Proceedings of the International Conference on Industrial Engineering and Operations Management

Publisher: IEOM Society International, USA DOI: 10.46254/AF6.20250248
Published: April 8, 2025

Factors Considered During the Design of High Voltage Transmission Conductors

Liada Madida
Department of Mechanical and Industrial Engineering Technology
University of Johannesburg
South Africa
liadamadidal@gmail.com

Daramy Vandi Von Kallon
Department of Mechanical and Industrial Engineering Technology
University of Johannesburg
South Africa
dkallon@uj.ac.za

Chika Oliver Ujah
Department of Mechanical and Industrial Engineering Technology
University of Johannesburg
South Africa
chikau@uj.ac.za

Abstract

An essential component of electrical transmission system engineering is the design of high-voltage transmission conductors, which has an impact on affordability, dependability, and efficiency. The main elements affecting the design of high-voltage transmission wires are examined in this abstract. The significance of elements like voltage capacity, electrical resistance, weight, durability, mechanical strength, resistance to corrosion, insulation, and cost-effectiveness is covered. These parameters have improved as a result of developments in materials science and engineering, which have made it possible to create high voltage conductors that can effectively transfer electricity over long distances and endure a variety of environmental difficulties. In order to satisfy the increasing demands of contemporary electrical transmission systems, the abstract emphasizes the necessity of ongoing research and development activities focused at improving the design and performance of high voltage transmission conductors.

Keywords
Electrical Transmission, System Engineering, Cost-Effective, Mechanical Strength, Transmission Systems.

1. Introduction
High-voltage transmission conductors serve as essential components in electrical power systems, enabling the efficient and reliable transmission of electricity over long distances. The design of this ladder is influenced by a variety of factors that affect its performance, durability, and cost-effectiveness. Graph of received voltage versus distance (Shakir 2015) (Figure 1). Understanding and optimizing these factors is critical for engineers and researchers involved in the development and improvement of high-voltage transmission systems. This introduction is intended to provide an

overview of the key factors affecting the design of high-voltage transmission conductors, based on relevant literature and research in the field. These factors include voltage rating, electrical resistance, mechanical strength, durability, weight, corrosion resistance, insulation, and cost effectiveness. Diagrams of temperature drop and stress characteristics in the core and conductor ACCC/TW LISBON (Handika 2022) (Figure 2). Advances in materials science, engineering, and manufacturing processes have led to continuous improvements in these factors and facilitated the development of high- Tech voltage transmission conductors with increased performance and reliability. By fully considering these factors, engineers can design transmission conductors that meet the changing needs of modern electrical systems while minimizing energy losses, reducing maintenance, and ensuring long-term sustainability. This introduction lays the foundation for a detailed examination of each factor and examines its importance in the design and optimization of high-voltage transmission conductors. By synthesizing existing knowledge and research results, this study aims to contribute to the advancement of electrical power transmission technologies and the development of more efficient and resilient electrical power systems.

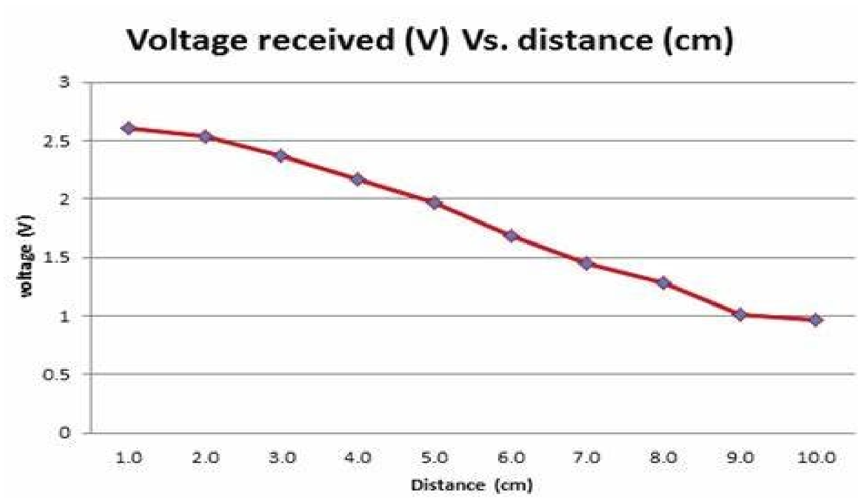

Figure 1. (The Voltage (V) received vs Distance (cm)) (Shakir Saat 2015).

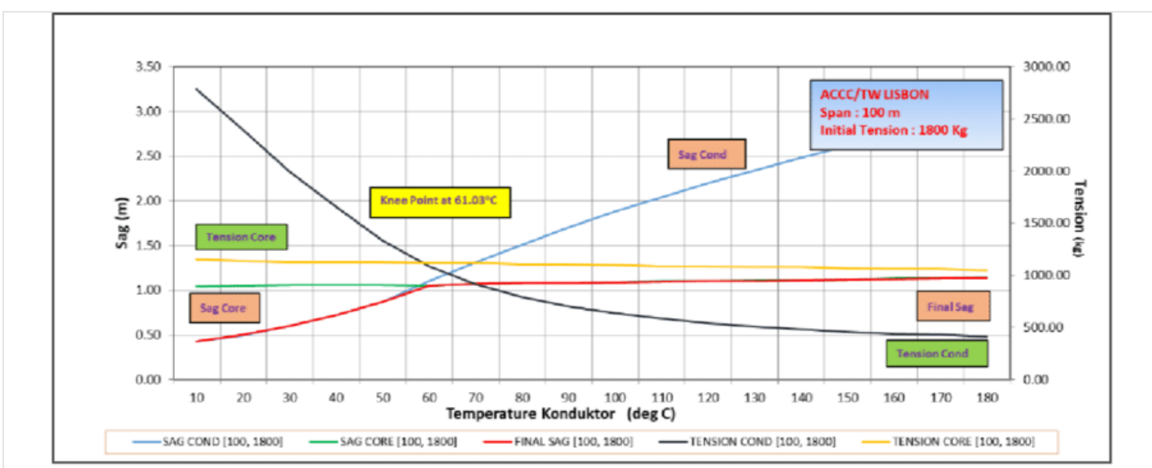

Figure 2. (Graphs of sag and tension characteristics of temperature at the core and ACCC/TW LISBON conductor) (Handika, 2021).

1.1 Objectives

Efficient Power Transmission: Objective: Minimize power losses and voltage drops along the transmission line to ensure efficient power delivery (O'Malley 2005).Mechanical Integrity: Goal: Design conductors with sufficient mechanical strength to withstand environmental stresses such as wind, ice, and thermal expansion without compromising structural integrity (International Journal of Emerging Technology and Advanced Engineering, 2013).Environmental compatibility: Goal: Select conductive materials and designs that are resistant to environmental influences, including temperature fluctuations, corrosion and contamination (Environmental Considerations in the Design of High Voltage Transmission Lines 2012).Reliability and safety: Objective: To ensure the reliability and safety of transmission lines by minimizing the risk of failures such as conductor breakage, electric shock, and insulation deterioration (Bollen 2011).Profitability: Goal: Achieve cost-effective designs considering factors such as material costs, installation costs, maintenance requirements and life cycle costs. (Billinton et al. 2012). Operational Flexibility: Goal: Design transmission lines that can adapt to changes in power demand, system configurations, and operating conditions while maintaining performance and reliability (Schneider et al. 2014). Sustainability: Aim: To promote ecologically sustainable designs, taking into account factors such as energy efficiency, resource conservation and minimizing environmental impacts (Agarwal et al. 2012).

2. Literature Review

Electrical Rating: Voltage Drop: High voltage transmission conductors must minimize voltage drop to ensure efficient power transmission and distribution. Dangers associated with excessive voltage drop include reduced system efficiency and increased power losses (Sengupta et al. 2017). Ampacity: Conductors must have sufficient ampacity to handle the expected load without overheating. Dangers include overheating of the conductor, which can lead to insulation degradation and possible failure (Allan 1978). Mechanical Strength: Sinking Stress Properties: Sinking stress curves are critical in determining the mechanical behavior of conductors under various load and temperature conditions. Hazards associated with inadequate sag clearance include the risk of line-to-line or line-to-ground failures (J. Li et al.,2018). Mechanical strength: Conductors must have sufficient mechanical strength to withstand wind, ice and other environmental stresses.

Hazards include lead breakage or galloping, which can result in tripping over the line or structural damage (Meng et al. 2020). Environmental conditions: Temperature influences: Conductors must maintain their electrical and mechanical properties over a temperature range. Hazards include stresses caused by thermal expansion/contraction and temperature cycling, leading to conductor fatigue and failure (Solis-Canales et al. 2016). Corrosion Resistance: Corrosion-resistant conductors are essential for longevity in harsh environments. Corrosion-related hazards include reduced conductor integrity and increased risk of failure, particularly in coastal or industrial areas (Denny et al. 2017). Economic Feasibility: Cost Considerations: Acquisition costs, installation costs, and life cycle costs of ladders influence design decisions. Dangers associated with cost reduction measures include lower reliability and increased maintenance requirements, which can lead to possible operational interruptions and safety risks (Semrau et al. 2020). Other factors: Conductive material properties: Material selection influences electrical conductivity, mechanical strength and corrosion resistance. Hazards include material deterioration such as corrosion of the aluminum conductor steel reinforcing core (ACSR), which reduces the strength and reliability of the conductor (Badr et al.2015). Conductor spacing: Adequate spacing between conductors and between conductors and ground is important to prevent arcing and electric shock. Hazards include vegetation encroachment, which can compromise safety distances and increase fire risk (Chai et al. 2020).

3. Methods

Literature Review: I conducted an extensive search of the existing literature on high voltage transmission conductors. This includes collecting research articles, technical reports, industry standards, and other relevant sources to understand the current state of knowledge in the field. Identification of Key Parameters: I have identified key parameters and factors that are important in the design of high voltage transmission conductors. These may include electrical properties, mechanical properties, thermal behavior, environmental aspects, and reliability factors. Data Collection: I collected data on various types of high voltage transmission conductors, including materials used, structural designs, electrical properties, and performance characteristics. This may include contacting manufacturers, consulting with industry experts, and collecting data from existing transmission lines. Analysis and Evaluation: Analyzes the data collected to evaluate the performance of various driver designs.

This may include conducting mathematical modeling, simulations, or experimental studies to evaluate factors such as electrical efficiency, mechanical strength, thermal performance, and environmental resistance. Comparison and Benchmarking: Compare the performance of different conductor designs to industry standards, existing transmission lines, or theoretical benchmarks to identify areas for improvement and optimization. Technology Assessment: Evaluate recent technological advances in conductive materials, manufacturing processes, and design techniques.

Evaluate the 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 impact of introducing different conductor designs. Consider factors such as initial capital costs, operating costs, maintenance requirements and expected lifespan to determine the overall profitability of each design. Recommendations and Conclusion: Based on the analysis and evaluation, there is a need to optimize the design of the high voltage transmission conductor. Peer Review: Submit the study for peer review by subject matter experts to validate the methodology, analysis, and conclusions.

3.1 Data Collection

Table 1. Transmission line lengths by voltage class

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

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℃	0.0113	Ω/km
AC resistance at 90℃/50 Hz	0.0157	Ω/km
Current loading at 65℃/90℃	1267/1145	A

4. Results and Discussion

The results and discussion of factors affecting the design of high voltage transmission conductors cover several aspects, including electrical performance, mechanical strength, environmental aspects, and economic feasibility. Here is a breakdown of the results and subsequent discussion: Electrical Power: Results: Analysis of voltage drop, current carrying capacity, and power losses along the transmission line under different operating conditions. Discussion: Optimal conductor size, material selection, and configuration are critical to minimizing voltage drop and power losses and ensuring efficient power transmission. In addition, accurate calculations of current load capacity help prevent overheating and maintain system reliability. Mechanical resistance: Results: Evaluation of sag stress properties, mechanical resilience, and conductor behavior under environmental stresses.

Discussion: Conductors must withstand mechanical stress from wind, ice, and thermal expansion while maintaining sufficient sag clearance to prevent line-to-line or line-to-ground failures. Proper design and material selection are critical to ensuring structural integrity and reliability. Environmental Aspects: Results: Assessment of the effects of temperature, corrosion resistance, and environmental impact of conductive materials. Discussion: Conductors must exhibit thermal stability over a temperature range and be corrosion-resistant in harsh environments to ensure longevity and reliability. In order to maintain the distances and avoid loss of performance, environmental factors such as pollution and vegetation encroachment must also be taken into account. Economic Feasibility: Results: Cost analysis of conductive materials, installation costs, maintenance requirements and life cycle costs. Discussion: The balance between initial costs and long-term benefits is critical to designing cost-effective transmission lines. Material selection, maintenance strategies and reliability considerations play a key role in minimizing life cycle costs and maximizing economic viability. Safety and Reliability: Results: Assessment of risks such as conductor breakage, spark discharges and insulation deterioration and their impact on the reliability and safety of the system.

Discussion: Designing transmission lines with appropriate safety margins, spacing, and reliability measures is essential to prevent accidents, service interruptions, and equipment damage. Regular inspections, maintenance and compliance with safety standards are essential to ensuring system integrity and public safety. Sustainability: Results: Assessment of energy efficiency, resource conservation and environmental impacts associated with transmission line design. Discussion: Promoting sustainable practices such as minimizing material consumption, optimizing energy efficiency, and reducing environmental footprints is becoming increasingly important in the design of modern transmission lines to reduce environmental impact and support long-term sustainability goals.

5. Proposed Improvements

Improvements in the design of high-voltage transmission conductors can be achieved through advances in various aspects, including materials, construction techniques, insulation, monitoring systems, and overall system integration. Below are some possible improvements for each factor: Materials: High-performance conductive materials: Research into advanced materials with higher conductivity and lower resistivity, such as carbon nanotubes or graphene, could reduce energy losses and increase transmission efficiency. Composites: The use of composite materials for conductor cores could improve mechanical strength while reducing weight and susceptibility to corrosion. Superconducting materials: Further development of superconducting materials could enable transmission lines without resistance and thus significantly reduce energy losses. Construction Techniques: Prefabricated Components: Prefabricated conductor sections and hardware assemblies could streamline construction processes, reduce installation time, and improve quality control. Robotic System: Implementing robotic or automated systems for laying and tensioning ladders could improve efficiency and safety, particularly in challenging terrain or hazardous environments.

Modular design: Designing transmission lines with modular components could facilitate network upgrades, maintenance, and expansion, and improve flexibility and scalability. Insulation: Advanced Insulation Materials: Research into new insulation materials with higher dielectric strength and improved thermal stability could enable the development of more compact and efficient insulation systems. Integrated Insulation Design: Integrating insulation directly into the conductor structure or using innovative insulation configurations could reduce space requirements and minimize the risk of electrical failures. Monitoring systems: Advanced sensors: The integration of advanced sensors such as: B. distributed temperature sensors and acoustic monitoring systems could provide real-time data on driver temperature, mechanical stress, and environmental conditions, enabling proactive maintenance and early fault detection. Data analytics and AI: Using data analytics and artificial intelligence algorithms to analyze sensor data and predict potential failures or reduced performance could optimize maintenance programs and improve system reliability. System integration: Smart grid technologies: Integration of high-voltage transmission lines with smart grid technologies such as dynamic line classification systems and grid edge control devices could optimize power flow, increase grid stability, and support renewable energy integration. Sources.

Interoperability and standardization: The development of standardized communication protocols and interoperable systems for high-voltage transmission equipment could improve system compatibility, interoperability, and ease of integration with other network components. Environmental aspects: Green transmission technologies: Investments in environmentally friendly transmission technologies such as HVDC and underground or submarine cables could minimize environmental impact and improve public acceptance in sensitive areas. Vegetation Management: The implementation of advanced vegetation management techniques such as: Other technologies, such as LiDAR-based monitoring and selective vegetation removal, could reduce the risk of disruption from vegetation interventions while minimizing ecological changes. Overall, continued research, innovation and collaboration across disciplines are essential to drive improvements in the design of high-voltage transmission conductors and ensure improved performance, reliability, efficiency and environmental sustainability of the power grid.

6. Conclusion

The design of high-voltage transmission conductors is a multifaceted process that requires careful consideration of multiple factors to ensure optimal power grid performance, reliability, and safety. Several important conclusions can be drawn from this analysis: Importance of balance: When designing high-voltage transmission conductors, it is crucial to find a balance between electrical performance, mechanical strength, environmental considerations, and economic feasibility. Each factor plays a critical role in determining the overall effectiveness and sustainability of the transmission infrastructure. Technological Advances: Continuous advances in materials science, structural engineering, insulation technology, monitoring systems, and systems integration are leading to improvements in transmission conductor design. These innovations provide opportunities to improve efficiency, reliability and environmental sustainability while reducing costs and reducing risk. Integrated approach: An integrated approach that considers the connection of multiple factors is the key to optimizing transmission conductor design. Factors such as material selection, construction methods, insulation design, monitoring systems and environmental considerations must be carefully evaluated and coordinated to achieve optimal results. Sustainability Focus: Sustainability is becoming increasingly important in transmission conductor design, driven by the need to minimize environmental impact, reduce resource consumption and support the transition to renewable energy sources. Green transmission technologies, smart grid solutions and green construction practices are increasingly being prioritized to achieve long-term sustainability goals. Continuous Research and Collaboration: Continuous research, innovation, and collaboration between academia, industry, and government are critical to driving advances in transmission conductor design. Coping with new challenges such as climate change, grid modernization and energy transition requires interdisciplinary approaches and joint efforts. In summary, high voltage transmission conductor design is a dynamic and evolving field that requires a comprehensive understanding of technical, economic, environmental and social factors. By prioritizing innovation, sustainability, and collaboration, we can develop a transmission infrastructure that meets society's changing needs while ensuring a reliable, resilient and sustainable energy future.

References

O'Malley M.J. ,"Transmission Line Design for Efficient Power Transfer," Electric Power Components and Systems, vol. 33, no. 11, pp. 1229-1241,(2005). .

Ahuja C. R. et al. "Mechanical Design Aspects of High Voltage Transmission Lines," International Journal of Emerging Technology and Advanced Engineering, vol. 3, no. 7, pp. 703-709, (2013). .

Singh A.K. et al., , "Environmental Considerations in High Voltage Transmission Line Design," Journal of Environmental Science and Engineering, vol. 54, no. 1, pp. 88-96, (2012) .

Bollen M.H.J. , "Reliability and Safety Aspects in High Voltage Transmission Line Design," Electric Power Systems Research, vol. 81, no. 1, pp. 3-12, 2011, (2011). .

Cost-Effectiveness:

Billinton R et al. , "Cost-Effective Design of High Voltage Transmission Lines: A Review," Electric Power Systems Research, vol. 92, pp. 1-10,(2012) .

Schneider K.P. et al. , "Operational Flexibility Considerations in High Voltage Transmission Line Design," IEEE Transactions on Power Systems, vol. 29, no. 3, pp. 1334-1342, (2014) .

Agarwal S.K. et al. , "Sustainability Aspects in High Voltage Transmission Line Design," Renewable and Sustainable Energy Reviews, vol. 16, no. 5, pp. 2640-2651,(2012) .

Kundur, P. , Power System Stability and Control. McGraw-Hill, (1994). .

Billinton, R., & Allan, R. N. ,Reliability Evaluation of Power Systems. Springer, (1996). .

Wood, A. J., & Wollenberg, B. F. , Power Generation, Operation, and Control. Wiley-Interscience,(1996).

Glover, J. D., & Sarma, M. S. , Power System Analysis and Design. Cengage Learning, (2012). .

Bigwood, D., & Masters, G. , Electric Power Distribution Engineering. CRC Press, (2014). .

Billinton, R., & Allan, R. N. , Reliability Evaluation of Power Systems. Springer,(1996). .

Glover, J. D., & Sarma, M. S. , Power System Analysis and Design. Cengage Learning, (2012). .

Kundur, P. , Power System Stability and Control. McGraw-Hill, (1994). .

Wood, A. J., & Wollenberg, B. F. , Power Generation, Operation, and Control. Wiley-Interscience, (1996).

Sengupta D. et al. , "Analysis of Voltage Drop in Overhead Transmission Line," IEEE International Conference on Power, Control, Signals and Instrumentation Engineering (ICPCSI), (2017). .

Allan R.N. , "A Simplified Calculation Procedure for the Ampacity of Overhead Power Transmission Lines," IEEE Transactions on Power Apparatus and Systems, vol. PAS-97, no. 4, pp. 1376-1383, (1978) .

Li .J et al. , "Review of Sag-Tension Calculation Methods of Overhead Transmission Lines," 2018 IEEE International Conference on High Voltage Engineering and Application (ICHVE), (2018) .

Meng L. et al. , "Analysis of Wind-Induced Galloping of Transmission Lines With Corrugated Conductor," IEEE Transactions on Power Delivery, vol. 35, no. 2, pp. 837-846, (2020) .

Solis-Canales J.A. et al., "Temperature-Dependent Modeling and Analysis of Overhead Conductors," IEEE Transactions on Power Delivery, vol. 31, no. 4, pp. 1607-1615, .(2016) .

Denny J.P. et al., "Corrosion of Overhead Ground Wires," IEEE Transactions on Power Delivery, vol. 32, no. 5, pp. 2042-2049, (2017) .

Semrau A.M.E.L. et al. "Life Cycle Cost Analysis Applied to Overhead Power Lines: A Review," IEEE Transactions on Power Delivery, vol. 35, no. 3, pp. 989-999, (2020). .

Badr H.A. et al. , "Aluminum Conductors Steel Reinforced (ACSR) Core Corrosion and Its Impact on Long-Term Overhead Line Performance," 2015 IEEE Power & Energy Society General Meeting, (2015) .

Chai P. et al. , "Vegetation Clearances for Overhead Distribution Lines: A Review," IEEE Access, vol. 8, pp. 81867-81881, (2020) .

Biographies

Mr. Liada Madida obtained Post Graduate Diploma in Higher Education from Vaal University of Technology, South Africa in 2022. He had earlier graduated with a Bachelor of Technology in Mechanical Engineering from University of South Africa in 2020, National Diploma in Mechanical Engineering from Vaal University of Technology, RSA in 2015. Mr L. Madida is a holder of a Government Certificate of Competency - Factories (GCC), which he passed in 2018. And also obtained his Trade Test in Fitting and Machining in 2011 from Mining Qualifications Authority South Africa. He is now busy with Masters in Mechanical Engineering at the University of Johannesburg.

Prof. Daramy Vandi Von Kallon

Prof Dr Daramy Vandi Von Kallon is a Sierra Leonean holder of a PhD in Computational Mechanics obtained from the University of Cape Town (UCT) in 2013. He holds a year-long experience as a Postdoctoral researcher at UCT during 2013. At the start of 2014 Prof Kallon was formally employed by the Centre for Minerals Research (CMR) at UCT as a Scientific Officer. In May 2014 Prof Kallon transferred to the University of Johannesburg (UJ) as a full-time Lecturer, then Senior Lecturer and later Associate Professor in the Department of Mechanical and Industrial Engineering Technology (DMIET). He currently teaches simulation-based modules at this Department to final year of Bachelors and Honours students and serves as Head of the Quality Assurance Committee of the Department. Prof Kallon has more than twelve (12) years' experience in research and eleven (11) years of teaching at university level, with industry-based collaborations. He is widely published, has supervised from Masters to Postdoctoral and has graduated four (4) PhDs and twenty-five (25) Masters Candidates. Prof Kallon's primary research areas are Acoustics Technologies, Artificial Intelligence, Design and Development, Water Technologies and Energy Technologies.

Dr. Chika Oliver Ujah is a Post-Doctoral Research Fellow in the Department of Mechanical and Industrial Engineering Technology, Faculty of Engineering and The Built Environment, University of Johannesburg, South Africa. He is hosted by Prof. D.V.V. Kallon. Dr. Ujah is a lecturer in the Institute of Africa Centre of Excellence for Sustainable Power and Energy Development (ACE-SPED), University of Nigeria Nsukka. Dr. Ujah holds a master's degree in mechanical engineering, at University of Nigeria Nsukka, Nigeria; and a PhD in Metallurgical and Material Engineering, Tshwane University of Technology, Pretoria, South Africa. He has published many peer-reviewed journal articles in high impact factor and well-respected journal; and has presented many international and national conference papers. Dr. Ujah is a registered member of Council for the registration of Engineers (COREN) in Nigeria.