



e-ISSN: 2319-8753 | p-ISSN: 2347-6710

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International Journal of Innovative Research in
SCIENCE | ENGINEERING | TECHNOLOGY



INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

Volume 10, Issue 9, September 2021

ISSN INTERNATIONAL
STANDARD
SERIAL
NUMBER
INDIA

Impact Factor: 7.569



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Load Flow Analysis Using Static Load Model

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ABSTRACT: Static load model was used to model the Nigerian 330kV transmission network in Electrical Transient Analyzer Program (ETAP) 12.6 software as a test case for the load flow analysis. The load flow analysis having full dependency on a total power generation of 4000MW from 11 generators and a total power consumption of 3014.08MW from 19 load buses showed that a total load demand of 3014.474MW was recorded as against 3014.08MW that was on the bus before simulation. The analysis showed that the operating voltage was good enough for all the buses as no single bus was below 280.5kV (minimum voltage limit) or above 346.5kV (maximum voltage limit) which obviously depicts that the load flow on the network was adequate and resistance free from every standard.

KEY WORDS: Load flow, Static load model, Transmission network, Bus load, Power generation.

I. INTRODUCTION

In interconnected power systems, which today are very complex, there is a great need to improve utilization, while still maintaining reliability and security. While some transmission lines are charged up to the limit load, others may be overloaded, which influences the values of voltage and reduces system stability and security. For this reason, it is very important to control the power flows along transmission lines to meet transfer of power needs. High voltage transmission lines are the most effective way of getting the power from the generating station to the load and to interconnected power system.

Power quality problems have always been a serious challenge in power transmission and distribution networks. Nowadays with the unplanned expansion of the networks and installation of different kinds of loads, power distribution and transmission system face serious power quality issues [1]. These power quality issues include harmonics, excessive reactive power burden, load unbalancing, voltage instability etc [1]. The FACTS device is meant to enhance controllability as well as increase power transfer capability of the network [2].

Voltage stability plays a major role in keeping the system operational. Because of its importance an impressive amount of work has been devoted to it in view of recent blackouts that have been attributed to it. Voltage stability is mainly concerned with maintaining acceptable voltage profile under all operating conditions [3]. Major information obtained from load flow analysis include magnitudes and phase angles of load bus voltages, reactive powers and voltage phase angles at generator buses, real and reactive power flows on transmission lines alongside power at the reference bus [4].

II. RELATED WORKS

The Nigerian electricity grid presently consists of eleven active generating stations which include three hydro and eight thermal plants with a total installed generating capacity of 6500MW and nineteen buses (load). The 330kV transmission network is about 5000km [5]. The hydro plants are Kainji, Jebba and Shiroro while the others are thermal. At the present, most of the generation units have broken down because of limited available resources for the required level of maintenance [5].

Voltage instability is the cause of system voltage collapse, which makes the system voltage decay to a level from which they are unable to recover. The consequence of voltage collapse may lead to a partial or full power interruption in the system. The only way to save the system from voltage collapse is to reduce the reactive power load or add additional reactive power prior to reaching the point of voltage collapse. The recent development and use of FACTS controllers in power transmission system have led to many applications of these controllers not only to improve the voltage stability of the existing power network resources but also to provide operating flexibility to the power system [3].

In power system, voltage instability is one of the major problems increasing on daily basis. Voltage instability problems arise mainly due to the increase in demand of load and inability of the power system to fulfill that demand of

reactive power. To address these problems technical advancements have been made and are still in progress. These advancements are made in Power Electronics, their high performance and rapid response is of great importance which enables high end power and voltage stability and other essential benefits [1].

Transmission lines consist of tower footings, tower, insulators, and the line conductors. Overhead transmission lines are suspended from insulators, which are themselves supported by towers or poles. The span between two towers is dependent upon the allowable sag in the line. For steel towers with very high voltage lines, the span is normally 370m – 460m [6]. However, the network has been known to have significant deficiencies in voltage level and power flow along the transmission lines [7]. Nigerian power transmission system requires continuous up-grading and expansion to cater for the need of ever-growing power demand [8]. Improvement of voltage control and reactive power support are difficult task because they are strongly influenced by random load fluctuations. Static load can be used to provide and justify efficient power flow analysis because it can be regarded as average bus load and very importantly, very efficient to conduct load flow study to find the magnitude of voltage, phase angle, real power and reactive power of the system [9].

III. MATERIALS AND METHOD

For the purpose of carrying out an efficient load flow analysis using static load model, the Nigerian 330kV transmission network was used as a test case. Useful data were collected from the National Control Centre (NCC) comprising of transmission route lengths, impedance, transmission lines power rating, generators active power, bus data, power factor, transformers rating, base load, etc. ETAP 12.6 software was a veritable engineering tool used for the modelling of the network. The method and procedure adopted in this research are described accordingly.

Table 1 Data Considerations Made in Software

| S/N | Parameter/System | Unit/Dimension |
|-----|--------------------------------------|--------------------------------|
| 1 | 330kV transmission line route length | 4577km |
| 2 | Susceptance of transformer | 1.428×10^{-7} Siemens |
| 3 | Susceptance of reactor | 1×10^{-7} Siemens |
| 4 | Reference voltage | 100% |
| 5 | Power Generation | 4000MW |
| 6 | Maximum load demand | 3014.08MW |
| 7 | Estimated network reactive power | 991.5MVAR |
| 8 | Firing angle range | $90^\circ - 180^\circ$ |
| 9 | Susceptance of capacitor bank | 1×10^{-7} Siemens |
| 10 | Installed generating capacity | 6500MW |
| 11 | Conductor type | ACSR |
| 12 | Conductor size | 350mm ² |
| 13 | Number of committed generators | 11 |
| 14 | System type | 3-phase AC |
| 15 | Impedance/phase + | 0.04856k Ω |
| 16 | Impedance/phase - | 0.04856k Ω |
| 17 | Impedance/phase 0 | 0.17908k Ω |
| 18 | System frequency | 50HZ |
| 19 | Base MVA | 100MVA |
| 20 | System voltage | 330kV |
| 21 | Conductor resistivity at 20°C | 2.83×10^{-8} |
| 22 | Total MVA | 4170MVA |
| 23 | Voltage Limit: Maximum | 346.5kV (+ 5%) |
| 24 | Voltage Limit: Minimum | 280.5kV (-15%) |



Table 2 Buses in the Nigerian 330kV Transmission Network

| Bus Number | Bus Name |
|------------|---------------|
| 1 | Kainji |
| 2 | Birnin-Kebbi |
| 3 | Jebba TS |
| 4 | Jebba GS |
| 5 | Osogbo |
| 6 | Ayede |
| 7 | Olorunsogo |
| 8 | Ikeja-West |
| 9 | Akamgba |
| 10 | Egbin (Slack) |
| 11 | Aja |
| 12 | Omotosho |
| 13 | Benin |
| 14 | Ajaokuta |
| 15 | Geregu |
| 16 | Sapele |
| 17 | Delta |
| 18 | Aladja |
| 19 | Onitsha |
| 20 | Okpai |
| 21 | New-Haven |
| 22 | Alaoji |
| 23 | Afam |
| 24 | Shiroro |
| 25 | Katampe |
| 26 | Kaduna |
| 27 | Kano |
| 28 | Jos |
| 29 | Gombe |
| 30 | Yola |

Table 3 Interconnection of Buses in the Nigerian 330kV Transmission Network

| S/N | Bus Name | | Length (KM) |
|-----|------------|--------------|-------------|
| | From | To | |
| 1 | Kainji | Birnin-Kebbi | 310 |
| 2 | Kainji | Jebba TS | 81 |
| 3 | Jebba TS | Jebba GS | 8 |
| 4 | Jebba TS | Osogbo | 157 |
| 5 | Osogbo | Ayede | 119 |
| 6 | Ayede | Olorunsogo | 60 |
| 7 | Olorunsogo | Ikeja-West | 30 |
| 8 | Ayede | Ikeja-West | 137 |
| 9 | Osogbo | Ikeja-West | 235 |
| 10 | Ikeja-West | Akamgba | 18 |
| 11 | Ikeja-West | Egbin | 62 |
| 12 | Egbin | Aja | 14 |
| 13 | Egbin | Benin | 218 |
| 14 | Ikeja-West | Benin | 280 |
| 15 | Ikeja-West | Omotosho | 160 |
| 16 | Osogbo | Benin | 251 |
| 17 | Omotosho | Benin | 120 |
| 18 | Benin | Ajaokuta | 195 |
| 19 | Ajaokuta | Geregu | 5 |
| 20 | Benin | Sapele | 50 |
| 21 | Benin | Onitsha | 137 |
| 22 | Sapele | Aladja | 63 |
| 23 | Benin | Delta | 107 |
| 24 | Delta | Aladja | 30 |
| 25 | Onitsha | Okpai | 56 |
| 26 | Onitsha | New-Haven | 96 |
| 27 | Onitsha | Aladja | 138 |
| 28 | Alaoji | Afam | 25 |
| 29 | Jebba TS | Shiroro | 244 |
| 30 | Shiroro | Katampe | 144 |
| 31 | Shiroro | Kaduna | 95 |
| 32 | Kaduna | Kano | 230 |
| 33 | Kaduna | Jos | 197 |
| 34 | Jos | Gombe | 265 |
| 35 | Gombe | Yola | 240 |

From tables 2 and 3, the Nigerian 30 bus 330kV transmission network is as represented in fig.1

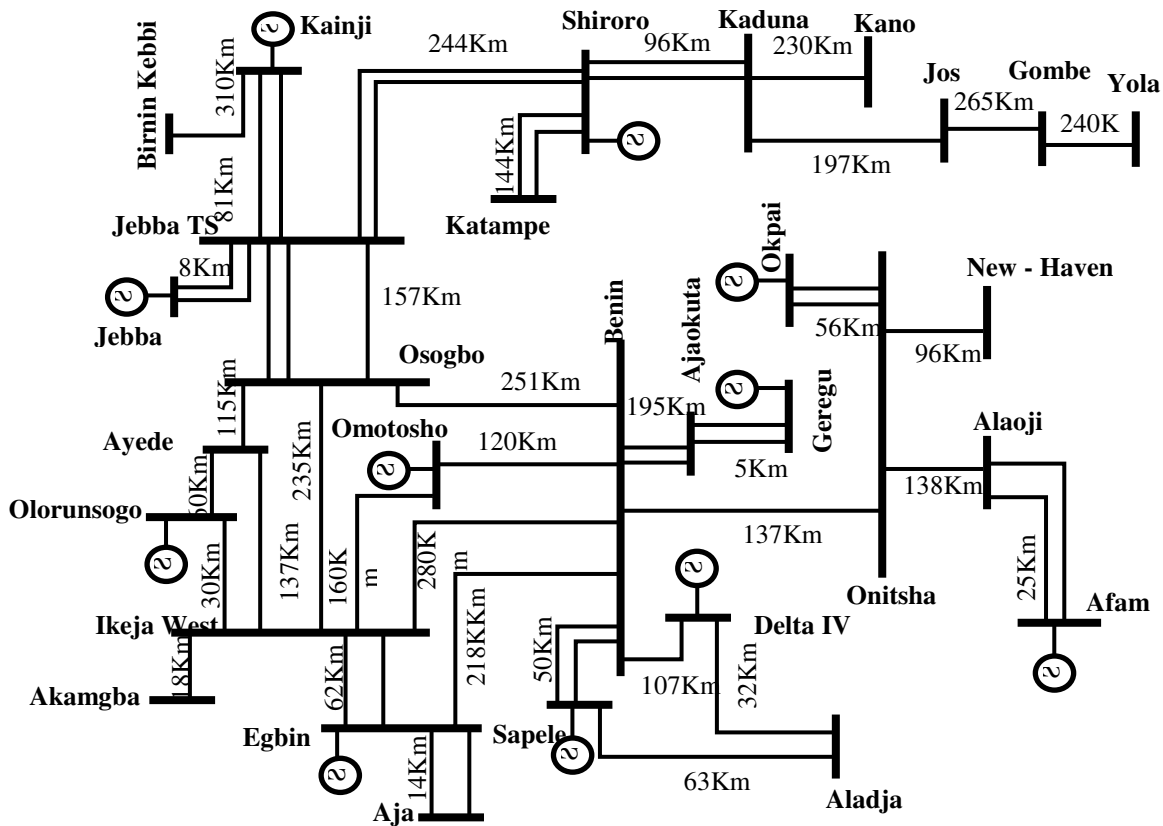


Fig. 1 One Line Diagram of the Nigerian 30 Bus 330kV Transmission Network

In a polynomial configuration

$$P = P_0(a_0 + a_1V + a_2V^2)$$

$$Q = Q_0(b_0 + b_1V + b_2V^2)$$

Where

V is the p.u value of the bus voltage.

P_0 and Q_0 are the real power and reactive power consumed at the specific bus under the reference voltage.

For all the loads, equations (1) and (2) are modelled as:

$$a_0 + a_1 + a_2 = 1 \quad (1)$$

$$b_0 + b_1 + b_2 = 1 \quad (2)$$

a_0 and b_0 are the parameters for constant power load component where

$$a_0 = b_0 = 1$$

and

$$a_i = b_i = 0 \text{ for } i = 1, 2, 3.$$

a_1 and b_1 are the parameters for constant current (1) load component where

$$a_1 = b_1 = 1$$

and

$$a_i = b_i = 0 \text{ for } i = 0, 2, 3.$$

a_2 and b_2 are the parameters for constant impedance load component where

$$a_2 = b_2 = 1$$

and

$$a_i = b_i = 0 \text{ for } i = 0, 1, 3.$$

For the purpose of this, the network is modelled using static load model such that:

$$P = P_0 \left(\frac{V}{V_0} \right)^{np} \quad (3)$$

and

$$Q = Q_0 \left(\frac{V}{V_0} \right)^{nq} \quad (4)$$

Where

n_p and n_q are the parameters while P_0 and Q_0 are active and reactive powers at unity voltage conditions.

Following that

$$P = P_0 \left(\frac{V}{V_0} \right)^{n_p}$$

Where

$n_p = 1$

and

$V = V_0$ at unity pf

If $V = 330\text{kV}$ then P in each of the 19 load buses becomes:

Birnin Kebbi = 182MW, Jebba = 15.5MW, Osogbo = 174MW, Ayede = 274MW, Ikeja-West = 375.08MW, Akangba = 312MW, Aja = 80MW, Benin = 74MW, Ajaokuta = 51MW, Aladja = 56MW, Onitsha = 139MW, New-Haven = 121MW, Alaoji = 220MW, Katampe = 234.5MW, Kaduna = 212MW, Kano = 231MW, Jos = 81MW, Gombe = 112MW and Yola = 70MW

Having gotten a total power generation of 4000MW from 11 generators, a total load of 3014.08MW from 19 load buses and from the static loads so far realized coupled with the network parameters, the network components are connected and load flow analysis was performed accordingly in ETAP 12.6 software.

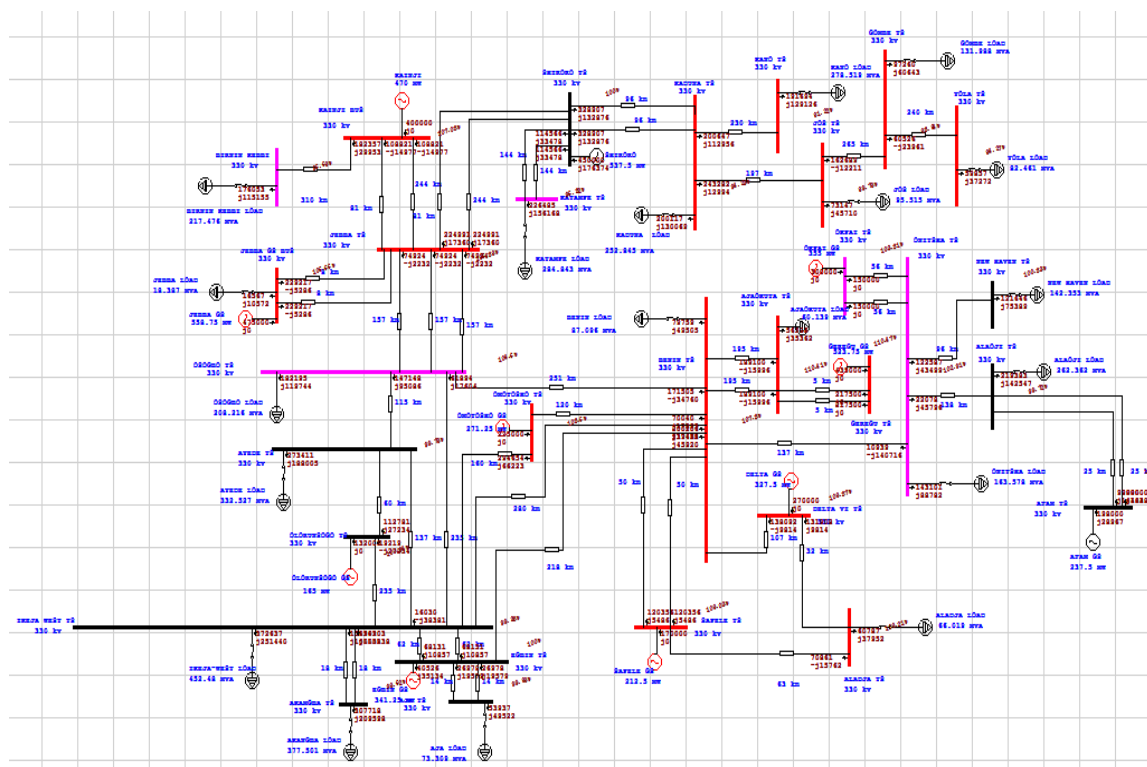


Fig.2 Nigerian 30 Bus 330kV Transmission Network Modelled in ETAP 12.6 Software

IV. RESULTS AND DISCUSSION

The results obtained from the load flow analysis using static load model on the Nigerian 330kV transmission network are as indicated in table 4 and fig.3 respectively.

Table 4 Bus Load

| S/N | Bus Name | Initial Load (MW) | Load After Simulation (MW) |
|-----|--------------|-------------------|----------------------------|
| 1 | Birnin Kebbi | 182 | 181.96 |
| 2 | Jebba | 15.5 | 15.51 |
| 3 | Osogbo | 174 | 173.97 |
| 4 | Ayede | 274 | 274.01 |
| 5 | Ikeja-West | 375.08 | 375.11 |
| 6 | Akangb | 312 | 312.01 |
| 7 | Aja | 80 | 80.01 |
| 8 | Benin | 74 | 74.22 |
| 9 | Ajaokuta | 51 | 51.031 |
| 10 | Aladja | 56 | 56.021 |
| 11 | Onitsha | 139 | 138.98 |
| 12 | New-Haven | 121 | 121.01 |
| 13 | Alaoji | 220 | 220.01 |
| 14 | Katampe | 234.5 | 234.4 |
| 15 | Kaduna | 212 | 212.021 |
| 16 | Kano | 231 | 231.011 |
| 17 | Jos | 81 | 81.12 |
| 18 | Gombe | 112 | 112.03 |
| 19 | Yola | 70 | 70.04 |

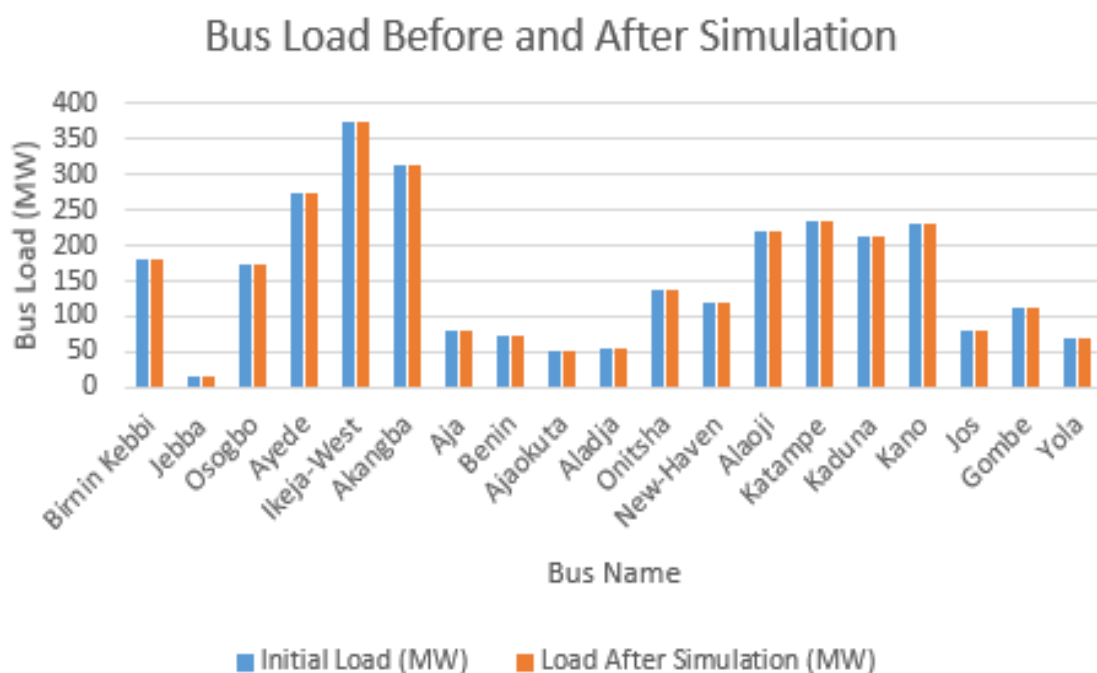


Fig. 3 Bus Load Before and After Simulation

Table 5 Bus Voltage Magnitude

| S/N | Bus Name | Initial Load (MW) | Voltage Magnitude (%) |
|-----|--------------|-------------------|-----------------------|
| 1 | Birnin Kebbi | 182 | 90.121 |
| 2 | Jebba | 15.5 | 99.982 |
| 3 | Osogbo | 174 | 91.963 |
| 4 | Ayede | 274 | 99.982 |
| 5 | Ikeja-West | 375.08 | 99.991 |
| 6 | Akangb | 312 | 99.982 |
| 7 | Aja | 80 | 99.982 |
| 8 | Benin | 74 | 102.13 |
| 9 | Ajaokuta | 51 | 101.011 |
| 10 | Aladja | 56 | 101.002 |
| 11 | Onitsha | 139 | 91.971 |
| 12 | New-Haven | 121 | 99.982 |
| 13 | Alaoji | 220 | 99.982 |
| 14 | Katampe | 234.5 | 91.933 |
| 15 | Kaduna | 212 | 101.002 |
| 16 | Kano | 231 | 101.002 |
| 17 | Jos | 81 | 102.021 |
| 18 | Gombe | 112 | 101.011 |
| 19 | Yola | 70 | 101.011 |

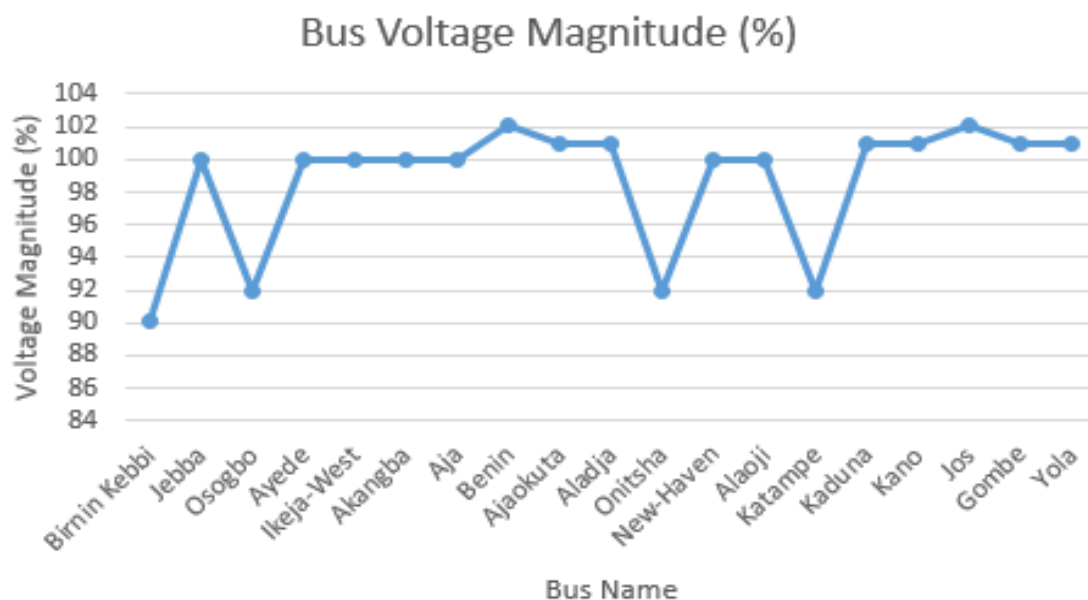


Fig. 4 Bus Voltage Magnitude

Table 6 Bus Operating Voltage

| S/N | Bus Name | Initial Load (MW) | Operating Voltage (KV) |
|-----|--------------|-------------------|------------------------|
| 1 | Birnin Kebbi | 182 | 297.400 |
| 2 | Jebba | 15.5 | 329.941 |
| 3 | Osogbo | 174 | 303.478 |
| 4 | Ayede | 274 | 329.941 |
| 5 | Ikeja-West | 375.08 | 329.970 |
| 6 | Akangb | 312 | 329.941 |
| 7 | Aja | 80 | 329.941 |
| 8 | Benin | 74 | 337.029 |
| 9 | Ajaokuta | 51 | 333.336 |
| 10 | Aladja | 56 | 333.307 |
| 11 | Onitsha | 139 | 303.504 |
| 12 | New-Haven | 121 | 329.941 |
| 13 | Alaoji | 220 | 329.941 |
| 14 | Katampe | 234.5 | 303.379 |
| 15 | Kaduna | 212 | 333.307 |
| 16 | Kano | 231 | 333.307 |
| 17 | Jos | 81 | 336.669 |
| 18 | Gombe | 112 | 333.336 |
| 19 | Yola | 70 | 333.336 |

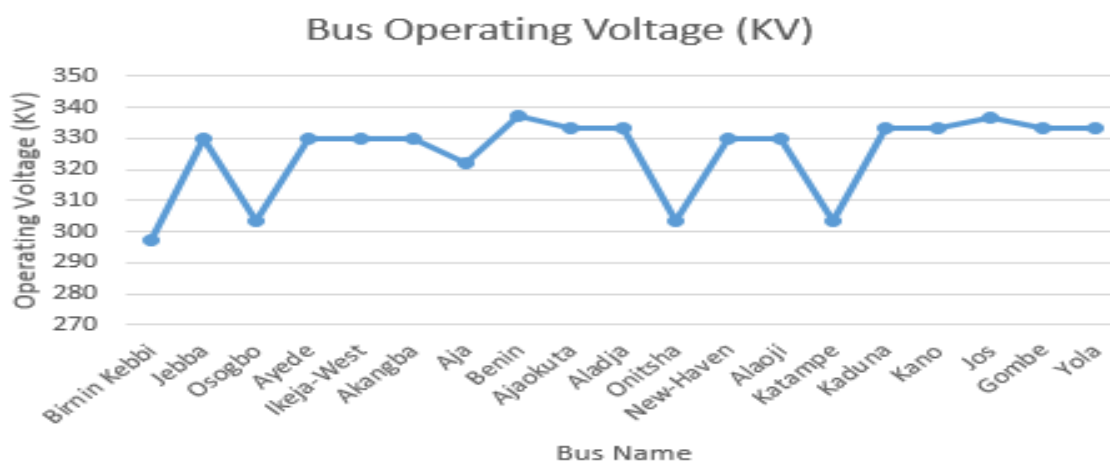


Fig. 5 Bus Operating Voltage

V. CONCLUSION

The Nigerian 330kV transmission network was used as a test case for the analysis. The load flow analysis using Static Load Model carried out on the Nigerian 330kV transmission network with a total power generation of 4000MW from 11 generators and a total power consumption of 3014.08MW from 19 load buses showed a power flow indicating convergence of the appropriate order.

The analysis showed that a total load demand of 3014.474MW was recorded as against 3014.08MW that was on the bus before simulation. The operating voltage was also good enough for all the buses as no one bus was below 280.5kV (minimum voltage limit) or above 346.5kV (maximum voltage limit). This result indicates that the load flow on the network was adequate and resistance free from every standard.



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