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Design and calculation of overhead transmission line

A graduation project submitted to the Department of Electrical Engineering, in partial fulfillment for the requirements for the award of the degree of Bachelor of Electrical Engineering

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بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

((وَوَهَبْنَا لَهُمْ مِنْ رَحْمَتِنَا وَجَعَلْنَا لَهُمْ لِسَانَ صِدْقٍ عَلِيًّا)) مره ايه (٥٠)

صدق الله العلي العظيم

SUPERVISOR CERTIFICATION

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(Design and calculation of overhead transmission line) prepared by
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We certify, as an examining committee, that we have read this project report entitled " **Design and calculation of overhead transmission line**" examined the students (**Shahad mukhlalas, Zeina ahamed , Fatima quadier**) in its contents and found the project meets the standard for the degree of Bachelor of Science in Electrical Engineering.

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DEDICATION

First and foremost. I would like to thank my parents for their love and support throughout my life thank you for giving me strength to reach and to my siblings who always there to support and guide me.

ACKNOWLEDGEMENT

Praise be to ALLAH who enabled us to complete this work under his benediction.

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ABSTRACT

The electrical power system is a vital foundation of modern infrastructure, consisting of three main networks: generation, transmission, and distribution. The 132kV overhead transmission line plays a crucial role in connecting power plants with distribution networks, and its design requires high precision to ensure efficiency and sustainability in energy transmission.

This research aims to design and analyze a 132kV overhead transmission line, focusing on the electrical and mechanical factors influencing its performance. The following topics will be covered in this research to explain the design process of the overhead transmission line:

- Definition of the line's main components
- Selection of the appropriate phase conductor
- Insulation coordination and clearance distances
- Choice of insulators and their specifications
- Tower spotting and structural
- Calculation of conductor sag and geometric variations
- Calculation of span lengths and compliance with safety requirements
- Tower geometry analysis and selection of appropriate tower types
- Earth wire analysis and effectiveness

LIST OF FIGURES

Figure (2.1)	overhead and underground cable	8
Figure (3.1)	ACCC conductor and comparison of ACCC and ACSR	15
Figure (3.2)	ACSR conductor	16
Figure (3.3)	Configuration of bundled conductor	18
Figure (3.4)	wooden poles A and H type	20
Figure (3.5)	RCC poles single and double circuit	21
Figure (3.6)	Construction of transmission tower	23
Figure (3.7)	the pin type insulator.	27
Figure (3.8)	Suspension Insulators	27
Figure (3.9)	Disc equivalent circuit	29
Figure (3.10)	Use of cross arm long	31
Figure (3.11)	Use of cross arm long	32
Figure (3.12)	The corona effect in transmission overhead line	33
Figure (3.13)	Conductor suspension between two supports	39
Figure (3.14)	A conductor between two equal level supports	42
Figure (3.15)	wind effect on the conductor	44
Figure (3.16)	The SLIM device	45
Figure (4.1)	Equivalent circuit of the short-line mode	47
Figure (4.2)	Equivalent circuit of the Pi model	47
Figure (4.3)	single configuration	54
Figure (4.4)	double configuration	54
Figure (4.5)	Four-conductor bundle	55
Figure (4.6)	overhead Ground wire	64

LIST OF TABLES

Table (3.1)	Conductor Mechanical and Electrical Properties	16
Table (3.2)	Show the string efficiency for 9 discs in different value of k	30
Table (3.3)	Normal clearance for overhead lines	41
Table (4.1)	Inductance and capacitance	57
Table (4.2)	The values of inductance reactance and susceptance	59
Table (4.3)	Voltage drop for each conductor type	60
Table (4.4)	The losses for each conductor type	62
Table(4.5)	Efficiency for each conductor type	63
Table(5.1)	The Result of Calculations	66

LIST OF ABBREVIATIONS

AC	Alternating Current
OHTL	Overhead Transmission Line
CU	Copper Conductor
ACSR	Aluminum conductor Steel Reinforced
AAAC	All Aluminum Alloy Conductor
ACAR	Aluminum Conductor Alloy
AAAC	All Aluminum Alloy Conductor
AAC	All Aluminum Conductor
TL	Transmission Line
HV	High Voltage
MW	Megawatt
kV	Kilovolt
V	Volt
A	Ampere
R	Resistance
I	Current
V	Voltage
Z	Impedance
XL	Inductive Reactance
XC	Capacitive Reactance
GMR	Geometric Mean Radius
GMD	Geometric Mean Distance
D	Diameter
R	Radius
L	Length
v_0	Critical Disruptive Voltage

p_c	Corona power losses
s	Air Density Factor
F	Frequency
W	Angular Frequency

TABLE OF CONTENTS

Dedication	I
Acknowledgement	II
Abstract	III
List of Figure	IV
List of Table	V
List of Abbreviations	VI
Table of Contents	VIII

Chapter One: Introduction

1.1 Introduction	1
1.2 Historical Overview	2
1.3 Motivation	3
1.4 Aim of This Project	4
1.5 Chapters Layout	5

Chapter Two: Transmission Line

2.1 An Overview of Transmission Line	6
2.2 Type of Transmission Line	7
2.3 Overhead or Underground	8
2.4 Specification of 132KV Transmission Line Design	9
2.5 Compound of overhead Transmission Line	9

Chapter Three: Mechanical Calculation

3.1 Introduction	11
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3.2 Phase conductor	11
3.2.1 Conductor Materials	11
3.2.2 Typically used Conductor Material	12
3.2.3 Type of Conductor	14
3.2.4 ASCR For 132kv	16
3.2.5 Conductor Arrangement	17
3.2.6 Conductor Configurations	18
3.3 Line Support	19
3.3.1 Type Line Support	19
3.4 Tower Selection	22
3.4.1 Construction of Transmission Towers	22
3.4.2 Type of Towers	23
3.4.2.1 Medium Voltage (MV) Towers	24
3.4.2.2 High Voltage (HV) Tower	24
3.5 Insulator	25
3.5.1 Insulator Type	26
3.5.2 Potential Distribution over Suspension Insulator String	28
3.5.3 String Efficiency	29
3.5.4 String Efficiency for 132 kv	29
3.5.5 Methods of Improving String Efficiency	30
3.6 Corona Effect	32
3.6.1 Factors Affecting Corona	33
3.6.2 Critical Disruptive Voltage	34
3.6.3 Power losses	36

3.6.4	Corona Benefits and Disadvantages	37
3.6.5	Methods of Decreasing Corona Effect	38
3.7	Overhead Line Sag	38
3.7.1	Factors Affecting Sagging in Transmission Lines	39
3.7.2	Why is Sag Provided in the Transmission Lines	40
3.7.3	Sag and Tension of The Conductor	41
3.7.4	Sag Calculation	41
3.7.5	Wind and Ice Loading Effect	43
3.7.6	Methods to Prevent Excessive Sagging in OTL	44

Chapter Four: Electrical Calculation

4.1	Introduction	46
4.2	Electrical models	46
4.3	Electrical Parameters	48
4.3.1	Resistance of Transmission Lines (R)	48
4.3.2	Inductance of Transmission Lines (L).	50
4.3.3	Capacitance of Transmission Lines	51
4.4	Electrical Parameters (GMD and GMR)	52
4.4.1	The Geometrical Mean Distance (GMD)	53
4.4.2	Geometrical Mean Radius (GMR)	55
4.5	Practical Calculation of Inductance and Capacitance	56
4.6	Calculation of Line Reactance	57
4.7	Impedance of The Transmission	58
4.8	Performance of Overhead Transmission Line	59
4.8.1	Voltage Drop	59

4.8.2 Losses	60
4.8.3 Efficiency	62
4.9 Earth Wire	63
4.9.1 Construction and Purpose of Ground Wires	64
4.9.2 Types of counterpoise	65
4.9.3 Shielding or Protective Angle	65
Chapter Five: Conclusion and Future Work	
5.1 Result of Calculation	66
5.2 Conclusion	67
5.3 Future Work	68
References	69

Chapter One

Introduction

1.1 Introduction

The electrical power system is a critical element in the backbone of modern infrastructure, responsible for meeting the energy demands of societies. It is composed of three main components: generation, transmission, and distribution. Among these, overhead transmission lines play an essential role in transferring electricity from power plants to distribution networks.

132kV overhead transmission lines are vital for transmitting large amounts of electrical energy over long distances with high efficiency. The design of these lines requires a thorough understanding of both electrical and mechanical factors to ensure optimal performance, reduce energy losses, and maintain safety standards. As the demand for electricity continues to grow, the need for reliable and efficient transmission line designs becomes crucial to ensure uninterrupted service and minimize energy waste

Designing these transmission lines involves several critical considerations, including the selection of appropriate conductors, determination of insulator specifications, sag calculation, clearance requirements, and mechanical load analysis on towers. Additionally, environmental and geographical factors must be incorporated to ensure the design is safe, durable, and sustainable. This study focuses on the design of 132kV overhead transmission lines, utilizing international standards such as IEC and EN to ensure a reliable and efficient design process.

According to IEC 60826, overhead transmission line design should comprehensively consider both electrical and mechanical parameters to meet system requirements and provide long-term operational sustainability[1].

We will outline the primary design considerations and present the necessary calculations to develop the 132kV overhead transmission line.

1.2 Historical Overview

The idea of transmitting electricity over long distances was first realized in the late 19th century. Nikola Tesla and George Westinghouse were instrumental in developing alternating current (AC) systems, which paved the way for electricity to be transmitted across greater distances with minimal losses. However, early transmission systems operated at lower voltages, and the design of transmission lines was still in its early stages. As the need for efficient electricity transmission grew alongside industrialization and urbanization, the demand for improved systems became more apparent [2].

By the mid-20th century, the increasing demand for electricity led to the need for high-voltage transmission systems to meet the energy needs of cities and industrial areas. During this period, 132kV overhead transmission lines emerged as a reliable and efficient solution for transmitting energy over long distances, with reduced power losses compared to lower voltage systems

Over time, significant technological advancements improved the design and efficiency of 132kV transmission lines. New materials such as aluminum conductors and composite insulators helped strengthen and enhance the reliability of the transmission lines. In the 1970s, the introduction of advanced materials like silicone rubber for insulators improved performance in harsh environmental conditions.

Today, 132kV overhead transmission lines are the backbone of regional electrical grids, especially in countries with high energy demands. Modern designs focus on improving aesthetic integration into natural landscapes, particularly in areas with sensitive terrain. There is also an increasing emphasis on reducing environmental impact, using materials and designs that minimize the ecological footprint of power lines while maintaining optimal energy transmission.

1.3 Motivation

The growing global demand for electricity, fueled by industrialization, urbanization, and technological advances, has made efficient power transmission essential. 132kV overhead transmission lines offer an effective solution for transmitting power over long distances.

- Growing Energy Demand as population and technological use increase, so does electricity demand. 132kV transmission lines ensure reliable power delivery with minimal loss, especially in remote areas.
- Ensuring Energy Reliability and Security Reliable power is critical to both industrial and domestic sectors. The design of 132kV transmission lines helps reduce outages and ensures stable.
- Integration of Renewable Energy With the shift to renewable energy, 132kV lines play a crucial role in integrating solar, wind, and hydropower into national grids.
- Minimizing Environmental Impact Modern 132kV transmission lines incorporate advanced materials and designs that reduce environmental impact and improve energy efficiency [3].

1.4 The Aim of This Project

The primary aim of this study is to design and analyze 132kV overhead transmission lines, focusing on optimizing their efficiency, reliability, and integration with renewable energy sources. This study aims to achieve the following specific objectives:

- **Design of 132kV Transmission Lines:** To develop an efficient design for overhead transmission lines that ensures minimal energy loss, adequate clearance, and meets all relevant safety standards.
- **Evaluation of Electrical and Mechanical Parameters:** To assess the electrical and mechanical factors affecting the performance of 132kV transmission lines, including conductor size, insulation specifications, and load-bearing capacities of towers.
- **Integration with Renewable Energy:** To explore how 132kV transmission lines can support the integration of renewable energy sources, such as wind and solar power, into existing power grids.
- **Minimizing Environmental Impact:** To investigate ways to reduce the environmental footprint of transmission lines through the use of advanced materials and eco-friendly designs.
- **Reliability and Security:** To ensure that the designed transmission lines meet the reliability and security requirements necessary for uninterrupted power supply, particularly during peak demand periods

1.5 Chapters Layout

- ✚ **Chapter One:** Introduction
- ✚ **Chapter Two:** Transmissions Line
- ✚ **Chapter Three:** Mechanical Calculation
- ✚ **Chapter Four:** Electrical Calculation
- ✚ **Chapter Five:** Conclusion and Future Work

Chapter Two

Transmission Line

2.1 An Overview of Transmission Line

Transmission lines are an integral part of modern electrical power systems, responsible for the efficient transfer of electrical energy from power generation plants to distribution networks, ensuring a stable and reliable supply of electricity. As the demand for electricity continues to grow globally, the design, construction, and operation of transmission lines have become essential to meet these needs efficiently and sustainably. This section provides a detailed overview of transmission lines, focusing on their purpose, components, types, importance, and challenges.

Transmission lines are specialized electrical conductors designed to carry high-voltage electricity from power plants to substations, where the voltage is reduced for local distribution. The primary function of these lines is to ensure the effective and efficient transportation of electricity over long distances, minimizing power loss and maintaining a stable supply to consumers [4].

The importance of transmission lines cannot be overstated in the context of modern power systems. They form the backbone of the electrical grid facilitating the long-distance transmission of electricity. These lines are crucial for connecting remote power generation facilities to densely populated urban areas and industrial regions, ensuring that electricity is available to meet the diverse demands of society. Additionally, they play a critical role in grid stability, enabling the balancing of load across regions and preventing blackouts during high-demand periods .

2.2 Type of Transmission Lines

Transmission Lines are one of the most essential systems used for long-distance electricity transmission. These lines are highly effective in terms of cost and ease of maintenance when compared to underground lines. Overhead transmission lines are used to transfer electricity from power stations to substations or directly to residential and industrial areas. They can be classified based on various criteria such as voltage levels, line length, and the type of transmission. This chapter provides a detailed overview of these classifications.

1. By Voltage

- **High Voltage Transmission Lines (HVTL):** These lines operate at voltages exceeding 100 kV and are used for long-distance power transmission between generation plants and substations or major industrial areas.
- **Medium Voltage Transmission Lines:** Operating within a voltage range of 33 kV to 100 kV, medium voltage lines connect high voltage transmission lines to local distribution networks.
- **Low Voltage Transmission Lines:** These lines operate at voltages below 33 kV and are primarily used for the final stage of electricity distribution.

2. By Line Length

- **Short Transmission Lines:** These lines span distances of less than 50 kilometers.
- **Medium Transmission Lines:** These lines extend between 50 kilometers and 200 kilometers.
- **Long Transmission Lines:** These lines extend over 200 kilometers and are typically designed for high voltage transmission (HVTL).

3. By Transmission Type

- **Overhead Transmission Lines:** These are the most common type of transmission line used worldwide. They are mounted on towers or poles above the ground.
- **Underground Transmission Lines:** While less common, underground transmission lines are used in areas with high population density or where aesthetics and environmental concerns are significant.

2.3 Overhead or Underground Cable

Electric power can be transmitted or distributed using either underground cables or overhead lines. Figure (2.1) shows the overhead and underground cable. Underground cables are rarely used for power transmission, primarily for two reasons.

Firstly, power is typically transmitted over long distances to load centers, and the installation costs for underground transmission are significantly high.

Secondly, electric power must be transmitted at high voltages for economic reasons. Providing the necessary insulation for underground cables to withstand such high voltage levels is a challenging task. Therefore, for long-distance power transmission, overhead lines are generally used. With the continuous growth in power demand and the subsequent increase in voltage levels, the importance of overhead line transmission has grown considerably [5]



Figure 2.1 Overhead and underground cable

2.4 Specification of 132KV Transmission Line Design

Transmission line conductors and towers are familiar elements in electrical infrastructure. However, each transmission line has unique characteristics that impact both its design and environmental effects. This section outlines the key design specifications for a 132kV overhead transmission line, which include the following:

- **Line Identifier & Voltage Rating:** The transmission line under consideration operates at a nominal voltage of 132kV, which is close to its RMS (root mean square) voltage. The actual voltage may fluctuate due to line resistance, distance, and interaction with connected equipment.
- **Line Length & Route Characteristics:** The total length of the transmission line is (150) km. The route traverses varying altitudes, which influence insulation requirements and mechanical design.
- **. Altitude & Environmental Factors:** The altitude range of the transmission line is (above30) meters. Weather conditions such as wind, ice, and temperature variations affect tower design and conductor selection.
- **Design Load District:** The wind and ice loading conditions determine tower dimensions, span length, and conductor mechanical strength.

Proper wind dampening techniques are implemented to reduce conductor oscillations. By considering these factors, the transmission line is designed to ensure reliability, efficiency, and minimal environmental impact.

2.5 Compound of overhead Transmission Line

An overhead line may be used to transmit or distribute electric power. The successful operation of an overhead line depends to a great extent upon the mechanical design of the line. While constructing an overhead line, it should be ensured that mechanical strength of the line is such so as to

provide against the most probable weather conditions. In general, the main components of an overhead line are:

- Conductors which carry electric power from the sending end station to the receiving end station.
- Supports which may be poles or towers and keep the conductors at a suitable level above the ground.
- Insulators which are attached to supports and insulate the conductors from the ground.
- Cross arms which provide support to the insulators.
- Miscellaneous items such as phase plates, danger plates, lightning arrestors, anti-climbing wires etc.

Chapter Three

Mechanical Calculations

3.1 Introduction

The mechanical calculation of an overhead transmission line is a crucial step in the design process, ensuring that all components can withstand various operational and environmental conditions without failure. An overhead line consists of towers, conductors, insulators, earth wires, fittings, and foundations, all of which are subjected to mechanical forces and external factors such as wind, ice loading, and temperature variations.

3.2 Phase Conductor

Since the conductor is one of the major cost components of a line design, it is essential that the most appropriate conductor type and size be selected for optimum operating efficiency [6]. A systematic approach should be taken in the selection of the conductor. Factors such as tension loads, ice and wind loads, current loading of the line, voltage stability, environmental effects, electrical losses, ambient conditions, and many others must be considered in the process. The goal is to select a conductor that exemplifies the best conductivity-to-weight ratio and/or strength-to-weight ratio at a minimal cost for the application. The electrical and mechanical properties, thermal properties, and stress-strain relationship of the conductor will dictate the choice of conductor type and size for a given design. It is the purpose of this paper to provide basic information concerning various conductor designs available to transmission and distribution engineers and planners.

3.2.1 Conductor Materials

The conductor is one of the important items as most of the capital outlay is invested for it. Therefore,

proper choice of material and size of the conductor is of considerable importance. The conductor material used for transmission and distribution of electric power should have the following properties [7]:

- high electrical conductivity.
- high tensile strength in order to withstand mechanical stresses.
- low cost so that it can be used for long distances.
- low specific gravity so that weight per unit volume is small.

All above requirements are not found in a single material. Therefore, while selecting a conductor material for a particular case, a compromise is made between the cost and the required electrical and mechanical properties.

3.2.2 Typically Used Conductor Material

Electrical conductors in overhead transmission lines are used to efficiently transport electrical power. These conductors are typically stranded to enhance flexibility, where individual wires are arranged around a central wire in successive layers (6, 12, 18, 24, etc.). The total number of individual wires in a stranded conductor can be calculated using the formula: $3n(n + 1) + 1$ where n represents the number of layers around the central wire. During manufacturing, the layers are twisted in opposite directions to enhance cohesion and stability [5]

Following are different type of material use for transmission lines

- 1. Copper (Cu) :** The extensively used, high conductivity material as conductor for electrical machines or equipment, is copper. Malleability, weld ability and solder ability are most important properties of copper. Copper in pure form is having good conductivity. But the conductivity of standard grade copper is reduced due presence of impurities.

- 2. Aluminum (Al)** Aluminum is an element which is a silver-white, light weight, soft, non-magnetic and ductile metal, Aluminum is the third most abundant element (after oxygen and silicon) and most abundant metal found in earth's crust. The main ore of aluminum is bauxite. Aluminum is having low density, high ductility, good corrosion resistance and good conductivity, which makes it suitable to use as electric conductor for transmission and distribution of electricity.
- 3. Cadmium-Copper Alloy** The cadmium copper alloys contain cadmium from 0.6 to 1.2%. This small addition of cadmium increase the tensile strength and corrosion resistance of copper. The conductivity of cadmium copper alloys is 90 to 96% of pure copper.
- 4. Phosphor Bronze** Phosphor bronze is an alloy of copper with 3.5 to 10% tin and up to 1% phosphorus. Sometimes, it is also called as "Phos-Bronze". The phosphorus is added as deoxidizing agent during melting. Phosphor bronze is having good strength, toughness, low coefficient of friction and fine grains. The addition of phosphorous increase the fluidity of molten which results in improved cast ability of alloy, and cleanup the grain boundaries which improves the mechanical properties of alloy
- 5. Galvanized Steel** Pure Iron and steel get rusted or corroded in open whether conditions. To avoid the corrosion, of sheet and wire etc. made of these metals are coated with Zinc. For Zinc coating Hot-dip galvanization is used. In this process the iron or steel is dipped in molten Zinc at a temperature around 4490C. When exposed to atmosphere, the zinc reacts with oxygen (O₂) and forms the substance zinc oxide (ZnO), which further reacts with carbon dioxide and form zinc carbonate (ZnCO₃).

Selecting a conductor for overhead transmission lines requires evaluating electrical conductivity, tensile strength, weight, cost, and sag characteristics. Based on these factors, aluminum and ACSR conductors are the most widely used due to their balance between cost and performance, while copper remains an option for applications requiring superior electrical performance regardless of cost.

3.2.3 Types of Conductors

Due to the advantages of aluminum conductors over copper in terms of cost, conductivity, mechanical strength, and weight, aluminum conductors have become the primary choice for overhead transmission lines. Although an aluminum conductor has a larger diameter than a copper conductor of the same resistance, this is actually beneficial in reducing the corona effect, as corona discharge decreases with an increase in conductor diameter.

Several types of overhead conductors are used in transmission and distribution lines to transport electrical energy from power generation stations to consumers. These conductors are typically stranded to enhance flexibility, as solid wires are difficult to handle and are prone to crystallization at support points due to wind-induced vibrations.

1. All-Aluminum Conductor (AAC)

Also known as ASC (Aluminum Stranded Conductor), AAC is made up of strands of EC grade (Electrical Conductor grade) aluminum. It offers a conductivity of about 61% IACS (International Annealed Copper Standard). Despite its high conductivity, AAC has limited mechanical strength, making it suitable only for urban distribution networks with short spans rather than long-distance high-voltage transmission lines.

2. All-Aluminum Alloy Conductor (AAAC)

This conductor is made from aluminum alloy 6201, which contains magnesium and silicon, providing greater mechanical strength than AAC,

with a conductivity of 52.5% IACS. AAAC is lighter than ACSR of equivalent strength, making it a suitable choice for distribution networks, especially in coastal areas due to its excellent corrosion resistance. However, it is not widely used in primary transmission networks. Figure (3.1) show ACCC conductor and comparison of ACCC and ACSR[8].

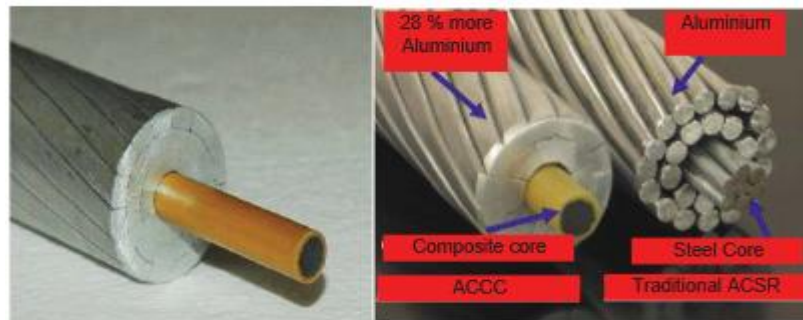


Figure (3.1) ACCC conductor and comparison of ACCC and ACSR

3. Aluminum Conductor, Steel-Reinforced (ACSR)

ACSR consists of a solid or stranded steel core surrounded by layers of high-purity aluminum (1350). The steel core can be galvanized or aluminum-coated to protect against corrosion. This steel core provides additional mechanical strength, significantly reducing sag compared to other aluminum conductors. ACSR conductors are available with steel content ranging from 6% to 40%, depending on the required mechanical strength. They are primarily used for long-distance transmission lines and in applications requiring high tensile strength, such as river crossings.

4. Aluminum Conductor, Alloy Reinforced (ACAR)

ACAR conductors are composed of high-purity aluminum (1350) strands wrapped around a high-strength aluminum-magnesium-silicon alloy (6201) core. ACAR offers improved electrical and mechanical properties compared to ACSR, making it suitable for both transmission and distribution lines. When designing 132 kV overhead transmission lines, several factors must be considered when selecting the conductor type,

including current-carrying capacity, electrical losses, mechanical tensile strength, and corrosion resistance.

ACSR conductors are the most commonly used in this voltage class due to their optimal combination of high mechanical strength and good electrical conductivity.

3.2.4 ASCR FOR 132KV

Composed of aluminum wires surrounding a steel core which enhances the mechanical strength of the conductor. The tensile strength of aluminum ranges from 16-20 kg/mm², while steel has a U.T.S of about 136 kg/mm², providing the conductor with significant mechanical in.

Figure (3.2) Show ACSR Conductor.

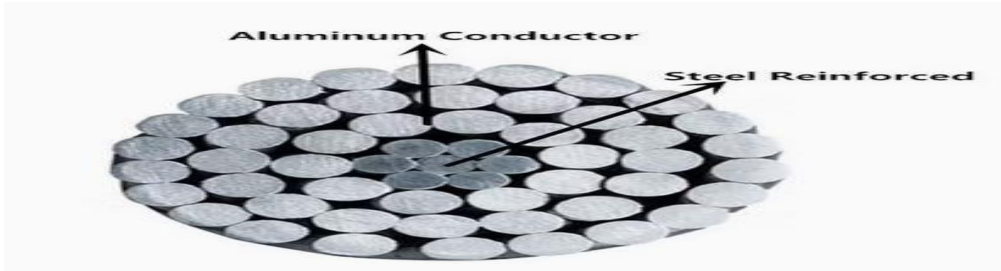


Figure 3.2 Show ACSR conductor

The Table (3.1) presents the mechanical and electrical properties of the conductors used in the design and implementation of 132KV overhead transmission lines.

Voltage	132KV
Code name of Conductor	PANTHER ACSR
No of Conductor/phase	4
Stranding/Wire diameter	'30/3.00+'7/3.00
Total Section Area	261.5 mm ²
Overall diameter	21mm
Approx. weight	947g/km
Man Allowable Temperature	75° c

Table (3.1) Conductor Mechanical and Electrical Properties

The advantages of ACSR conductors include:

1. Enhanced tensile strength while maintaining a lightweight structure.
2. Reduced sag, allowing for longer spans between towers.
3. The possibility of using shorter transmission towers due to minimized sag

3.2.5 Conductor Arrangement

The arrangement of conductors in overhead transmission lines is a crucial factor influencing electrical performance, efficiency, and reliability. Various conductor configurations, such as single, double, and bundled conductors, impact power loss, corona discharge, and mechanical stability.

Types of Conductor Arrangement:

1. **Single Conductor Configuration:** A single conductor per phase is used.
 - **Application:** Common in low and medium voltage systems (up to 132kV).
 - **Advantages:** Simple design, cost-effective, easy maintenance.
 - **Disadvantages:** High line losses, increased reactance, and corona effects at higher voltages
2. **Double (Twin) Bundle Conductor:** Two conductors per phase, spaced at a fixed distance.
 - **Application:** Used in high-voltage lines (132kV - 220kV).
 - **Advantages:** Reduces losses, decreases reactance, and enhances power transmission capacity.
 - **Disadvantages:** Higher installation costs and complex maintenance.
3. **Bundle Conductor (Multi-Conductor per Phase)** A phase consists of two, three, or four conductors bundled together.
 - **Application:** Used in extra-high and ultra-high voltage (400kV and above).

- Advantages: Reduces corona discharge and radio interference. Lowers line reactance and improves stability. Enhances power transfer without increasing voltage levels.
- Disadvantages: Higher cost, complex tower design, increased right-of-way requirements.

Figure (3.3) Typical configuration of bundled conductors using 3 or 4 conductors per phase in high voltage transmission lines.

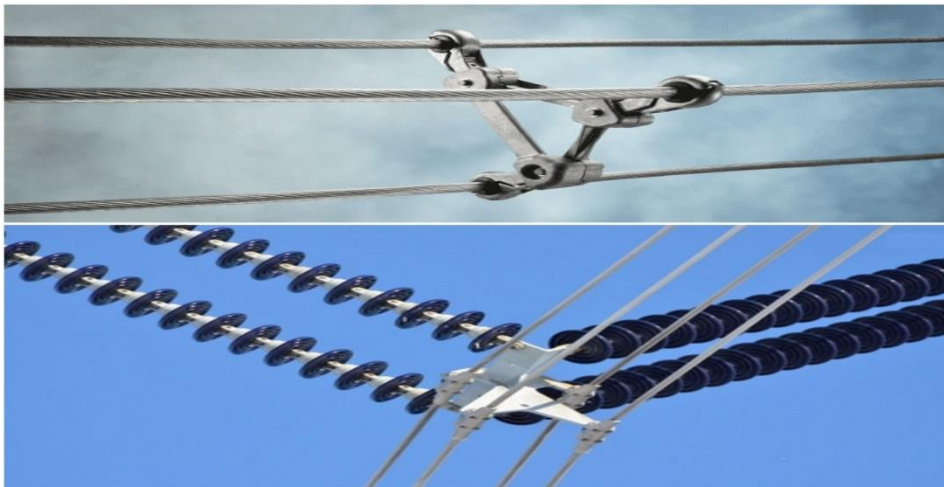


Figure (3.3) Configuration of bundled conductors

3.2.6 Conductor Configurations

Conductor configuration in transmission lines refers to the physical arrangement of conductors in each phase. Various configurations are used depending on the voltage level and line requirements. The most common types include:

- Vertical Arrangement: Conductors positioned in a vertical stack.
- Horizontal Arrangement: Conductors aligned in a horizontal row, commonly used in open terrains.
- Triangular/Delta Configuration: Optimized for reducing inductive reactance and enhancing transmission efficiency.

3.3 Line support

Line supports are essential components in electrical power transmission and distribution systems, playing a crucial role in holding conductors at a safe height above the ground. These supports ensure the reliable and safe operation of the system. The ideal line support should be light weight without compromising mechanical strength, capable of withstanding mechanical loads and wind forces, have a long life span, be easy to maintain, and be cost-effective.

The Line supports should have the following properties:

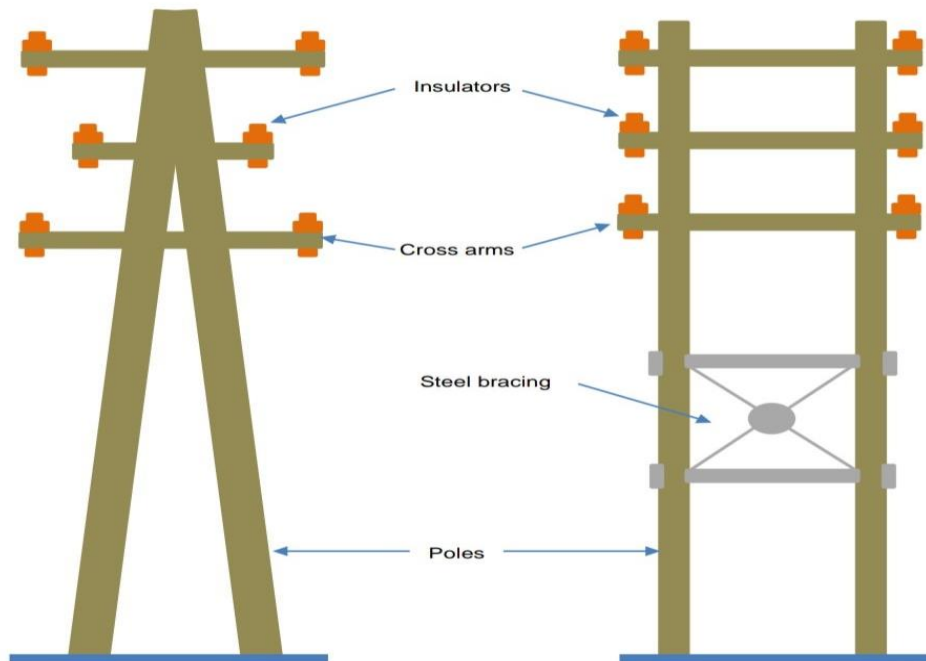
- High mechanical strength to with stand the weight of conductors and wind loads etc.
- Light in weight without the loss of mechanical strength.
- Cheap in cost and economical to maintain.
- Longer life.
- Easy accessibility of conductors for maintenance.

3.3.1 Type of line Support

The line support used for transmission and distribution of electric power are of various types The choice of supporting structure for a particular case depends upon the line span, X-sectional area, line voltage, cost and local conditions:

1.Wooden poles : These are made of seasoned wood and are suitable for lines of moderate X-sectional area and of relatively shorter spans, say up to 50 metros. Such supports are cheap, easily available, provide insulating properties and, therefore, are widely used for distribution purposes in rural areas as an economical proposition The wooden poles generally tend to rot below the ground level, causing foundation failure. In

order to prevent this, the portion of the pole below the ground level is impregnated with preservative compounds like creosote oil. Double pole structures of the 'A' or 'H' type are often used Figure (3.4). to obtain a higher transverse strength than could be economically provided by means of single poles.



Figure(3.4) Wooden poles A and H type

The main objections to wooden supports are :

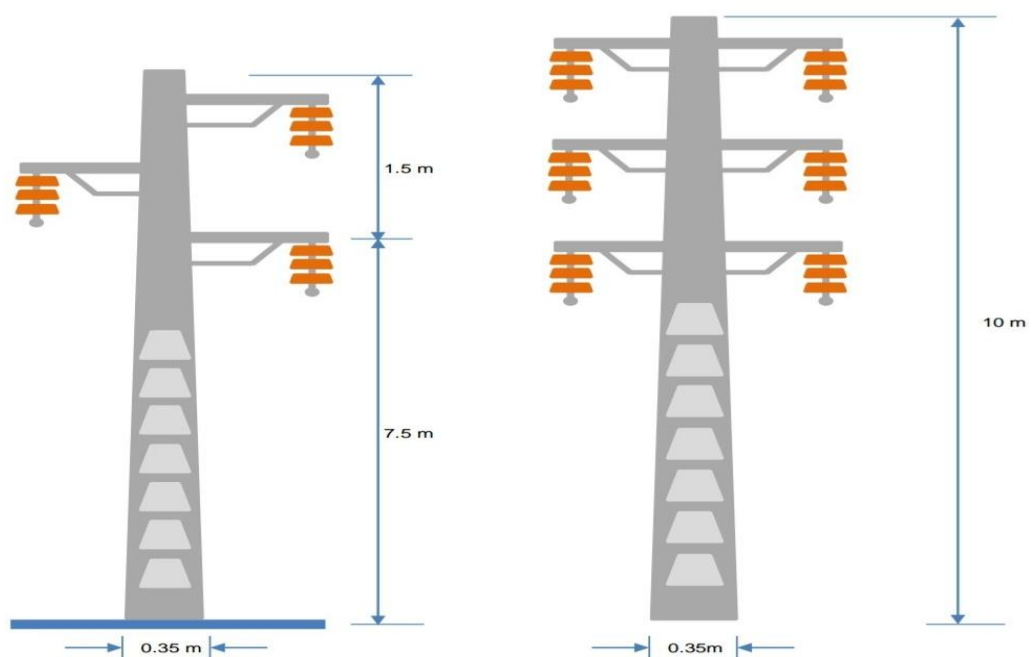
- tendency to rot below the ground level
- comparatively smaller life (20-25 years)
- cannot be used for voltages higher than 20 kV
- less mechanical strength and
- require periodical inspection.

2. Steel poles : The steel poles are often used as a substitute for wooden poles. They possess greater mechanical strength, longer life and permit longer spans to be used. Such poles are generally used for distribution

purposes in the cities. This type of supports need to be galvanized or painted in order to prolong its life. The steel poles are of three types [9].

- rail poles
- tubular poles and
- rolled steel joints.

3.RCC poles :The reinforced concrete poles have become very popular as line support in recent years. They have greater mechanical strength, longer life and permit longer spans than steel Moreover, they give good outlook, require little maintenance and have good insulating properties. Figure. (3.5) shows R.C.C. poles for single and double circuit. The holes in the poles facilitate the climbing of poles and at the same time reduce the weight of line support.



Figure(3.5) RCC poles single and double circuit

The main difficulty with the use of these poles is the high cost of transport owing to their heavy weight. Therefore, such poles are often manufactured at the site in order to avoid heavy cost of transportation.

3.4 Tower Selection

The towers used in overhead transmission lines play a pivotal role in ensuring the proper functioning and cost-effectiveness of the power transmission system. Not only do these towers define the aesthetic appearance of the power line, but they also significantly impact its operational reliability. The design, material selection, and structural configuration of the towers influence both the mechanical strength required to withstand the forces exerted by the conductors and the overall investment required for the line. By ensuring the towers are appropriately designed for specific voltage levels and circuit configurations, engineers can optimize performance and minimize long-term costs.

3.4.1 Construction of Transmission Towers

Transmission towers represent the primary structural support for overhead transmission lines. These towers are designed to carry heavy electrical conductors at a safe height above the ground, ensuring adequate ground clearance and operational safety. Additionally, they must withstand various natural calamities such as high winds, storms, and seismic activities. As such, transmission tower design is a critical engineering task that incorporates principles from civil, mechanical, and electrical engineering disciplines.

A typical transmission tower consists of the following main components are illustrated in Figure (3.6)

- Peak of the Tower
- Cross Arm
- Boom
- Cage
- Tower Body
- Legs
- Stub/Anchor Bolt and Base Plate

- a) **Peak of the Tower:** This is the topmost portion above the upper cross arm. The earth shielding (ground) wire is usually connected to the tip of this section to protect conductors from lightning strikes.
- b) **Cross Arm:** Cross arms support the transmission conductors. Their dimensions depend on the transmission voltage level, line configuration, and minimum angle required for optimal stress distribution.
- c) **Cage:** The cage is the segment between the body of the tower and the peak. It holds and supports the cross arms.
- d) **Tower Body :** The body of the tower extends from the lower cross arms to the base near ground level. It plays a vital role in ensuring sufficient clearance between the lowest conductor and the ground, thereby preventing electrical hazards and ensuring compliance with safety standards.

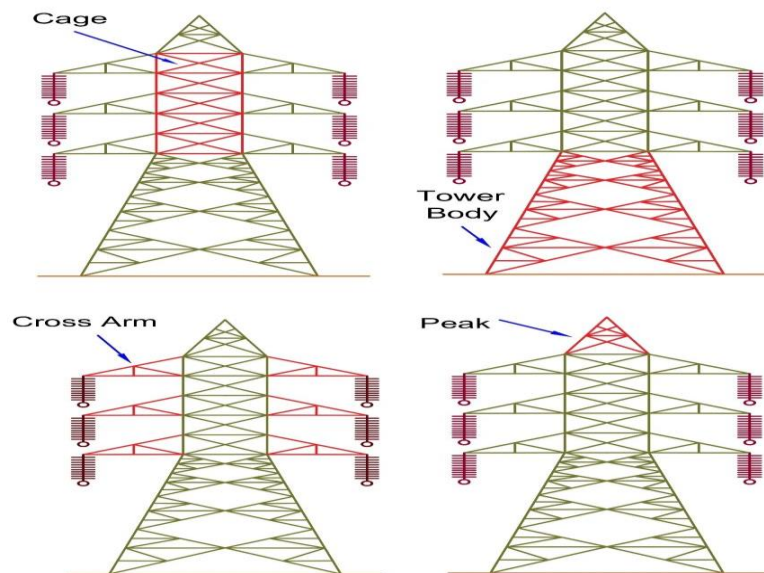


Figure (3.6) Construction of transmission towers [10]

3.4.2 Type of Towers

The overhead line towers shape differs from country to country and from a utility operator to another. there are six different tower shapes

designed for both medium and high voltages, for simple and double circuits, and with one earth wire or two earth wires.

3.4.3.1 Medium Voltage (MV) Towers

Two types of towers are used for medium voltage (MV) lines, based on the following configurations:

1. Single Fork Tower

- Configuration: Single circuit (Simplex) with one earth wire arrangement.
- Shape: The tower has the shape of a fork, with three cross arms all positioned on one side of the tower.
- Usage: Suitable for medium voltage lines requiring a simple and efficient structure to support lower electrical loads.

2. MV Double Fork Tower

- Configuration: Double circuits (Duplex) with two earth wires.
- Shape: The tower features two forks, with one circuit's cross arms on one side and the other circuit's cross arms on the opposite side.
- Usage: Ideal for dual-circuit lines, providing increased capacity and greater stability for higher electrical loads.

3.4.3.2 High Voltage (HV) Tower

Four types of towers are designed for high voltage (HV) transmission lines, which require more complex designs to accommodate higher mechanical loads and environmental factors. These towers are designed to withstand larger forces and ensure efficient power distribution across long distances:

1. S Shape Tower

- Configuration: Single circuit (Simplex) with one earth wire arrangement.
- Shape: The tower takes the shape of the letter S, with two cross arms on one side and the third cross arm on the opposite side.
- Usage: Used in high-voltage lines that require a balanced yet compact design, capable of withstanding mechanical stresses.

2. Single Pi Tower

- Configuration: Single circuit (Simplex) with two earth wire arrangements.
- Shape: The tower is shaped like the Greek letter Pi (Π), with the three-phase conductors aligned horizontally.
- Usage: Suitable for high-voltage lines that need enhanced structural stability, with the added benefit of two earth wires for greater safety.

3. Double T Tower

- Configuration: Double circuits (Duplex) with two earth wire arrangements.
- Shape: The tower takes the shape of the letter T, with two levels of cross arms, one circuit's cross arms on one side and the other circuit's cross arms on the opposite side.
- Usage: Designed for lines with two circuits, allowing efficient power distribution and increased electrical capacity.

4. HV Double Fork Tower

- Configuration: Double circuits (Duplex) with two earth wire arrangements.
- Shape: Similar to the MV Double Fork Tower, but with longer middle cross arms for enhanced mechanical stability.
- Usage: Ideal for high-voltage transmission lines that require additional support for increased mechanical stresses.

3.5 Insulator

Insulators play a crucial role in supporting overhead line conductors on poles or towers in such a way that the conductor currents do not flow to the ground through the supports. This is achieved by securing the line conductors with insulators that provide the necessary insulation between the conductors and the supports, thus preventing leakage currents from the conductors to the ground. Insulators used in overhead transmission lines must have the following desirable characteristics:

- High mechanical strength to withstand the load of the conductors, wind load, and other external forces.

- High electrical resistance of the insulator material to prevent leakage currents to the ground.
- High relative permittivity of the insulator material to ensure a high dielectric strength.
- The insulator material must be non-porous, free of impurities and cracks, as these defects can lower its permittivity.
- A high ratio of puncture strength to flashover strength.

Porcelain is the most commonly used material for overhead line insulators, although glass, steatite, and specialized composite materials are also used to a lesser extent. Porcelain is made by firing a mixture of kaolin, feldspar, and quartz at high temperatures. It is mechanically stronger than glass and causes fewer issues with leakage currents.

3.5.1 Insulator Type

The proper operation of overhead transmission lines largely depends on the correct selection of insulators. There are various types of insulators, with the most common being pin type, suspension type, strain insulator, and shackle insulator

1. **Pin Type Insulators:** These are typically used for voltages up to 33 kV. The conductor is secured to the insulator via a groove, and the insulator is attached to the pole's cross-arm. Pin-type insulators become inefficient and uneconomical for voltages above 33 kV due to their large size. Figure (3.7) show the pin type insulator. The insulators must withstand both mechanical and electrical stresses. Electrical breakdown can occur by flash-over (arc between the conductor and pin) or puncture (discharge through the insulator body). The safety factor of an insulator is determined by the ratio of puncture strength to flashover voltage, with a higher safety factor ensuring flash-over occurs before puncture.

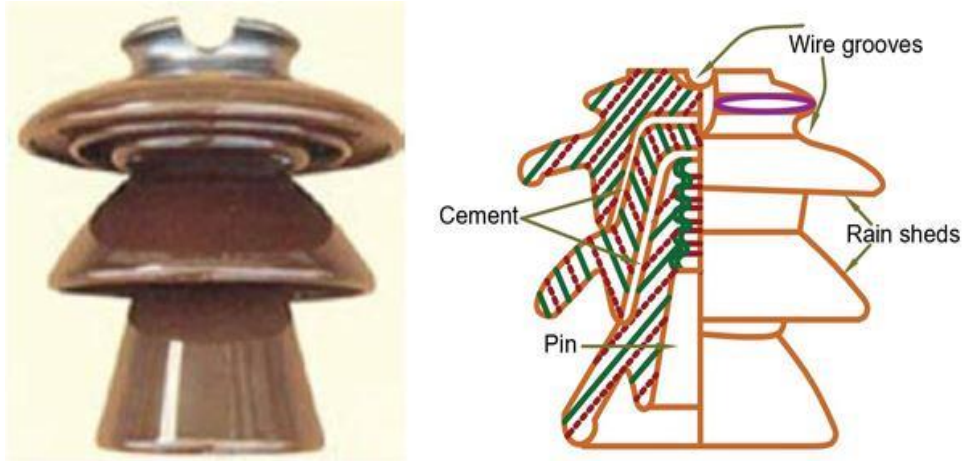


Figure (3.7) The pin type insulator

- Suspension Type Insulators:** Used for high voltages above 33 kV, suspension insulators consist of multiple porcelain discs connected in series. Each disc is designed for a low voltage (e.g., 11 kV), and the number of discs required depends on the operating voltage. Advantages of suspension insulators include their cost-effectiveness at high voltages, flexibility to accommodate mechanical stresses, and ease of replacement of individual discs. They are also more suitable for high-voltage applications and are often used with steel towers Figure(3.8)show the suspension type insulator.

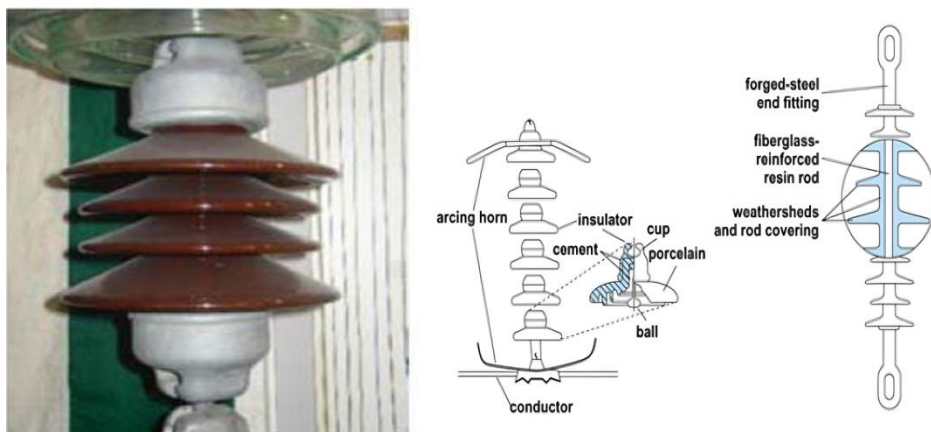


Figure (3.8) Suspension Insulators

- Strain Insulators:** These are used to relieve excessive tension in the line, particularly at the dead ends or sharp curves. For low-voltage lines (< 11 kV), shackle insulators serve as strain insulators, while high-voltage lines

require an assembly of suspension insulators in vertical alignment to handle increased tension.

4. **Shackle Insulators:** Once used for strain applications, shackle insulators are now typically employed in low-voltage distribution lines. They can be installed either horizontally or vertically, with the conductor being secured by a soft binding wire.

The careful selection of insulator types ensures safe and efficient transmission of electrical power while minimizing the risk of failure due to mechanical or electrical stresses.

3.5.2 Potential Distribution over Suspension Insulator String

The suspension insulator string consists of porcelain discs connected in series through metallic links. Figure (3.9) (a) shows a 3-disc suspension insulator string. The porcelain part of each disc is located between two metallic links, and thus each disc forms a capacitor, denoted as C , as shown in Figure (3.9) (b). This type of capacitance is known as self-capacitance or mutual capacitance.

If there were only mutual capacitance between the discs, the charging current would be the same through all the discs, and therefore, the voltage across each element would be the same, for example, $V/3$, as shown in Figure (3.9)(b). However, in reality, there is also capacitance between the metallic fittings of each disc and the tower or ground, which is referred to as shunt capacitance, denoted as $C1$.

Due to the shunt capacitance, the charging current is not the same through all the discs in the string, as shown in Figure (3.9)(c). Therefore, the voltage across each disc will be different. It is evident that the disc closest to the line conductor will have the highest voltage. Hence, referring to Figure (3.9) (c), $V3$ will be higher than $V2$ or $V1$.

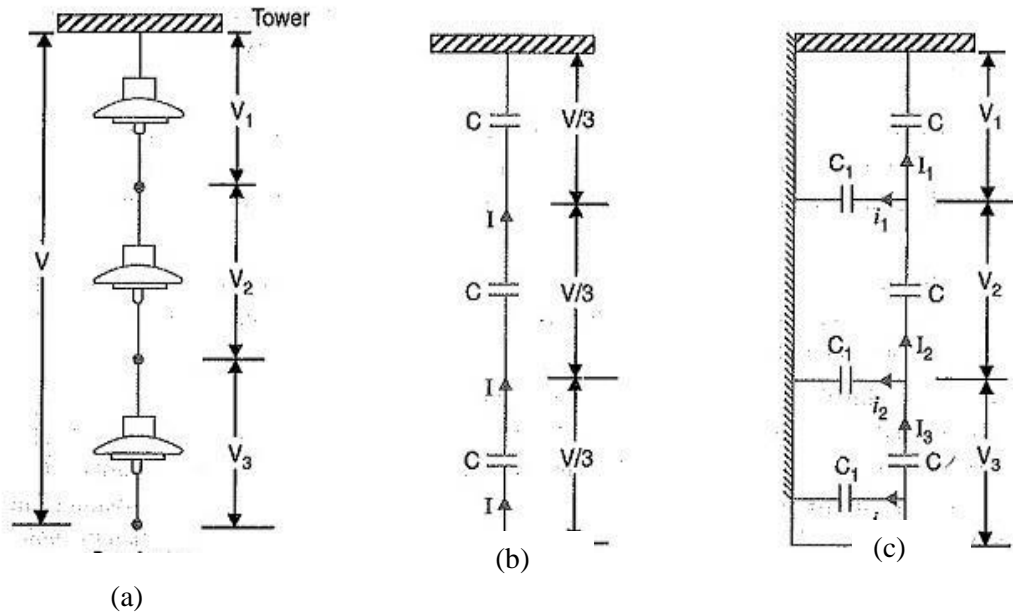


Figure (3.9) Disc equivalent circuit

3.5.3 String Efficiency

String Efficiency refers to how effectively the voltage is distributed across a string of suspension insulators. As previously mentioned, the voltage is not equally distributed, and the disc closest to the conductor has a significantly higher voltage. The String Efficiency expressed through in equation(3.1)

$$\eta \% = \frac{v_{total}}{n \times v_{disc}} \cdot 100 \quad (3.1)$$

Where:

- n is number of is in string.
- v_{total} is the voltage across the whole string.
- v disc is the voltage across the disc closest to the conductor,

String efficiency is important because it defines how uniformly voltage is distributed across the insulator string.

3.5.4 String Efficiency for 132 kv

In the analysis of the 132 kV transmission line, 9 discs of suspension insulators were used. Table (3.2) shows the string efficiency for 9 discs at different values of k:

K	v2	v3	v4	v5	v6	v7	v8	v9	vt	η%
0.125	1.1250	1.3906	1.8301	2.498	30464	4.835	6.736	9.328	32.208	38.364%
0.1	1.100	1.3100	1.6510	2.1571	2.8716	3.8589	5.1978	6.9742	26.1176	41.6098%
0.09	1.0900	1.278	1.5812	2.0267	2.6492	3.4997	4.6382	6.1392	23.902	43.2593%
0.07	1.0700	1.2149	1.4448	1.7759	2.2288	2.8329	3.6227	4.6407	19.831	47.480%
0.06	1.0600	1.1836	1.3782	1.655	2.0306	2.5245	3.1619	3.9732	17.9673	50.2458%
0.05	1.0500	1.1525	1.3126	1.5384	1.8402	2.2322	2.7313	3.3579	36.2150	53.654%
0.04	1.0400	1.1216	1.2481	1.4245	1.6574	1.9557	2.3299	2.7927	14.5697	57.981%
0.03	1.0300	1.0909	1.1845	1.3137	1.4821	1.6945	1.9569	2.2760	13.028	63.600%
0.02	1.0200	1.0604	1.1220	1.2061	1.3142	1.448	1.6114	1.8060	11.588	71.29%

Table (3.2) show the string efficiency for 9 discs in different value of k

3.5.5 Methods of Improving String Efficiency

As previously discussed, the voltage distribution in a string of suspension insulators is not uniform. The highest voltage appears across the insulator closest to the line conductor and gradually decreases toward the cross-arm. This uneven distribution results in excessive electrical stress on the first insulator, making it more susceptible to breakdown or flashover. If this insulator fails, it can lead to a cascading failure of the entire string.

Therefore, improving the string efficiency is essential by ensuring a more uniform voltage distribution across all insulator units. This can be achieved through various methods, such as using grading rings, connecting parallel capacitors to each insulator unit, or optimizing the tower design to minimize voltage imbalance. The various methods for this purpose are:

1. Using Longer Cross-Arms

The efficiency of an insulator string depends on the ratio of shunt capacitance to mutual capacitance, represented by K . A lower value of K results in higher string efficiency and more uniform voltage distribution. One way to reduce K is by decreasing the shunt capacitance, which can be

achieved by increasing the distance between the conductor and the tower using longer cross-arms. as shown in the Figure (3.10).

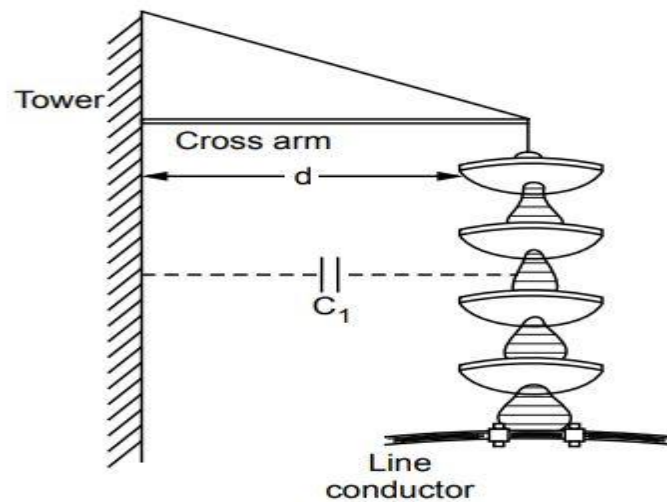


Figure (3.10) Use of cross arm long

2. Grading the Insulators by Capacitance:

In this method, insulators of varying sizes and capacitances are selected so that the topmost insulator has the lowest capacitance, and capacitance progressively increases toward the bottom insulator (nearest to the conductor). Since voltage is inversely proportional to capacitance, this approach helps to equalize the voltage distribution across the string. However, this method requires a variety of differently sized insulators, which can increase design complexity and cost. Nevertheless, good results can be achieved by using standard insulators for most of the string while employing larger units near the conductor.

3. Using a Guard Ring:

Voltage distribution across the insulator string can be equalized by employing a guard ring, which is a metallic ring electrically connected to the conductor and surrounding the bottom insulator. The guard ring introduces additional capacitance between metal fittings and the conductor, ensuring that shunt capacitance currents are balanced with the line capacitance currents. As a result, the charging current remains uniform

throughout the insulator string, leading to a more even voltage distribution and improved string efficiency. The grading is shown in the Figure. (3.11)

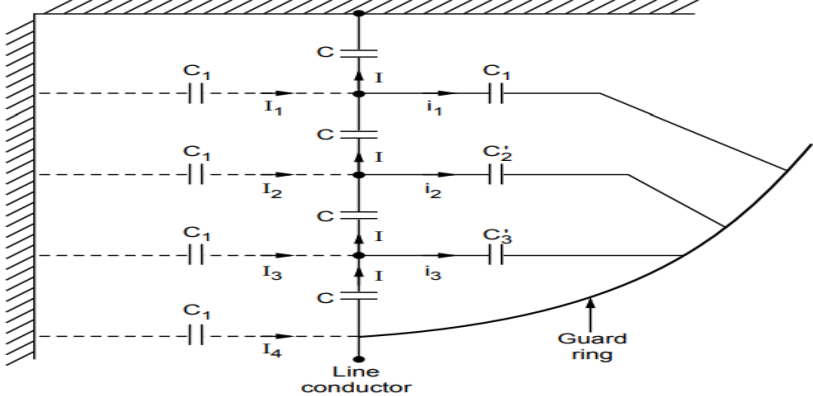


Figure (3.11) Use of cross arm long

3.6 Corona Effect

When an alternating potential difference is brought across two conductors whose spacing is big in comparison to their diameters, there is no apparent change in the condition of atmospheric air surrounding the wires if the introduced voltage is low. Nevertheless, when the applied voltage surpasses a specific value, known as critical disruptive voltage, the conductors are surrounded by a faint violet glow known as corona

The corona phenomenon is accompanied by a hissing sound, ozone production, power loss and radio interference. Figure (3.12) show the corona effect in transmission over headline.

The higher the voltage is raised, the bigger and higher the luminous envelope becomes, and bigger are the sound, the power loss and the radio noise. If the introduced voltage is raised to breakdown value, a flash-over will happen between the conductors due to the insulation breakdown. The phenomenon of violet glow, hissing noise and ozone gas production in an overhead transmission line is known as corona.

In the case the conductors are polished and smooth, the corona glow will be uniform across the conductor length otherwise the rough points will

seem brighter. With DC voltage, there is difference in the appearance of the two wires. The positive wire has uniform glow around it, while the negative conductor has spotty glow.



. **Figure(3.12) The corona effect in transmission overhead line.**

3.6.2 Factors Affecting Corona

The corona phenomenon is impacted by the physical state of the atmosphere as well as by the line conditions. The following are the factors upon which corona depends:

- Atmosphere. As corona is made due to ionization of air around the conductors, hence, it is impacted by the atmosphere physical conditions. In the stormy weather, the number of ions is more than normal and as such corona happens at lower voltage in comparison to fair weather.
- Conductor size. The corona effect is dependent on the conductor shape and conditions. The rough and irregular surface will give rise to more corona since unevenness of the surface reduces the value of breakdown voltage. Therefore, a stranded conductor has irregular

surface and therefore gives rise to more corona than a solid conductor.

- Conductor spacing. If the spacing between the conductors is big in comparison to their diameters, there may not be any corona effect. It is because bigger distance between conductors decreases the electrostatic stresses at the conductor surface, therefore avoiding corona formation.
- Line voltage. The line voltage significantly impacts corona. If it is low, there is no change in the condition of air surrounding the conductors and therefore no corona is formed. Nevertheless, if the line voltage has such a value that electrostatic stresses created at the conductor surface make the air around the conductor conducting, then corona is formed

3.6.3 Critical Disruptive Voltage

It is the minimum phase-neutral voltage at which corona occurs happens. Consider two conductors of radii r cm and spaced d cm apart. If V is the phase-neutral potential, then potential gradient at the conductor surface is given by the Equation (3.2)

$$q = \frac{v}{r \times \ln \frac{d}{r}} \text{ v/cm} \quad (3.2)$$

Where:

- q is Electric field at the surface of the conductor (V/cm). Corona starts when this exceeds the breakdown strength of air.
- v is Phase-to-neutral voltage (V).
- r is Radius of the conductor (cm).
- d is Distance between the centers of the two conductors (cm)

The concept of long-distance electric power transmission emerged in the late 19th century, pioneered by inventors such as Nikola Tesla and George Westinghouse, who played a vital role in advancing alternating current (AC) systems. These developments enabled efficient electricity transmission over extended distances with minimal losses

In order that corona is created the value of g must be made equal to the air breakdown strength. The air breakdown strength at 76 cm pressure and temperature of 25°C is 30 kV/cm (max) or 21.2 kV/cm (RMS) and is denoted by q_0 . If V_c is the line-neutral potential needed under these conditions, is given by the Equation (3.3)

$$q_0 = \frac{v_c}{r \times \ln \frac{r}{d}} \text{ v/cm} \quad (3.3)$$

Where:

- q_0 is air breakdown strength at 76 cm of mercury and 25°C=30 kV/cm (max) or 21.2 kV/cm (RMS)
- v_c Corona inception voltage (Volts) – the minimum line voltage at which corona discharge starts

Under typical conditions the value $s=1$, Correction must also be considered for the conductor surface condition. This is accounted for by multiplying the above formula by irregularity factor m .

Visual critical voltage. It is the minimum line-neutral voltage at which corona glow appears all along the line conductors. It has been noted that in the parallel conductor situations, the corona glow does not start at the disruptive voltage V_c but at a bigger voltage V_v , known as visual critical voltage. The line-neutral effective value of visual critical voltage is expressed by the following empirical equation (3.4)

$$v_c = 21.1 \times \delta \times m \times r \times \ln\left(\frac{d}{r}\right) \quad (3.4)$$

Where:

- $\delta = 1$ (stander pressure and temperature)
- $m = 1$ (for polished conductor)
- line voltage = 132kv
- conductor dimeter = 21mm = 1.05cm
- $d = 19.69 \text{ fet} = 6\text{m} = 600\text{cm}$

The calculations were performed using Equation (3.4) to determine the visual critical voltage. After substituting the appropriate values for the conductors and operating conditions, it was found that the visual critical voltage is (141.309 k v). This result reflects the influence of various factors such as conductor radius, spacing between conductors, and weather conditions on the onset of corona glow.

3.6.4 Power losses

Power loss due to corona. Formation of corona is typically accompanied by energy loss which is dissipated in the form of light, heat, sound and chemical action. When disruptive voltage is surpassed, the power loss due to corona is expressed by using Equation (3.5)

$$p_c = 242.4 \times \left(\frac{f+25}{\delta}\right) \times \sqrt{\frac{r}{d}} (v - v_o)^2 \times 10^{-5} \quad (3.5)$$

Where :

- f - supply frequency in Hz
- V – phase-neutral voltage (RMS)
- V_o – disruptive voltage (RMS) per phase

The calculations were performed using the appropriate equations (3.5) to determine corona losses. After substituting the relevant values for the conductors and operating conditions, it was found that there are no corona losses, as the operating voltage is lower than the critical voltage at which corona discharge occurs. This result indicates that the system operates within safe limits regarding energy loss due to corona, ensuring efficient power transmission without undesirable effects.

3.6.5 Corona Benefits and Disadvantages

Corona has numerous benefits and disadvantages. In the adequate design of a high voltage overhead line, a balance has to be struck between the benefits and disadvantages.

1. Benefits

- Due to corona creation, the air surrounding the conductor becomes conducting and therefore conductor virtual diameter is increased. The increased diameter decreases the electrostatic stresses between the conductors.
- Corona decreases the effects of transients created by surges.

2. Disadvantages

- Corona is accompanied by an energy loss. This impacts the line transmission efficiency.
- Ozone is generated by corona and may cause conductor corrosion due to chemical action.
- The current taken by the line due to corona is non-sinusoidal and therefore non- sinusoidal voltage drop happens in the line. This may cause inductive interference with neighboring communication lines.

3.6.6 Methods of Decreasing Corona Effect

It has been noted that intense corona effects are observed at a working voltage of 33 kV or above. Hence, adequate design has to be made to avoid corona on the sub-stations or bus-bars designed for 33 kV and bigger voltages otherwise highly ionized air may cause flash-over in the insulators or between the lines, causing considerable equipment damage. The corona effects can be decreased by the following actions:

- By increasing conductor size. By increasing conductor size, the voltage at which corona happens is increased and therefore corona effects are considerably decreased. This is one of the reasons that ACSR conductors which have a bigger cross-sectional area are used in transmission lines.
- By increasing conductor spacing. By increasing the conductor spacing, the voltage at which corona happens is increased and therefore corona effects can be eliminated. Nevertheless, spacing cannot be increased too much otherwise the cost of supporting structure (for example, bigger cross arms and supports) may increase to a considerable extent.

3.7 Overhead Line Sag

While building an overhead line, it is crucial that conductors are under safe tension. If the conductors are too stretched between supports in an attempt to save conductor material, the stress in the conductor may reach critical value and in some cases the conductor may break due to excessive tension. In order to secure conductor safe tension, they are not completely stretched but are allowed to have a dip or sag. The difference in level between support points and the conductor lowest point is called sag. Figure

(3.13) (a) shows a conductor suspended between two equal level supports

The conductor is not completely stretched but is allowed to have a dip. The conductor lowest point is O and the sag is S. The following items can be noted:

- When the conductor is suspended between two supports at the same level, it takes the shape of a catenary. However, if the sag is very small compared to the span, the sag-span curve resembles a parabola.
- The tension at any point on the conductor acts tangentially. Therefore, the tension at the lowest point (O) act horizontally, as shown in Figure (3.13) (b).
- The horizontal tension component remains constant throughout the length of the wire.
- The tension at the supports is approximately equal to the horizontal tension at any point on the wire. Therefore, if T is the tension at support B, it can be said that $T = T_0$.

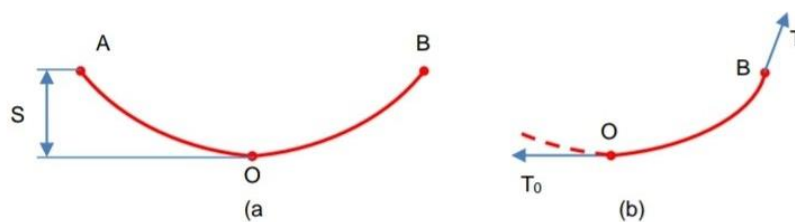


Figure (3.13) Conductor suspension between two supports

3.7.1 Factors Affecting Sagging in Transmission Lines

- Temperature: An increase in temperature causes the conductors to expand, resulting in greater length and increased sag while reducing tension within the conductor.

- Age: Over time, sag increases due to strand settling and metallurgical creep; therefore, conductors are initially installed with higher tension to compensate for these effects.
- Wind: Wind loading increases the tension on conductors by adding apparent weight, causing elastic elongation and additional sag with both horizontal and vertical components.
- Pole Movement: Movement of supporting poles can increase the span length, thereby increasing sag.
- Ice Accumulation: Ice or snow buildup increases the weight and diameter of conductors, further increasing sag, although this is less relevant in warmer regions.
- Other Factors: Conductor weight per unit length, span length, conductor tension, and tower height also affect the magnitude of sag. Proper vertical and horizontal clearances between conductors, as well as between conductors and structures, are essential for operational safety[11].

3.7.2 Why is Sag provided in the Transmission Line?

The sag is as a result of the tensioning of the line and must not be too low otherwise the safety clearances may not be met. Also, the sag had to be such that it caters for ice loading in the winter of temperate climates. If the sag is large, and the line becomes heavily loaded, then the sag will further increase and breach the safety clearances. Similarly, if the sag is low, then when the line contracts in the winter, low sag will indicate a high tension, and as a result of this contraction, the line may snap. Sag is inversely proportional to the tension of the line, For high tensions, the sag should be small. For low tensions, the sag should be high. Clearances must also be observed when stringing a line. The normal clearances for overhead lines are shown in the table (3.3) below.

Voltage level	Clearance to Ground
Less than 66kv	20feet (6.1m)
66kv to 110kv	21feet (6.4m)
110kv to 156kv	22feet (6.7m)
Greater than 16kv	223feet (7.0m)

Table (3.3) Normal clearances for overhead lines

3.7.3 Sag and Tension of The Conductor

This is an important point in the overhead line mechanical design. The conductor sag needs to be maintained to a minimum in order to decrease the required conductor material and to avoid extra pole height for sufficient clearance above earth level. It is also preferable that conductor tension is low to avoid the conductor mechanical failure and to allow the use of less strong supports. Nevertheless, low conductor tension and minimum sag cannot be achieved. It is because low sag means a tight wire and high tension, whereas a low tension means a loose wire and increased sag. Hence in reality, a compromise is made between the two.

3.7.4 Sag Calculation

In an overhead line, the sag has to be adjusted so that tension in the conductors is within safe boundaries. The tension is governed by conductor weight, wind effects, ice loading and temperature changes. It is a common practice to maintain conductor tension less than 50% of its ultimate tensile strength. For example, minimum safety factor in respect of conductor tension needs to be 2. We shall now find sag and conductor tension when (a) supports are at equal levels and (b) supports are at different levels.

When supports are at same levels. Consider a conductor between two

equal level supports A and B with O as the lowest point as presented in Figure (3.14).

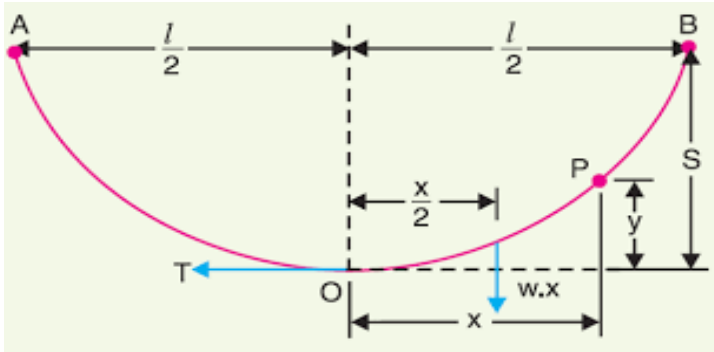


Figure (3.14) A conductor between two equal level supports

The equation for calculating the tower leg for supports at the same level is based on the model of suspended bridges, where the conductor between the two supports is tensioned in a curve. If the supports are at the same level and the conductor has its lowest point at point O, the parabolic curve equation is typically used to determine the tension and sag of the conductor.

The most commonly used equation for calculating the sag of the conductor is Equation (3.6)

$$sag = \frac{w \times L^2}{8 \times T} \tag{3.6}$$

Where:

- W is the weight per unit length of the conductor.
- T is the tension in the conductor.
- L is the horizontal distance from point O.

To calculate the tower leg, both the conductor's weight and the distance between the supports must be considered. This equation can be used to determine the tension and sag of the conductor at any point between the supports.

In the 132 kV transmission system, the sag in the transmission lines

was determined by using Equation (3.6) and the following parameters:

- *weight of the conductor* = $947 \frac{kg}{km} = 9.545 \frac{N}{m}$
- $L = 320$ meters (*span length between towers*)
- Wind effect=0
- $T = 4000N$

the sag value was calculated to be (30.55 meters). This result confirms that the design adheres to the necessary engineering standards, ensuring the stability and efficiency of the transmission system.

At a temperature of 32°C and with a tension value of (4557.27 N), the sag was found to be (2.73m). When the tension value was adjusted to 8000, the sag was recalculated and found to be (15.27 meters).

These results demonstrate the direct relationship between conductor tension and sag, highlighting how increased tension reduces sag, ensuring optimal performance and structural stability in the 132 kV transmission system.

3.7.5 Wind and Ice Loading Effect

The above equations for sag are correct only in still air and at normal temperature when the conductor is acted only by its weight only. Nevertheless, in real life a conductor may have ice coating and simultaneously exposed to wind pressure. The weight of ice acts vertically downwards for example, in the same direction as the conductor weight. The force due to the wind is assumed to act horizontally for example, at right angle to the conductor projected surface. Therefore, the complete force on the conductor is the vector sum of horizontal and vertical force as presented in Figure (3.15)

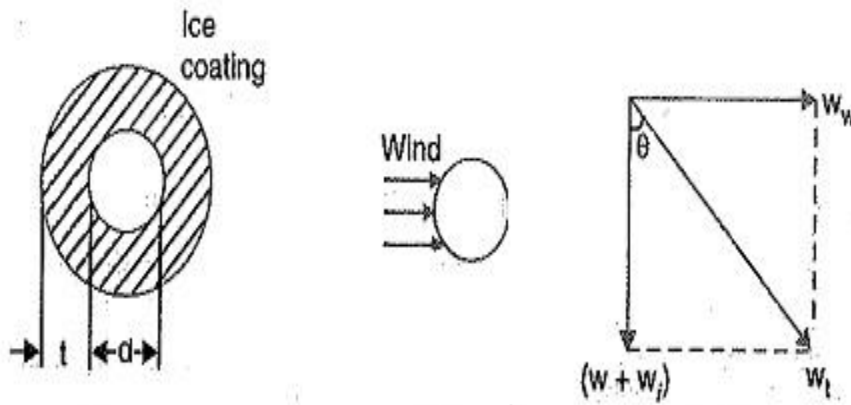


Figure (3.15) Wind effect on the conductor

3.7.6 Methods to Prevent Excessive Sagging in Overhead Transmission Lines

Sagging of overhead transmission lines due to high temperatures or heavy electrical loads is one of the major challenges faced by power system operators. Excessive sag not only reduces the line's power transfer capability but also increases the risk of contact with trees or nearby structures, potentially leading to serious electrical faults [12].

Traditionally, utilities have relied on two main strategies to address this issue:

1. Re-engineering the Line:

- ❖ Reducing the distance between transmission towers, as greater spacing leads to increased sag.
- ❖ Increasing tower heights or replacing the conductors with more suitable types.
- ❖ While effective, these solutions are often costly

2. Monitoring and Surveillance:

- ❖ Involves continuously monitoring sag levels to ensure they remain within acceptable limits.

- ❖ This is a more economical approach, but it does not address the need to increase power transmission capacity.

Recently, Material Integrity Solutions Inc. in Berkeley introduced an innovative solution by developing a device known as the “Sagging Line Mitigator.” This device aims to manage line sag in a cost-effective manner without the need for major structural modifications show in figure (3.16)



Figure (3.16) The SLiM device

The SLiM (Sagging Line Mitigator) is an innovative device designed to reduce excessive sag in overhead power transmission lines caused by high conductor temperatures. It automatically shortens the effective length of the conductor when temperatures rise, thereby preventing excessive thermal expansion and sag.

Developed as a cost-effective alternative to traditional solutions like tower raising or reconductoring, SLiM has been successfully tested by several power utilities. Its passive and durable design allows it to be installed and used like standard transmission hardware [13].

Chapter Four

Electrical Calculations

4.1 Introduction

The primary function of an overhead transmission line is to efficiently and reliably transport electrical energy from the generation station to the load centers or substations. Ensuring the effectiveness of this process requires thorough electrical design and analysis. Accurate electrical calculations are crucial to maintaining system stability, minimizing energy losses, and optimizing operational performance.

A well-designed transmission line should account for several key electrical parameters such as resistance, inductance, capacitance, and conductance per unit length. These parameters influence critical aspects of performance including voltage regulation, transmission efficiency, and the ability to handle fault conditions.

The quality of the transmission line design is highly dependent on the proper selection of conductors (such as ACSR or AAAC) and the configuration of the circuits (simplex, duplex, etc.). These choices directly affect the current-carrying capacity, impedance, and thermal limits of the line.

4.2 Electrical models

When analyzing the electrical performance of overhead transmission lines, the choice of the appropriate electrical model is crucial. The literature typically proposes three main models that vary in complexity and accuracy. The selection depends primarily on the length of the transmission line, as each model accounts for different electrical parameters and physical effects

1. Short-Line Model (Length ≤ 80 km)

The short-line model is the simplest approach and is used for overhead lines with lengths up to 80 kilometers. It only considers the series resistance (R) and inductive reactance (X) of the conductor, neglecting the shunt capacitance.

This model is suitable for short distances, but its accuracy diminishes with increased line length. Figure (8.1) shows equivalent circuit of the short-line mode

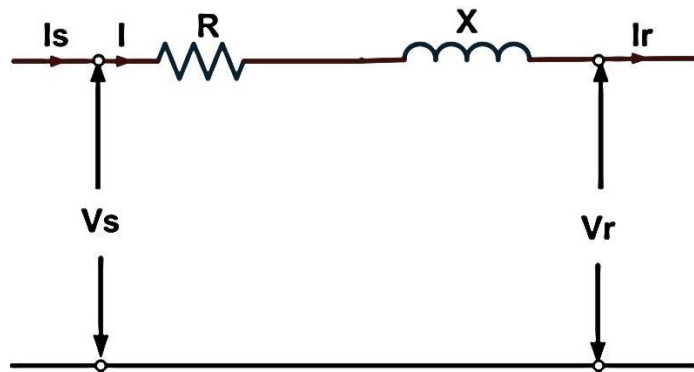


Figure (4.1) Equivalent circuit of the short-line mode

2. Pi Model ($80 \text{ km} < \text{Length} \leq 300 \text{ km}$)

For medium-length lines, the Pi model provides improved accuracy by including the effect of line capacitance. It assumes that the line's electrical parameters are lumped at specific points rather than continuously distributed. Figure (4.2) shows Equivalent circuit of the Pi model

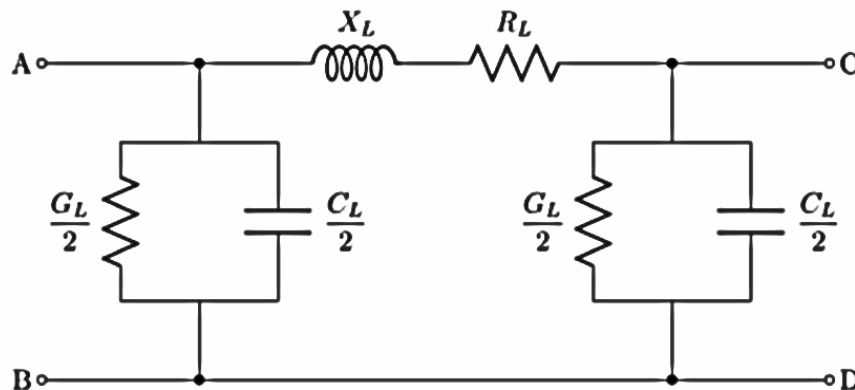


Figure (4.2) Equivalent circuit of the Pi model

3. Distributed Parameters Model ($\text{Length} > 300 \text{ km}$):

For long-distance transmission, a more accurate representation is required. The distributed parameters model considers the continuous distribution of resistance, inductance, capacitance, and conductance along the line.

4.3 Electrical Parameters

Transmission lines are defined by four fundamental electrical parameters that significantly influence their performance in delivering electric power over long distances. These parameters include:

- 1. Resistance (R):** The opposition to the flow of electric current, primarily due to the nature and properties of the conductor material.
- 2. Inductance (L):** A parameter resulting from the magnetic field generated around the conductors when current flows, which leads to the storage of energy in the magnetic field.
- 3. Capacitance (C):** Occurs between conductors, and between conductors and the ground, due to the potential difference. It allows the storage of energy in the electric field.
- 4. Conductance (G):** Represents the leakage current through the dielectric medium between conductors. Although usually small, it becomes significant in certain environmental conditions.

These parameters are not lumped but are distributed along the length of the transmission line. They play a vital role in determining the line's voltage regulation, power losses, efficiency, and overall stability. The magnitude of each parameter depends on several physical and geometric factors, such as the conductor type, cross-sectional area, spacing between conductors, line length, and the surrounding environmental conditions.

4.3.1 Resistance of Transmission Lines (R)

Resistance is one of the primary electrical parameters of a transmission line, representing the opposition to the flow of electric current through the conductor. It is a function of the conductor's material, length, and cross-sectional area, and is calculated using the formula (4.1)

$$R = \frac{\rho L}{A} \quad (4.1)$$

Where:

- R is the resistance (Ω)
- ρ is the resistivity of the conductor material ($\Omega \cdot m$)
- L is the length of the conductor (m)
- A is the cross-sectional area of the conductor (m^2)

The resistance in transmission lines causes power loss in the form of heat, known as I^2R loss, and contributes to the voltage drop along the line. This loss becomes significant in long-distance transmission, especially when using conductors with high resistivity or small cross-sectional area.

However, it is important to note that the DC resistance of a conductor, as given by the above expression, does not fully represent the actual resistance encountered in alternating current (AC) transmission lines. When AC flows through a conductor, the current distribution is not uniform across the cross-section. This phenomenon, known as the skin effect, causes the current to concentrate near the surface of the conductor, which increases the AC resistance compared to DC resistance.

Furthermore, overhead conductors are often stranded, meaning they consist of multiple smaller wires twisted together. The effective length of each strand is greater than the length of the composite conductor, further increasing the overall resistance.

The temperature also affects the resistance of conductors. As the temperature increases, the resistivity of metallic conductors increases. The relationship between resistance and temperature is approximately linear within practical operating ranges and the Equation (4.2) show it.

$$\frac{R_2}{R_1} = 1 + \alpha (t_2 - t_1) \quad (4.2)$$

where R_2 and R_1 are the resistances at temperatures t_2 and t_1 , respectively, and α is the temperature coefficient of resistance, which is specific to the conductor material.

Given these factors, the resistance of a conductor in practical transmission systems is typically determined using manufacturer data or through empirical measurements, rather than relying solely on theoretical calculations.

The resistance of the ACSR conductor is calculated using equation (4.2), where:

- $\rho = 2.82 \times 10^{-8} \Omega \cdot m$ is the resistivity of aluminum

- $L = 150 \text{ Km}$ is the length of the transmission line
- $A = 261.5 \text{ mm}^2 = 261.5 \times 10^{-6} \text{ m}^2$ is the cross-sectional area of the conductor

Substituting into equation (4.1), the resulting resistance is equal to 16.18Ω .

8.3.2 Inductance of Transmission Lines (L).

Inductance is a fundamental electrical parameter of transmission lines that quantifies the opposition to changes in current due to the magnetic field surrounding the conductors. As current flows through a transmission line, it produces a magnetic field, which links with both the same conductor and adjacent conductors. This phenomenon results in self and mutual inductance, affecting voltage regulation and the overall performance of the power system.

The inductance of a transmission line is influenced by the conductor configuration, spacing between phases, and the physical dimensions of the conductors. Accurate calculation of inductance is essential for determining reactive power flow, voltage drop, and line impedance.

(a) Inductance of a Line with Single Conductor per Phase

For a line consisting of a single conductor per phase, the Equation (4.3) show the inductance per unit length (in Henry per meter) .

$$L = 2 \times 10^{-7} \times \ln \frac{GMD}{GMR} \quad (4.3)$$

Where:

- GMD is Geometric Mean Distance (GMD) between conductors (m)
- GMR is Geometric Mean Radius (GMR) of the conductor (m), provided by the manufacturer or calculated based on conductor geometry.

This formula assumes transposed lines and uniform current distribution

over the conductor surface.

(b) Inductance of a Line with Bundled Conductors

To mitigate corona discharge and reduce the inductive reactance, high-voltage transmission lines often use bundled conductors per phase. In this configuration, the equivalent radius of the bundle replaces the GMR in the inductance formula.

1. For a two-conductor bundle in from (4.4)

$$GMR = \sqrt{r' \cdot d} \quad (4.4)$$

2. For a three-conductor bundle in from (8.5)

$$GMR = \sqrt[3]{r' \cdot d^2} \quad (4.5)$$

Where:

- d is Spacing between sub-conductors within the bundle (m)
- r' is GMR of an individual conductor

The inductance per unit length is then calculated using the Equation (4.3). This approach provides a more realistic evaluation of the inductive properties of modern transmission lines with bundled conductors.

4.3.3 Capacitance of Transmission Lines

Capacitance is another key electrical parameter of transmission lines, representing the ability to store electric charge between conductors due to the potential difference. In overhead transmission lines, capacitance exists between phase conductors and also between each conductor and the ground. This phenomenon results in a charging current, which affects voltage regulation and reactive power flow, particularly in long lines.

The magnitude of capacitance depends on the conductor geometry, spacing, height above ground, and configuration of the line (single or bundled conductors). As with inductance, the calculation of capacitance is essential for the accurate analysis and modeling of transmission line performance.

(a) Capacitance of a Line with Single Conductor per Phase

For a single conductor per phase, the line is assumed to be transposed and equidistant. The capacitance to neutral per unit length is given by Equation (4.6)

$$C = \frac{2 \times \pi \times \epsilon_0}{\ln \frac{GMD}{GMR}} \quad \{F/m\} \quad (4.6)$$

Where:

- C is Capacitance per unit length (F/m)
- ϵ_0 is Permittivity of free space (8.85×10^{-12})
- GMD is Geometric Mean Distance between conductors (m)
- GMR IS Geometric Mean of conductors (m)

(b) Capacitance of a Line with Bundled Conductors

In bundled conductors, the effective radius of the bundle is used instead of the single conductor radius. The equivalent radius for the bundle is calculated as:

1. For a two-conductor bundle in from (4.7)

$$GMR = \sqrt{r \cdot d} \quad (4.7)$$

2. For a three-conductor bundle in from (8.8)

$$GMR = \sqrt[3]{r \cdot d^2} \quad (4.8)$$

Where:

- d is Spacing between sub-conductors (m)
- r Radius of a single conductor (m)

The capacitance to neutral is then calculated using (4.6). This equation accounts for the reduced electric field intensity due to the bundled configuration, which decreases the overall capacitance per phase.

4.4 Electrical Parameters (GMD and GMR)

In the design and analysis of overhead transmission lines, accurate electrical modeling is essential for ensuring reliable performance and system efficiency. Among the key elements in this modeling are the electrical parameters that influence the transmission line's inductance, capacitance, and overall behavior. Two fundamental geometric-based parameters (GMD) and (GMR) play a vital role in calculating the inductive and capacitive characteristics of the line.

These parameters depend not only on the physical properties of the conductors but also on their spatial arrangement along the transmission path. GMD accounts for the average spacing between conductors or circuits, while GMR represents the effective radius of individual or bundled conductors. Understanding and correctly calculating these values is essential for precise determination of line impedance and admittance, which in turn influence power flow and voltage regulation.

4.4.1 The Geometrical Mean Distance (GMD)

The Geometrical Mean Distance (GMD) is the equivalent spacing between the conductor bundles of an overhead transmission line. It plays a critical role in determining both the inductance and capacitance of the line.

The method of calculating GMD depends on the number of circuits present. This section focuses on the most common configurations: single-circuit and double-circuit systems.

For a single-circuit configuration, the GMD is calculated using the distances between the three phase conductors D_{ab} , D_{bc} , D_{ac}

Figure (8.3) an example configuration of a one circuit configuration is shown, with the three phase conductors separated by distances D_{ab} , D_{ac} and D_{bc} .

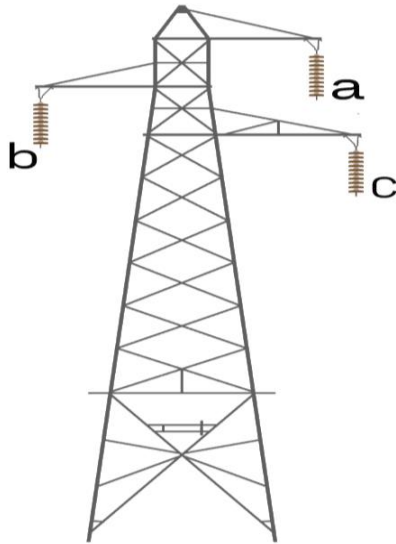


Figure (4.3) Single configuration

In a double-circuit overhead line, the configuration consists of two sets of conductors. The first circuit is formed by conductors a, b, and c, while the second circuit consists of a', b', and c', as illustrated in Figure (4.4)

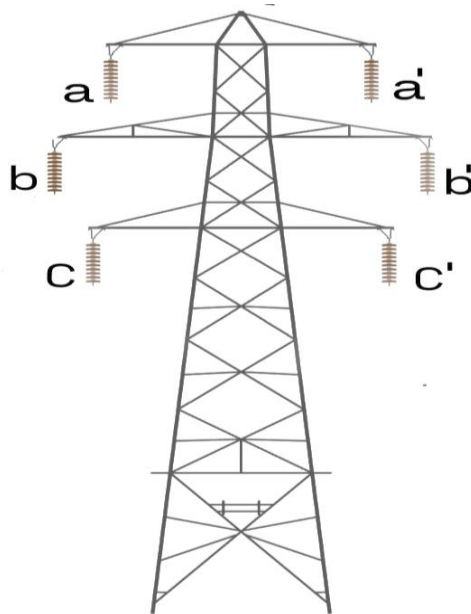


Figure (4.4) Double configuration

The Geometrical Mean Distance (GMD) for this configuration is calculated by determining the equivalent distances between the phase pairs of both circuits using the following expressions (4.9), (4.10), (4.11) and (4.12)

$$D_{ab} = \sqrt[4]{D_{ab} \times D_{a\bar{b}} \times D_{\bar{a}b} \times D_{\bar{a}\bar{b}}} \quad (4.9)$$

$$D_{ac} = \sqrt[4]{D_{ac} \times D_{a\bar{c}} \times D_{\bar{a}c} \times D_{\bar{a}\bar{c}}} \quad (4.10)$$

$$D_{bc} = \sqrt[4]{D_{bc} \times D_{b\bar{c}} \times D_{\bar{b}c} \times D_{\bar{b}\bar{c}}} \quad (4.11)$$

$$GMD = \sqrt[3]{D_{ab} \times D_{bc} \times D_{ac}} \quad (4.12)$$

These expressions calculate the GMD of the circuits at a specific point of the overhead line. However, the conductor's disposition may vary along the line, resulting in different values for GMD at different points. To address this variation, an average GMD is typically used in practical design and analysis.

8.4.2 Geometrical Mean Radius (GMR)

The Geometrical Mean Radius (GMR) represents the effective radius of a conductor or a bundle of conductors, and it is crucial in the calculation of both inductance and capacitance of an overhead line. Figure (4.5) illustrates a four-conductor bundle with uniform spacing d .

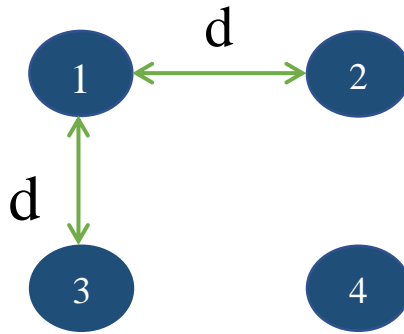


Figure (4.5) Four-conductor bundle

For a symmetrical conductor bundle, the GMR is calculated using the general formula (4.13)

$$GMR = \sqrt[n]{r' \cdot \prod_{i=2}^n d_{1 \rightarrow i}} \quad (4.13)$$

Where:

- r' is the effective radius for inductance calculation.

- r is the physical radius of a single conductor.
- $d_1 \rightarrow_i$ is the distance between the first conductor and the conductor in the bundle.
- n is the number of conductors in the bundle.

For capacitance calculations, the actual radius r is used instead of r' in Equation (4.14)

$$GMR_c = \sqrt[n]{r \cdot \prod_{i=2}^n d_{1 \rightarrow i}} \quad (4.14)$$

Simplified expressions for typical bundles:

For 2-conductor bundle in form (8.15)

$$GMR = \sqrt{r' \cdot d} \quad (4.15)$$

For 3-conductor bundle in form (4.16)

$$GMR = \sqrt[3]{r' \cdot d^2} \quad (4.16)$$

The GMR remains constant along the transmission line since the physical arrangement of the bundled conductors does not vary along its length.

4.5 Practical Calculation of Inductance and Capacitance

To evaluate the optimal configuration for a 132 kV overhead transmission line, the inductance and capacitance per kilometer were calculated for three configurations:

1. Double circuit (single conductor per phase)
2. Bundled conductors with two sub-conductors per phase
3. Bundled conductors with three sub-conductors per phase

The following assumptions were adopted:

- The Geometrical Mean Distance (GMD) between phases is constant at 6 m
- The spacing between sub-conductors within a bundle (d) is 0.3 m
- The conductor radius (r) is 1.05 cm across all configurations

The calculations were performed using the standard theoretical formulas for inductance and capacitance per unit length, as previously defined in Equations (4.3) and (4.6). The corresponding Geometrical Mean Radius (GMR) values for each configuration are summarized are calculations in Equation (4.13), (4.15) and (4.16). The Capacitance calculations utilize the same structural assumptions, with the actual conductor radius substituted for the GMR.

The inductance and capacitance values obtained from the calculations are presented in Table (4.1)

Configuration	GMD	GMR	Inductance (H/km)	Capacitance (F/km)
single conductor	4.943m	0.247 m	5.98×10^{-7}	1.94×10^{-11}
Bundled (with two sub conductors)	7.934m	0.0495m	1.015×10^{-6}	1.123×10^{-11}
Bundled (with three sub conductors)	7.56m	0.0405m	1.046×10^{-6}	1.279×10^{-11}

Table (4.1) inductance and capacitance

4.6 Calculation of Line Reactance

The performance of an overhead transmission line is strongly influenced by its electrical parameters, primarily the inductance (L) and capacitance (C). After determining these values based on the conductor arrangement, it is necessary to calculate the corresponding line reactance inductive reactance (XL) and capacitive reactance (Xc).

This reactance is crucial for understanding voltage and current behavior along the transmission line. The inductive reactance is calculated using the formula (4.17).

$$XL = 2\pi fL \quad (4.17)$$

where:

- XL is the inductive reactance (Ω/km)
- f is the system frequency (Hz)
- L is the inductance per unit length (H/km).

The capacitive reactance and susceptance are calculated using the formula (4.18) and (4.19)

$$XC = \frac{1}{2\pi fC} \quad (4.18)$$

$$Y = 2\pi fc \quad (4.19)$$

where:

- XC is the capacitive reactance (Ω/km)
- f is the system frequency (Hz)
- C is the capacitance per unit length (F/km).
- Y is the susceptance per unit length ($\Omega^{-1} m^{-1}$)

The following table (4.2) summarizes the values of inductance reactance and susceptance the calculated reactance for different conductor configurations for 150 km.

	Single conductor	Bundled (with 2 sub conductors)	Bundled (with 3 sub conductors)
inductive reactance Ω	28.16 Ω	47.82 Ω	49.27 Ω
Y ($\Omega^{-1} m^{-1}$)	9.14×10^{-4}	5.29×10^{-4}	6.026×10^{-4}

Table (4.2) the values of inductance reactance and susceptance

8.7 Impedance of The Transmission

The impedance of the transmission line will be calculated using Equation (4.20).

$$Z = R + jXL \quad (4.20)$$

Where:

- Z is the impedance of the line [Ω]
- R is the resistance of the line [Ω]
- XL is the inductive reactance of the line [Ω]

4.8 Performance of Overhead Transmission Line

The performance of an overhead transmission line is influenced by various factors that determine its efficiency in delivering electrical power from generation stations to load centers. Key parameters such as voltage drop, voltage regulation, and transmission efficiency play a crucial role in the overall performance of the transmission system. Understanding these parameters and their interrelationship is essential for designing systems that minimize losses and ensure reliable power delivery.

4.8.1 Voltage Drop

Voltage drop in a transmission line refers to the reduction in voltage as the electrical power travels along the line from the sending end (V_S) to the receiving end (V_R). This drop is primarily caused by the inherent resistance (R), inductance (L), and capacitance (C) of the line. Voltage drop affects the receiving-end voltage, and if not controlled, it can lead to inefficiencies in the power delivery system. The equation used to calculate the voltage drop show in form (4.21)

$$\Delta V\% = \frac{V_S - V_R}{V_R} \cdot 100 \quad (4.21)$$

Where:

- V_R is voltage at the receiving end and is equal to (132kv)
- V_S is voltage at the sending end and calculated by form (4.22)

$$V_S = AV_R + BI_R \quad (4.22)$$

Where:

- A is equal to form (4.23)
- B is equal impedance (z)

$$A = D = 1 + \frac{ZY}{2} \quad (4.23)$$

Equation (8.20) is used to calculate the voltage drop for different types of conductors in power transmission lines. The equation is based on the resistance and reactance values of the conductors, as well as the sending end voltage. The receiving end voltage, which is 132 kV, is used along with specific values for the resistance is equal to 16.8 Ω and reactance of different conductor types. the voltage drop for each conductor type is calculated, and the results are presented in the table (4.3)

single conductor	Bundled (2 sub conductors)	Bundled (3 sub conductors)
26.37%	38.47%	39.31%

Table (4.3) voltage drop for each conductor type

4.8.2 Losses

The purpose of an overhead line is to transmit energy from a generation point to a delivery point. The power losses during the transmission and distribution will reduce the energy delivered with the same proportion. This means that, if 5% of the power is lost in the overhead line, then 5% of the energy carried will also be lost. Because of this, it is really important to reduce the power losses as much as possible.

The electrical losses in an overhead line are generally caused by two

physical phenomena: the Joule effect, due to the conductor's resistance and the Corona effect, caused by the ionization of the air around the conductor. The accepted losses for an overhead line will always be lower than 5% combining the Joule effect and the corona effect

The joule effect loss is the difference between the power loss at the sending loss and that of the end of the line. To calculate the power losses, the current at sending must be calculated using Equation (4.24)

$$I_S = CV_R + DI_R \quad (4.24)$$

Where:

- C is equal to form (.25)
- D is equal to form (8.23)

$$C = Y \left(1 + \frac{ZY}{4} \right) \quad (4.25)$$

The Joule losses can then be calculated according to Equations (4.26) and (4.27).

$$PS = \sqrt{3} \times VS \times IS \times \text{COS}(\phi_S) \quad (4.26)$$

$$\Delta P\% = \frac{PS - Pr}{Pr} \times 100 \quad (4.27)$$

Where:

- PS is the power at the sending end [W]
- Pr is the power at the end of the line [W]
- ΔP is the power losses [W]
- VS is the voltage at the substation [V]
- ϕ_S is the power factor at the send of the line according to Equation (4.28)

$$\text{Cos}\phi_S = \cos(\text{arg}\vec{v}_S - \text{arg}\vec{i}_S) \quad (4.28)$$

Where:

- $\cos \phi_s$ is the power factor at the sending end
- v_s is the voltage at the sending end [V]
- I_s is the current at the sending end [A]

the losses for each conductor type are calculated, and the results are presented in the table (4.4)

Single conductor	Bundled (2 sub conductors)	Bundled (3 sub conductors)
25%	15.4%	17.1%

Table (4.4) the losses for each conductor type

4.8.3 Efficiency

Transmission efficiency refers to the ratio of the power received at the load center to the power sent from the generation station. It is directly impacted by the losses incurred due to voltage drop, resistance, and other factors. A high-efficiency system ensures that power is transmitted with minimal losses, reducing operational costs and improving system reliability. Equation (4.29) is used to calculate the efficiency

$$\eta\% = \frac{P_R}{P_S} \times 100 \quad (4.29)$$

Where:

- P_R is Power receiving is equal to 120MW
- P_S is Power sending (MW)

the efficiency for each conductor type is calculated, and the results are presented in the table (4.5)

single conductor	Bundled (2 sub conductors)	Bundled (3 sub conductors)
79.946%	86.645%	85.435%

Table (4.5) Efficiency for each conductor type

After analyzing the performance of the transmission line under different conductor configurations, it was observed that the arrangement of conductors plays a crucial role in determining the overall efficiency of the line. Among the various configurations studied, the highest efficiency was achieved when the conductors were arranged in a bundle of two sub conductors. This configuration effectively reduces corona losses and improves voltage regulation, leading to enhanced transmission performance. Therefore, it can be concluded that using a 2-subconductor bundle is an optimal choice for improving the efficiency and reliability of 132kV overhead transmission lines

4.8 Earth Wire

Lightning strike is one of the main reasons behind the sudden outages of an overhead line, and the earth wire comes as a protection schema to reduce these unexpected outages. Therefore, the earth wire's main function is to not only to protect the phase conductors from possible lightning but also to return the phase-to-earth short-circuit current. Consequently, they should be designed and specified adequately to serve their function. In addition, an earth wire is installed with a shield angle that is defined between 10° and 35°

The grounding of the TL structures shall perform several functions, such as the dissipation into the ground of lightning strikes, line-to-ground fault currents, and induced currents in the ground wires [14]

4.8.1 Construction and Purpose of Ground Wires

The overhead earth wire or ground wire is the form of lightning protection using a conductor or conductors. It is attached from support to support above the transmission line and well-grounded at regular interval. The earth wire intercepts the direct lightning strikes, which would strike the phase conductors. The ground wire has no effect on switching surges.

Figure (4.6) show overhead ground wire.

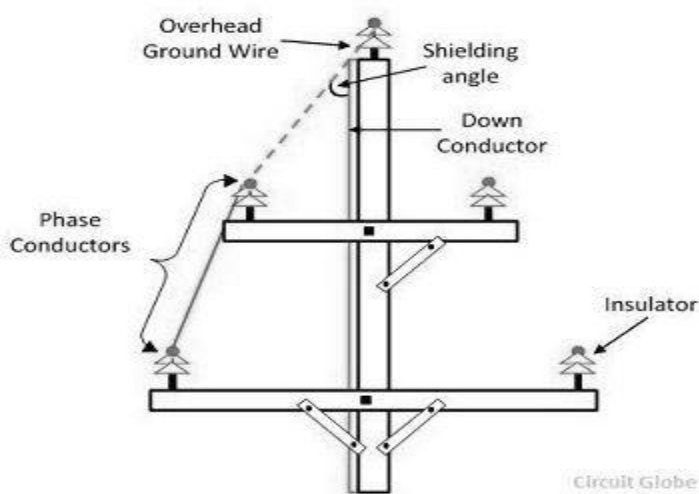


Figure (4.6) Overhead Ground wire.

When the lightning strikes an earth wire at mid-span, waves are produced which travel in opposite directions along the line. The waves reach the adjoining tower, which passes them to earth safely. The earth wire is effective only when the resistance between the tower foot and earth is sufficiently low. If the resistance between them is not low and the earth wire or tower will be struck by the lightning, then the lightning will be raised to the very high potential, which will cause a flash over from the tower to one or more phase conductors. Such a flashover is known as back flashover. The back flash over only occurs when the product of the tower conductor and tower impedance exceeds the insulation levels of the line. It can be minimized by reducing tower footing resistance using driven rods and counterpoises where soil resistivity is high.

The counterpoise is the conductor buried in the ground. The wire is usually made up of galvanized steel. The counterpoise for an overhead terminal consists of a special ground terminal that reduces the surge impedance of the ground connection and increases the coupling between the ground wire and the conductor.

4.8.2 Types OF counterpoise

There are Two types of counterpoise are used in the transmission line, i.e., the parallel counterpoise and the radial counterpoise.

- Parallel Counterpoise: is made up of one or more counterpoise buried under the transmission line through its length. The counterpoise line connected through the over earthed wire at all the towers and poles.
- Radial Counterpoise: is made up of many wires extending radially from the tower legs. The number and length of wires are determined by the tower location and soil conditions.

4.8.3 Shielding or Protective Angle

The shielding or protective angle is the angle between the vertical earth wire and the phase conductor which is to be protected. Usually, the angle between the vertical through the earth wire and the line joining the earth wire through the outermost phase conductor is taken as a shielding angle. shielding-angle for effective shielding, the protective angle should be kept as small as possible. The angle between 20° and 30° is quite safe, and it should not be kept above 40° . Two wires are used in modern high voltage system with wider spacing between the conductor. The protection afforded by the two-wire earth wire is much better than the single wire. Also, the surge impedance for two earth wires is low and the coupling effect of the wire increases

Chapter Five

Conclusion and Future Work

5.1 Result of Calculations

The following table (5.1) presents the final results of all transmission line design calculations

No	Parameter	Calculated Value	unit
1	Receiving end voltage (Vr)	132	KV
2	Selected conductor type	ASCR	-
3	Total Section Area of conductor	261.5	<i>mm²</i>
4	Overall diameter of conductor	21	<i>mm</i>
5	Approx. weight of conductor	947	<i>g/km</i>
6	No of disc insulator	9	
7	string efficiency for 9 disc	63.6	%
8	Relative density δ	1	-
9	Distance between the centers of the two conductors (d)	6	<i>m</i>
10	visual critical voltage (v_c)	141.309	KV
11	Safety clearance to ground	6.7	<i>m</i>
12	Maximum sag in tension 8000N	30.55	<i>m</i>
13	length of the transmission line	150	<i>Km</i>
14	<i>span length between towers</i>	320	<i>Km</i>
15	Resistance(R)	16.18	Ω
16	Inductance(L)	1.015×10^{-6}	(H/km)
17	Capacitance (C)	1.123×10^{-11}	(F/km)
18	Impedance(Z)	$50.479 \xrightarrow{71.317}$	Ω

19	Geometrical Mean Distance(GMR)	7.934	<i>m</i>
20	Geometrical Mean Radius (GMR)	0.0495	<i>m</i>
21	inductive reactance (<i>XL</i>)	47.82Ω	Ω
22	Susceptance (<i>Y</i>)	5.29×10^{-4}	(Ω ⁻¹ <i>m</i> ⁻¹)
23	A parameter	0.987368	-
24	B parameter	50.479	-
25	voltage drop	38.47	%
26	Sending end voltage (<i>Vs</i>)	180.471	KV
27	D parameter	0.987368	-
28	C parameter	2.6351×10^{-4}	-
29	Sending current(<i>Is</i>)	635.99 $\xrightarrow{-35.169}$	A
30	Receiving current(<i>Ir</i>)	656.079 $\xrightarrow{-36.869}$	A
31	<i>Sending end power factor</i>	0.696643	-
32	Power receiving <i>Pr</i>	120	MW
33	Power receiving <i>Ps</i>	138.495	MW
34	Efficiency of transmission line	86.645	%

Table (5.1) The Result of Calculations

5.2 Conclusion

This project focused on analyzing the performance of a medium-voltage overhead transmission line using the distributed parameter model, with the goal of calculating voltage drop, line current, and power losses resulting from electrical effects. The study investigated the influence of different conductor configurations including single and bundled arrangements on the overall transmission efficiency.

The line under study operates at a voltage level of 132 kilovolts (kV), which is commonly used in electrical power transmission networks to

ensure efficient delivery over long distances.

The results showed that the impact of the corona effect was negligible, indicating that the line can be considered as operating with no significant corona losses. When using a Bundled 2 Sub conductor configuration, a transmission efficiency of 86.6% was achieved, with 15.4% of the transmitted power lost due to Joule heating. In addition, the use of nine insulator discs led to an improved voltage distribution efficiency exceeding 50%, which further increased as the voltage distribution factor decreased.

This study demonstrated the crucial role that conductor configuration and insulation design play in the performance of high-voltage transmission lines. By applying accurate mathematical models and practical parameters, the project provides a realistic insight into how transmission efficiency can be significantly affected by technical choices. Moreover

5.3 Future Work

Based on these findings, several future development paths are proposed:

1. Investigating the use of larger bundled conductors (e.g., Bundled 4 Sub) to achieve lower resistance and improved efficiency.
2. Developing dynamic simulation models using advanced tools such as MATLAB/SIMULINK or ETAP to evaluate system behavior under various environmental and loading conditions.
3. Assessing the impact of environmental factors (such as temperature, wind, and conductor sag) on the efficiency of both conductors and insulators.
4. Exploring the possibility of reducing the number of insulator discs while maintaining effective voltage distribution, through improved design or materials, which may lead to cost reduction without compromising performance.

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