

Long-Distance Power Transmission: Comparative Insights From Nigeria And The United States.

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Abstract: This paper carried out a critical review on the long-distance power transmission system in Nigeria and the U.S., considering the differences in infrastructure, technology, and operational efficiency. Information was gathered from previous journals of energy and power sustainability and reliability. It was discovered that the U.S., has a more reliable long-distance transmission system with little drawbacks compared to Nigeria that is facing several challenges in their long-distance transmission system. The paper suggested that the federal government of Nigeria should work on its national grid by investing into its energy and power sector, thereby increasing the reliability and efficiency of its long-distance transmission system.

Keywords— Energy, Power, Reliability, Efficiency, Grid, Voltage, Transmission

1. INTRODUCTION

The efficiency of power transmission towards a long distance range in any country depends on the general development of such country. It is crucial to ensure a reliable power supply in large and geographically diverse countries like Nigeria and the United States considering its population and enhancement of socio-economical development. In Nigeria, the most populous country in Africa has this incessant problem of lack of reliable power supply which has brought about retarded growth, slow economic development, and poor quality of life for its citizens. Despite the effort of the government to resolve this issue of lack of reliable power supply, several challenges abounds and poses as a threat towards its complete investment and potential reliability in providing its intended function [1]. These challenges include limited energy distribution framework, regulatory policies, and infrastructural development issues. In the US, the transmission networks are more advanced due to their high level of socio-economic development with an advanced technological base and regulatory policies. Their power transmission operation base is one of the largest and most complex transmission networks in the world. They are also face with challenges of aging infrastructure and the need for total maintenance and modernization [2].

This paper will focus on the comparative analysis of the high-voltage transmission systems in Nigeria and the United States considering the differences in infrastructure, technology, and operational efficiency. By spotting out these differences, the

paper will identify important facts that can be learned from each system to improve the reliability and sustainability of long-distance electricity transmission.

2. BACKGROUND AND CONTEXT

In this section, the paper will try to analyze the power transmission networks in both countries including historical context, common challenges, and existing infrastructures.

2.1 POWER TRANSMISSION IN NIGERIA

Nigeria is a very large country with an estimated population of 232,679,000 people [3] occupying a land mass of 356,667 sq. miles. The country consists of six Geo-political zones which are divided into 36 states including the federal capital territory. The provision of adequate power for ensuring the industrialization of the country depends on the following activities:

1. Generation of adequate power
2. The effective transmission of the generated power to all parts of the country.
3. The successful distribution of the generated power to the consumers.

Electricity production in Nigeria began in the year 1985 when it was first produced in Lagos as stated by Niger Power Review in 1985. The maximum capacity that was generated then was 60KW with a simultaneous maximum demand less than 60KW. The responsibility of electricity supply was taken over by the Nigerian Government under the jurisdiction of the Public Works Department (PWD) in 1946. In 1960, there was

an establishment of a central body by the legislative council which transferred the duty of electricity supply and development to the hands of a central body known as the Electricity Corporation of Nigeria (ECN). License was also given to the Nigerian Electricity Supply Company (NESCO) to produce electricity in some strategic locations in Nigeria. The Niger Dams Authority (NDA) was in charge of constructing and maintaining of dams and other works on the River Niger and other locations in Nigeria. The NDA was established by an act of parliament in 1995; its produced electricity was sold to ECN for distribution and sales at utility voltages. In 1972, there was a combination in operation between the ECN and NDA which resulted into the development of a new organization known as the National Electric Power Authority (NEPA). The new organization was obliged to produce and distribute electricity power supply to every area in the country and also its financial responsibility for various obligations. They were also obliged to make an effective utilization of the human, financial and other resources available to the electricity supply industry throughout the country.

Currently, Nigeria has about 23 grid-connected generating plants in operation in the electricity supply industry (NESI) with a total installed capacity of 10,396.0MW and available capacity of 6,056MW. Most of the generation plants are thermally oriented with an installed capacity of 8,457.6MW and an available capacity of 4,996MW. The national grid is made up of 4,889.2km of 330kv line, 6,319.33km of 132kv line, 6,098MVA transformer capacity at 330/132Kv and 8,090MVA transformer capacity at 132/33Kv [4].

[5] Examined the problems of power generation in Nigeria by carrying out a descriptive survey research on the staffs of Power Holding Company of Nigeria (P.H.C.N). The misuse of funds, system disorders, corruption and embezzlements, bureaucratic delays, lack of spare parts were discovered to be among the problems of generating adequate power in Nigeria.

[6] Discovered a gross power imbalance between the generation and the required power demand which has resulted into a defective economy in the last three decades. They suggested the use of renewable energy sources in mitigating the power issue experienced in Nigeria. [7] Examined the structure of the Nigerian power sector by identifying the problems in the structure and proposing a new structure for effective power generation, transmission and distribution. They identified the problem of defectiveness in the current structure in the perspective of the ownership of the power infrastructures, passive involvement of state governments and undue influence of the federal government. They proposed a new structure that gives room for every state government to own power plants and distributes power in their various states.

[8] Researched on the Nigeria electricity power supply system by identifying the transformations in the physical structure and organization of electricity power generating station. A small generating station was observed as it metamorphosed

into 16 generating stations, a transmission company and 11 distributed companies. From the survey, it was revealed that with the right policies in place, private sectors participating in electricity generation will be encouraged, which will lead to the rapid development of the power sector.

The federal government of Nigeria has privatized the operations of the Power Holding Company of Nigeria (PHCN) for the distribution of power to homes and industries. They did so in order to resolve the challenges leading to inadequate power supply. Several private bodies have ventured into the business of power generation in Nigeria; the likes of Afam power station, Eleme power station, Aba geometric power plants, Azura power plant, Trans-Amadi power plant, and Omoku power plant are all working together to add their own quota to the national grid so as to improve the amount of power generated.

2.2 POWER TRANSMISSION IN THE UNITED STATES

The largest and most complex power transmission networks in the globe is being operated in the United States with a high-voltage transmission lines which are essential for transmitting electricity from generation plants to where it is needed for consumption. The high-voltage transmission lines are usually located in remote areas with high population density and industrial activities. The structure of the US transmission system is listed below;

1. The Eastern Interconnection
 2. The Western Interconnection
 3. The Electric Reliability Council of Texas (ERCOT)
- Source: [9]

The U.S. grid is constructed on an extensive network of transmission which has working voltages between 69kV and 765Kv, with higher voltages typically used for long-distance transmission in order to reduce power losses [10]. The length of the transmission network in the U.S. exceeds 160,000 miles and it was constructed to solve the problems of a growing and technologically advanced economy [11].

Recently, the U.S. national grid has experienced several strains due to rising demand, the integration of renewable energy sources, and ageing of already existing infrastructure [12]. The integration of other advanced technologies to produce more reliable power has been one of the key strengths of the U.S. transmission system. The various technological upgrades have assisted in managing the intermittent nature of renewable energy sources like wind and solar, which is becoming an important aspect in the U.S. power generation plan [13]. The challenges faced by the U.S. transmission system can't be compared with the challenges Nigeria's transmission system is experiencing. The transmission system also faces challenges such as aging infrastructure which presents reliability risks, with the collapse of the national grid and frequent power outages. The need for significant investments in transmission infrastructure to support the clean

energy transition and enhanced grid reliability has been suggested by the U.S. department of Energy. The U.S. regulatory framework also plays an important role in shaping the transmission landscape. Transmission lines are regulated at both the federal and state levels, with the Federal Energy Regulatory Commission (FERC) overseeing interstate electricity transmission [14].

3 KEY COMPONENTS OF POWER TRANSMISSION SYSTEM

In this section, the paper will try to carry out a critical analysis on the design and the carrying capacity of transmission lines in Nigeria and the U.S.

3.1 TRANSMISSION LINE STRUCTURE AND CAPACITY

In Nigeria, the High Voltage (HV) and Extra High Voltage (EHV) transmission lines are constructed using lattice steel structures which help to deliver high voltages amounting to 132KV and 330KV [15]. They operate at different voltage levels which includes 66KV, 132KV, 330KV, and up to 750KV for the generation of extra high voltage transmission. In the U.S, the long distance transmission lines with high voltage have a primary voltage at 230kv, 345kv, and 500kv. The ultra high voltage (UHV) systems have up to 765kv and more [10]. The support system is similar to the one used in Nigeria which is supported by lattice steel towers which depends on the voltage level and regional considerations. The long distance transmission voltages have an initial rating between 69kv and 500kv or more, while local distribution systems operate at lower voltages such as 12kv or 34.5kv. When designing the long-distance transmission lines in U.S, some design considerations are observed; the transmission lines is built on lattice steel structures where the height and clearance depends on voltage levels, safety, and environmental factors, the weather conditions including wind, ice loading, and storms influence the design and operation of the transmission system, the clearance between the power lines and ground is also considered [16].

3.2 Voltage Levels and Distance

In Nigeria, the transmission systems operate at various voltage levels which are listed below;

- ❖ Low voltage at 230/415V
 - ❖ Medium Voltage at 11KV and 33KV
 - ❖ High voltage at 66KV, 132KV, and 330KV
 - ❖ Extra High Voltage at 400KV, 500KV, and 765KV
 - ❖ Ultra High Voltage which is above 800KV
- Source: [17]

The transmission lines cover long distances to transport electricity over the national grid.

In the U.S, the voltage level is classified as follows;

- ❖ Low voltage system which is three phase four wire with ratings 120/240V, 208/120V

- ❖ Medium voltage system with ratings 4.16kv, 12kv, 34.5kv
- ❖ High voltage system with ratings 69kv, 115kv, 138kv
- ❖ Extra high voltage system (EHV) with rating 230kv, 345kv, 500kv
- ❖ Ultra high voltage (UHV) which has a rating above 765kv

Source: [18]

3.3 Substation Technology

In Nigeria, the substations at every end of the transmission line require extensive equipments for safety and stabilization at high voltages. These equipments include transformers, circuit breakers, SCADA system, Bus-bar, insulation meggaring, and gantries [19]. The substations are designed to step up the voltage for long-distance transmission which could be 132KV or 330KV and also to step down high voltages ranging from 66KV, 33KV, or 11KV for distribution to homes and industries.

In the U.S, the substation has three transmission components for transforming high voltages from the transmission lines to lower voltages for distribution. The transmission substations step up or step down the voltage for long-distance transmission for regional distribution. The switchyards acts as hubs where multiple transmission lines meet together making it possible for routing and switching without the aid of a transformer [20]. The final transmission components are the distribution substations which step down the high voltages for distribution to consumers and industrial users.

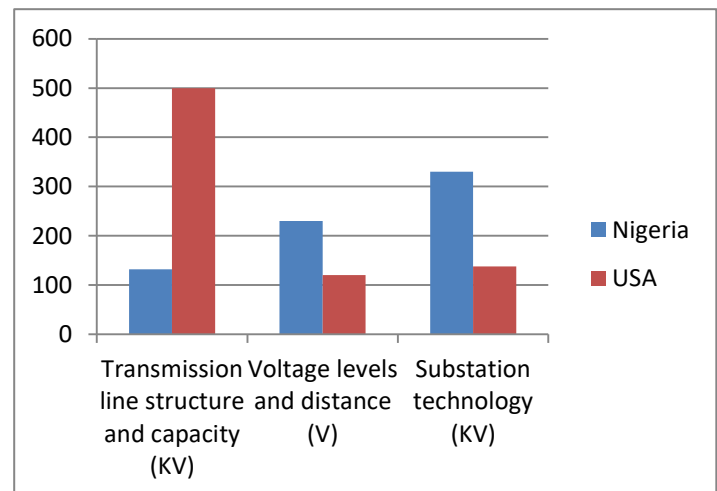


Fig. 1. A component bar chart showing the various components of transmission system for both Nigeria and the U.S.

3.4 Transmission Losses

Several factors influence the transmission losses in Nigeria long distance transmission system, these factors such as adverse weather conditions (high winds or low temperatures) which can lead to power outages [21]. Voltage losses increase

as distance and load increases, which make it necessary for the transmission system to be designed efficiently for minimizing losses.

In U.S, transmission losses are only evident due to resistive losses in the conductors used for power transmission [22]. The increase in distances and height of the transmission system leads to an increase in its power losses, especially in regions where electricity is transmitted over hundreds of miles. The power losses produced in the long-distance transmission lines is directly proportional to the square of the current, so operating at high voltages allows for lower currents and reduced resistive losses [23]. Transmission losses can also occur due to weather and environmental conditions as factors such as temperature, humidity, and ice formation especially in harsh climates affects the transmission system leading to transmission losses [24].

3.5 Grid Reliability and Stability

High-voltage lines are very important for grid reliability, but their failure can lead to large-scale instability and outages, which can affect many customers. The system employs redundant and complex protection schemes to prevent failures, ensure rapid recovery, and maintain stability during transmission line failures. In Nigeria, the national grid experiences several downtimes leading to the collapse of the grid thereby making it impossible to distribute electricity to consumers and industrial users [25]. The federal government of Nigeria has introduced complex protection schemes to resolve the issue of consistent grid collapse. They privatized the generation and distribution companies making it possible for a large number of people to delve into power generation so as to add their own quota of produced electricity power to the national grid to increase its stability and reliability.

In the U.S, the stability and reliability of the grid is a very important aspect in the transmission system, ensuring continuous and quality power delivery while minimizing disruptions. Several factors are maintained in other to achieve this stability and reliability. The interconnected system allow for load-sharing and rerouting of electricity during outages or peak demand periods, enhancing reliability and preventing localized failures from collapsing the national grid [26]. Smart technologies e.g. smart meters, phasor measurement units (PMUs) have been used to modernize the grid system. They assist in the monitoring and controlling of the grid operations. Other factors considered for maintaining the reliability and stability of the grid are load balancing and frequency control, protection systems, renewable energy integration, cyber security and physical security, and maintaining grid reliability standards [27].

3.6 Maintenance and Upgrade

In Nigeria, high-voltage transmission lines are challenging to maintain due to safety requirements and the difficulty of scheduling planned outages without overloading or destabilizing the grid. As higher voltages require larger equipment and more extensive clearances, upgrading or

maintaining existing lines often demands additional land and resources, particularly in densely populated areas.

The U.S long-distance transmission system uses complex protection scheme, including automatic relays, to ensure grid stability in case of faults or failures. Maintaining the long distance transmission line is crucial but challenging. Planned outages must be coordinated to avoid the collapse of the national grid, especially for lines carrying heavy loads.

4 DISCUSSIONS

The table below gives a direct comparative analysis of long-distance transmission system between the United States and Nigeria.

Table 1: Comparative analysis of high voltage transmission between the U.S. and Nigeria

Transmission components	The U.S.	In Nigeria
Infrastructural size	Has about 160,000 miles of transmission lines.	Has about 13,000 km of transmission lines.
Transmission technology	Utilizes HVDC and HVAC systems for long-distance transmission.	Utilizes more of HVAC. The use of HDVC is minimal.
Grid capacity	Can carry an enormous amount of megawatts.	Limited capacity with frequent power overloads
Grid complexity	Divided into three interconnections eastern, western, and ERCOT.	A less structured national grid.
Efficiency	Has average transmission efficiency between 94-96%.	Average transmission efficiency less than 60%
Reliability	Has a high reliability with less power interruptions.	Frequent collapse of the national grid leading to total blackout in the country
Technological advancement	Has included smart grids, real-time monitoring, and advanced HVDC technology.	Less adoption of modern technology

Investments in Upgrades	Always investing in energy generation especially from renewable means.	Lack of proper funding for upgrading the national grid.
Regulatory framework	Has a well structured regulatory framework.	Regulatory framework not well structured.
Integration with renewable energy	Has integrated wind, solar, and hydro-power sources for energy generation.	Ineffective renewable energy inclusion due to lack of infrastructures.

Sources: [28][29][30][31][32][33]

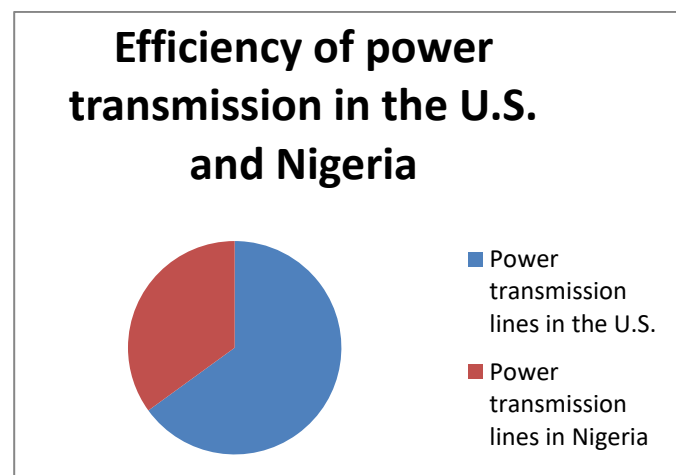


Fig. 2. Chart showing the overall efficiency of the U.S. transmission system to that of Nigeria.

5 CONCLUSION

The study on the long-distance transmission lines in Nigeria and the USA shows the differences and similar challenges in the structure of the countries various national grid infrastructure, transmission losses, and reliability. Both countries face similar technical limitations of high-voltage transmission over long distances but their upgrades and smart technologies for enhancing the efficiencies of their grid system is incomparable. The U.S has invested heavily in advanced technologies, including Extra High Voltage (EHV) and Ultra High Voltage (UHV) to minimize losses and improve grid stability. Nigeria on the other hand has less funding to incorporate these advanced technologies in improving the grid stability. The study has shown that the U.S. has a better long-distance transmission system than Nigeria. The federal government of Nigeria should work on its national grid by investing into its power sector, funding of

research to discover other advanced technologies that can improve the efficiency and stability of the national grid.

References

- [1] Amoah M & Beecham. (2024). AD814: Nigerians lack reliable electricity, leaving most discontent with government's effort. AfroBarometer Publications. No. 814
- [2] Christopher D. (2021). Electric power transmission networks. Handbook of Energy and Policy. Pg 665-674. ISBN: 978-0-12-814712-2
- [3] United Nations, 2024
- [4] Nwalado E, Obro S, & Ofuasias J. (2012). The problems of power generation in Nigeria: implication for economic development. Multidisciplinary Journal of Emperical Research Vol 10, No 1.
- [5] Adeoye S & Oladimeji T. (2020). Power generation in Nigeria: the past, present and the future. Journal of Earth & Environmental Sciences Research. Vol 2 No.2 ISSN: 2634-8845.
- [6] Ebigenibo G. (2021). Nigeria power sector: a new structure required for effective and adequate power generation, transmission and distribution. Global Journal of Engineering and Technology Advances. Vol 7 No.1 pg 6-18. ISSN: 2582-5003
- [7] Oluremi O. (2016). The Nigerian power sector investment opportunities and guidelines. Federal Ministry of Power, Works & Housing. Revised 2016.
- [8] Oladimeji A, Ayodeji S, Eluntunji B, & Joseph O. (2019). Nigeria electricity power supply system: the past, present and the future. IEEE PES/IAS Power Africa. DOI: 10.1109/PowerAfrica.2019.8928767
- [9] Energy Protection Agency. (2024). U.S Grid Regions. Retrieved from <https://www.epa.gov/green-power.market/us-grid-regions>
- [10] Accelerate Geospatial Insights. (2021). U.S. Electric Power Transmission Lines. Retrieved from <https://www.arcgis.com>
- [11] Chibukie P, Salihu A, & Ugbe C. (2024). A comprehensive review of recent developments in smart grid through renewable energy resources integration. Heliyon. Vol 10 Issue 3.
- [12] U.S. Department of Energy. (2010). Electric power industry needs for grid-scale storage applications. Retrieved from <https://www.energy.gov/oe/articles>

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- [13] Hassan Q, Algburi S, Sameen A, Salman H, and Jaszczur M. (2023). A review of hybrid renewable energy system: solar and wind-powered solutions-challenges, opportunities, and policy implications. *Results in Engineering*, Elsevier Journals. Vol 20.
- [14] Kathryn C, Karen P, and Todd A. (2021). Electricity regulation and the federal energy regulatory commission. Resource for the Future publications.
- [15] Okoye U & Omolola A. (2019). A study and evaluation of power outages on 132kv transmission network in Nigeria for grid security. *The International Journal of Engineering and Science*. Vol 8 No. 11 Pg 53-57. ISSN:23-9-1809.
- [16] Fathima A, Prabakaran N, & Jackson J. (2018). Hybrid-Renewable energy systems in microgrids. Woodhead Publishing Series in Energy. ISBN: 978-0-08-102493-5.
- [17] Kayode O, Agbetuyi A, Owolabi B, Obiakor C, & Fagbuaro O. (2018). Power sector reform in Nigeria: challenges and solutions. *IOP Conference Series*. Pg 413. DOI:10.1088/1757-899X/413/1/012037.
- [18] Federal Energy Regulatory Commission. (2024).
- [19] Nigerian Electricity Supply and Installation Standards Regulations. (2015). NESIS Regulations. Vol. 1.
- [20] Edvard C. (2018). What is distribution substation and its main components?. *Electrical Engineering Portal (EEP)*. Retrieved from <https://electrical-engineering-portal.com>
- [21] Komolafe M & Udofia M. (2020). Review of electrical energy losses in Nigeria. *Nigerian Journal of Technology*. Vol 39 No.1 Pg 246-254.
- [22] Laughton M & Warne D. (2003). Conductor loss. *Electrical Engineer's Reference Book*. 16th Edition.
- [23] Belu, R. G., & Lacy, F. (2020). A multidisciplinary undergraduate course in energy engineering. *ASEE Virtual Annual Conference Content Access*. 10.18260/1-2--34022
- [24] Charles F, Brent B, Kenneth S, Peter L, Alisa W, Sahil G, Yue L, & Jeremy S. (2020). Climate change impacts and costs to U.S. electricity transmission and distribution infrastructure. *Energy (Elsevier Journal)*. Vol. 195.
- [25] Mojisola M & Bello S. (2023). Electric grid reliability: an assessment of the Nigerian power system failures, causes and mitigation. *Covenant Journal of Engineering Technology*. Vol 7 No.1.
- [26] Khoussi S & Mattas A. (2017). A brief introduction to smart grid safety and security. *Handbook of System Safety and Security*. Pg 225-252.
- [27] Muhammad K. (2024). Smart grids and renewable energy systems: perspectives and grid integration challenges. *Energy Strategy Reviews (Elsevier Journal)*. Vol. 51
- [28] Tebepah E & Amadi H. (2024). Electric transmission upgrades in Nigeria: the present status. *International Journal of Engineering Research and Development*. Vol. 20 Issue 4 Pg 128-133.
- [29] Caleb J, Musasa K, & Innocent E. (2020). Transmission systems: HVAC vs HVDC. *International Conference on Industrial Engineering and Operations Management Detroit, Michigan, USA*. August 10-14.
- [30] Felix K & Obiageli L. (2021). Enhancement of transmission efficiency and voltage profile in the Bauchi axis of Nigerian power grid using a VSC-HVDC system. *American Journal of Electrical and Electronic Engineering*. Vol. 9 No. 1 Pg 12-20.
- [31] Chisom O. (2024). Effective engineering management: principles and practices from project planning to execution. *Iconic Research and Engineering Journal*. 7(12).
- [32] Odera O, Chisom O, & Chrysogonus O. (2024). Integrated control systems in modern automobiles. *Iconic Research and Engineering Journal*. Vol. 7 Issue 11 Pg 126-132.
- [33] Belu, R. (2009). A project based power electronics course with an increased content of renewable energy applications. *Annual Conference & Exposition, Austin, Texas*. 10.18260/1-2--4994