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Managing Complexity: A Comprehensive Study of the Matiari to Lahore ±660kV DC Transmission Line Project

Chen Hongtao[1], Zhu Ying Lin[2]

Abstract

The construction of a ±660kV DC transmission line, such as the Matiari to Lahore project in Pakistan, represents a significant and complex undertaking requiring advanced project management expertise. This project involves foundation laying, tower assembly, and wiring, necessitating collaboration across multiple professions and departments. To ensure success, it is critical to adopt cost-effective strategies that minimize expenses, accelerate construction timelines, and prioritize safety. This paper explores various strategies to optimize the construction of ±660kV DC transmission lines. Key strategies include the use of energy-efficient technologies, such as high-efficiency conductors and transformers, which reduce operational costs and energy losses. Additionally, durable materials like advanced composites and corrosion-resistant alloys enhance infrastructure longevity and reliability. Modular construction methods, which allow for pre-fabrication of components, are emphasized for their ability to speed up construction, improve quality control, and reduce waste. These methods also enhance safety by minimizing on-site construction time and exposure to hazardous conditions. Conducting rigorous safety audits is essential for identifying potential hazards and ensuring appropriate safety measures. Employing sophisticated project management software improves organizational coherence, facilitates communication, tracks progress, and identifies potential issues early. Interdisciplinary project management teams are crucial for enhancing coordination and ensuring project success. These teams integrate experts from engineering, construction, logistics, and environmental science to address diverse project challenges effectively. Stakeholder engagement and community involvement are also emphasized to address concerns, gain support, and ensure the project meets the needs of all parties involved. Transparent communication and proactive engagement help prevent delays and disruptions. By incorporating these strategies, we aim to optimize construction efficiency while maintaining the critical infrastructure integrity of the ±660kV DC transmission line. This paper provides valuable insights into best practices and innovative approaches for future large-scale and complex projects.

Keywords: ±660kV DC Transmission Project, Transmission Line, Power Engineering, Construction

1. Introduction

1.1. Background and Significance

The primary objective of the Pakistani project to build the Matiari to Lahore 660kV DC transmission line is to create technical, safety, quality, and environmental standards for conductor line construction. This strategy is supposed to ensure the conductor line construction has been carried out in a safe and efficient manner while improving the project's quality and service.

1.2. Pakistan Matiari to Lahore ± 660kV DC Transmission Line Project

The 114.655-km (260-mile) Matiari to Lahore 660 kV DC transmission line in Punjab, Pakistan, has 260 towers. To circumvent Lal-Suhanra Forest Park, the route begins south of Yazman, crosses Chak 72/DB, turns right into Hasilpur Road, and travels north by east. The project involves six tower types: ZP1, ZP2, JP1, JP2, and JP3.

1.3. Research Objectives and Methodology

Building foundations, iron towers, and the G1493 tensile string tower are all included in tender lots VI and VII. A 4-split JL1/G3A-1250/70-76/7 conductor with 500mm of spacing is used on the 660kV DC line. It specifies insulator strings and optical cables. Construction-related concerns are prioritized in the plan, ensuring cost-effectiveness and safety for project success. (Ahmad & Zeeshan, 2022)

2. Environmental and Technical Factor

2.1. Weather Conditions

The efficient deployment of the ±660 kV DC voltage level relies heavily on precise technical planning and favorable weather conditions(Rehman & Deyuan, 2018). The transmission line is built to withstand winds up to 160 km/h at a height of 10 meters, temperatures as low as -5 °C, on average 25 °C, and as high as 75 °C for the conductor. It experiences 32 days of yearly precipitation and a constant wind speed of 31.1 m/s for 10 minutes at 10 meters. The line needs to stay free of ice(Ahmad & Wang, 2019). The minimum and yearly average temperatures are, respectively, -5 °C and 25 °C. With a wind speed of 44.44 m/s (31.1 m/s), the fundamental wind speed is 15 °C. In addition to accident circumstances and 32 thunderstorm days, installation and operating overvoltage situations are described. Specific circumstances indicate readings longer than 10 minutes, and wind speeds are measured at 10 meters high and 3 seconds.

2.2. Line direction and leg specifications

The design in question has been optimized to provide maximum efficiency in terms of single-circuit functionality. It is oriented to directly face Lahore City (Shaikh et al., 2016), thereby ensuring that the data transmission is not hindered by any obstacles. Furthermore, figure 1 clearly depicts the tower leg reference points, thereby ensuring that the design can be implemented with ease. Overall, the design is both reliable and effective and is sure to meet the requirements of the project.

2.3. Crossover Situation

This segment involves the crossing of two non-navigable rivers, two motorways, twelve general roads, two 132kV power lines, one 35kV power line, and two non-electrified train tracks. Notable crossings include the 132kV power line span from G1663 to G1664, the 35kV power line span from G1548 to G1549, the railway crossing from G1662 to G1663, the 132kV power line span from G1741 to G1742, and the railway crossing from G1744 to G1745(Simkovic, 2017). These crossings pose significant challenges and

[1]Corresponding Author, Senior Project Manager, University of Geoscience Beijing, Department of Electrical Engineering, 306660890@qq.com
[2] Senior Design Manager, Henan Agriculture University, department of engineering of Architectural Design, 18995715@qq.com

require careful planning and execution to ensure the project's success in this complex crossover situation. (Alamri, Hossain, & Asghar, 2021)

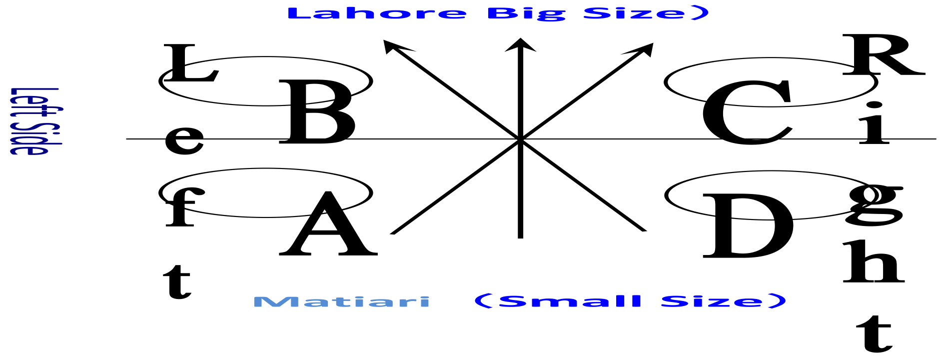

Figure 1: Line Direction and leg reference points

2.4. Technical parameters of conductors and optical cables

This project employs four JL1/G3A-1250/70-76/7 steel-cored aluminum stranded conductors, with a split spacing of 500mm, adhering to the project's technical specifications. These conductors have a cross-sectional area of 1322.16mm2, a diameter of 47.35mm, and are composed of an outer layer made of high-conductivity aluminum (76/4.58) encapsulating a steel core (7/3.57). Additionally, the conductors exhibit a modulus of elasticity of 62200 N/mm2, a thermal expansion coefficient of 21.1/°C×10-6, a calculated weight of 4011.1kg/km, a rated breaking force of 294.23KN, and a maximum operating tension with a safety factor of 101.7 (2.75). Furthermore, the DC resistance at 20°C for these conductors measures 0.02291 Ω/km(Yang et al., 2017). These conductor specifications are in accordance with the project's requirements, ensuring their suitability for the task at hand. (Ali, 2022)
This project uses 2 OPGW, the model is OPGW-15-120-2 (24 cores). The main technical parameters are shown in Table 1.

Table 1: OPGW Parameter list

Project	OPGW-15-120-2
Calculate the cross-sectional area (mm2)	121.0
Calculated outer diameter (mm)	15.2
Calculated weight (kg/m)	0.711
Calculate the breaking force (N)	101300
Elastic Modulus (N/mm2)	132000
Linear expansion coefficient (1/ °C)	13.8 × 10-6
Breaking stress (N/mm2)	836.00
Maximum operating stress/safety factor (N/mm2)	280/2.98
Average operating stress/percent (N/mm2)	115/13.76%
Short-circuit thermal stability allowable current (kA)	20.1

2.5. Conducting and connecting tube

The crimping tube's outer diameter (D) governs the die selection formula. S=0.8660.993D+0.2, where D is the outside diameter in millimeters, is the simplified formula for the greatest margin (S) after pressing. Conductor Tensile Tube - Made from durable aluminum with an outer diameter of 125mm, die to margin of 70mm, and maximum margin after pressing of 69mm and Steel anchor - Made from sturdy steel with an outer diameter of 30mm, die to margin of 25.6-25.7mm(Yang et al., 2017), and maximum margin after pressing of 26mm.
Connecting tube, crafted from high-grade aluminum with an outer diameter of 125mm, die to margin of 70mm, and maximum margin after pressing of 69mm (Raza et al., 2014) and Steel Pipe - Built from tough steel with an outer diameter of 30mm, die to margin of 25.6-25.7mm, and maximum margin after pressing of 26mm. (Biberman, Schwartz, & Zahid, 2023)

2.6. Insulation Coordination and Types of Insulator Strings

2.6.1. Pollution consideration and Insulation configuration

Construction in this strongly populated bidding region follows the relevant plans. According to pollution levels, synthetic insulator configurations range from 8.5/33.4 in regions with medium pollution to 9.2/38.4 in places with significant pollution. In places with medium and moderate pollution, the tensile string uses triple 420kN insulators, with 73 and 81 pieces, respectively. At 500 meters above sea level, the tower air gap values are 1.70 meters for the working voltage gap and 4.40 meters for the operating overvoltage clearance, with a maximum operating overvoltage multiple of 1.82 pu for the whole line. Assembly drawings of single-joint and duplex composite insulator are shown in figure 3 and 4.

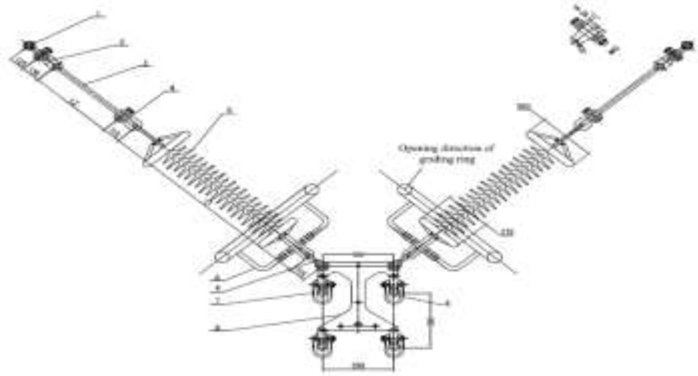

Figure 2: Assembly drawing of single-joint composite insulator.

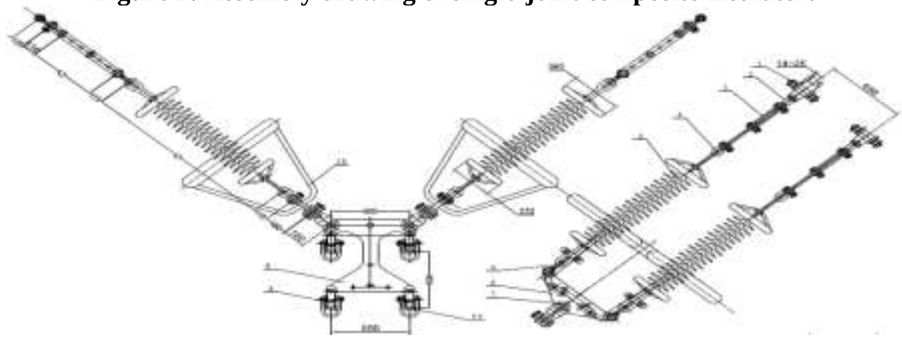

Figure 3: Assembly drawing of duplex composite insulator.

2.6.2. Types of insulator strings and fittings

2.6.2.1. String of insulators

Utilize disc insulator string and composite insulator strings for tension in this project, and use double hanging points on towers for dual series connections.

Table 2: Main conductor fittings strings

Name	Applicable
300kN Synthetic Insulator Single V-shaped Suspension String	normal load
420kN Synthetic Insulator Single V-shaped Suspension String	large load
300kN Synthetic Insulator Double V Type Suspension String	important crossover

The project incorporates various components, including triple 420kN disc insulator strings, a double V-shaped cage for jumpers at an 85-degree angle, single-connected 120kN OPGW fittings, line-wide grounding, and twisted conductor clamps for tension and overhang. The string types are specified by code and name as follows:

1- Dangling V String: SSVS300 (300 kN composite insulator single V-shaped suspension string) and SSVS420 (420 kN composite insulator single V-shaped suspension string assembly drawing).

2- Tensile String: TSDT420 (420kN disc suspension insulator triple tensile string assembly drawing).

3- Jumper String: SSJS160 (160kN composite insulator jumper string assembly drawing).

To streamline usability and maintenance, the tension string assembly incorporates PQT and DB plates (MLHVDC-MLL-CSI-DD-TE-0408A, 0409A) while employing a distinctive color scheme. This scheme entails the insertion of one brown ceramic insulator adjacent to the tension hanging point for every nine gray insulators, ensuring ease of identification and maintenance efficiency. (Bukhari, Mashwani, & Bhatti, 2022)

2.6.2.2. Main fittings

Lianta fitting:

In this fitting tensile string hanging point hardware adopts the GD hanging board or combined hanging board, and hanging string hanging point hardware adopts the EB hanging board.

Joint plate

In this project, the overhanging and tensioning connecting plates are used as integral connecting plates, as shown in Figures 4 and 5.

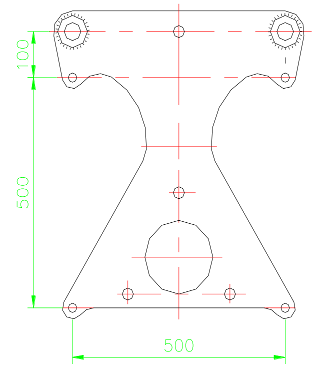

Figure 4:Overhanging gussets

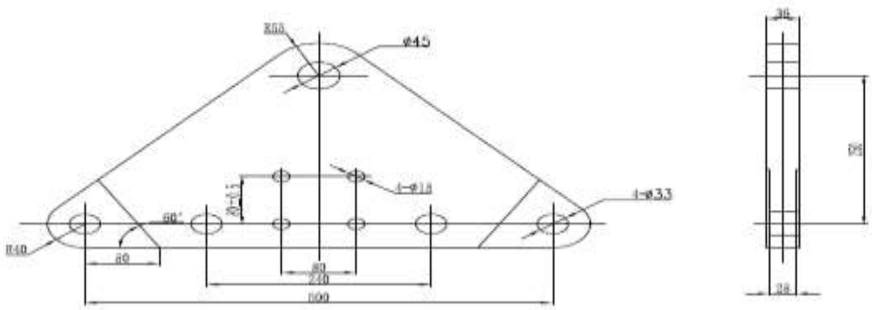

Figure 5: Tension resistant board as integral connecting plates

2.6.2.3. Tensile series length adjustment table

This volume gives the length of the PTQ adjustment plate (hole position) and the DB adjustment plate length (hole position) when the inner and outer limbs of the tensile string are assembled. (Downs, 2019)

The length combinations of the PTQ adjustment plate (PTQ-64620-1000) are as follows:

Table 3

PTQ-64620-1000 Adjustment length (mm)						
620	640	740	760	860	880	1000

The length combinations of the DB adjustment plate (DB-64135-235) are as follows:

Table 4

DB-64135-235 Adjustment length (mm)				
135	160	185	210	235

3. Construction Process and Regulations

The construction process and the regulations governing the installation of high-voltage transmission lines. The meticulous execution of these processes and adherence to safety and quality standards are vital for the successful completion of the project. In this section each addressing specific aspects of the construction process and its regulations. Let's explore these sections in detail:

3.1. Uniform Regulations on Fitting Bolts and Pins

The construction of high-voltage transmission lines requires precise installations, especially when it comes to fitting bolts and pins. The uniform regulations set forth in this section aim to standardize the installation procedures, ensuring that each bolt and pin is secured properly. Here are the key regulations in detail:

Direction of Penetration: For bolts and pins that can be inserted vertically, the regulation states that they should penetrate from top to bottom. Bolts and pins that can be inserted in line with the conductor should follow a directional rule - from small to large. In the horizontal direction, they should be inserted from the inside of the tower to the outside. (ESCAP, 2022)

Bowl Head Hanging Plate: The orientation of the large mouth of the bowl head hanging plate depends on the type of pins used. If "W" type pins are used, for single V series, the large mouths should face upward, and for double V series, they should face the power supply side. If "R" type pins are used, the large mouths of the porcelain bottle should face downward for single V series, and for double V series, they should face the power supply side. (Farias, 2021)

OPGW Suspension String Bolts and Pins: When it comes to OPGW suspension string bolts and pins, they should be oriented to ensure that the large side faces from the power supply side to the power receiving side.

Conductor Tensile Insulator String: This section defines the orientation of the large mouth of the disc insulator. If "R" type pins are used, the large mouth of the porcelain bottle should face downward. If "W" type pins are used, the large mouth should face upward.

The regulation also specifies the direction for bolts and pins to pass through - vertically from top to bottom and horizontally from the outside of the harness to the inside. (Gul et al., 2019)
Vibration Hammers and Spacer Rods: Detailed instructions are provided for the installation of anti-vibration hammers and spacer rods. It specifies the direction of installation and the type of hammers used. Furthermore, the installation position of conductor anti-vibration hammers is determined. For the linear tower and the anti-vibration tower of the tension tower, these hammers are installed at equal distances based on the exit of the conductor clamp as the starting point. (Henares & Delina, 2022)
Hardware Pin Opening Regulations: This section regulates the opening of pins. Split pins and closed pins that can be inserted vertically should go from top to bottom. Those that can be inserted in line with the conductor should go from small to large. The horizontal direction is from the inside of the tower to the outside. The regulation also specifies the opening degree, which should be between 30 degrees and 60 degrees, except when specified by the design or the manufacturer. It emphasizes the coordination between R cotter pins and their mounting apertures to prevent loosening due to long-term vibration. If necessary, pliers should be used to ensure that the opening degree meets the requirements.
Conductor Equalizing Ring and Shielding Ring: The regulation provides guidance on the installation orientation of the conductor equalizing ring and the shielding ring. For a V-shaped string of a linear tower, the pressure equalizing ring should be installed upward. In the case of an insulation string of a tensile tower, the equalizing ring and the shielding ring should face the same direction as the drainage, which is downward. (Hussain et al., 2020)
Adjustment Plate Orientation: This section outlines the installation requirements for the orientation of the adjustment plate. For the straight-line tower V-string fan-shaped adjustment plate, it should face upwards. For the tensile insulator string, specific instructions are provided for two types of DB fan-shaped adjustment plates based on their position relative to the tower body and the conductor.
Color Coding of Tension-Resistant Series Porcelain Insulators: To facilitate operation and maintenance, the regulation introduces a color-coding scheme for tension-resistant series porcelain insulators. It specifies the arrangement of brown and gray porcelain insulators to characterize the quantity. (Iftikhar & Hossain, 2020)

3.2. Jumper Technology and Installation

The installation of jumpers is a crucial aspect of any electrical tower project. This section delves into jumper technology, covering various aspects, including appearance requirements, electrical clearance, jumper length and sag, and jumper guide plates.
Appearance Requirements: The aesthetics of jumpers are important, not just for the visual appeal but also for safety. The regulation emphasizes that jumpers should exhibit a natural, smooth appearance. The curves should be smooth, and the jumpers should be free from twists or deformations.
Electrical Clearance: Maintaining the appropriate electrical clearance within the tower is crucial. The regulation specifies that the electrical clearance should meet design requirements to ensure safety during operation and maintenance.
Jumper Length and Sag: Jumpers should be of the correct length and sag. The regulation states that the length and sag of the jumper should match the design values. Deviations from these values should be addressed promptly.
Jumper Guide Plate: The deflection direction of the jumper guide plate is crucial. The regulation dictates that it should be at an angle of 30°, and its installation should follow the requirements of the project's drawings before construction.
Bolt Tightening and Threading: Properly tightening and threading the bolts is essential to secure the jumpers in place. The regulation emphasizes that the bolts should be installed in strict accordance with the requirements. This includes ensuring that the bolts are flat, the correct number of spring washers are used, and the torque of the bolts meets the required standards.
Hard Jumper Aluminum Tube Bending: To maintain the structural integrity of hard jumper aluminum tubes, the bending degree should not exceed 5%. The regulation further specifies that ground assembly should be supported by a simple special platform to ensure flatness and concentricity of the aluminum tube connection. This includes using the correct supporting spacers and ensuring that the bolts are flat, the right number of spring washers are used, and the bolt torque meets standard requirements. (Karim, n.d.)

3.3. Conductor Spacer and Ground Conductor Installation

The installation of conductor spacers and ground conductors is a fundamental part of constructing a power transmission line. This section provides detailed regulations to ensure that conductor spacers are installed systematically and ground conductors meet the required standards.
Sequential Installation: The regulation outlines the correct order of installation, emphasizing the need to first fasten the two upper sub-conductor clips, then install and fasten the middle two sub-conductor clips, and finally install the two lower sub-conductors. This sequence is crucial to ensure a systematic approach.
Spacer Bar Surface: Ensuring that the surface of the spacer bar is smooth, flat, and free from scratches is vital. The regulation highlights the importance of the spacer bar's condition to guarantee its effectiveness.
Sag Deviation: It is essential to keep the sag of any two sub-conductors within an allowable relative deviation of 50mm. When installing the spacers, care should be taken to distribute the force evenly, avoiding concentrating it on one or two spacers.
Installation Distance: The installation distance of the first spacer bar at the gear end should not exceed ±1.5% of the secondary gear distance. The middle should stay within ±3% of the secondary gear distance. Positions between two poles should be roughly the same, and the spacer bar's plane should be perpendicular to the conductor.
Installation Point: The starting point for the installation of the first spacer bar at the end of the tension tower is based on the midpoint between the tension clamp of the near tower and the far tower. For large corner towers, the spacer bar should be installed according to the outer polar line, aligning the inner side with the outer side. (Khalid et al., 2023)

3.4. Construction Process Flow and Labor Organization

This section provides an overview of the construction process flow and the organization of labor, ensuring that the project is executed efficiently and safely. The labor division organization details the number of personnel required for various operation points. (Khan et al., 2021)

3.4.1. Construction Process Flow

Guide Rope Display: The process of deploying guide ropes is essential for safe and systematic construction. Different types of ropes are used to serve specific purposes, and the section outlines the deployment process.

Tow Rope Display: The use of small tractors and tensioners for deploying traction ropes is detailed.

Conductor Spread: The regulation prescribes the arrangement of sub-conductors, emphasizing the need for precise execution.

Tight Line Construction: The section covers both rough tightening using a stranding mill and fine-tuning using a lever hoist, with methods for observing and adjusting sag.

Accessory Installation: For linear tower accessories, specific tools are used for installation, and spacer bars are installed manually. (Khan et al., 2022)

3.4.2. Labor Organization and Division of Labor

Preliminary Preparation: Preparing for construction and ensuring safety measures are in place.

Over the Blockade: Managing the closing work across power lines and ensuring safety.

Trailer: Hardware inspection, cleaning, and installation of essential components.

Rope Show: Monitoring pulleys, passing ropes, and troubleshooting. (Liu et al., 2023)

4. Tension Pay-off and Detailed Construction Procedures

4.1. Technical Preparation and Selection of Tools

Technical preparation for the Tension Pay-off construction is a critical phase that sets the foundation for the entire project. It encompasses several key steps and quality assurance measures:

Joint Reviews and Documentation Approval: Prior to commencing the construction, a meticulous review of design documents is conducted, ensuring alignment with the project's specifications. Construction work guidance documents are approved to guide the construction process.

Personnel Training and Certification: The workforce involved in the project undergoes rigorous training, including safety protocols and specific skill sets required for the construction of high-voltage transmission lines. Special work certificates are provided to the trained personnel, certifying their competence.

Ground Conductor Crimping Assessment: The project assesses the crimping of ground conductors to ensure they meet design breaking force standards, which is essential for the structural integrity and safety of the transmission lines. (Lohana et al., 2021)

4.2. Pay-off Block Suspension and Construction Sections

The Tension Pay-off construction involves precise procedures for the suspension of pay-off blocks and the management of conductor installation. This section provides a detailed breakdown:

Conductor Suspension Configuration: The conductors are suspended in a specific 1x manner, with two tricycles suspended on each pole's cross arm. To manage vertical load and envelope angles exceeding 30 degrees, double pulley suspension is employed, ensuring safety during the construction process.

Linear Tower Pay-off Pulley Suspension : This specific procedure includes the use of a specially-made pulley hanger and V-shaped string insulators. It utilizes two three-wheel pay-off pulleys with a defined spacing, ensuring the safe lifting and hanging of insulator strings and pay-off blocks.

Setting of Other Pulleys : When dealing with horizontal pay-off tension checks, the positioning of the traction force and the vertical pitch of the pay-off pulley are crucial aspects. A detailed formula is provided to calculate the vertical pitch and ensure that the conductor remains within its vertical range.

Additional Suspension Considerations: The document outlines the importance of conductor-supporting pulleys for special situations where the conductor may touch the ground during installation. Grounding pulleys are also installed in tension and traction fields to prevent induced electricity injuries during pulling and releasing.

4.3. Guide Rope, Traction Rope, and Optical Cable Details

This part is concerned with the deployment of guide ropes and traction ropes, which are essential for systematic and safe construction:

Guide Rope Deployment: The process of deploying guide ropes is explained in detail. Different types of ropes are used, each serving specific purposes. The deployment process ensures safe and systematic construction.

Traction Rope Deployment: The document outlines the use of small tractors and tensioners for deploying traction ropes. It specifies how these components are used to facilitate the construction process. (Mahmood & Alam, 2022)

4.4. Conductor Spread and Tight Line Construction

The Conductor Spread and Tight Line Construction phase is a crucial aspect of the Tension Pay-off process. It ensures that the conductors are correctly installed and secured:

Conductor Spread: This section focuses on the precise arrangement of sub-conductors, emphasizing the need for accurate execution to ensure that the transmission lines meet safety and quality standards.

Tight Line Construction: This part covers both rough tightening and fine-tuning of the conductors. The methods for observing and adjusting sag are detailed, ensuring that the transmission lines have the correct tension for efficient and reliable operation.

Attachment Construction: Subsections detail the installation of conductor accessories, conductor marking, and precautions for composite insulators, ensuring that these components are integrated correctly and safely. (Qu et al., 2023)

4.5. Sag Observation and Attachment Procedures

Sag observation is a critical aspect of ensuring that the transmission lines maintain their proper configuration and tension over time:

Sag Observation Guidelines: This subsection outlines the principles for selecting observation files, observing slack, conducting conductor tightening, relaxation observation methods, slack checks, and conductor marking.

Efficient Conductor Reel Replacement and Tight Line Construction: In this part, the procedures for replacing conductor reels and tightening the lines are explained, including balancing the tension, sub-conductor tightening order, and other relevant aspects to ensure the stability and integrity of the transmission lines. (Rahman et al., 2022).

5. OPGW Optical Cable Construction and Quality Assurance

In the world of telecommunications and electrical transmission, OPGW (Optical Ground Wire) optical cables play a critical role. They provide a dual purpose, serving as both a grounding conductor and a conduit for optical fibers. Proper installation is essential to ensure the reliability and safety of these cables. This article outlines the procedures, safety measures, and quality assurance steps for OPGW optical cable construction. (Razia et al., 2023)

5.1. OPGW Installation Procedures

Before diving into the installation procedures, it's crucial to mention that the information and guidelines mentioned here should always be considered in conjunction with the specific manufacturer's installation guide for the OPGW optical cable being used. That said, the installation process can be broken down into several key steps:

5.1.1. Pre-installation Preparations

Before any construction begins, it is vital to familiarize yourself with the manufacturer's installation guide. This guide contains important information regarding the specific cable you are working with. Understanding these details is critical for a safe and efficient installation process. (Ul-Haq et al., 2021)

5.1.2. Safety Measures and Precautions

Safety is of utmost importance during OPGW installation. Safety measures should be implemented to protect workers and ensure the longevity of the cable. Key points include:

Electromagnetic Induction: If your installation site is near other transmission lines, especially high-voltage power lines, follow relevant safety regulations to prevent electromagnetic induction voltage. Ensure that labor safety measures are in place. When working at high altitudes, formulate additional safety measures to ensure safe production.

Protection during Construction: Pay close attention to protecting the optical cable during installation. Install the ground conductor according to the recommended pitch for each tension section. Avoid wearing down the ground conductor when laying out the conductor to minimize losses. (Reynolds et al., 2018)

5.1.3. Tensioning the Ground Conductor

It's crucial to tension the ground conductor appropriately. Take care to protect the optical cable during this process. After the OPGW ground conductor is tightened, install accessories promptly. This includes installing the anti-vibration hammer within 24 hours. (Sachdeva, 2021)

5.1.4. Installation of Remaining Conductors

Following the completion of the wiring, reserve and fix the remaining conductors at both ends on the remaining cable rack. The OPGW cable should not have any other connectors except at the junction box connector. Special attention should be given to ensuring that the OPGW is not disconnected at the straight-through position of the tensile string. (Siddiqui et al., 2023)

5.1.5. Fittings Assembly

Before assembling the fittings, it is important to check the connection size according to relevant standards. Pay attention to the connection with the hanging points of various tower types.

5.1.6. Dealing with Discrepancies

During the construction process, if there is a significant difference between the products supplied by the supplier and the drawings, it's essential to notify the owner and the designer promptly to coordinate and resolve the problem.

5.1.7. Installation of Accessories

In addition to the instructions provided in this document, it is crucial to install related accessories (such as pre-twisted conductors, splice boxes, residual cable racks, OPGW lead-off clamps) according to the manufacturer's installation instructions and requirements attached to the box.

5.1.8. Grounding

The OPGW should be grounded one by one. The grounding lead is provided as a set with the suspension string and the tensile string, and it should be connected to the grounding hole of the grounding bracket with M16 bolts. On the iron tower where the joint box is installed, the tensile strings on both sides of the tower need to be connected to the grounding lead. Grounding leads on other towers should be made, and the grounding conductor of the optical cable fittings on the large side of the tower should be installed. (Sultan & Mehmood, 2020)

5.2. Relevant Provisions of the Strong Clause

In any OPGW installation project, it's important to adhere to relevant provisions to ensure safety, quality, and compliance. Some of the strong clause provisions that should be followed include:

5.2.1. Complete Technical Documents

Before installing the conductors, ensure you have complete and effective technical documents. This includes details about conductor construction, laying out, tightening, and the installation of accessories. These documents are critical for the proper execution of the project.

5.2.2. Intermediate Tower Acceptance

The iron towers in the conductor-laying section should pass intermediate acceptance before conductor-laying construction can commence. This step helps ensure that the towers are structurally sound and suitable for conductor installation. (Wentao & Hang, 2023)

5.2.3. Avoiding Incompatible Connections

Avoid connecting conductors or overhead ground conductors of different metals, specifications, and twisting directions within a tensile section. This prevents incompatibilities that could compromise the safety and functionality of the cable.

5.2.4. Qualified Operators

Only qualified technical workers who have undergone special training, passed an examination, and hold an operation certificate should perform hydraulic pressure connections of conductors or overhead ground conductors. The operator's steel stamp should be affixed to the crimping pipe after a successful connection.

5.2.5. Testing Conductor Connections

Conductors or overhead ground conductors must be connected with matching splices and tension clamps. A grip strength tensile test should be performed on test specimens before the construction of the conductor. At least three test pieces (which may include connecting pipes and tension clamps) should be tested, and their test holding strength should be at least 95% of the designed and calculated breaking force of the conductor or overhead ground conductor.

5.2.6. Proper Conductor Cutting and Connection

Conductor cutting and connection should adhere to several key requirements, such as not injuring the steel core when cutting the aluminum strand and ensuring neat incisions. The connection part of the conductor and the overhead ground conductor should not have quality problems like poor stranding, broken strands, and missing strands. There should be no obvious loose strand phenomenon near the nozzle after connection. (Zhangpeng, n.d.)

5.2.7. Crack Prevention

Cracks are strictly prohibited in the straightened connecting pipe. If a crack is detected and it doesn't meet the requirements, it should be cut off and reconnected.

5.2.8. Tension Pay-off Method

The conductor construction of OPGW overhead ground conductor must adopt the tension pay-off method, which contributes to the integrity and performance of the cable.

5.2.9. Suspension Clamp Alignment

After the suspension clamp is installed, the insulator string should be vertical to the ground. While slight deviations (up to 5 degrees) along the line direction and the vertical position are permissible in some cases, excessive deviations should be avoided.

These strong clause provisions are integral to the safe and effective installation of OPGW optical cables. Adherence to these guidelines helps ensure the structural integrity and longevity of the cables.

5.3. Raw Material Inspection and Storage Measures

The quality of materials used in OPGW installation is paramount. These materials should be thoroughly inspected and properly stored to prevent issues during construction. Key measures include:

5.3.1. Material Entry Inspection Control

Materials supplied by the manufacturer must be accompanied by quality certificates, inspection reports, and other relevant quality assurance documents. All materials should be tested and assembled at the material station and should only be sent to the construction site after passing inspection.

5.3.2. Loading and Unloading of Materials

Proper procedures should be followed during the loading and unloading of materials. This includes ensuring that the conductor spool is firmly secured to prevent deformation or falling apart during transportation.

5.3.3. Storage of Materials

Materials of different varieties and specifications should be stored separately and clearly marked. A designated area should be set aside for scrapped and substandard products. Warehouses should have measures in place to protect against rain and moisture.

5.3.4. Synthetic Insulator Care

Synthetic insulators should not be stacked directly on the ground but should be isolated with dunnage to prevent damage, particularly from rodent bites. Ensuring the quality and integrity of materials is essential for a successful installation project.

5.4. Conductor Protection and Safety Measures

During various stages of the installation process, it's vital to take steps to protect the conductors and ensure the safety of the installation team. These measures include:

5.4.1. Protective Measures During Conductor Transportation

Conductor spools should be securely fastened to prevent deformation and disintegration during transportation. When loading, unloading, and transporting the guide and grounding spools, use appropriate hangers for hoisting. Conductor spools should be stored vertically, not flat and stacked. Secure conductor spools in the middle of the transport vehicle and support them with wood. Storage areas for spools should be flat and free of stones and water. Spools should be inspected regularly, and any damage should be repaired.

5.4.2. Conductor Landing Protection Measures

Choose a suitable location for the stretch field, minimizing the landing distance of the lead and the length of the remaining lead. isolation protection measures for soft materials such as tarpaulins in the grounding operation site of the conductor. A designated person should monitor the conductor in the grounding operation field to prevent damage due to vehicle pressure, personnel stepping on it, or equipment interaction. Implement anti-fouling protection measures after conductor landing.

5.4.3. Conductor Protection Measures During Deployment

Minimize the pay-off tension value, while ensuring safety distance from crossover objects. Check the spool for damage before pay-off and repair if necessary. Arrange the bobbin frame in a fan shape to prevent the conductor from grinding against the side of the spool. Maintain conductor-laying tools and equipment, ensuring they operate smoothly. The lead-out direction of the conductor should be perpendicular to the axis of the spool. Anchor Operation Protection Measures. Use anchor ropes with low rotational forces, covered with rubber tubes where they contact conductors. Check the model, strength, and smoothness of conductor clamps before installing. Avoid sliding or rolling of conductor clamps on conductors. Hang the tail conductor, other than the conductor clamp, with a soft rope, maintaining an appropriate distance to prevent bending and loose strands. Ensure the conductor ropes and anchor ropes have spacers when in contact with conductors. Preventing Conductors from Whipping Each Other Minimize the time interval between releasing the conductor, tightening the conductor, and other construction processes.

Consider the anti-vibration requirements of the lead near the anchor during tension near the anchor. In cases where conductors are twisted with each other, avoid tightening them, and prevent conductors from jumping. (Zifeng & Dickens, 2020)

5.4.4. Conductor Protection During Tightening

Stagger the conductor catchers and maintain a sufficient distance from the pulley to prevent them from topping the pulley. Avoid dragging tools on the conductor, or cover contact points with a rubber tube. Ensure proper care of the remaining lines. Do not tighten the conductor when sub-conductors are twisted, and avoid abrupt or sharp changes in tension. Limit the envelope angle of the conductor on tight conductor pulleys to prevent internal injury.

5.4.5. Accessory Installation Protection Measures

Install accessories promptly after tightening the conductor to avoid conductor vibration and mutual whiplash. When installing accessories and spacers, conduct a comprehensive inspection of the conductor. Conductor hooks used to install accessories should be covered with rubber, with adequate contact length. Mark accessories with markers, avoiding hard objects like pliers or wrenches for marking. Install protective rubber tubes on conductors before removing the pay-off pulley. Use soft ropes for transmitting accessories, ensuring that tools and materials do not collide with conductors. Avoid striking conductors with hard objects; if necessary, use wooden or rubber hammers. Cover grooves and openings of flywheels with rubber and ensure reliable brakes. Pre-install the conductor protection hose when installing or removing the flying car.

These conductor protection and safety measures are critical for ensuring the longevity and safety of the OPGW optical cable during installation.

6. Conclusion and Implications

6.1. Summary of Findings

In conclusion, our examination of this critical infrastructure project has revealed several key findings:

The successful realization of the project depends on meticulous engineering and construction, as detailed in the preceding sections. A multidisciplinary approach, combining expert project management and a strict adherence to safety standards, is crucial for the project's success. The deployment of a ±660kV DC transmission line, as demonstrated in the Matiari to Lahore project in Pakistan, represents a remarkable fusion of technical precision, stringent quality standards, and an unwavering commitment to safety.

6.2. Recommendations and Implications for Future Projects

Based on the findings outlined in this study, we can make the following recommendations and draw implications for future infrastructure projects:

Future projects should adopt a multidisciplinary approach that prioritizes expert project management and stringent safety standards to ensure success. The deployment of high-voltage DC transmission lines, such as ±660kV lines, should follow the technical precision and quality standards demonstrated in this project. Innovation and best practices should continue to be embraced to usher in a new era of efficient, safe, and sustainable construction for large-scale infrastructure projects.

In the ever-evolving landscape of infrastructure development, these recommendations and implications are essential for achieving success and ensuring that projects of this magnitude become a testament to our capabilities in engineering and construction.

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