TRANSMISSION CONSTRAINTS ON THE NIGERIAN NATIONAL GRID: A COMPREHENSIVE REVIEW OF THE BOTTLE-NECKS AND THE POTENTIAL SOLUTIONS

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ABSTRACT

The Nigerian national grid (NNG) is plagued by significant transmission constraints, resulting in inefficient electricity delivery across the country. Inadequate transmission and distribution facilities are primary contributors to Nigeria's epileptic power situation, affecting the manufacturing, service, and residential sectors, and ultimately hindering economic growth. The paper utilizes review-based methodology to bring to lime light the transmission constraints and the potential solutions in the highly beleaguered NNG. The transmission infrastructure in Nigeria is characterized by inefficiencies, substantial power losses, and unreliable supply. Outdated metering systems exacerbate the problem, while inadequate investment in transmission and distribution systems' infrastructure has worsened the situation. Despite recent power sector reforms, over half of the population remains without access to electricity. To overcome these challenges, Nigeria must adopt a smart grid model incorporating renewable energy sources to enhance efficiency and reliability. Alternative fuel sources, such as regasification, should be explored to address chronic fuel supply issues. Distributed generation systems, including community mini-grids and off-grid systems, can extend electricity access to remote rural communities. Increased investment in transmission infrastructure, combined with these measures, can alleviate transmission constraints on the Nigerian national grid, ultimately improving electricity access and reliability.

Keywords: Smart grid model, Transmission constraints, Distributed generation systems, Energy Storage Integration, Aging infrastructure, insufficient transmission capacity, high transmission losses.

1. INTRODUCTION

The Nigerian National Grid is a complex network of power transmission lines and infrastructure responsible for distributing electricity across the country. It serves as the backbone of Nigeria's power system, connecting power generation plants to distribution networks that ultimately deliver electricity to consumers. However, the grid faces significant challenges, particularly in terms of transmission constraints that hinder its efficiency and reliability as observed by a well-researched works of (Onah *et al.,* 2021); (Onah *et al.*, 2015); and (Adebayo *et al., 2024*).

The Nigeria National Grid has undergone various developments in recent years aimed at reforming and improving the country's power sector (Wale and Yannick, 2020). These developments can be categorized into three phases: Early Development (Pre-2000), Post-2000 Reforms and Privatization, and Recent Developments (2015-Present). In the first instance, the Nigerian national grid was established in the 1960s, with the construction of the first 132 kV transmission lines connecting major cities such as Lagos, Ibadan, and Kaduna. The grid expanded gradually over the following decades, with the addition of 330 kV lines and substations to support growing electricity demand. The early 2000 reforms marked a turning point for the Nigerian power sector, with the introduction of reforms aimed at addressing chronic inefficiencies and underinvestment. The Key milestones include but not limited to the Electric Power Sector Reform Act (2005). This legislation paved the way for the unbundling of the vertically integrated National Electric Power Authority (NEPA) into separate generation, transmission, and distribution entities. The privatization of generation and distribution companies was completed in 2013, while the transmission segment remained under government control through the TCN.

In recent years, efforts have been made to modernize the grid and address transmission constraints. Key initiatives include Transmission Rehabilitation and Expansion Program (TREP): Launched in 2015, TREP aims to upgrade transmission infrastructure, increase grid capacity, and reduce losses.

Partnerships with International Organizations: The TCN has collaborated with organizations such as the World Bank, African Development Bank (AfDB), and Siemens AG to secure funding and technical expertise for grid modernization projects. The Nigerian national grid is a critical but underperforming component of the country's power sector, with significant infrastructure and operational challenges. Aging infrastructure, inadequate investment, and technical inefficiencies are major contributors to the grid's poor performance. Historical reforms and recent initiatives have made some progress, but much more needs to be done to modernize the grid and ensure reliable electricity supply.

Transmission constraints on the Nigerian National Grid are a major obstacle to the country's power sector development. These constraints manifest in various forms, including inadequate and inefficient power plants, poor transmission and distribution facilities, and outdated metering systems. As a result, more than half of Nigeria's population lacks access to electricity, and those who do have access often experience epileptic power supply.

The impact of these transmission constraints is far-reaching, affecting the manufacturing, service, and residential sectors of the economy and, consequently, the country's overall economic growth. Despite recent reforms in the power sector, the situation remains critical, with many Nigerians relying on private generators for their electricity needs. This dependence on generators not only leads to increased noise and pollution but also results in high expenditures on imported fuel.

This work explores the various aspects of these constraints, their impacts, and potential solutions to enhance the grid's performance and reliability.

1.1 Overview of the Nigerian National Grid

The Nigerian national grid is the backbone of the country's electricity transmission network, responsible for evacuating power generated by electricity plants and distributing it to distribution companies (DisCos) across the nation. This section provides a detailed description of the grid's infrastructure, operational characteristics, and historical development, offering a foundation for understanding the transmission constraints discussed in subsequent sections Grid. The Nigerian national grid is a high-voltage transmission network that operates at 132 kV and 330 kV levels. It comprises the following key components. Installed Generation Capacity: As of 2023, Nigeria's installed generation capacity stands at approximately 13,000 MW, but only about 4,000–5,000 MW is typically available due to gas supply constraints, maintenance issues, and transmission bottlenecks. Transmission Capacity: The grid's transmission capacity is estimated at 8,500 MW, but operational constraints often limit this to 5,000–6,000 MW. Load Demand: Peak electricity demand in Nigeria is estimated at 25,000 MW, far exceeding the available supply and transmission capacity. The grid consists of approximately 20,000 km of transmission lines, with a mix of 132 kV and 330 kV lines. These lines connect power generation stations to load centres across the country. There are over 170 substations nationwide, including both 330/132 kV and 132/33 kV substations. These substations step down voltage levels for distribution to end-users. The grid is equipped with power transformers that facilitate voltage conversion and ensure efficient power flow across the network. The Transmission Company of Nigeria (TCN) operates the National Control Centre (NCC) in Osogbo, which serves as the central hub for grid monitoring, dispatch, and control. Regional control centres support the NCC in managing grid operations, (Komolafe & Udofia, 2020). The work of (Ugwoke *et al.*,2020) highlights a lack of consensus on a unified framework for improving energy access in Nigeria. To address the gap, they propose an integrated framework that combines multiple disciplines aiming to develop a comprehensive roadmap for energy planning, design, and operation that incorporates renewable energy to enhance localized energy access in Nigeria

1.2 Operational Characteristics of the Nigerian National Grid

The grid operates at a nominal frequency of 50 Hz. However, frequent deviations from this standard occur due to imbalances between generation and load demand, leading to system instability. Again, voltage fluctuations are common, particularly in areas with weak grid infrastructure. This results in poor power quality and equipment damage. The Nigerian grid is prone to frequent system collapses, with an average of 10–15 major collapses annually as observed by (Onah *et al.,* 2023). These collapses are often triggered by: Overloading of transmission lines, inadequate spinning reserves to balance supply and demand and weak grid infrastructure and lack of redundancy.

The National Control Centre Oshogbo is responsible for monitoring the frequency. The system has a frequency tolerance of $\pm$ 1.25% which implies if the frequency gets to 51.25Hz or 48.75Hz, a system collapse will occur. NCC has obligations to instruct GenCos to either ramp up or ramp down generation to improve the frequency. The Nigerian national grid faces significant transmission constraints that undermine its ability to deliver reliable electricity across the country. These constraints stem from technical, financial, and regulatory factors, creating bottlenecks in the power sector and limiting access to electricity for millions of Nigerians. This section examines these factors in detail, highlighting their root causes and impacts on grid efficiency.

Technical and commercial losses occur due to inefficiencies in the transmission network, including line losses, transformer losses, and poor maintenance. Technical losses are estimated at 8–10% of total power transmitted. Commercial Losses arise from electricity theft, metering inaccuracies, and non-payment by consumers. Commercial losses are estimated at 25–30%, significantly higher than the global average. Technical inefficiencies are among the most critical issues affecting Nigeria's transmission network, (Onah and Ohwo, 2025). These challenges include outdated infrastructure, insufficient capacity, high transmission losses, and inadequate operational tools Much of Nigeria's transmission infrastructure has exceeded its design life span, with components such as transformers and substations operating beyond their efficiency benchmarks. For example, many transformers are overloaded in service areas, leading to frequent breakdowns and reduced reliability. Additionally, the radial nature of the grid limits operational flexibility and increases susceptibility to disturbances. The transmission network is unable to evacuate the full generation capacity of Nigeria’s power plants. While the installed generation capacity ranges between 5,300 MW and 12,522 MW, the transmission system can only reliably transport about 4,000 MW. This mismatch results in load rejections by distribution companies and wasted generation potential. Nigeria’s transmission losses are estimated at 7.4%, significantly higher than global benchmarks of 2–6%2. These losses occur due to long transmission distances, poorly maintained lines, and outdated technologies that fail to deliver stable voltage profiles. The grid lacks modern communication equipment and real-time monitoring systems such as Supervisory Control and Data Acquisition (SCADA). This deficiency hamper’s fault detection and system optimization. Moreover, unfinished transmission projects further exacerbate inefficiencies by leaving parts of the network disconnected or underutilized. The financial constraints facing Nigeria’s transmission sector are rooted in inadequate funding mechanisms, liquidity challenges, and tariff shortfalls. Government funding for transmission projects has been insufficient to meet the growing demand for electricity. For instance, political pressures have often prioritized expanding grid coverage over enhancing system reliability in high-demand areas. This misallocation of resources has left critical infrastructure underfunded. Between 2015–2019, cumulative tariff shortfalls amounted to ₦1,678 billion (~US$6 billion), with ₦524 billion (~US$1.7 billion) recorded in 2019 alone. These shortfalls disrupt the payment chain within the electricity market, reducing liquidity for investments in grid modernization (Tebepah, *et al*., 2024). Despite privatization efforts in generation and distribution sectors, transmission remains under government control through the Transmission Company of Nigeria (TCN). The lack of private-sector involvement limits access to alternative funding sources that could accelerate infrastructure upgrades. Regulatory inefficiencies also contribute significantly to Nigeria's transmission constraints. Issues such as policy enforcement gaps, unclear mandates, and inadequate planning have compounded technical and financial challenges. Regulatory uncertainty has plagued Nigeria’s power sector for decades. While frameworks like the Electric Power Sector Reform Act (2005), aimed to improve governance, inconsistent enforcement has hindered progress4. For example, tariff regulations designed to attract investment have often been poorly implemented. The absence of coordinated resource planning between generation, transmission, and distribution entities leads to mismatches between supply and demand. This results in underutilized sections of the grid while high-demand areas remain underserved. The Electricity Act 2023 introduced provisions for decentralizing Nigeria's electricity market and fostering competition. While promising on paper, its implementation will require significant effort to address long-standing regulatory inefficiencies. The combined effects of technical, financial, and regulatory constraints have far-reaching implications: Frequent power outages disrupt industrial activities and increase operational costs for businesses reliant on alternative energy sources. Limited access to electricity affects quality of life for millions of Nigerians. Over-reliance on diesel generators contributes to greenhouse gas emissions.

Addressing Nigeria's transmission constraints requires a multi-pronged approach that tackles technical inefficiencies, improves funding mechanisms, and strengthens regulatory frameworks. Modernizing infrastructure through smart grid technologies and increasing private-sector participation are essential steps toward achieving a reliable and sustainable electricity supply for Nigeria, (Onah *et al.,* 2023). Again, Nigeria's renewable energy market is expected to grow from 3.44 gigawatts in 2025 to 5.51 gigawatts by 2030. Government support and tech advancements will drive this growth. However, natural gas penetration might slow it down. Solar PV tech improvements will create opportunities. Hydropower, Nigeria's second-largest electricity source, will continue to play a significant role, with several large projects underway (*BloombergNEF*, 2023); (Tebepah *et al*., 2024).

1.3 Impact of Transmission Constraints

The limitations of Nigeria's electricity transmission system have profound economic, social, and environmental consequences. These impacts are far-reaching, affecting industrial productivity, household welfare, public health, and environmental sustainability.

Nigeria's unreliable power supply results in annual economic losses estimated at $26.2 billion (₦10.1 trillion), equivalent to about 2% of the country's GDP (Onah *et al.*, 2023). The inability of the transmission network to evacuate sufficient power disrupts industrial operations, particularly in energy-intensive sectors such as manufacturing, agriculture, and telecommunications. Businesses are forced to rely on costly diesel generators, which increase operational expenses and reduce competitiveness. For instance: Temperature-sensitive industries (e.g., food processing) face frequent spoilage due to power outages. Small and medium-sized enterprises (SMEs), which form the backbone of Nigeria's economy, struggle to scale due to unreliable electricity. Nigeria ranks 171 out of 190 countries in "Getting Electricity" according to the World Bank's Doing Business report (World Bank, 2020; World Bank., 2021). This poor ranking discourages foreign direct investment (FDI), as investors perceive the unreliable power supply as a significant risk to business operations. Transmission constraints lead to load rejections by distribution companies (DISCOs), resulting in stranded generation capacity. This inefficiency disrupts the payment chain across the electricity market, reducing revenues for generation companies (GENCOs) and the Transmission Company of Nigeria (TCN). The financial instability hampers reinvestment in grid modernization. The concerns in Nigeria's electricity transmission system stem from inadequate capacity, a very significant transmission losses, poor protective devices, and out of date technology. To address these challenges, there is urgent need to implement advanced technologies that would sense, communicate, meter and control in order to ensure efficient, and reliable, power supply, (Ajao *et al.*, 2017); (Orovwode *et al*., 2020) (Oruma *et al.*, 2024).

Approximately 85 million Nigerians—43% of the population—lack access to grid electricity, making Nigeria the country with the largest energy access deficit globally. This energy poverty disproportionately affects rural areas where transmission infrastructure is sparse or non-existent. Frequent power outages disrupt daily life for millions of Nigerians: Households face limited access to essential services such as water supply and telecommunications; Students are unable to study effectively at night due to lack of lighting; hospitals and healthcare facilities struggle to operate critical equipment during outages, endangering lives. Urban centres with better transmission infrastructure receive more reliable electricity compared to rural areas, exacerbating regional inequalities. Additionally, wealthier households can afford backup generators, while poorer households remain entirely dependent on the unreliable grid. Studies have shown that inadequate electricity supply contributes to increased crime rates in rural areas by limiting economic opportunities for youth and reducing public safety measures such as street lighting. The reliance on diesel generators as backup power sources contributes significantly to Nigeria's greenhouse gas emissions. Diesel generators emit pollutants such as carbon dioxide (CO2), nitrogen oxides (NOx), and particulate matter, which harm both human health and the environment. In rural areas without reliable grid electricity, households often resort to using firewood or charcoal for cooking and heating. This practice accelerates deforestation and contributes to land degradation. Transmission constraints limit Nigeria's ability to integrate renewable energy sources such as solar and wind into the national grid. This shortfall delays progress toward meeting climate goals and transitioning to a sustainable energy mix. Poorly maintained transmission infrastructure often results in oil spills from transformers or other hazardous waste leaks during equipment failures, further damaging ecosystems, (Sunday, & Mutah, 2024); (Adeshina, *et al.*, 2024); (Onah and Ohwo., 2025)

2. METHODOLOGY

Grid modernization is a global priority as countries strive to meet growing energy demands, integrate renewable energy sources, and enhance grid reliability. This section reviews successful grid modernization initiatives from various countries, highlighting their strategies, technologies, and policies. It also examines the applicability of these best practices to Nigeria's unique challenges (Paul, 2006). Germany has been at the forefront of integrating renewable energy into its grid through its Energiewende (Energy Transition) policy. The country's focus on decentralization and advanced grid automation has enabled it to manage high levels of variable renewable energy (VRE) such as wind and solar. Deployment of smart grid technologies, including advanced metering infrastructure (AMI) and real-time grid monitoring systems. Integration of grid-compatible inverters to maintain voltage stability despite high VRE penetration. Expansion of energy storage systems to balance supply and demand fluctuations. In the work done by (Onah and Jemiriayigbe, 2025), a comprehensive overview of the challenges and potential solutions for Nigeria's national grid, is emphasized. The paper provided multifaceted approach that can address the country's electricity sector woes.

The lessons Nigeria has to learn include but not limited to: Investment in smart grid technologies can enhance Nigeria's ability to integrate renewable energy sources like solar and wind. Decentralized grid models, such as mini-grids, could be particularly effective in rural areas with limited transmission infrastructure. Again, in United States, Grid Resilience Innovative Partnership (GRIP) Program is the order of the day. The United States has launched several programs to modernize its aging transmission and distribution networks. The Grid Resilience Innovative Partnership (GRIP) Program is a notable example (U.S. Department of Energy, 2023).

The Key Initiative are as proposed: A $10.5 billion funding program aimed at upgrading transmission infrastructure to withstand climate risks such as hurricanes and wildfires; Emphasis on digitalization through smart meters, automated grid management, and predictive maintenance technologies; Development of integrated modernization plans with clear performance metrics for utilities. In this case Nigeria can adopt similar funding mechanisms to attract private sector investment in grid resilience projects.

Digitalization, including automated fault detection systems, could significantly reduce the, frequency of grid collapses in Nigeria. China has made unprecedented investments in its electricity grid under its 14th Five-Year Plan (2021–2025). With $442 billion allocated for grid modernization, China aims to expand its transmission capacity while integrating advanced technologies. Their key initiatives include but not limited to: Deployment of ultra-high-voltage (UHV) transmission lines to transport electricity over long distances

efficiently; Integration of renewable energy sources into the national grid through advanced control systems; Use of artificial intelligence (AI) for real-time system optimization (World Bank., 2020).
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The take-home for Nigeria in this regard include but not limited to; UHV transmission lines could address Nigeria's geographical challenges by efficiently connecting remote generation sites to demand centre; Leveraging AI for predictive analytics could improve operational efficiency in Nigeria's transmission network. Malawi provides an example of successfully integrating renewable energy into a developing country's grid. Through partnerships with international organizations, Malawi has enhanced its transmission infrastructure to accommodate utility-scale solar PV projects. Collaboration with development partners such as the Southern Africa Energy Program (SAEP) for technical support and funding; Use of energy storage systems to stabilize the grid during periods of high solar generation. Nigeria has got to borrow a leaf in forming a partnership with international donors and organizations can provide funding and technical expertise for Nigeria's Transmission Rehabilitation and Expansion Program (TREP. Again, energy storage systems can mitigate the intermittency challenges associated with solar power in Nigeria (Nwagu, *et al.*, 2025). The international best practices are to integrated resource planning: which has got to do with coordinating generation, transmission, and distribution investments to optimize system performance. Countries like Germany and the United States have adopted IRP frameworks that align infrastructure development with long-term energy goals.

It is applicable to Nigeria in that an IRP framework could help synchronize Nigeria's generation capacity expansion with transmission network upgrades, reducing stranded capacity issues policy Countries such as India have introduced policies mandating utilities to purchase a certain percentage of their power from renewable sources. These policies are supported by financial incentives for compliance. Similar policies could accelerate the integration of renewable energy into Nigeria's national grid while promoting private sector participation. Digitization and Smart grids equipped with digital technologies enable real-time monitoring, fault detection, and automated responses. For example: The European Union has invested $184 billion in smart meter deployment and digitalization by 2030. Digitizing Nigeria's transmission network would improve operational efficiency, reduce outages, and enhance customer satisfaction.

2.1 Challenges in Adopting Best Practices

While these case studies offer valuable insights, implementing similar initiatives in Nigeria requires addressing several challenges:

(i) Funding Constraints: Modernizing the Nigerian grid will require significant investment—estimated at $100 billion over the next two decades (Avwioroko, 2023).

(ii) Regulatory Barriers: Existing regulatory frameworks must be updated to accommodate modern technologies such as distributed generation and energy storage.

(iii) Capacity Building: Training programs are needed to equip Nigerian engineers and technicians with the skills required for operating advanced grid technologies.

The experiences of Germany, the United States, China, and Malawi demonstrate that targeted investments in infrastructure, digitization, and policy reforms can transform electricity grids into resilient, efficient systems capable of meeting modern energy demands. By adopting these best practices—tailored to its unique context—Nigeria can address its transmission constraints while unlocking economic growth opportunities and improving access to reliable electricity across the country.

2.2 Policy Recommendations and Solutions

To address the transmission constraints identified, Nigeria must adopt a comprehensive and multi-faceted strategy encompassing technical, financial, and regulatory reforms. This section proposes actionable solutions tailored to the challenges facing the Nigerian national grid, supported by international best practices and contextualized for Nigeria's unique energy landscape.

Nigeria's transmission constraints require bold reforms across technical, financial, regulatory, and environmental domains. By adopting these policy recommendations and implementing them systematically, Nigeria can transform its national grid into a reliable, efficient, and sustainable backbone for economic growth and social development.

Key Findings

i. Technical Constraints: Aging infrastructure, insufficient transmission capacity, high transmission losses, and inadequate operational tools are major technical challenges. The grid lacks modern communication equipment and real-time monitoring systems, such as Supervisory Control and Data Acquisition (SCADA) systems.

ii. Financial Constraints: Inadequate funding for transmission projects, tariff shortfalls, and limited private sector participation have exacerbated financial challenges. Cumulative tariff shortfalls have disrupted the payment chain within the electricity market, reducing liquidity for investments in grid modernization.

iii. Regulatory Challenges: Regulatory uncertainty, policy enforcement gaps, and the lack of integrated resource planning have compounded the grid's inefficiencies. The Electricity Act 2023 offers potential for decentralization and competition but requires **eff**ective implementation.

3. CONCLUSION

The Nigerian national grid faces significant transmission constraints that hinder the efficient delivery of electricity across the country. These constraints are rooted in technical inefficiencies, financial limitations, and regulatory challenges. The grid's inability to evacuate generated power reliably has profound economic, social, and environmental impacts, affecting industrial productivity, household welfare, and environmental sustainability. By addressing the challenges identified in the study systematically, Nigeria can transform its national grid into a robust, efficient, and sustainable backbone for economic growth and social development.

4. RECOMMENDATIONS

The following recommendations should be adopted:

i. Quantitative Analysis: Conduct detailed economic and technical analyses to quantify the benefits of proposed solutions.

ii. International Collaborations: Explore partnerships with countries that have successfully modernized their grids to leverage best practices and technologies.

iii. Policy Implementation: Monitor the effectiveness of regulatory reforms and propose adjustments as needed to ensure consistent progress in grid modernization.

iv. Technical Modernization: Invest in smart grid technologies, expand transmission capacity, and integrate renewable energy sources to enhance grid efficiency and reliability.

v. Financial Reforms: Increase funding for transmission projects through public-private partnerships and cost-reflective tariffs. Establish a dedicated transmission development fund to support ongoing infrastructure upgrades.

vi. Regulatory Strengthening: Implement consistent enforcement of existing regulations and adopt integrated resource planning to align generation, transmission, and distribution investments with long-term energy goals.

vii. Environmental Sustainability: Promote renewable energy integration and reduce reliance on fossil fuels to mitigate environmental impacts.

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