator discs shown at #'s 15, 16, 18 & 19.

In conclusion, Punctured Insulator Detectors can proactively identify potential punctures and internal flaws within energized insulators before they escalate into catastrophic failures. This early detection capability translates into fewer power outages.

6.5 String Replacement

Reliable and efficient transmission of electricity across vast distances underpins the functioning of modern society. At the heart of this critical infrastructure lie high-voltage transmission lines, carrying electricity.

6.5.1 Role of Insulators

Insulator string isolates the high-voltage conductor carrying electricity from the grounded metallic towers supporting the line.

Consequences of Insulator Failure:

- Short Circuits: A compromised insulator can allow current to flow through the tower structure, causing a short circuit. This results in a surge of uncontrolled current that can damage equipment, trigger outages, and pose a fire hazard.
- Safety Hazards: A failing insulator can energize the tower structure, creating a serious electrical safety risk for personnel working on or near the line.
- Arcing: High voltage can cause arcing (sparking) between the conductor and the tower if the insulator fails. This arcing can ignite surrounding materials, leading to fires and potential damage to the transmission line itself.

6.5.2 String Replacement Necessity

Insulator strings on transmission lines are critical components designed to withstand high voltage and ensure safe and reliable power transmission. However, various factors can necessitate their replacement. Here's a breakdown of these factors along with relevant technical specifications:

1. Ageing and Degradation:

2. Detection of Punctures or Internal Defects:

3. Environmental Damage:

By considering these factors and the associated technical specifications, transmission line operators can make informed decisions about when to replace insulator strings. This proactive approach helps ensure the continued safe and reliable operation of the power grid.

6.5.3 Planning and Preparation for Transmission Line String Replacement

This section delves into the critical pre-work activities that ensure a smooth and successful transmission line string replacement project. Here, we explore each stage with a focus on technical considerations:

1. Pre-Replacement Inspections and Assessments:

- **Visual Inspection:** A thorough visual inspection of the entire line section, focusing on the targeted string(s) for replacement. This includes identifying any cracks, chips, surface erosion, or hardware damage on the insulators.
- **Infrared Thermography:** This non-destructive testing technique can detect abnormal temperature variations on the insulator surface, potentially indicating internal flaws or hotspots. A temperature of 50 to 60 celsius is taken as the upper limit for safe operation.
- **Partial Discharge (PD) Testing:** Specialized PD testing equipment can identify the presence and location of partial discharges within the insulator, suggesting potential internal defects.
- **Leakage Current Measurement:** Measuring leakage current can provide insights into the overall health of the insulator string and its ability to withstand voltage.
- **Corona Camera Inspection:** Advanced corona cameras can detect corona discharge emanating from the string, which could be an indicator of surface contamination or developing cracks.

2. Selection of Appropriate Replacement String Type:

Technical factors to consider when selecting the replacement string type include:

- **Voltage Rating:** The new string must have an equal or higher voltage rating than the original string to ensure safe operation at the line voltage.
- **Mechanical Strength:** The replacement string needs to have adequate mechanical strength to withstand the weight of the conductors and dynamic loads like wind and ice.
- **Environmental Considerations:** Factors like pollution levels, humidity, and temperature extremes can influence the choice of material. For example, composite strings may be preferred in highly polluted environments due to their superior hydrophobicity (water repelling) properties.
- **Weight:** Lighter weight composite strings can be advantageous, especially for older tower designs with limitations on weight capacity.
- **Cost:** Porcelain strings are generally less expensive than composite strings, but the long-term maintenance and replacement costs associated with porcelain should be factored in.

Jindal Steel and Power, Raigarh's Shift to Polymer Insulators: A Balancing Act Between Longevity and Reliability

Jindal Steel and Power (JSPL) has opted for a strategic shift, replacing porcelain insulator discs with polymer alternatives in its transmission lines. This decision, while seemingly counterintuitive due to the perceived shorter lifespan of polymer, prioritizes operational reliability and addresses a key challenge associated with porcelain insulators in the company's specific operating environment.

The Challenge: Porcelain's Susceptibility to Flashovers

Porcelain insulators, while traditionally used for their durability, exhibit a significant drawback in environments prone to dust accumulation. Dust deposits act as conductive paths on the insulator surface, lowering its electrical resistance. When rain falls, these conductive paths can trigger flashovers - uncontrolled discharges of electricity that bypass the intended path through the conductor.

Frequent Flashovers Lead to Porcelain Disc Degradation

Repeated flashovers on porcelain insulators pose a significant threat to their integrity. The high-intensity electrical discharge can cause cracks and micro-fractures within the porcelain discs, compromising their long-term strength and increasing the risk of failure.

JSPL's Solution: Self-Cleaning Properties of Polymer

Polymer insulators, on the other hand, offer a distinct advantage in dusty environments. Their hydrophobic (water-repellent) surface characteristic prevents dust from adhering readily. Furthermore, rainwater effectively washes away any accumulated dust, minimizing the risk of flashover events.

Balancing Lifespan with Operational Reliability

While polymer insulators may have a nominally shorter lifespan compared to porcelain, JSPL prioritizes the operational reliability they provide. By minimizing flashovers and subsequent disc damage, polymer insulators offer a more dependable solution in the long run.

6.5.4 Procedure of Hotline String Replacement

Essential Tools and Equipment:

The following is a list of essential tools and equipment required for hotline string replacement up to 400 kV:

- **Yoke Assemblies:**
    - Single Pole Back Yoke (Cold End Yoke) - 1 unit
    - Single Pole Front Yoke (Hot End Yoke) - 2 units
- **Strain Carrier Components:**
    - Single Pole Strain Carrier - 1 unit
    - Strain Carrier Pole Clamp - 1 unit
    - Strain Carrier Trunnion - As required
- **Insulated Tools and Support:**
    - Cradle Sticks - 3 units
    - Epoxy Glass Insulated Ladders - 1 unit
    - Ladder with Hook - 1 unit
    - Yoke - 1 unit (purpose not specified)
- **Ropes and Lifting Equipment:**
    - Hand Line - 1 unit
    - Side Control Rope (Ladder) - 1 unit
    - Set of Rope Block - 1 unit
- **Safety Gear:**
    - Safety Sling with "0" Shackle - 1 unit

    - Slings - 3 units
- **Miscellaneous:**
    - Tarpaulin - 1 unit
    - Hot Man Bag with Tools - 1 unit
    - Hand Tools - 1 set

Safety is paramount in hotline work. By following these guidelines, utilizing the appropriate equipment, and prioritizing clear communication and qualified personnel, string replacement on energized lines can be conducted efficiently while minimizing risks.

String Replacement Procedure - Hotline Work (Up to 400 kV)

Preparation:

- Clean tools required for the job with lead-free petrol and arrange them on a tarpaulin.

Ladder Setup:

- Place the ladder on a wooden log and secure it with ladder clamps.
- Tie hot-man hand tools and the front yoke to the ladder for easy access.
- Fix the ladder yoke to the ladder and secure it with a safety pin.
- Attach the safety sling D-shackle to the ladder.
- Tie a side control rope to each main leg of the ladder for horizontal control. Coil and tie the remaining rope near the ladder yoke.

Cradle Assembly:

- Arrange the cradle sticks unevenly (for cold-man insertion) on either side of the center stick.
- Place and secure four/three cradle spacers evenly on the cradle and tighten them with a screwdriver.
- Tie two snub ropes of sufficient length to the cold-man side of the cradle for attaching it to the strain carrier pole.

Sending Crew and Hand Line:

- Dispatch the crew to the tower with PPEs. One crew member should carry the sling and hand line.
- Place the hand line on the tower directly above the designated ladder base location.
- Test the hand line by lowering the hook and pulling it back up.

Securing the Ladder:

- Request two personnel to sit on the tower at the designated ladder base location.
- Send the ladder base (tied with a snub rope) and screwdriver up the hand line.
- Fix the ladder base at the appropriate horizontal plate on the tower. One person holds the base while another secures it with a screwdriver.
- Tie the snub rope attached to the base with the tower structure.
- Hoist the ladder using the hand line with a clove hitch on both rungs.
- Attach the ladder to the base using a washer and tighten the nut and bolt.

Securing the Ladder and Setting Up Block & Tackle:

- Attach the ladder safety sling to the tower with a "0" shackle and remove the hand line.
- Fix one sling on the tower above the ladder base. Attach the free end of the block and tackle set to this sling and keep the rope inside the tower.
- The worker on the ladder climbs to position the ladder below the conductor where the string replacement will occur.

Raising the Ladder and Checking Leakage Current:

- Two personnel control the side control ropes to raise the ladder slowly and parallel to the conductor.
- Bring the ladder closer to the conductor by adjusting the control ropes. Touch the ladder to the conductor and use the leakage current monitor to check for leakage.

Preparing the Hot Man:

- Ensure the hot man is ready to begin work.

Cold End Yoke and Hot Man Access:

- Send the cold end yoke and instruct the cold man to fix it.
- The hot man ascends the ladder and touches the conductor with the hot man clamp, then secures the clamp firmly. Ensure the hot man is comfortable and stable.

Hot End Yoke and Strain Carrier Installation:

- Instruct the hot man to fix the hot end yoke with the attached strain carrier pole clamp after tying the yoke to the conductor.

Strain Carrier Pole and Cradle:

- Send the strain carrier pole up the hand line and instruct the cold man to pass it to the hot man for insertion into the hot end yoke. Use the trunion jack to manage the load.

- Send the cradle arrangement up the hand line and have the cold man pass it to the hot man for insertion into the hot end yoke rings.

String Removal:

- Verify the cradle is secure and all insulators are seated. Instruct the cold man to tie the ladder with the strain carrier pole and cold end.
- Set up the hand line lifting arrangement on the second insulator of the string.
- The cold man holds the first insulator and pulls the string slightly towards him. Remove the cotter pin/insulator pin. The cold man then places the hand line between the second and third insulators. Slowly raise the hand line while the cold man removes the string from the cradle and lowers it to the ground.

String Replacement:

- Replace faulty insulators with new, clean ones. Check the "R"/"M" pin of the string and send it up the hand line.
- Once the string reaches the cross arm, instruct the cold man to place it on the cradle while slowly releasing the hand line.
- The cold man takes the load slowly, ensuring proper string alignment on the hot man's side. The hot man then connects the string with the conductor and secures it.

Lowering the Load and Dismantling:

- Slowly release the load on the strain carrier pole, checking for proper insulator seating.
- Retrieve the cradle first and send it down to the ground.
- Detach and lower the strain carrier pole.

Hot Man Descent and Equipment Removal:

- Instruct the hot man to remove the hot man bag and descend the ladder safely.
- The hot man removes the hot end yoke and secures it to the ladder for descent.

Final Steps:

- Both hot man and cold man collaborate to remove all tools and tackles in reverse order, prioritizing safety and proper handling.

6.6 Structural Stability Testing (NDTs) of Towers

The structural stability test of transmission tower lines is an evaluation process to ensure the safety and reliability of power transmission infrastructure. This test involves non-destructive tests to ensure their integrity and safety, key tests include the ultrasonic pulse velocity test, which measures the velocity of ultrasonic pulses to detect internal flaws or variations. The rebound hammer test assesses the surface hardness of concrete to infer its strength. Hardness tests evaluate the resistance of tower materials to deformation, while thickness measurements verify the uniformity and adequacy of material thickness. Coating inspections ensure protective coatings are intact and effective. These non-destructive tests collectively help to identify potential weaknesses and ensure the transmission towers can maintain their structural integrity under various adverse conditions, thereby guaranteeing uninterrupted power transmission and minimizing the risk of outages or accidents.

6.6.1 Scope of Work

Before commencing the structural stability test of transmission tower lines, it is essential to conduct a safety toolbox talk and complete a comprehensive checklist. The safety toolbox talk will cover key safety protocols, potential hazards, and the necessary protective measures to ensure the safety of all personnel involved in the testing process. This discussion will also reinforce the importance of using personal protective equipment (PPE) and adhering to safety guidelines. Additionally, a detailed checklist must be filled out prior to starting the tests, ensuring that all required equipment is available, safety measures are in place, and the testing environment is secure. This preparatory step is crucial to identify and mitigate risks, ensuring a safe and efficient testing process.

6.6.2 Methodologies for Performing Non Destructive Tests (NDTs)

7 tests have been performed to analyze the health of the 220kV transmission line towers. The first test performed is the central alignment test.

Central Alignment Test

The central alignment test is a critical procedure performed during the preventive maintenance of 220 kV transmission line towers. It ensures the tower's central axis remains vertical, essential for maintaining structural integrity and safe operation.

Method Using Yarn and Pendulum Bob:

This is a simple yet effective method for verifying the central alignment of a transmission line tower. Here's how it's conducted:

1. **Preparation:**
    - Access the tower using appropriate safety gear and following established climbing procedures.
    - Gather the necessary materials: strong yarn, weights (for pendulum bob), tape measure, and a plumb bob (optional).

2. **Tying the Yarn:**
    - Secure one end of the yarn to a fixed point near the bottom leg of one side of the tower.
    - Extend the yarn diagonally upwards and tie it firmly to a corresponding point on the opposite bottom leg.
    - Repeat this process to create intersecting diagonals using yarn on all four sides of the tower, essentially forming a large "X" at the tower's base.
3. **Hanging the Pendulum Bob:**
    - Attach a weight to the yarn at the point where the two diagonals intersect in the center of the tower's base. This creates a simple pendulum bob.
4. **Measuring the Deviation:**
    - Allow the pendulum bob to settle and hang freely.
    - Measure the horizontal distance from the plumb line (either from the string itself or using a separate plumb bob) to the center of the pendulum bob at the bottom.
5. **Evaluating Results:**
    - Compare the measured deviation to the acceptable limit. Typically, the deviation should not exceed **0.2% of the total tower height**. For example;
      Let height of tower = 50 m =5000 cm
      Acceptable deviation = 0.2% of 5000 cm
      $= (0.2\times 50000)/100$
      = 10 cm

Benefits of Yarn and Pendulum Bob Method:

- **Simple and cost-effective:** Requires minimal equipment and readily available materials.
- **Easy to perform:** Can be conducted by qualified personnel with basic training.
- **Quick and efficient:** Provides a rapid assessment of the tower's central alignment.

Limitations:

- Accuracy may be affected by wind or swaying of the tower.
- Not suitable for very tall towers where the yarn length might introduce measurement errors.

Alternative Methods:

For greater precision, especially with tall towers, advanced techniques like **laser alignment or electronic inclinometers** might be employed.

Conclusion:

The central alignment test using yarn and a pendulum bob is a valuable tool for ensuring the structural integrity of 220 kV transmission line towers. It's a simple yet effective method that can be incorporated into routine maintenance programs to identify potential alignment issues and take corrective actions if necessary.

In the rest 6 tests, 3 of them are performed on the steel angles and bracings of the tower, and the rest 3 are performed on the RCC foundation of the tower.

Tests on steel:

1. Ultrasonic Thickness Test

2. Leeb Hardness Test

3. Coating Thickness Test

Test on RCC foundation:

1. Ultrasonic Pulse Velocity Test

2. Rebound Hammer Test

3. Cover Meter Test

1.ULTRASONIC THICKNESS TEST ON STEEL PART

Ultrasonic Testing (UT) uses high frequency sound energy to conduct examinations and make measurements. Ultrasonic inspection can be used for flaw detection or evaluation, dimensional measurements, material characterization. Ultrasonic thickness testing is a widely used non-destructive test technique for measuring the thickness of a material from one side. It is fast, reliable, and versatile.

Working principle:

Ultrasonic thickness gauges work by very precisely measuring how long it takes for a sound pulse that has been generated by a small probe called an ultrasonic transducer to travel through a test piece and reflect back from the inside surface or far wall. Because sound waves reflect from boundaries between dissimilar materials, this measurement is normally made from one side in a "pulse/echo" mode. The transducer contains a piezoelectric element which is excited by a short electrical impulse to generate a burst of ultrasonic waves. The sound waves are coupled into the test material and travel through it until they encounter a back wall or other boundary. The reflections then travel back to the transducer, which converts the sound energy back into

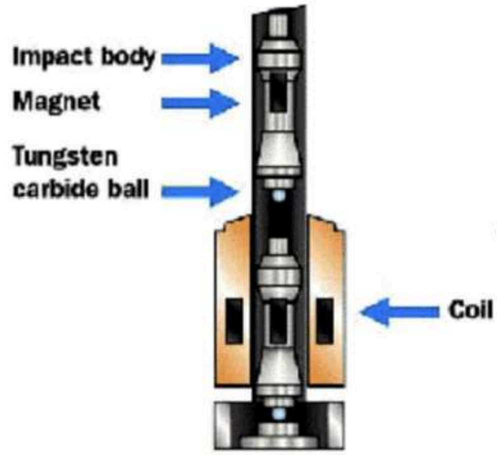
electrical energy. In essence, the gage listens for the echo from the opposite side. Typically, this time interval is only a few millionths of a second. The gage is programmed with the speed of sound in the test material, from which it can then calculate thickness using the simple mathematical relationship.
Working formula:

$$T = (V) \times \ (t/2)$$

where
T = thickness,
V = the velocity of sound in the test material,
t = the measured round-trip transit time
It is important to note that the velocity of sound in the test material is an essential part of this calculation. Different materials transmit sound waves at different velocities, generally faster in hard materials and slower in soft materials, and sound velocity can change significantly with temperature Thus it is always necessary to calibrate an ultrasonic thickness gage to the speed of sound in the material being measured, and accuracy can be only as good as this calibration. Sound waves in the megahertz range do not travel efficiently through air, so a drop of coupling liquid is used between the transducer and the test piece in order to achieve good sound transmission. Common copulations are glycerine, propylene glycol, water, oil, and gel. Only a small amount is needed, just enough to fill the extremely thin air gap that would otherwise exist between the transducer and the target. Accuracy: Many factors affect measurement accuracy in a given application, including proper instrument calibration, uniformity of material sound velocity, sound attenuation and scattering, surface roughness, curvature, poor sound coupling, and back wall non-parallelism. All of these factors should be considered when selecting a gauge and transducer. With proper calibration, measurements can usually be made to an accuracy of +/- 0.001" or 0.01 mm, and in some cases, accuracy can approach 0.0001”- or 0.001-mm. Accuracy in a given application can best be determined through the use of reference standards of precisely known thickness. In general, gauges using delay line or immersion transducers for Mode 3 measurements are able to determine the thickness of a part most precisely.

2. LEEB HARDNESS TEST ON STEEL PART

It is a rebound test method, which means that in order to determine the hardness value of a test piece, the velocity of an impactor is measured before and after the impact. The ratio of rebound velocity to the impact velocity is the measure of the dynamic Leeb hardness of the test specimen.



Working Principle:

According to Leeb's dynamic principle, The hardness test method works by the bounce of a specimen body which is to be tested on the surface. Then the rebound of velocity is measured comparative to the incident velocity. Outcomes depend on the hardness of the test materials. The value of the hardness and the speed of the rebound increases with the increase in the hardness of the test object.

Measurement method: In the Leeb hardness testing method, the hardness value can be calculated from the energy loss of an impact body after impacting upon a metal. This Leeb quotient is equivalent to the measure of that energy loss due to deformation. In the Leeb hardness testing method, the hardness value can be calculated from the energy loss of an impact body after impacting upon a metal. This Leeb quotient is equivalent to the measure of that energy loss due to deformation. When an impact device accelerates an impact body with the help of spring force, the velocity of the impact body gets segregated into three phases:

Approach phase – Here, the impact body is accelerated in the direction of the test surface with the help of the spring force.

Impact phase – In this phase, the impact body as well as the specimen remain in direct contact. The specimen gets plastically or elastically deformed and the impact body comes to the standstill. This elastic springback nature of the impact body, as well as the specimen, helps the impact body to rebound.

Rebound phase – Here, the impact body is again accelerated out of the impact phase with the resultant energy. These velocities are measured without any contact through an induced voltage, produced by a magnet moving in a deδined coil of the impact device. This induced voltage is logged electronically where the peak values, the point of the impact phase as well as the rebound phase, are used to determine the Leeb hardness. The ratio of the rebound velocity (vr) to the impact velocity (vi) multiplied by a factor of 1000, shows the Leeb hardness value.

These velocities are measured without any contact through an induced voltage, produced by a magnet moving in a deδined coil of the impact device. This induced voltage is logged electronically where the peak values, the point of the impact phase as well as the rebound phase, are used to determine the Leeb hardness, as seen in the δigure below. The ratio of the rebound velocity (vr) to the impact velocity (vi) multiplied by a factor of 1000, shows the Leeb hardness value.

Hardness = (VR:VI) x 1000

3. COATING THICKNESS TEST ON STEEL PART

Due to corrosion, the steel zinc-coating in steel transmission towers will get thinner and even fall off from steel member surfaces, during the long term usage of the steel structures. Without the protection of zinc-coating, the steel in the towers was very easy to oxidize, and when the corrosion process began, the steel member would soon lose its weight and the effective section of the steel members would decrease. Thus the thickness of steel members' zinc coating becomes a very important parameter to predict the reliability of the exposed steel members. when testing the total thickness. However, steel coating usually contains not only zinc-coating but coat of painting and other layers, and zinc-coating can hardly be separated during the measurement. The standard thickness of the coating film with the undercoat paint is set within the range of 60 to 90 μm.

3. ULTRASONIC PULSE VELOCITY TEST ON RCC

It is performed to determine

i. Quality of concrete and density

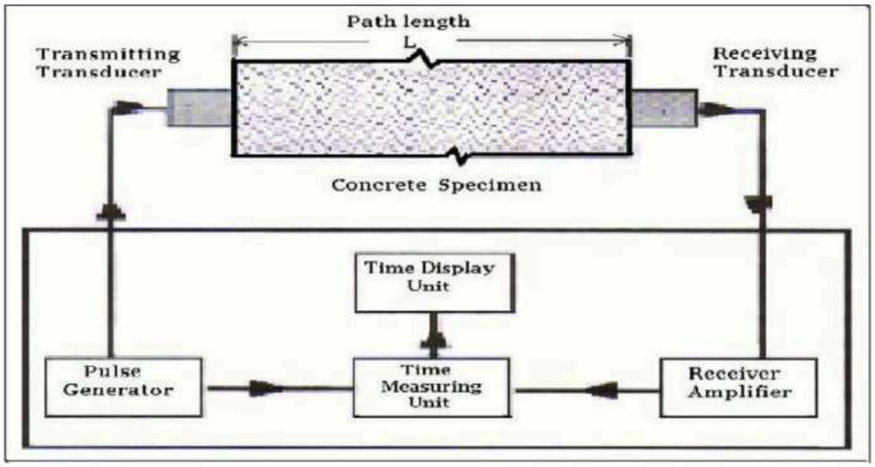
ii. Presence of cracks voids, honeycomb and other imperfections

iii. Changes in the structure of concrete which may occur with time.

iv. Quality of one element of concrete in relation to another i.e. comparative quality analysis and

v. gradation of concrete

vi. The values of dynamic elastic modulus of the concrete



Methodology of testing

In this test method, the ultrasonic pulse is produced by the transducer which is held in contact with one surface of the concrete member under test. After traveling a known path length L in the concrete, the pulse of vibrations is converted into an electrical signal by the second transducer held in contact with the other surface of the concrete member and an electronic timing circuit enables the transmit time(T) of the pulse to be measured.

The pulse velocity(V) is given by:

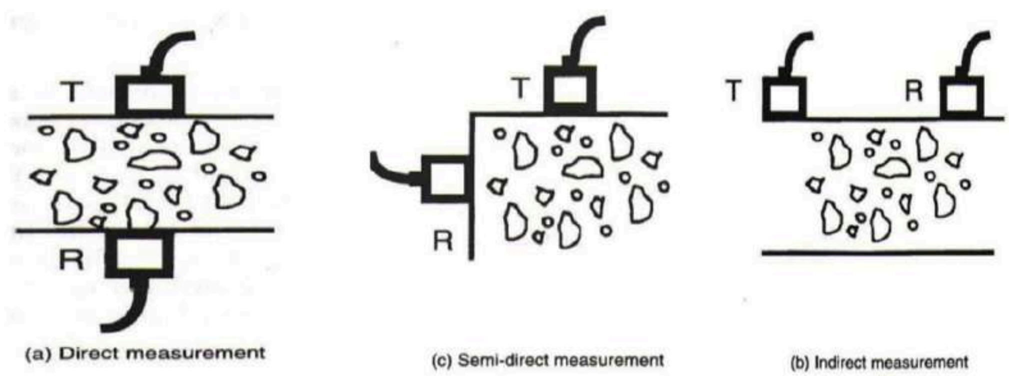
$$V = L/T$$

Once the ultrasonic pulse impinges on the surface of the material, the maximum energy is propagated at right angles to the face of the transmitting transducer and obtained when the receiving transducer is placed on the opposite face of the concrete member (direct measurement). However, in many situations two opposite faces of the structural member may not be accessible for measurements. In such cases, the receiving transducer is also placed on the same face of the concrete members (indirect method). To ensure that the ultrasonic pulses generated at the transmitting transducer pass into the concrete and are then detected by the receiving transducer by using semidirect method.

If there is a very rough concrete surface, it is required to smoothen and level an area of the surface where the transducer is to be placed, for that we use grease to clean the surface area. A minimum path length of 150 mm is recommended for the direct transmission method. The natural frequency of transducers should preferably be within the range of 20 to 150 kHz. Generally, high frequency transducers are preferable for short path lengths and low frequency transducers for long path lengths Transducers with a frequency of 50 to 60 kHz are useful for most all-round applications. Since size of aggregates in6luences the pulse velocity measurement, it is recommended that the minimum path length should be 100 mm for concrete in which the nominal maximum size of aggregate is 20 mm or less and 150 mm for concrete in which the nominal maximum size of aggregate is between 20 to 40 mm. Transducers are held on corresponding points of observation on opposite faces of a structural element to measure the

ultrasonic pulse velocity by direct transmission.
Velocity Criterion for Concrete Quality Grading

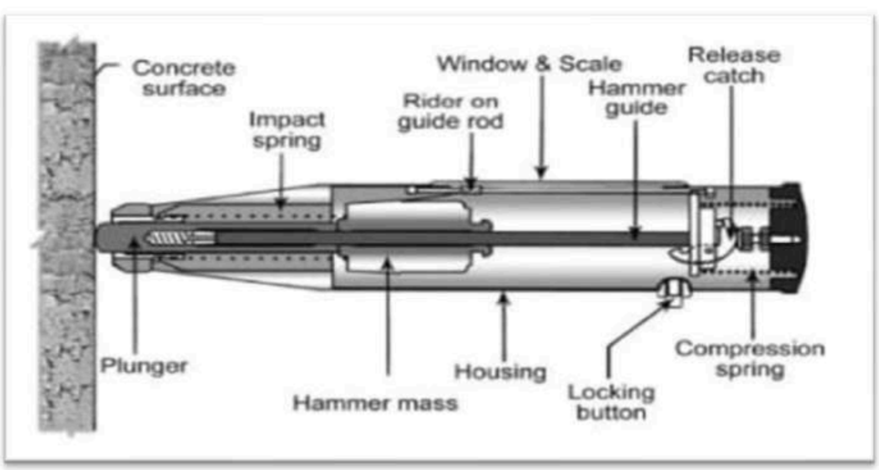
S.No.	USPV by cross probing (km/sec)	Concrete Quality Grading
1	Above 4.5	Excellent
2	4.5 to 3.5	Good
3	3.5 to 3.0	Medium
4	Below 3.0	Doubtful



5. REBOUND HAMMER TEST ON RCC

It is performed to determine:

• To check the compressive strength of concrete with the help of suitable correlations between rebound index and compressive strength.
• Uniformity of concrete over the structure
• Quality of the concrete
• Grade of concrete



Principle of working:
When the plunger of a rebound hammer is pressed against the surface of the concrete, the spring-controlled mass rebounds and the extent of such rebound depends upon the surface hardness of concrete. The surface hardness and therefore the rebound is taken to be related to the compressive strength of the concrete. The rebound is read off along a graduated scale and is designated as the rebound number or rebound index.

Testing Procedure:
1.For testing, smooth, clean and dry surface is to be selected. Rough surface results incomplete compaction, loss of grout, spalled or tooled surfaces do not give reliable results and should be avoided.
2.The point of impact should be at least 25 mm away from any edge or shape discontinuity.
3.For taking a measurement, the rebound hammer should be held at right angles to the surface of the concrete.
4. The test can thus be conducted horizontally on vertical surfaces or vertically upwards or downwards on horizontal surfaces. If the situation demands, the rebound hammer can be held at intermediate angles also, but in each case, the rebound number will be different for the same concrete.
5.Rebound hammer test is conducted around all the points of observation on all accessible faces of the structural element. Concrete surfaces are thoroughly cleaned before taking any measurement. Around each point of observation, six readings of rebound indices are taken and average of these readings after deleting outliers as per IS/ISO 16269.

Interpreting the Results

S. No	Location	Rebound Number	Quality of Concrete
1	Point 1	Above 40	Very Good Layer
2	Point 2	30 - 40	Good Layer
3	Point 3	20 - 30	Fair
4	Point 4	Below 20	Poor

5. COVER METER TEST ON RCC
Rebar locator test was conducted by Hilti PS 85. The purpose of scanning is basically to have a better idea of the location, spacing and cover of reinforcing steel. This has got two purposes one is to ease the Drilling of holes with diamond tip drills and second is to give an idea of a steel inside structure which Otherwise, cannot be ascertained for a structure for which no reinforcing details are available. The detection of reinforcements and their spacing is a prerequisite before extraction of concrete cores.

Working Principle: The equipment used at site for the determination of cover and locating reinforcement bars was model Hilti PS 85 manufactured. Hilti PS 85 uses electromagnetic pulse induction technology to detect rebar. Coils in the probe are periodically charged by current pulses and thus generate a magnetic field. On the surface of any electrically conductive material which is in the magnetic field eddy currents are produced. They induced a magnetic field in the opposite direction. The resulting change in voltage can be utilized for the measurement. When rebars corrode the resulting volume expansion leads to concrete spalling and consequently to the cracking of the plaster. Extensive deterioration affects not only the residents' safety but also the structure's service life.

Testing procedure: Place the Hilti PS 85 on the test surface and move it slowly in chosen direction. Continue sweeping until the ri6le scope is in the center of the screen. When it is centered exactly the LED indicator will light. The rebar is directly beneath the measurement center. This center line is marked on the surface under test by means of a pointed marker. The Hilti PS 85 is moved away parallel to the center line to locate the next bar and the center line of the next line is obtained following the same procedure. This new center line is also marked on the surface by means of pointed marker. Depending on the requirement 3 such bars are located and the average spacing is given as the spacing of the bars. The covers for each case are noted and the average of the cover is also given as the cover.

Cover Depth (IS:456 2000): -Minimum required cover depth for Beam:30mm, Column: 40mm, Slab: 15 ±5 mm RCC wall in contact with water 45 ±10mm & for general RCC wall 20mm ± 5mm

6.7 Earthing Maintenance

Designing a safe and effective earthing system requires careful consideration of soil properties. Soil resistivity, especially how it changes with moisture, temperature, and depth, significantly impacts the resistance of the grounding electrode. This knowledge is crucial for achieving a low and stable earthing resistance throughout the system's lifespan at minimal cost. Factors like soil layering (stratification), electrode type and size, and burial depth further complicate achieving the desired earthing resistance.

6.7.1 Theory of Soil Resistivity

Resistance is that property of a conductor which opposes electric current flow when a voltage is applied across the two ends. Its unit of measure is the Ohm (Ω) and the commonly used symbol is R.

Resistance is the ratio of the applied voltage (V) to the resulting current flow (I) as defined by the well known linear equation from Ohm's Law:

$$V = I \times R$$

where: V is Potential Difference across the conductor (Volts)
I is Current flowing through the conductor in (Amperes)
R is Resistance of the conductor in (Ohms)

Resistivity is also sometimes referred to as "Specific Resistance" because, from the above formula, Resistivity (Ω-m) is the resistance of a material between the opposite side of the cube of the material with side of 1 meter. It is measured in Ω-m.

$$1\Omega\text{-m} = 100\Omega\text{-cm}$$

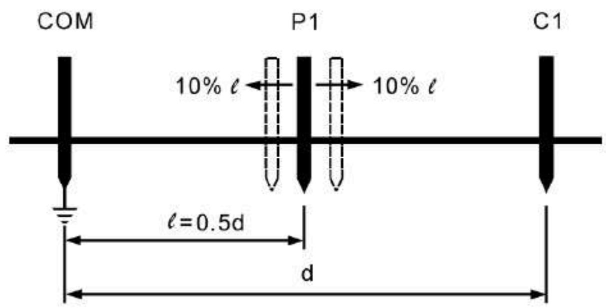
The following table shows how typical values alter with changes in soil

Type of Soil or Water	*Typical Resistivity Ωm*	*Usual Limit Ωm*
Sea water	2	0.1 to 10
Clay	40	8 to 70
Ground well & spring water	50	10 to 150
Clay & sand mixtures	100	4 to 300
Shale, slates, sandstone etc	120	10 to 100
Peat, loam & mud	150	5 to 250
Lake & brook water	250	100 to 400
Sand	2000	200 to 3000
Moraine gravel	3000	40 to 10000
Ridge gravel	15000	3000 to 30000
Solid granite	25000	10000 to 50000
Ice	100000	10000 to 100000

6.7.2 Soil Resistivity Testing Procedure

The main purpose of soil resistivity testing is to gain valuable information for designing and maintaining effective earthing systems in electrical installations.

- **Fall of Potential Method**
  The Fall of Potential Method is a simple and common way to measure earth resistance, especially for small systems. It involves placing two stakes in the ground and measuring voltage drop. However, for accurate results in larger systems, the stake placement is crucial. The method recommends taking three measurements with the voltage stake positioned at slightly different distances. If the readings agree, the average is your earth resistance. If not, you need to reposition the stakes farther away or in a different direction and repeat the measurements until you get consistent results.



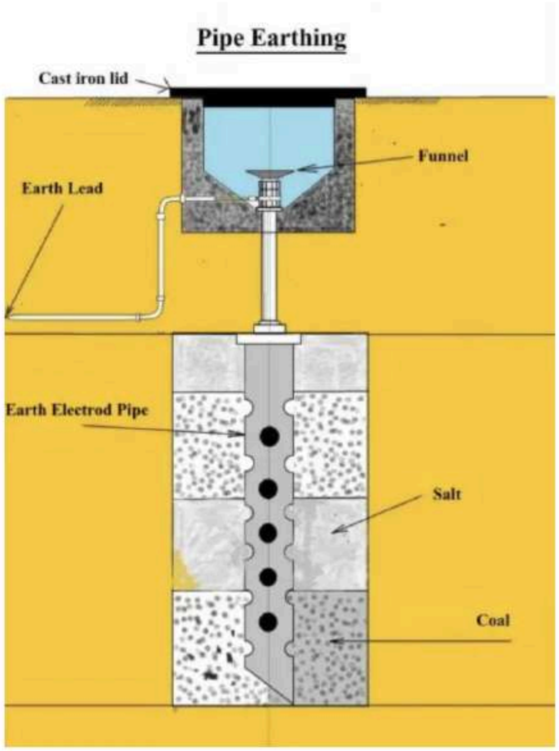
- **The 62% Method**
  The Fall of Potential method can be adapted slightly for use with medium sized earthing systems. This adaptation is often referred to as the 62% Method, as it involves positioning the inner test stake at 62% of the earth electrode-to-outer stake separation (recall that in the Fall-of-Potential method, this figure was 50%). All the other requirements of test stake location - that they be in a straight line and be positioned away from other structures - remain valid. When using this method, it is also advisable to repeat the measurements with the inner test stake moved ±10% of the earth electrode-inner test stake separation distance, as before. The main disadvantage with this method is that the theory on which it is based relies on the assumption that the underlying soil is homogeneous, which in practice is rarely the case. Thus, care should be taken in its use and a soil resistivity survey should always be carried out. Alternatively, one of the other methods should be employed.
- **The Slope Method**
  This method is suitable for use with large earthing systems, such as sub-station earths. It involves taking a number of resistance measurements at various earth system to voltage electrode separations and then plotting a curve of the resistance variation between the earth and the current. From this graph, and from data obtained from tables, it is possible to calculate the theoretical optimum location for the voltage electrode and thus, from the

resistance curve, calculate the true resistance. The additional measurement and calculation effort tends to relegate this system to use with only very large or complex earthing systems. For full details of this method, refer to paper 62975, written by Dr G.F. Tagg, taken from the proceedings of IEE volume 117, No 11, Nov. 1970.

- **The Star-Delta Method**
  This technique is well suited to use with large systems in built up areas or on rocky terrain, where it may be difficult to find suitable locations for the test electrodes, particularly over long distances in a straight line. Three test electrodes, set up at the corners of an equilateral triangle with the earth system in the middle, are used and measurements are made of the total resistance between adjacent electrodes, and also between each electrode and the earthing system. Using these results, a number of calculations are performed and a result can be obtained for the resistance of the earth system. This method, developed by W. Hymers, is described in detail in Electrical Review, January 1975.
- **The Four Potential Method**
  This technique helps overcome some of the problems associated with the requirement for knowing the electrical center of the earthing systems being tested. This method is similar in set up to the standard Fa measurements are made with the voltage electrode at different positions and a set of equations are used to calculate the theoretical resistance of the system. The main drawback with the Four Potential method is that, like with the Fall of Potential method, it can require excessive electrode separation distances if the earthing system being measured is large.

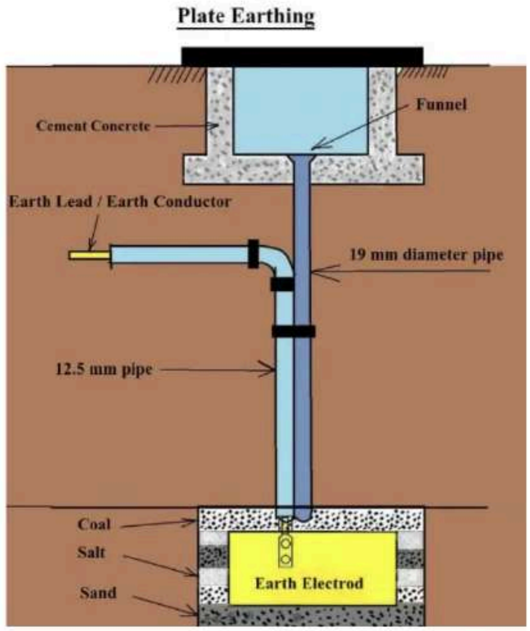
6.7.3 Different types of Earthing Techniques

1. Pipe Earthing



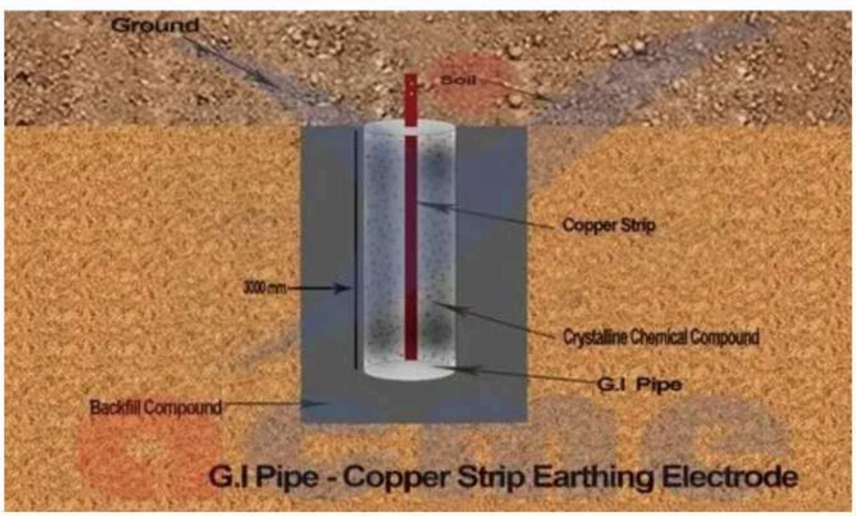
- Uses a galvanized steel pipe (typically 38mm diameter, 2 meters long) driven vertically into the ground.
- Effectiveness depends on soil moisture and fault current. Moister soil allows for deeper placement.
- Considered a cost-effective and efficient earthing method.

2. **Plate Earthing**



- Employs a copper or galvanized iron plate buried vertically in a ground pit, less than 3 meters deep.
- Maintaining soil moisture around the plate is crucial for optimal performance.
- The plate connects to electrical conductors to divert electrical charges into the earth.

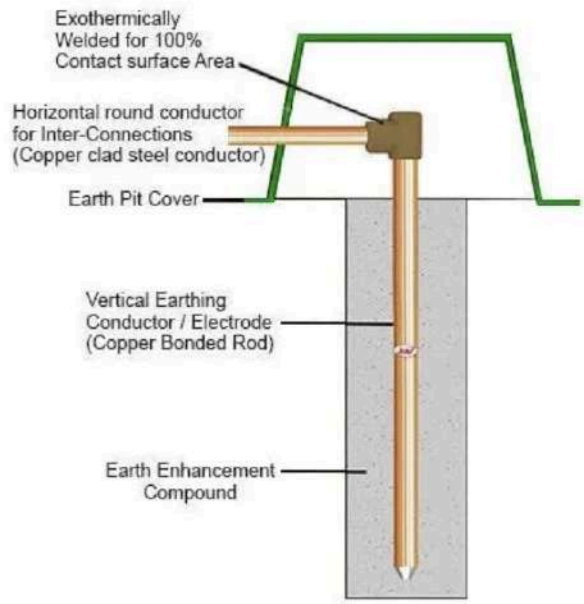
3. **Strip or Wire Earthing**



- Utilizes flat strip electrodes (minimum cross-sectional area 6.0 mm²) buried horizontally in trenches at least 0.5 meters deep.
- Galvanized iron or steel strip electrodes require a larger minimum cross-sectional area (25 mm x 1.6 mm).

- A minimum conductor length of 15 meters buried in the ground is recommended for sufficient earthing.

4. **Rod Earthing**



- Involves driving a copper rod (sometimes encased in galvanized steel pipe) vertically into the ground.
- The depth of the rod placement directly affects the earthing resistance (deeper = lower resistance).
- This method is suitable for sandy soil and offers a cost-effective solution.
- The rod diverts short-circuit current safely into the ground.

5. **Chemical Earthing**

- An earthing pit with chemical earthing requires as much as 50 liter water every year.
- Bentonite which is used in chemical earthing has a resistivity of 3 ohms.
- A chemical earthing pit has a life of about 6-8 years.
- As the life cycle is low, there is a recurring cost of copper, drilling, and re-installation in the case of chemical earthing.
- Chemicals used in the chemical earthing leaches out in the soil leading to soil pollution and is not chemically inert

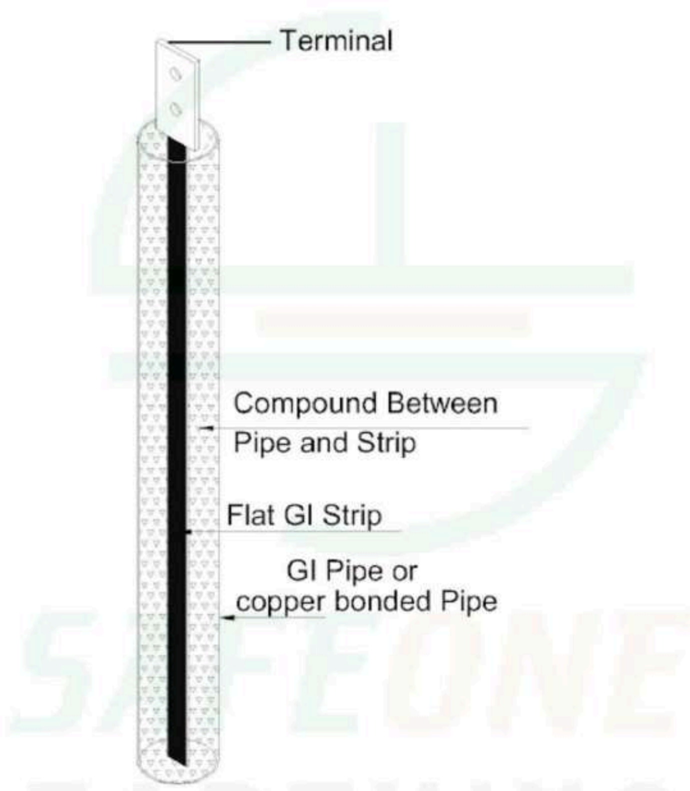
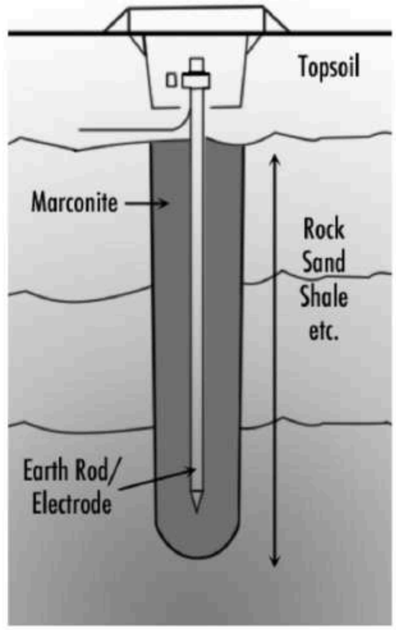


Fig: chemical earthing

6. **Marconite Concrete Conductive Earthing**

- **Marconite:Cement:Water** ratio is **3:1:1** by weight
  It is also available as premix of standard 25kg
- Marconite has resistivity of **0.001 ohm m**. The final mixture has a resistivity of **0.1 ohm m**.
- It is **versatile**: suits most ground conditions
- It has long **life span of 25 years** and thus acts like a permanent solution for 25 years, with no periodic maintenance like adding water, in case of charcoal and salt earthing, making it cost effective.

- It is chemically inert, thus is non corrosive to steel and copper.



Case Study

Jindal Steel and Power, Raigarh: Upgrading Earthing with Marconite Concrete
The Challenge:

Jindal Steel and Power, Raigarh, a steel making company in India, encountered a critical issue with their 220 kV transmission towers. Routine testing revealed high tower foot resistance in over half (more than 50) of their 242 towers. This high resistance compromises the effectiveness of the earthing system, posing a safety risk and potentially impacting equipment functionality.

The Traditional Solution (Salt & Charcoal Earthing):
Traditionally, salt and charcoal backfill have been used as a cost-effective earthing solution. However, this method has limitations:

- **Moisture Dependence:** Salt and charcoal rely on consistent moisture content in the soil to maintain conductivity. This can be problematic in dry climates or during seasonal changes.
- **Maintenance Intensive:** Regular watering and top-up of the salt and charcoal mixture are necessary to ensure effectiveness, increasing maintenance costs.
- **Corrosion Concerns:** Salt can accelerate the corrosion of metallic earthing components over time, leading to system deterioration.

What is Marconite?

- Marconite is a synthetic, electrically conductive material specifically designed for earthing applications.
- Unlike Bentonite clay, it's not a natural mineral.
- It appears dark gray and has a granular consistency.

Marconite as Earthing Material:

- Replaces traditional sand and aggregate in earthing concrete.
- Mixing ratio: 3 parts Marconite to 1 part cement by weight, with 1 liter of water per 4 Kg of total mix.
- Marconite premix option available: pre-weighed Marconite and cement powder in a 25 Kg bag, requiring only 5 liters of water for mixing.

Properties:

- **Low resistivity:** 0.001 ohm m (Marconite itself)
- Final concrete mix resistivity: 0.1 ohm m
- Relatively dry mix with a density of 1300 Kg/m^3 after pouring.
- Curing time: touch dry within hours, fully cured in several days.
- Water content is adjustable but affects final strength and drying time.

Benefits:

- **Low resistivity:** Ensures effective earthing performance.
- **Versatile:** Suitable for most ground conditions.
- **Long-term reliability:** Over 25 years of lifespan.
- **Cost-effective:** Permanent solution with minimal maintenance compared to traditional methods (charcoal & salt) that require frequent watering.
- **Chemical inertness:** Does not corrode steel or copper components.

Benefits Achieved at Jindal Steel and Power, Raigarh:
By implementing Marconite concrete conductive earthing, Jindal Steel and Power, Raigarh achieved several key benefits:

- **Enhanced Safety:** Lower tower foot resistance ensures a more effective earthing system, minimizing the risk of electrical accidents for personnel and equipment.
- **Improved Reliability:** Consistent earthing performance, independent of weather conditions, reduces the risk of equipment malfunctions and downtime.

- **Reduced Maintenance Costs:** Minimal maintenance requirements of Marconite lead to significant cost savings compared to the ongoing maintenance needs of salt and charcoal backfill.
- **Increased System Lifespan:** The long-lasting properties of Marconite contribute to the overall longevity of the earthing system.

Fig: Pouring fresh cast mixture and electrode into the earthing pit.

Conclusion:
Jindal Steel and Power, Raigarh's case exemplifies the significant advantages of Marconite concrete conductive earthing over traditional salt and charcoal methods. By prioritizing safety, reliability, and cost-effectiveness, Marconite offers a superior solution for long-term earthing system performance.

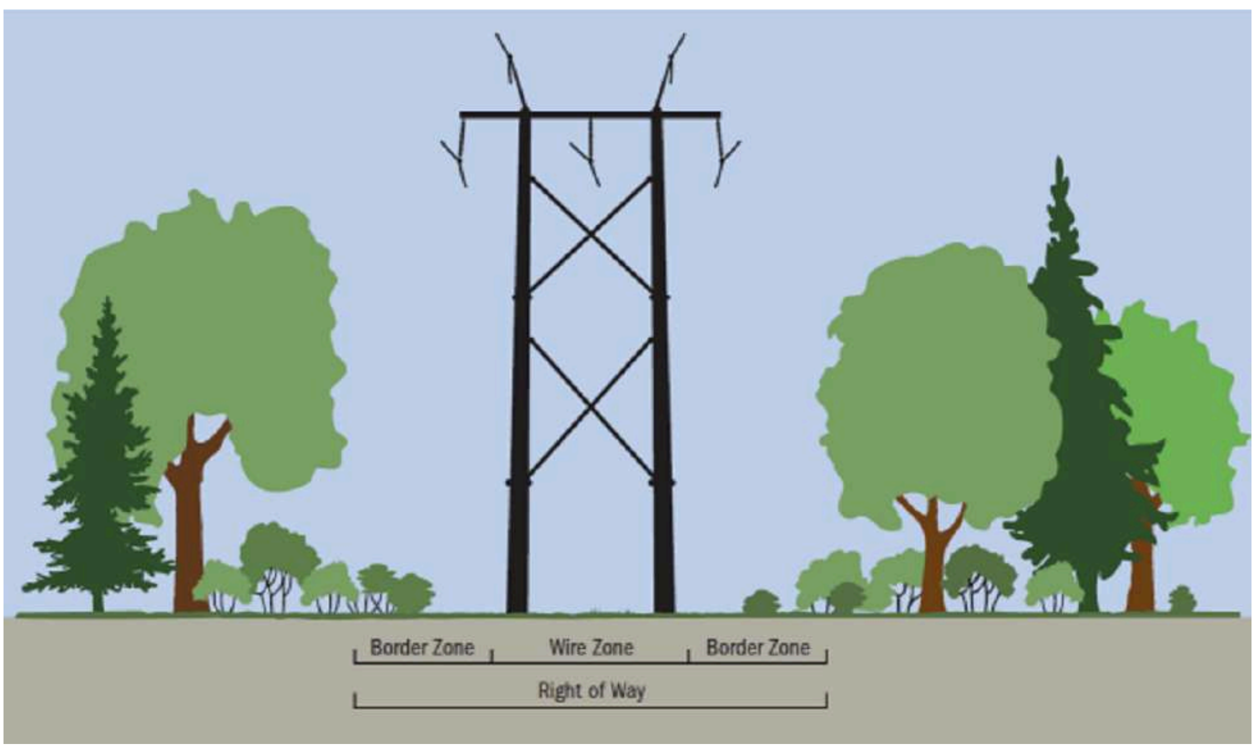
6.8 Right Of Way (ROW)

ROW is a designated strip of land specifically for constructing, operating, maintaining, and ensuring the safety of a transmission line. The Right of Way (ROW) for transmission lines refers to a designated corridor of land crucial for the following purposes:

- **Construction:** This strip of land facilitates the building of transmission line towers and infrastructure.
- **Operation and Maintenance:** The ROW allows for the safe and efficient operation of the transmission line, including maintenance activities.
- **Safety:** Maintaining a clear ROW minimizes the risk of electrical hazards by keeping the power lines clear of obstructions.

Here's a breakdown of key aspects of ROW in transmission lines for India:

- **Location:** The transmission line runs through the center of the designated ROW corridor.
- **Width Determination:** The maximum width of the ROW varies depending on several factors:
    - **Voltage Level:** Higher voltage transmission lines typically require wider ROWs due to increased safety clearances and potential for larger conductor swing.
    - **Wind Speed:** Areas with higher wind speeds necessitate wider ROWs to account for conductor movement.
    - **Conductor Sag:** The natural dip of the conductors between towers influences ROW width.
    - **Tower Design:** The type and dimensions of the towers used impact the required clearance within the ROW.
    - **Safety Regulations:** National and regional safety standards dictate minimum clearances around the transmission lines.
- **Regulatory Body:** The Ministry of Environment and Forest (MoEF) in India sets forth guidelines for ROW width based on voltage level and other considerations.



Obtaining ROW:

Acquiring the land for the ROW can be a complex process involving negotiations with landowners and following established legal procedures. Compensation is typically provided to those whose land falls within the designated ROW.

Importance of ROW Management:

Effective ROW management is essential for ensuring the safe, reliable, and efficient operation of transmission lines. This involves:

- **Vegetation Management:** Controlling vegetation and **tree growth** within the ROW to prevent interference with the power lines.
- **Debris Removal:** Regularly removing **metallic duct particles, dry grass**, and vegetation and any tall structures like **sheds** must be removed from the line corridor and tower corridor to minimize the risk of short circuits between lines.
- **Access Management:** Maintaining **access for maintenance crews** and ensuring unauthorized access is restricted.
- **Public Awareness:** Educating the public about the importance of ROW and the potential hazards associated with transmission lines.

Fig: tree trimming and access for maintenance crew

By adhering to established ROW regulations and implementing proper management practices, India can ensure the safe and efficient operation of its transmission network.

ROW For Different Transmission Line Voltage

Transmission Line Voltage	Right of Way in Meters
11 kV	7
33 kV	15
66 kV	18
110 kV	22
132 kV	27
220 kV	35
400 kV S / C (Single Circuit)	46
400 kV D / C (Double Circuit)	46
± 500 kV HVDC	52
765 kV S / C (Single Circuit With Delta Configuration)	64
765 kV D / C (Double Circuit)	67
± 800 kV HVDC	69
1200 kV	89

Width Clearance For Conductor / Bundle Conductor

The following width clearance would be permitted for below each conductor or conductor bundle

Transmission line with bundle conductor	Width Clearance below each conductor or Bundle conductor (meter)
Up to 400 kV Twin Bundle	3
400 kV Triple Conductor	5
400 kV / ± 500 kV HVDC / 765 kV Quadruple Bundle	7
± 800 kV HVDC / 765 kV Hexagonal Bundle	10

Minimum Clearance Between Trees and Transmission Line

The minimum clearance between trees and transmission is given as below.

Transmission Line Voltage	Minimum Clearance Between Transmission Line and Trees
11 kV	2.6
33 kV	2.8
66 kV	3.4
110 kV	3.7
132 kV	4
220 kV	4.6
400 kV	5.5
± 500 kV HVDC	7.4
765 kV D / C	9
± 800 kV HVDC	10.6
1200 kV	13

Minimum clearances in meters between lines when crossing each other

Nominal System Voltage	11-66 KV (in m)	110-132KV (in m)	220KV (in m)	400KV (in m)	800KV (in m)
Low and medium	2.44	3.05	4.58	5.49	7.94
11-66 KV	2.44	3.05	4.58	5.49	7.94
110-132KV	3.05	3.05	4.58	5.49	7.94
220KV	4.58	4.58	4.58	5.49	7.94
400KV	5.49	5.49	5.49	5.49	7.94
800KV	7.94	7.94	7.94	7.94	7.94

Thus, the Right of Way (ROW) is a crucial designated corridor for constructing, operating, and maintaining transmission lines. Proper ROW management is essential for safety and reliability. This includes vegetation control, access management, public awareness, and meticulous debris removal. By eliminating metallic particles, dry grass, and vegetation within the ROW, the risk of short circuits and wildfires is minimized. Effective ROW management safeguards the integrity of transmission lines, guaranteeing efficient power delivery.

7. Relay Protection and Fault Detection

7.1 Faults

An electrical fault is an abnormal condition in an electrical system that causes electricity to flow unintentionally. This can happen in various ways, disrupting the normal flow of current and potentially leading to hazards or equipment damage.

Causes of faults in transmission lines:

• **Open circuit faults**, which are caused by break in conductor at the joint, mal operation in circuit breakers or isolators

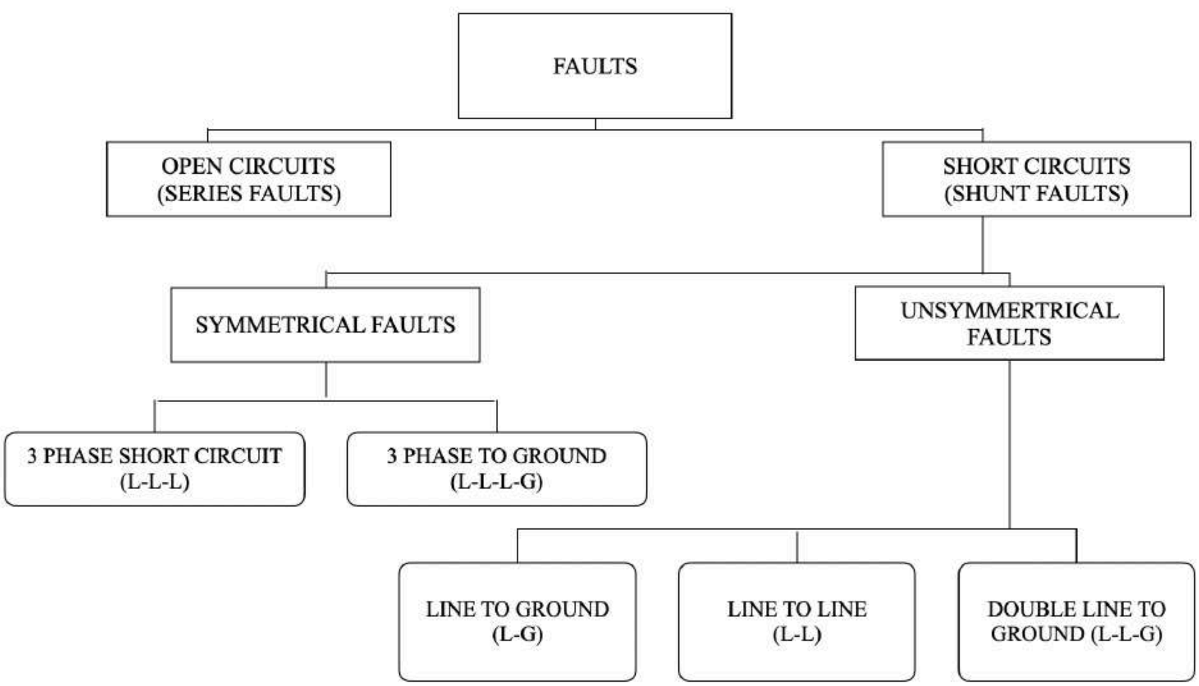
• **Short circuit faults**:

i. Overvoltages due to **switching surges** or **lightning** may cause flashover on the surface of insulators and may lead to puncture of insulators

ii. External objects falling on the transmission lines such as tree branches, birds, snakes, etc that lead to **L-G, L-L, L-L-G, L-L-L faults**.

iii. Certain foreign particles, like **metallic dust, cement dust**, from industries or salt in coastal areas accumulate on the insulator surface and lead to flashover.

7.2 Classification of Faults:



7.3 Effects of Faults

• Faults lead to surge in current, which can lead to overheating and high mechanical forces, thus may damage the equipment.
• Arcs associated with short circuiting may result in fire hazards.
• Unbalanced faults lead to negative sequence currents and heating in rotating machines.
• Faults lead to eventual loss in system stability
• Most importantly, it leads to revenue losses of industries due to interruption of power

Some Fault Statistics

Element	Percentage of Total Faults
Overhead lines	50%
Underground Cables	9%
Transformers	10%
Generator	7%
Switchgear	12%
Control Equipments	12%

Faults in Transmission Lines

Fault Type	Percentage Probability
L-G	85%
L-L	8%
L-L-G	5%
L-L-L	2%

Note: these are the general trends seen in the industry, not specific data of any specific organization or company.

7.4 Components of Protection System

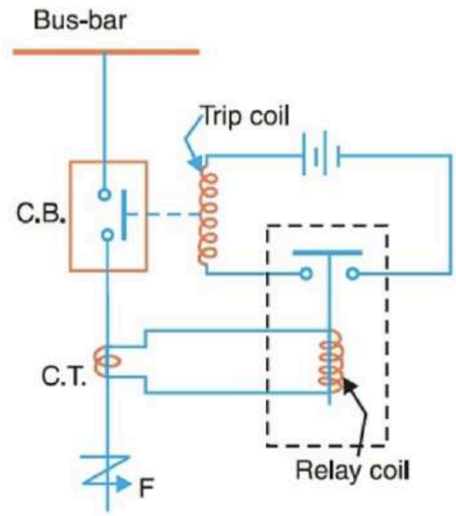


Fig: schematic diagram of working of protective system

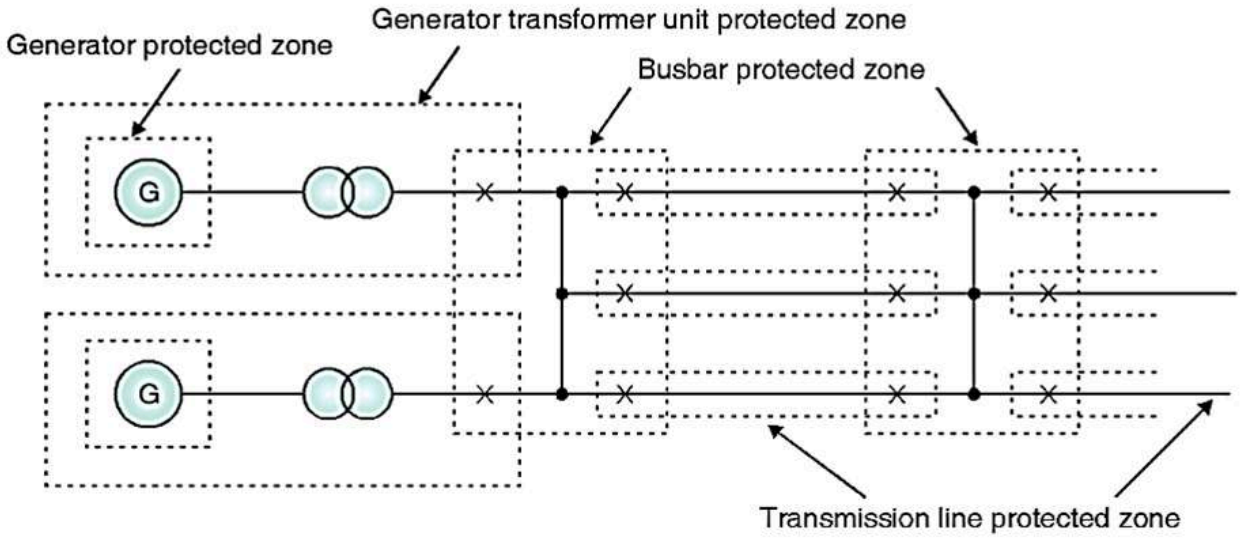
- The **Transducers (CT and PT)** are used to reduce the current and voltages to standard lower values (5A, 110V) and to isolate the protective relays from high voltages of the power system. The burden of transducers should be as minimum as possible so that the main circuit characteristics are not changed.
- The **Protective Relays** detects the abnormal conditions and sends a tripping signal to the circuit breaker. Relays can be over current, over voltage, under voltage, directional, differential, over (or) under frequency, earth fault, negative sequence relays.
- When the relay closes the **trip circuit**, the battery energizes the trip coil and operates the circuit breaker when fault occurs. The voltage may drop to a very low value and hence the power will not be available at the substation to supply power to the tripping circuit.
- Thus a battery power bank is kept in reserve to supply DC power. Sometimes, fault rectification may take 8-12 hours, thus battery capacity must be sufficient.
- The trip coil activates the circuit breaker operating mechanism to operate the **circuit breaker**, which has a fixed and a moving contact. The moving contact opens or closes the circuit breaker.
- The moving contact movement leads to arc formation, thus arc quenching mechanism is used.

7.5 Protective Relay

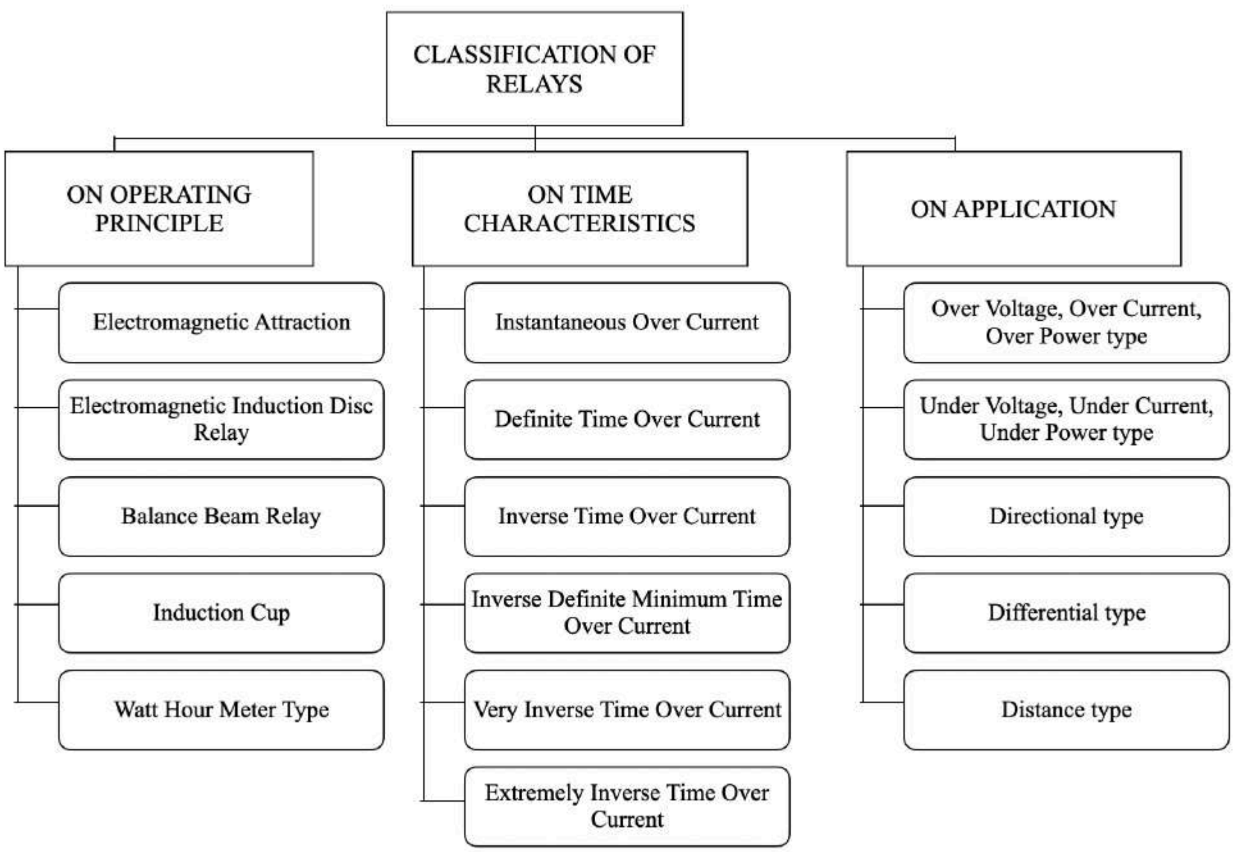
Relay is a sensing device which senses abnormal conditions in the power system and sends a signal to the circuit breaker to remove faulty parts from the rest of the system. The basic electrical quantities which are likely to change during abnormal conditions are current, voltage, phase angle (direction) and frequency. Relays utilize one or more of these quantities to detect abnormal conditions on a power system.

Protective Zones

A part of the power system protected by a certain protective scheme is called protective zone or zone of protection. The entire power system is covered by several protective zones and no part of the system is left unprotected.



7.6 Types of Protective Relay



REL 511 is the Distance Protection Relay used in 220kV transmission line protection in Jindal Steel and Power, Raigarh.

7.7 Distance Protective Relay

Distance relaying is considered for protection of transmission lines where time lag control cannot be permitted and selectivity cannot be obtained by overcurrent relaying. It operates when the fault occurs with a certain distance from the relay. It is used for main lines and secondary lines. It measures V/I at relay location which gives the measure of distance between the relay & fault location. The impedance of the fault loop is proportional to distance between relay location & fault point. For a given setting, the distance relay picks up when impedance measured by it is less than set value. These generally use the balance beam structure or induction cup structure.
Balance Beam.

REL 511 is a type of impedance relay. The REL 511 is a microprocessor-based, numerical distance protection relay commonly used for protecting transmission lines against short-circuit faults. It utilizes advanced algorithms and digital signal processing to analyze voltage and current measurements, providing fast, accurate, and reliable fault location.

Functionality:

- **Impedance Measurement:** Continuously monitors voltage and current on the protected line section and calculates the impedance (resistance and reactance) using digital processing techniques.
- **Zone Comparison:** Compares the calculated impedance with pre-programmed impedance zones stored in its memory. These zones represent different sections of the protected line, with Zone 1 closest to the relay and subsequent zones extending outwards.
- **Fault Detection and Location:** If the calculated impedance falls within a zone, it signifies a fault within that zone's corresponding section of the line. This allows for pinpointing the fault location with greater accuracy compared to simpler protection schemes.
- **Trip Signal Initiation:** Depending on the zone and relay settings, a trip signal is sent to the circuit breaker to isolate the faulted section, minimizing equipment damage and system disruption.

Key Features of REL 511:

- **Multi-step impedance measurement:** Offers multiple impedance measuring points for improved fault location accuracy.
- **Directional discrimination:** Can distinguish between fault current flowing towards or away from the protected line, enabling selective tripping and minimizing unnecessary outages.
- **Phase selection:** Provides the ability to select specific phases for fault analysis, which is helpful in situations with single-phase or phase-to-ground faults.
- **Communication capabilities:** Supports communication protocols for integration with supervisory control and data acquisition (SCADA) systems, allowing for remote monitoring and analysis of relay data.

- **Flexible settings:** Settings can be configured to adapt to specific line characteristics and protection requirements.

Enhanced with Autoreclosing Function:
The REL 511 offers an advanced autoreclosing function, providing additional benefits for system reliability:

- **Configurable Reclosing:** The reclosing function can be programmed for single-phase, two-phase, or three-phase autoreclosing. It allows selection from eight single-shot or multi-shot reclosing programs to suit different system needs.
- **High-Speed or Delayed Reclosing:** The three-phase autoreclosing open time can be set for either high-speed autoreclosing (for temporary faults) or delayed autoreclosing (to allow system components to cool down before re-energizing).
- **Synchronization Check and Energizing Options:** Three-phase autoreclosing can be configured with or without the use of a synchronism check or energizing function. The synchronism check ensures voltage synchronization between the line and the system before reclosing, while the energizing function can be used to control the closing of circuit breakers during the reclosing sequence.

Benefits of Using REL 511 with Autoreclosing:

- **Improved System Reliability:** The autoreclosing function allows for automatic re-energizing of the line after a fault, potentially restoring power quickly if the fault was transient.
- **Reduced Outage Duration:** By attempting to re-energize the line automatically, autoreclosing can minimize customer outage duration compared to manual restoration procedures.
- **Enhanced System Stability:** Successful autoreclosing can help maintain system stability by preventing cascading outages that could occur due to prolonged line outages.

Fig: REL 511 (Distance Protective Relay)

Distance Protective Relay are again of three types:
1. Impedance Relay
2. Reactance Relay
3. Mho Relay

The universal relay torque equation of protective relays is given as follows:

$$T = K_1 I^2 - K_2 V^2 + K_3 VIcos(\theta - \tau) + K$$

where:

$K_1 I^2$ is the component due to over current

$K_2 V^2$ is the component due to over voltage

$K_3 VIcos(\theta - \tau)$ is the component demonstrating direction

K is the component due to spring constant

For distance protective relay, directional component is absent, i.e. $K_3 = 0$ and spring constant $K = 0$

Thus, for distance protective relay

$$T = K_1 I^2 - K_2 V^2$$

This means the operating torque is produced by the current coil and restraining torque by the voltage coil, which means that an impedance relay is a voltage restrained over-current relay.
For the operation of the relay the operating torque should be greater than the restraining torque, i.e.,

$$K_1 I^2 > K_2 V^2$$

Here V and I are the voltage and current quantities fed to the relay.

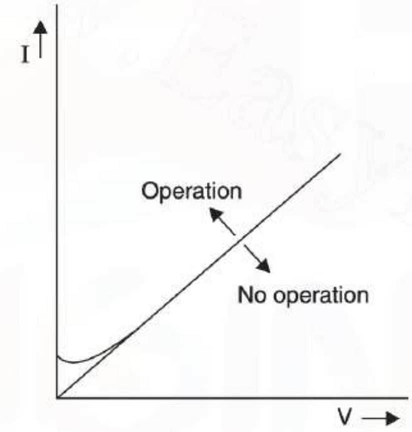
$$V^2 / I^2 < K_1 / K_2$$

or $$Z < \sqrt{K_1 / K_2}$$; Z is impedance

or $Z <$ constant (design impedance)

Therefore, the impedance relay will operate only if the impedance seen by the relay is less than a prespecified value (design impedance).

Operating characteristic on V-I diagram



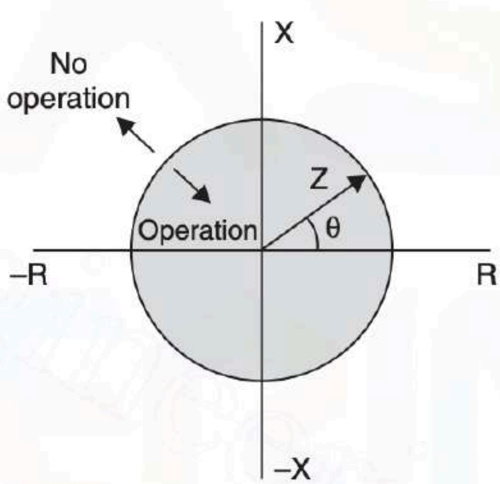
The operating characteristic of an impedance relay on V-I diagram is shown above, where V and I are voltage and current respectively.

• The **operating zone** of the impedance relay lies above the plotted line in the V-I diagram, as at any point in this region, the value I would be always more than the value of V, for a graph with same scaling on X and Y axis. Thus $Z < \sqrt{K_1/K_2}$, satisfying the condition for relay operation.

• By similar logic, the **non operating zone** is below the plotted line as the value I would always be less than the value of V, for a graph with the same scaling on X and Y axis. Thus $Z > \sqrt{K_1/K_2}$, not satisfying the condition for relay operation.

The initial bend in the graph is due to the presence of spring torque.

Operating characteristic on R-X diagram



The operating characteristics of the impedance relay is plotted in the R-X diagram.

We know, $Z = \sqrt{R^2 + X^2}$

where R is resistance,
X is reactance and
Z is impedance

This is clear from the characteristic that if the impedance as seen by the relay lies within the circle the relay will operate; otherwise, it will not. The position of one value of Z is shown in the figure with angle θ with the +R-axis. This means that the current lags the voltage by angle θ. In case the two were in phase, the Z vector would have coincided with +R-axis. In case the current was lagging the voltage by 180°, the Z vector would coincide with – R-axis. When I lags behind V, the Z vector lies in the upper semi-circle and Z lies in the lower when I leads the voltage. Since the operation of the relay is independent of the phase relation between V and I, the operating characteristic is a circle and hence it is a non-directional relay.

7.8 Identification and Response to Transient Faults by REL 511

REL 511, a numerical distance protection relay plays a crucial role in identifying and responding to faults by utilizing its advanced features and settings. Here's how it assists in managing transient faults:

Transient Faults:

Transient faults are temporary abnormalities in the electrical system that disappear on their own within a short duration (milliseconds to a few seconds) without causing permanent damage. Examples include:

- **Lightning strikes:** A lightning strike on a transmission line can create a momentary high-current path, disappearing quickly.
- **Falling branches:** Tree branches or other objects briefly touching the line can cause a transient fault.
- **Animal contact:** Birds or animals making momentary contact with energized conductors can create a transient fault.

REL 511's Role in Transient Fault Management:

- **Fast Fault Detection:** The REL 511 utilizes digital signal processing for rapid detection of changes in voltage and current. This allows for swift identification of a potential fault, including transient events.
- **Zone-Based Discrimination:** The relay is programmed with pre-defined impedance zones representing different sections of the protected line. During a transient fault, if the

calculated impedance falls outside these zones (indicating a fault beyond the protected line or a system abnormality), the relay typically doesn't trip the circuit breaker.

- **Coordination with Other Protection Schemes:** The REL 511 can be coordinated with other protective relays, like overcurrent relays, which might have time-delay settings. These overcurrent relays might not trip for a brief transient fault due to the time delay, allowing the transient event to clear itself without unnecessary outages.
- **Autoreclosing Function:** If the REL 511 is equipped with an autoreclosing function, it can be programmed for single-phase or high-speed three-phase autoreclosing. This allows for automatic re-energizing of the line after a fault, potentially restoring power quickly if the fault was indeed transient and self-clearing.

Overall, the REL 511, along with proper coordination and settings, plays a vital role in managing transient faults on transmission lines. By quickly identifying potential faults, discriminating based on impedance zones, and potentially enabling autoreclosing, it helps ensure system stability and minimizes unnecessary outages while still providing protection against sustained faults.

8. RECOMMENDATIONS

1. Increased Frequency of Inspection:
More Frequency of regular inspection (specially during monsoon) to locate any missing or damaged earthing parts.

2. Social Awareness:
Spread awareness among locals to prevent them from disconnecting the earthing.

3. Marconite Concrete Conductive Earthing:
Marconite concrete conductive earthing provides a lower tower foot resistance, thus improving the earthing system. The main problem with the traditional earthing system was its higher TFR values. But marconite provides 0.1 Ohm m soil resistivity, which is less than the standard 5 Ohm by a large margin.

4. Couple Ground Wire: To improve the lightning protection performance of the line and reduce the lightning trip rate of the line, the method of hanging the coupling line under the wire (or near it) can be used. The coupling line can act as a shunt and coupling when lightning strokes the tower, reduce the voltage borne on the tower insulation, and improve the lightning withstand level of the line.A link to a research paper discussing the couple ground wire has been attached for reference.
https://drive.google.com/file/d/1XutBTgmyfFTN5VNYSf5_TMIExXs-hdk-/view?usp=sharing

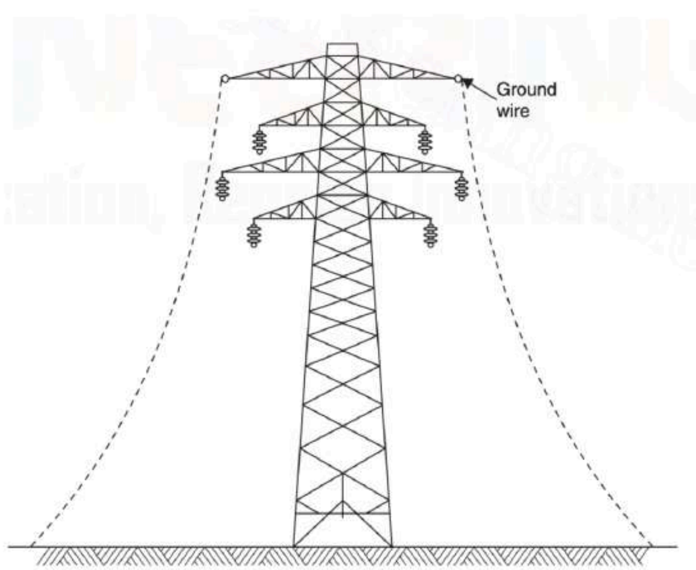


Fig: Double Ground Wire Protection for transmission lines

5. Laying of Secondary Line for DCPP and JPL Line

The laying of this secondary line, would ensure that in case one of the line trips, the other acts as a backup. This secondary line is to ensure continued power supply in case the main lines trip due to faults or maintenance activities. By having a redundant path for electricity, this project aims to enhance the reliability and security of power delivery.

9. CONCLUSION

In this project, we have analyzed the main reasons for the power outage, leading to a lack of reliability of 220kV transmission lines network. The biggest contributor to power outages is **lightning strikes**, causing more than half of the outages, then followed by faults due to external reasons such as **fire on vegetation/trees, flying tree branches hitting live lines, air borne tin and tarpaulin sheets coming in contact with conductors, animal activities** etc.

The measures to tackle these two big problems are:
1. **Preventive Maintenance**, which include Scheduled Patrolling, Hotline Maintenance, PID (Punctured Insulator Detection), String Replacement, Earthing Maintenance, Right of Way, etc for faults due to external reasons
2. Implementation of **Marconite Concrete Conductive Earthing**, to reduce the tower foot resistance value, for proper and easier dissipation current surges due to lightning surges.

Some additional recommendations for additional protection and mitigation of the problem of power outages are:
1. Increased frequency of inspection
2. Spreading social awareness to curb locals from disconnecting and taking away earthing parts
3. Laying of a secondary circuit in DCPP and JPL line, for one to act as back up in case of tripping of the other
4. Couple Ground Wire can be used to enhance the protection of the conductor by providing more effective shielding from lightning strikes.