

Review of the Design of High Voltage Transmission Conductors

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Abstract

High-voltage transmission conductors play a critical role in delivering electricity efficiently and reliably over long distances. This review covers several key elements, including material selection, conductor configuration, and optimization techniques to improve performance while ensuring cost effectiveness and reliability. The selection of materials for high voltage transmission conductors is analyzed, focusing on their mechanical properties, electrical conductivity, corrosion resistance, and environmental impact. The review highlights the importance of considering multiple factors when designing high voltage transmission conductors to achieve optimal performance, reliability, and cost effectiveness. Future research directions are identified, including advances in materials science, manufacturing techniques, and modelling methods, to further improve the efficiency and reliability of high-voltage transmission systems. This summary provides an overview of the key issues covered in a review of high-voltage transmission conductor design. It describes the scope of the review, including material selection, conductor configurations, optimization techniques, and future research directions, while emphasizing the importance of considering various factors to achieve optimal performance.

Keywords

Mechanical properties, Electrical conductivity, Corrosion resistance, Environmental impact, Transmission.

1. Introduction

Efficient electricity transmission over long distances is key to meeting growing energy needs and integrating renewable energy sources into the electricity grid (IEA 2020). Global energy consumption shows that oil and coal are the most used fuels in the world (IEA 2022) (Figure 1). High-voltage transmission cables form the backbone of energy systems and enable the reliable and efficient transport of electricity from the generation source to the end user. As the world population continues to grow and industrialization advances, the demand for electricity continues to increase (IEA, 2019). Transmission line lengths by voltage class from 66 kV to 400 kV with minimum and maximum length of line (Calgary AB 2018) (Table 1). This requires the development of a robust transportation infrastructure capable of meeting current and future energy needs. The design of high-voltage transmission cables requires various technical considerations, including material selection, conductor configuration, optimization techniques, and environmental factors. Material selection is a crucial aspect of conductor design and influences factors such as electrical conductivity, mechanical strength, corrosion resistance and weight (CIGRE 2016). Comparison of material properties for high voltage conductors (EPP 2013) (Table 2, 2013). Aluminium and aluminium alloys are widely used due to their

favourable combination of electrical and mechanical properties (Xie et al. 2020). Furthermore, advances in materials science have led to the development of composite materials such as carbon fibre reinforced polymers (CFRP), which offer improved strength-to-weight ratio of and resistance to environmental influences (Gupta and Chauhan 2018). Conductor configuration plays an important role in determining the performance and efficiency of high voltage transmission lines. Traditional bare conductors are commonly used but advances in conductor design have led to the introduction of bundled conductors and composite core conductors (Li and Li 2019).

Bundled conductors increase the effective cross section, reducing electrical losses and improving mechanical strength (CIGRE 2014). Composite core conductors contain non-metallic cores to reduce weight and alleviate problems such as galloping and icing (Han et al., 2017). Optimization techniques are used to maximize the performance and reliability of high voltage transmission cables. Conductor size, spacing and voltage are optimized to minimize sag, mitigate corona discharge, and ensure adequate spacing (CIGRE 2015). Advanced modelling and simulation tools such as finite element analysis (FEA) and computational fluid dynamics (CFD) are used to analyse conductor performance under various operating conditions and environmental factors (Zhang et al. 2021). Environmental aspects, including changes in wind, ice and temperature, present challenges in the design and operation of high-voltage transmission cables (CIGRE, 2017). Conductors must be designed to withstand these conditions while maintaining their electrical integrity and mechanical stability (Saha et al. 2018).

Average horizontal spacing with maximum allowable sag (EEP 2013) (Figure 2). Composites offer greater resistance to environmental influences and are therefore suitable for use in demanding operating environments (CIGRE 2020). In summary, high voltage transmission cable design is a multifaceted process that requires careful consideration of material selection, cable configuration, optimization techniques and environmental factors. Advances in materials science, engineering principles and modelling tools continue to drive innovation in cable design, enabling the development of a more efficient, reliable and resilient transmission infrastructure. Transmission line efficiency improvement trends show the maximum allowable sag and distance between conductors in a bundle (Sciencetech Blog 2018) (Figure 3) .

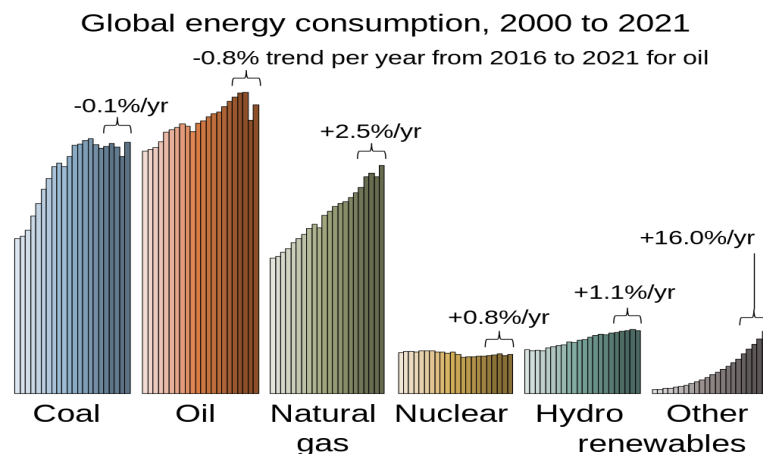


Figure 1. (The increasing trend in global electricity) (IEA 2022).

Table 1. (Transmission line lengths by voltage class) (Calgary AB, 2018)

Line-to-line voltage kV	Length of line km	
	Minimum	Maximum
66	40	120
110	50	140
132	50	160
166	80	180
230	100	300
400	400	800

Table 2. (Comparison of material properties for high voltage conductors) (Electrical engineering portal.com, 2013)

Characteristic	Value	Unit
Cross-section area	1600	mm ²
Conductor diameter	49.6	mm
Total thickness of insulation	27	mm
Total diameter	127.9	mm
DC resistance at 20°C	0.0113	Ω/km
AC resistance at 90°C/50 Hz	0.0157	Ω/km
Current loading at 65°C/90°C	1267/1145	A

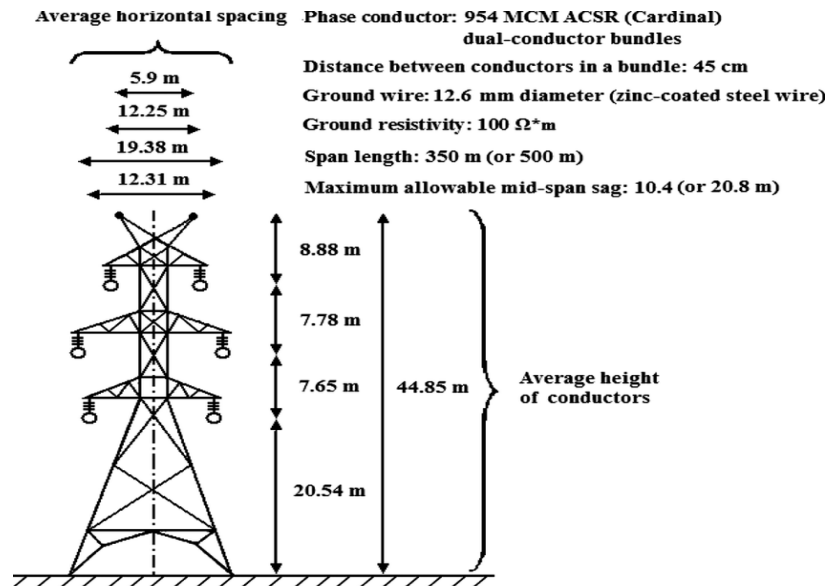


Figure 2. (Average horizontal spacing with maximum allowable sag) (EEP 2013).

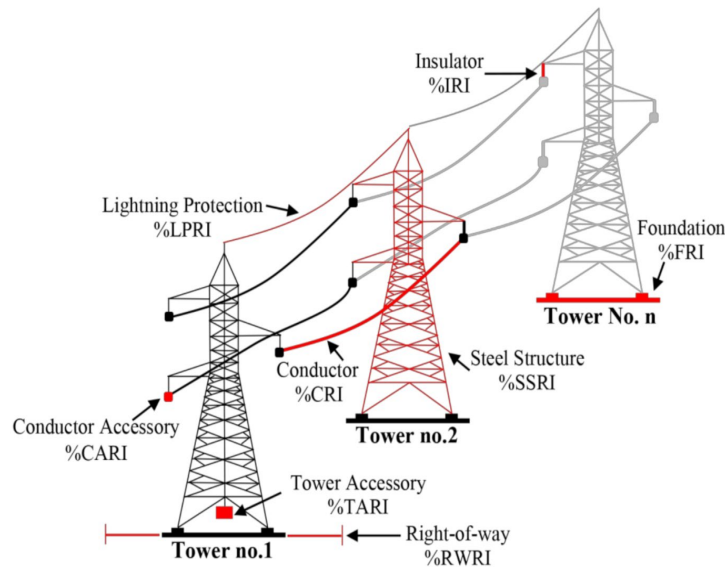


Figure 3. (Transmission line efficiency improvement trends) (Sciencetech Blog, 2018).

1.1 Objectives

High-voltage transmission cables are important elements of electrical systems because they enable the efficient and reliable transmission of electricity over long distances. The purpose of this test is: Examine material selection criteria: Examine key factors that influence material selection for high-voltage transmission cables, including electrical conductivity, mechanical strength, corrosion resistance, and weight. Evaluate cable configuration options: Evaluate different cable configurations, e.g. B. bare cables, bundled cables, and composite core cables, focusing on their advantages, limitations, and suitability for specific applications. Learn Optimization Techniques: Learn wire size, spacing, and tension optimization techniques to minimize slack, mitigate bowing, and ensure adequate clearance using advanced modelling and simulation tools for analysis. Address environmental issues: Discuss environmental factors such as wind, ice, and temperature changes and their effects on high-voltage transmission lines and explore the use of composite materials to increase resilience to environmental factors.

Strategies and technologies: High-voltage transmission cables are key elements of electrical systems whose task is to efficiently transport electrical energy over long distances. This report discusses various strategies and technologies used in the design of high voltage transmission cables to optimize their performance and reliability. Extended material selection: aluminium and aluminium alloys: Known for their high electrical conductivity, light weight, and corrosion resistance, these materials are widely used in high-voltage transmission cables (Bian et al. 2019). Composites: Carbon fiber reinforced polymers (CFRP) and other composite materials offer better strength-to-weight ratio and greater resistance to environmental influences, providing alternatives to improve conductor performance (Gupta and Chauhan, 2018). innovative cable configurations: Electrical wire harnesses: By increasing the effective cross-sectional area, electrical wire harnesses reduce electrical losses and improve mechanical strength, thereby increasing the overall efficiency of the transmission (Li and Li 2019). composite core cable:

The integration of non-metallic cores alleviates problems such as galloping and icing, thereby helping to improve reliability and reduce maintenance needs (Wang et al. 2021). optimization techniques: Cable size and spacing: Optimizing these parameters minimizes sag, corona discharge and electrical losses, ensuring optimal performance under various operating conditions (Bjorkqvist et al., 2017). Finite Element Analysis (FEA) and Computational Fluid Dynamics (CFD): Advanced modelling and simulation tools enable precise analysis of conductor behaviour, contributing to design optimization (Yang et al. 2020). Adaptability to the environment: Environmental Resistance: High voltage transmission cables must withstand wind, ice and temperature fluctuations. Composites provide better strength, thereby helping to increase durability and longevity (Saha et al. 2018). Galvanised coatings: The use of

galvanized coatings provides additional protection against corrosion, extending cable life in harsh environments (Zhu et al. 2019).

The research objective of a high voltage transmission cable design study is generally to evaluate and analyze various aspects related to the design, performance and efficiency of cables used in high voltage transmission systems. This review may include aspects such as material selection, structural design, electrical properties, thermal performance, environmental factors and overall reliability. Specific goals can be: Material analysis: Evaluate the suitability of various materials (e.g. aluminum, steel, composites) for high-voltage transmission cables in terms of conductivity, robustness, corrosion resistance and economics. Structural Design: Study of conductor design configurations, including conductor placement, conductor diameter, and overall geometry, to optimize mechanical strength and reduce deflection under various loading conditions.

Electrical parameters: Evaluate the electrical properties of conductors, such as resistance, reactance, and capacitance, to minimize power losses and improve the efficiency of transmission lines. Thermal analysis: Study of the thermal behavior of conductors under normal operating conditions and in overload situations to ensure safe operation and avoid overheating. Environmental Considerations: Evaluate the effects of environmental factors such as wind, ice, and dirt on conductor performance and reliability and identify design features that mitigate these effects. Reliability and Maintenance: Investigate the reliability of various cable designs under various operating conditions and maintenance requirements to optimize transmission line life and performance. Cost Analysis: Analyze the profitability of various cable projects considering initial investment, operating costs and expected lifespan. Technological Advances: Examine the latest developments in conductor design and manufacturing techniques, such as: B. Composites, carbon fibers or new coatings and evaluate their potential to improve performance and efficiency. To achieve these goals, a complete overhaul of the design of high-voltage transmission cables can improve the efficiency, reliability and sustainability of electrical transmission systems.

2. Literature Review

High-voltage transmission cables are essential elements of power transmission systems and are responsible for the efficient and reliable transport of electricity over long distances. The design of these ladders is a complex process that takes into account various factors including material selection, ladder configuration, optimization techniques and environmental factors. Material selection: Material selection in high voltage transmission cables is critical to ensure optimal performance and durability. Aluminium and aluminium alloys are widely used due to their high electrical conductivity, light weight and corrosion resistance (Bian et al. 2019). Although copper is less common due to its higher cost, it offers excellent conductivity and mechanical strength (Johansson et al. 2020). Composite materials such as carbon fibre reinforced polymers (CFRP) are also being investigated for their potential to improve strength-to-weight ratio and environmental resistance (Zhou et al. 2018).

Cable configuration: The configuration of high-voltage transmission cables has a significant impact on their performance and efficiency. Traditional bare conductors are commonly used but advances in conductor design have led to the introduction of stranded and composite core conductors. Composite conductors increase the effective cross section, thereby reducing electrical losses and improving mechanical strength (Li and Li 2019). Composite core conductors contain non-metallic cores to reduce weight and alleviate problems such as galloping and icing (Wang et al. 2021).

Optimization techniques: optimization techniques play a key role in optimizing the performance and reliability of high voltage transmission cables. Conductor size, spacing, and voltage are optimized to minimize sag, mitigate corona discharge, and ensure adequate spacing (Bjorkqvist et al. 2017). Advanced modelling and simulation tools such as Finite Element Analysis (FEA) and Computational Fluid Dynamics (CFD) are used to analyse conductor performance under various operating conditions and environmental factors (Yang et al. 2020).

Environmental aspects: Environmental factors present challenges to the design and operation of high-voltage transmission cables. Wind, ice and temperature fluctuations can affect driver performance and reliability. Conductors must be designed to withstand these conditions while maintaining their electrical integrity and mechanical stability (Zhu et al. 2019). Composites offer greater resistance to environmental influences and are therefore suitable for use in demanding operating environments (Saha et al. 2018). In summary, the design of high voltage transmission cables requires a comprehensive evaluation of material properties, conductor configuration, optimization techniques and

environmental aspects. Advances in materials science, engineering principles and modelling tools continue to drive innovation in cable design, enabling the development of a more efficient, reliable, and resilient transmission infrastructure.

3. Methods

Literature Review: I have conducted a thorough review of existing literature related to high voltage transmission conductors. This involves gathering research articles, technical reports, industry standards, and other relevant sources to understand the current state of knowledge in this field. **Identification of Key parameters:** I have Identified key parameters and factors that are important in the design of high voltage transmission conductors. This may include electrical characteristics, mechanical properties, thermal behavior, environmental considerations, and reliability factors. **Data Collection:** I gathered data on various types of high voltage transmission conductors, including materials used, structural designs, electrical properties, and performance characteristics. This may involve contacting manufacturers, consulting industry experts, and collecting data from existing transmission lines.

Analysis and Evaluation: Analyze the collected data to evaluate the performance of different conductor designs. This may involve conducting mathematical modeling, simulations, or experimental studies to assess factors such as electrical efficiency, mechanical strength, thermal performance, and environmental resilience. **Comparison and Benchmarking:** Compare the performance of different conductor designs against industry standards, existing transmission lines, or theoretical benchmarks to identify areas for improvement and optimization. **Technological Assessment:** Assess recent technological advancements in conductor materials, manufacturing processes, and design techniques. Evaluate their potential impact on improving the performance, efficiency, and reliability of high voltage transmission conductors.

Cost-Benefit Analysis: Conduct a cost-benefit analysis to evaluate the economic implications of adopting different conductor designs. Consider factors such as initial investment costs, operational expenses, maintenance requirements, and expected lifespan to determine the overall cost-effectiveness of each design. **Recommendations and Conclusion:** Based on the analysis and evaluation, there is a need for optimizing the design of high voltage transmission conductor. **Peer Review:** Submit the study for peer review by experts in the field to validate the methodology, analysis, and conclusions.

4. Data Collection

Table 3. (Transmission line lengths by voltage class) (Calgary AB 2018)

Line-to-line voltage kV	Length of line km	
	Minimum	Maximum
66	40	120
110	50	140
132	50	160
166	80	180
230	100	300
400	400	800

Table 4. (Comparison of material properties for high voltage conductors) (Electrical engineering portal.com 2013)

Characteristic	Value	Unit
Cross-section area	1600	mm ²
Conductor diameter	49.6	mm
Total thickness of insulation	27	mm
Total diameter	127.9	mm
DC resistance at 20°C	0.0113	Ω/km
AC resistance at 90°C/50 Hz	0.0157	Ω/km
Current loading at 65°C/90°C	1267/1145	A

Tables 3 and 4 show the data collection. Table 3 illustrates the lengths of each transmission line tested in studied in this paper, while Table 4 shows a comparison of materials of various transmission conductors used on the selected lines.

5. Results and Discussion

High-voltage cables, also known as high-voltage cables or overhead lines, are essential components of electrical transmission systems. These conductors are designed to efficiently transmit electricity over long distances, often from power plants to distribution centers or from one region to another. The main characteristics of high voltage transmission cables are: High voltage capability: High voltage cables are capable of handling high voltages, typically between 69 kilovolts (kV) and 765 kV, and in some cases even higher. Higher voltages reduce energy losses during transport and enable efficient power transmission over long distances. Low resistance: Conductors used in high-voltage power lines are made of materials with low electrical resistance, such as aluminum or copper.

The low resistance minimizes energy loss as heat during transfer, improving overall efficiency. Strength and Durability: High transmission cables are designed to withstand a wide range of environmental conditions, including high winds, ice loads and temperature fluctuations. They are often made of materials and structures with high mechanical resistance and durability to ensure reliable operation over long periods of time. Lightweight: To support the weight of transmission lines and reduce the load on supporting structures (such as towers or poles), tall transmission cables are designed to be lightweight. This helps minimize support structure costs and simplify installation and maintenance procedures. Corrosion resistance: Because transmission lines are often exposed to external influences, high transmission cables are usually coated or treated to prevent corrosion, thereby extending their service life and maintaining electrical performance. Insulation: Although overhead power lines primarily use high transmission rate conductors, they may need to be insulated in some sections to prevent power leakage or interference from nearby objects or structures. Examples of high-transmission conductors include various types of overhead power lines, such as bundled conductors, composite core conductors, and low-sag high-temperature conductors. The choice of conductor depends on factors such as voltage requirements, environmental conditions, and budget considerations for a particular transportation project.

5.1 Proposed Improvements

Improvements in the development of high-voltage transmission cables arise from the need for more efficient, reliable, and economical electrical transmission systems. Here are some key areas for improvement: Higher voltage ratings: A major improvement has been the development of conductors that can withstand even higher voltage levels. Advances in materials science and engineering have led to the development of conductors capable of transmitting electrical energy at voltages above 1,000 kV (1 megavolt) in high-voltage transmission systems. A higher voltage rating reduces energy losses and allows longer transmission distances without the need for intermediate stations. Reducing Electrical Losses: Improvements in cable design and materials have led to a reduction in electrical losses in transmission. Conductors with lower electrical resistance and improved thermal properties help minimize energy losses, thereby improving the overall efficiency of the transmission system. Greater mechanical resistance: High-voltage transmission cables are exposed to various mechanical stresses, including wind, ice and temperature fluctuations. Advances in materials and construction techniques have resulted in ladders with greater mechanical strength and durability, reducing the risk of ladder failure or damage during operation. Lightweight Structures: Lightweight ladders are easier to install and place less strain on supporting structures such as towers or transmission poles. Advances in materials technology have made it possible to develop lightweight conductors without compromising electrical performance and mechanical strength. Improved Corrosion Resistance: Corrosion can significantly shorten the lifespan of transmission cables.

Developments in coatings and materials have resulted in cables with greater corrosion resistance, extending their lifespan and reducing the need for maintenance. Reinforced Insulation: Insulation is essential to prevent power loss and ensure the safety and reliability of high-voltage transmission systems. Advances in insulating materials and techniques have led to improved insulating properties, which have enabled the development of more efficient and reliable high-voltage cables. Cost Effectiveness: Improvements in manufacturing processes and materials have contributed to the overall cost effectiveness of high voltage transmission cables. Lower material costs, lower energy losses and a longer service life help reduce overall system costs over the life of the transport infrastructure. Overall, continuous research and development efforts focused on materials, design and manufacturing processes have led to

significant improvements in the performance, reliability, and cost-effectiveness of high-voltage transmission cables, contributing to the development of power transmission systems around the world. World.

6. Conclusion

High-voltage transmission cables play a key role in providing efficient and reliable power over long distances in power systems. In this test, we examined various aspects of the design, including material selection, driver configuration, optimization techniques, and environmental considerations. The combination of these factors is crucial to ensure the efficiency, reliability and sustainability of the high-voltage transmission infrastructure. The choice of materials such as aluminium, aluminium alloys and composites such as carbon fibre reinforced polymers (CFRP) is crucial to achieve the desired balance between electrical conductivity, mechanical strength and resistance to heat and the environment. In addition, advances in conductor configurations such as: B. bundled conductors and composite core conductors, for improved performance and reliability by reducing electrical losses and mitigating problems such as galloping and icing. Optimization techniques, including wire sizing, spacing and tension, are essential to minimize sag, corona discharge and electrical losses.

Advanced modelling and simulation tools such as Finite Element Analysis (FEA) and Computational Fluid Dynamics (CFD) enable accurate analysis and optimization of driver performance under various operating conditions. In addition, environmental adaptability is essential to ensure the durability of high-voltage transmission cables in harsh environments. The use of composite materials and galvanized coatings provides resistance to environmental influences, increasing durability and reducing maintenance requirements. In summary, high voltage transmission cable design is a multidimensional process that requires careful consideration of various factors. By integrating advanced materials, innovative configurations, optimization techniques and environmental adaptability, we can develop a transmission infrastructure that meets growing electricity demand while ensuring efficiency, reliability and sustainability of the power system. Through ongoing research and development efforts, there is a need to further improve the design of high voltage transmission cables to meet the changing challenges and opportunities of the energy landscape and ultimately contribute to the resilience and sustainability of global electricity systems.

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