ISSN 2278 – 0211 (Online)

Identification of Critical Issues on Nigeria's Power Transmission Grid

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Abstract:
This research is aimed at considering critical issues affecting Nigeria's transmission grid. System data of Nigeria's transmission grid were obtained to create the grid's power flow simulator (PFS), using power system analysis software (PSA) and Aeronautical Reconnaissance Coverage Geographic Information System (ArcGIS) for spatial distribution and dimensioning of relevant grid elements. The PSA deploys the Newton Raphson (N-R) computation method to test for steady-state failure (SSF), available transfer capacity (ATC), voltage stability, and loading. From initial power flow computations, the critical region was mapped by an imperfect ring network, inadequate redundancy and critical portions of the voltage profile. Predominantly, these are applicable in the Northern region and approximately 70% of the nodes experience voltage violations. The buses are: Yola, Gombe, Kano, Maiduguri, Damaturu, Kaduna, and Jos. In order to improve the reliability, redundancy, ring network, and quality of power supply within the critical zone and, in general, improve Nigeria's overall network, there is an urgent need to reinforce it.

Keywords: *Transmission network, transmission grid, bus, voltage profile, transmission*

1. Introduction

Electricity supply involves three stages: generation, transmission and distribution [1]. The problems associated with the supply of electricity to consumers in developing countries like Nigeria are multidimensional [2, 3, 4]. Many practical power transmission network**s** in under-developed countries are composed of sparse generating stations commonly cited in isolated locations close to the raw fuel bases, which are commonly connected to the transmission grid using long transmission lines [5]. Nigeria's Power transmission grid network is characterized by major problems (sometimes referred to as technical issues) like voltage violation (voltage instability), long transmission lines, kind of transmission lines and pronounced power losses, which have a greater impact on power distribution, transmission and generation systems [6, 7]. The problems have caused the unavailability and unreliability nature of Nigeria's power supply. These have, in recent times, gotten worse at a disturbing rate [8, 9]. The unavailability prevents access to electricity, which is a major factor affecting economic growth, especially in developing countries like Nigeria [10, 11]. Also, the Nigeria 330 kV transmission network is affected by a series of challenges due to its long radial nature, weak transmission network and overloaded lines [12, 13]. Transforming more existing nodes to power voltage (PV) nodes has been proposed using flexible alternating current transmission system (FACTS) devices, such as static VAR compensators (SVCs). This may become insufficient after a load growth threshold and economically unjustified. Therefore, there is a need to expand the transmission system to convey an enormous amount of generated power from the generating station to the end users to boost the country's economic growth [14, 15, 16, and 17]. Also, to significantly reduce the amount of power losses, both transmission and distribution networks should be upgraded and monitored [18]. In order to achieve these, there is a need to identify and establish the cause and level of problems of the transmission network.

2. Methodology

2.1. Identification of Critical Zone(s) within the Nigerian Power Grid

In identifying a critical region of Nigeria's Transmission Network (NTN) comprising 53 buses, 63 transmission lines (2x350mm^2 per circuit), and 15 power stations, data were obtained from the Transmission Company and were used to model Nigeria's 330 kV NTN. The TN was simulated in NEPLAN software, as shown in figure 1. In order to identify steady state voltage violation clustering, load flow computation was performed on the NTN simulator using N-R and the Voltage Stability Algorithm (VSA) using the continuous load flow method. The VSA, as derived using the two-bus network, is presented in Equations 1 and 2.

$$E_r = E_s \frac{\cos(\emptyset_r + \theta)}{\cos \emptyset_r} \quad (1)$$

$$P_r = P_{rmax} = \frac{1}{2}\frac{E_s^2}{X}\left(\frac{\cos(\emptyset_r + 2\theta)}{\cos \emptyset_r} - \tan \emptyset_r\right) \quad (2)$$

Where $\tan \emptyset_r$ is Q_r/P_r, E_r and E_s are the receiving-end and sending-end voltages, respectively, P is the active power of the receiving-end, Q_r is the reactive power of the receiving-end, θ is the angular difference between the receiving-end and sending-end bus voltages, and X is the transmission line reactance.

2.2. Load Flow Computation

The load flow computation was performed using the modelled network simulator. The simulator computes load flow using the N-R algorithm, which is computed from basic Equations 3 to 4 and discussed in [19, 20].

$$I_{bus} = Y_{bus} V_{bus} \quad (3)$$

Where I_{bus} is the current of the bus, Y_{bus} is the bus admittance, and V_{bus} is the bus voltage.

Therefore, the current at every bus is as depicted by Equation 4.

$$I = YV \;\Rightarrow\; I_i = \sum_{j=1}^{n} Y_{ij} V_j \quad (4)$$

Where Y is the admittance matrix of the bus, V is the bus voltages vector, Y_{ij} is the bus admittance matrix elements, V_j is the bus voltages, and I_l is the currents at every bus.

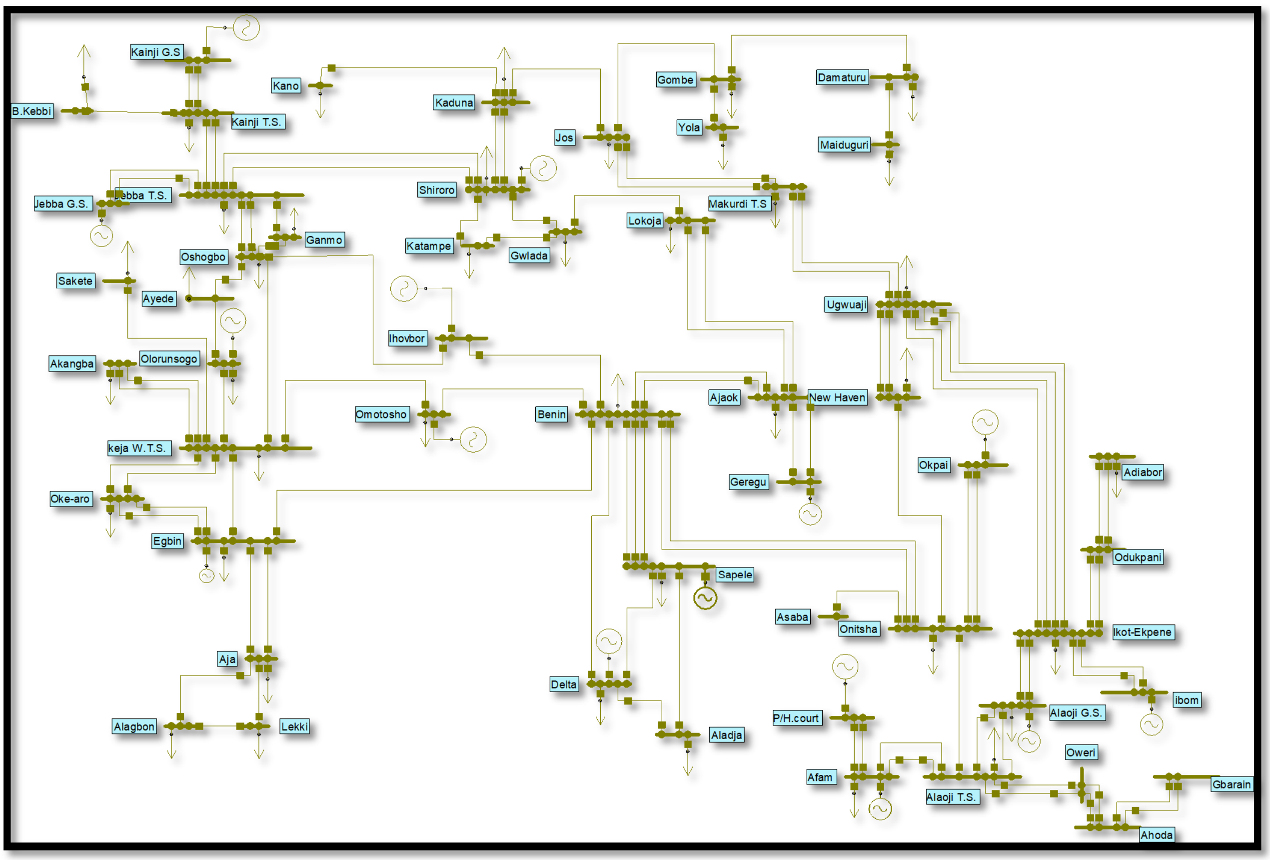

Figure 1: Created Network Model of Nigerian Power Transmission Grid in NEPLAN Software Indicating the Bus Names

Jacobean matrix gives the relationship between changes in the angle of the voltage, $\Delta\partial_i^{(k)}$, and magnitude of the voltage, $\Delta|V_i^{(k)}|$, with the small changes in real and reactive powers, $\Delta|P_i^{(k)}|$ and $\Delta|Q_i^{(k)}|$ represented by Equation 5.

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta|V| \end{bmatrix} \quad (5)$$

Where J_1, J_2, J_3, *and* J_4 are the Jacobian matrices, ΔP, ΔQ, $\Delta\boldsymbol{\delta}$, $\Delta\delta$ and $\Delta|V|$ are changes in real power (in Watts), reactive power (in Var), voltage angle (in Degrees) and Voltage magnitude (in Volts) respectively.

To perform the load flow line, parameters such as resistance, reactance, susceptance, capacitance, maximum current capacity, busloads, and generators were defined in the simulator using the obtained data.

3. Results

3.1. Identification of Critical Region(s) within the Nigerian Power Grid

In the identification of the critical region(s) within the Nigerian power transmission grid, the voltage profile and the steady state load flow of the base network are presented as follows:

3.2. Obtained Voltage Profile of the Buses on Steady State Load Flow Simulation of Nigerian Transmission Grid

The load flow results of the existing Nigerian 330 kV network as modelled and simulated in NEPLAN software are presented in figures 2 to 5. The obtained voltage profile, as presented in figure 2, shows that normal Steady State Load Flow is affected by a high violation of voltage clustered in the North-Eastern region having high line reactive power generation; Yola, Gombe, Kano, Maiduguri, Damaturu, Kaduna, and Jos.

The plots of Bus Voltage Angles, Percentage Line Loadings and Power Losses of the TG base Network are presented in figures 3 to 5. The Percentage Line Loading results of figure 4 show that the lines with more than 50% loadings are: Afam-Alaoji (101.43%), Alaoji-Onitsha (98.64%), Benin-Onitsha (87.93%), Alaoji G. S.-Ikot-Ekpene (86.45%), Delta-Sapele (82.11%), Benin-Sapele (80.15%), Ikeja West-Olorunsogo (75.18%) and Benin-Ihovbor (67.36%).

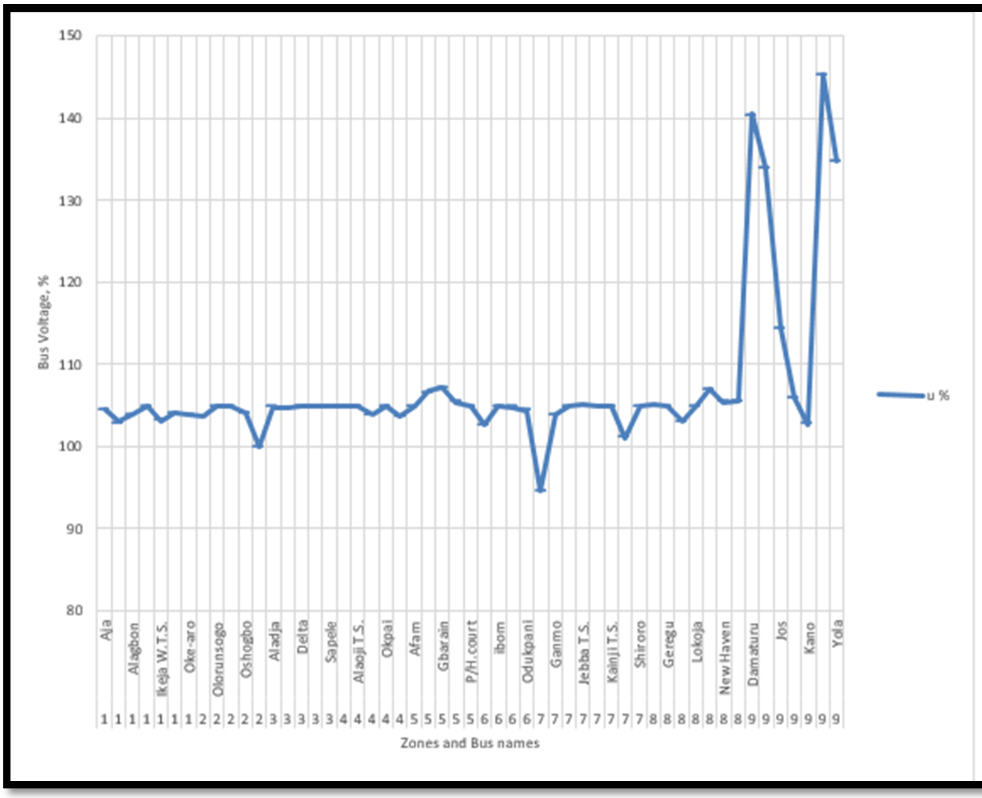

Figure 2: Obtained Voltage Profile on Initial 53-Bus Nigeria's Transmission Grid

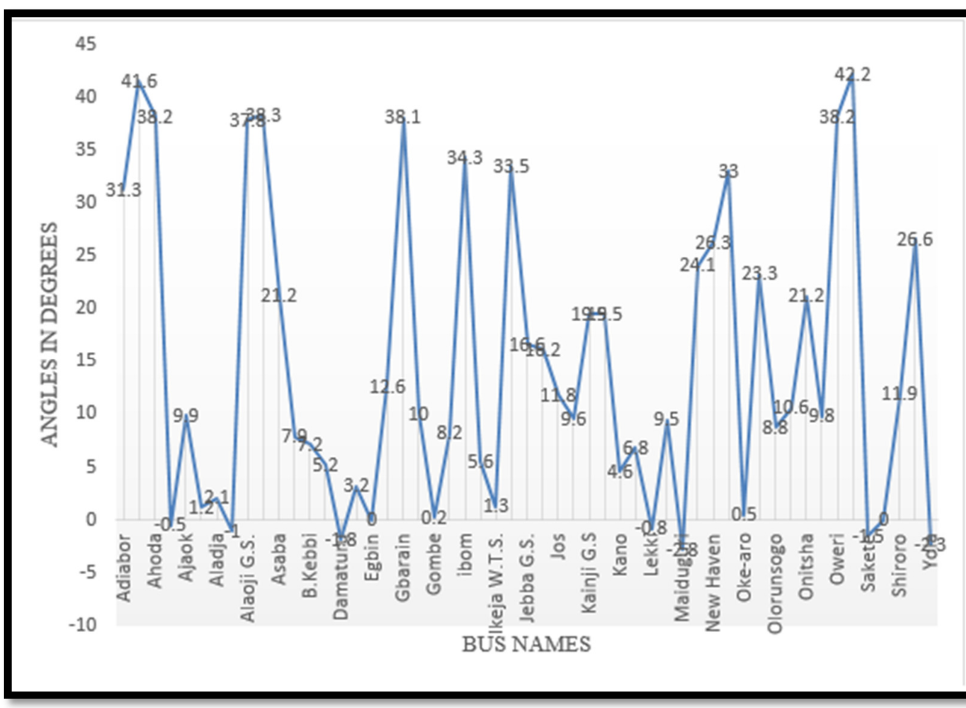

Figure 3: Plot of Bus Voltage Angles on Initial 53-Bus Nigeria's Transmission Grid

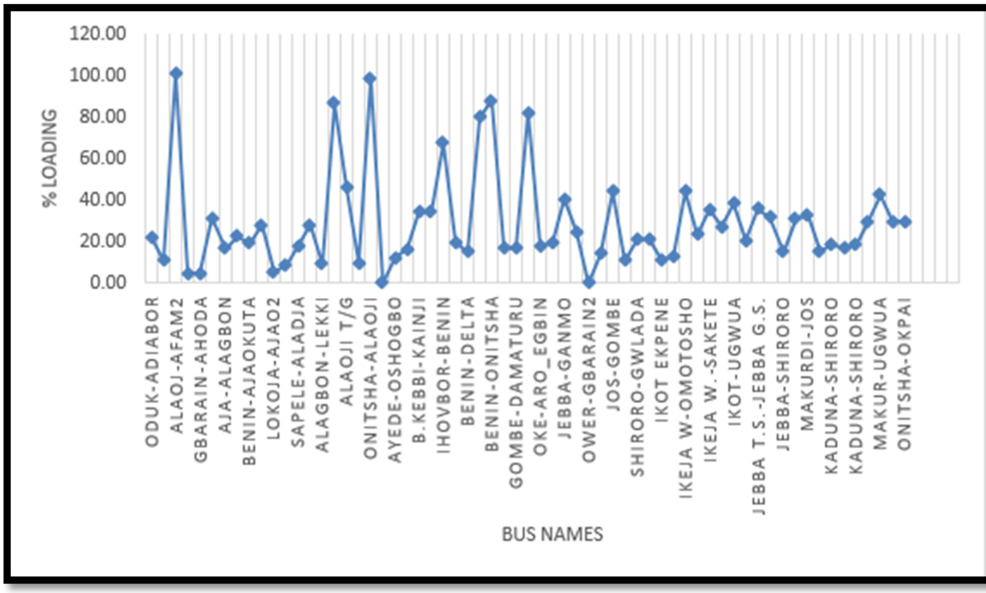

Figure 0: Percentage of Line Loadings on Initial 53-Bus Nigeria's Transmission Grid

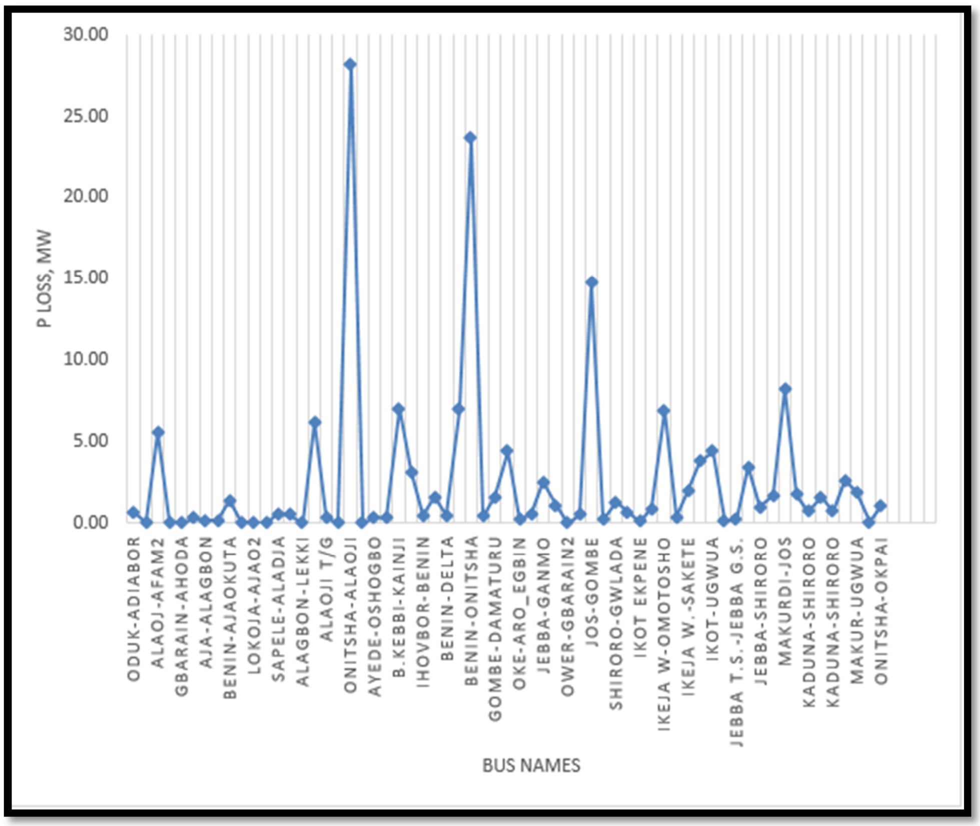

Figure 5: Power Losses on Initial 53-Bus Nigeria's Transmission Grid

4. Conclusion

The study identified a critical zone comprising the following buses: Damaturu (NE), Kano (NW), Kaduna (NW), Gombe (NE), Jos (NC), Maiduguri (NE) and Yola (NE) in the Nigerian power transmission grid. Five of these buses showed critical voltage violations from the initial load flow analysis, with the lowest value of about 14%. The buses are: Maiduguri Damaturu, Yola, Gombe, and Jos. Also, the critical zone significantly contributes to voltage profile violation (voltage instability), resulting in steady state failure (SSF) of the entire network. The analysis of results indicated that the existing network does not meet the necessary requirements for security under growing loads.

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