Power Flow and Contingency Assessment of the Existing 330kV Nigeria Power Grid to Cope With The Proposed Increase In Power Generation in 2014

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ABSTRACT

The power flow and contingency assessment of the existing 330kV Nigeria power grid was carried out using Newton-Raphson method in Matlab program with a view of ascertaining its capability to cope with the anticipated increase in generation to and above 10,000 MW come 2014. The simulation results of the 330kV grid indicate its reliability at a maximum allowable generation capacity of 5,522 MW without intolerable voltage and thermal violations. Violation limits employed are ±5% of base voltage 330kV (0.95 – 1.05) p.u. and 760MVA for thermal limits. The results also revealed the critical nature and importance of some buses like Ikeja-West, Shiroro, Oshogbo, Benin and their corresponding lines to the performance of the existing national 330kV power grid.

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1. INTRODUCTION

The transmission system of electric utilities in Nigeria today is interconnected into a large power grid. The national grid is designed to transfer electric energy generated from generating stations at various locations in the country to the distribution network which supplies the load as in fig. 1.

The federal government of Nigeria in her honest commitment to power reform in the country, on Tuesday 6th, December 2011 issued twenty (20) independent power producers with project licenses [1] with the aim of boosting electricity generation in the country. The 20 power producers are expected to add 6,258 mega watts of electricity to the existing national grid in a scheduled period of 36 months.
This honest effort is to justify the need of a National grid to provide efficient, adequate, secured, and reliable electrical power to the Nigerian populace. It is evidently clear that the transmission Network in Nigeria is characterized by frequent outages leading to disruption in activities and mode of living of Nigerians. The abysmal performance of the Nigeria transmission grid has led to some unwarranted questions by citizens on the relevance of grid transmission. The present available energy generated is not enough to meet the power demand of its populace leading to constant load shedding, frequent blackout and unacceptable outages.

The Nigerian National Grid is run and controlled by Power Holding Company of Nigeria Plc (PHCN), formerly known as National Electric Power Authority (NEPA). The (PHCN) is about being wound up by the Federal Government in the government's bid to actualize the 2005 power sector reform bill [2]. The Nigerian National Grid system has a total installed capacity of 5,482MW with maximum generating capacity of 5,317MW. The power stations are made up of seventy-nine generating sets out of which not up to30% are operative. The national grid is made up of interconnected network of 5650km of 330kV and 6687km of 132kV transmission lines, 60 number of 330kV circuits and 153 circuits of 132kV, 28 number of 330kV substations and 119 number of 132kV substations [3].

The control of the grid is effected by three regional control centers (RCC) in Lagos Ikeja West (RCC 1), Benin (RCC 2), and Shiroro (RCC 3) respectively. The operations in these regional control centers are co-coordinated, directed and supervised by the National Control center at Oshogbo and supplementary control center at Shiroro [3].

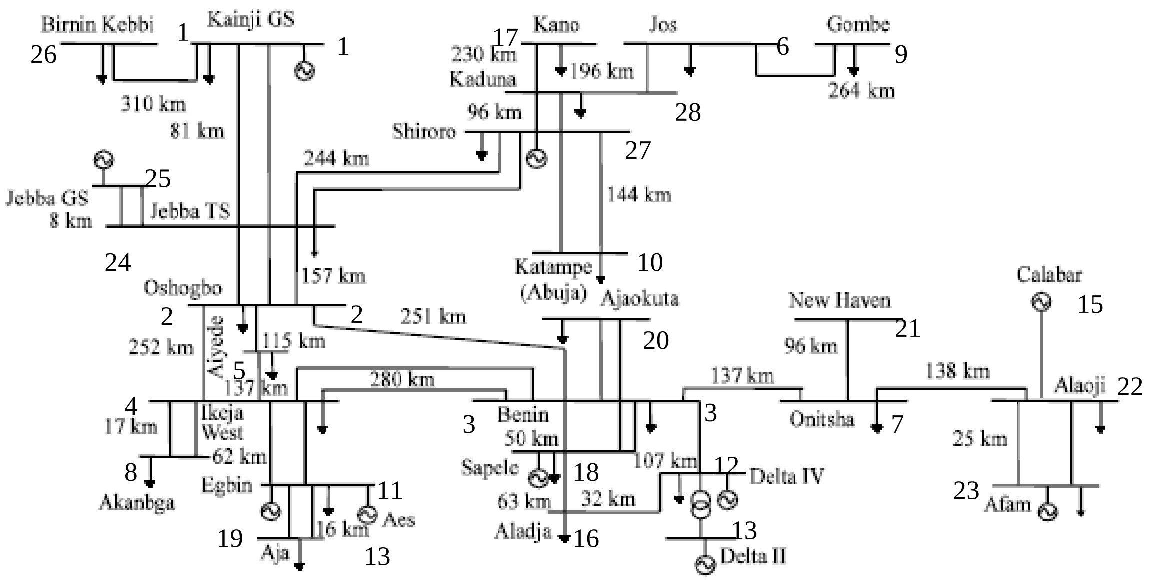

Fig. 1 Existing 330kV National Grid Network.

Objectively an operational power system generates electric energy in sufficient quantities at suitable localities, transmits it in bulk quantities to the load centers and distributes the same energy in proper form and quantity and at the lowest possible ecological and economical prices [4]. Geographically and economically, it is ideal to locate load centers where energy demand most exists, but in Nigeria, load centers are located with serious consideration to closeness to energy source of running of a practical generating plant. That is why we have Hydro-plants up North where swift flow of rivers would help in the running of generators while the steam/oil/gas fired plants are mostly located in the Niger Delta areas and Lagos.

The national grid has been characterized with deficient generation, insufficient and inefficient transmission, epileptic, weak and dilapidated distribution system that has seriously affected the living standard, security and economy of Nigerian populace. The weakness of the grid has been attributed to the large presence of single circuit radial lines and few double circuit lines with natural loadings (surge impedance loadings) between 300-363MW and thermal ratings at 760MVA per line [5, 6]. The radial nature of most lines in the national grid has made some of the transmission lines very important and critical to the integrity of the entire grid. These lines are Jebba/Oshogbo, Oshogbo/Benin, Benin/Ikeja-west and Benin/Onitsha [fig. 1]. These lines once disturbed reflect heavily on the entire power system and most times lead to a total system outage [7].

The challenges also include line vandalization, weak control centers, poor funding, and lack of adherence to research reports and improper or inadequate process of deregulation implementation by the federal government.

In this work, the load flow analysis of the 330kV Nigeria transmission network with existing 28 buses was carried out with Newton-Raphson algorithm written in Matlab language. The grid was very closely monitored at different generation levels up to and above 10,000MWsuperimposed on the grid. The maximum capacity of not less than 10,000MW nor more than 12,758MW was chosen because of the federal Government resolve to make this quantity of power available to the National grid by the year 2014 (next 36 months) [1]. In load flow studies, concentration is mainly on voltages at various buses and power injection into the transmission system [9].

2.1 MATHEMATICAL MODEL OF LOAD FLOW

Normally, for convenience, a balanced three phase power system is assumed with transmission network represented by its positive phase sequence impedances of linear lumped senses and shunt branches. Applying matrix notation, injected current and voltages of a network with admittance matrix Y are related by

$$\begin{bmatrix} I_1 \\ I_2 \\ \vdots \\ I_i \\ \vdots \\ I_n \end{bmatrix} = \begin{bmatrix} Y_{11} & Y_{12} \cdots\cdots Y_{1i} \cdots\cdots Y_{1n} \\ Y_{12} & Y_{22} \cdots\cdots Y_{2i} \cdots\cdots Y_{2n} \\ \vdots & \vdots \\ I_{i1} & I_{i2} \cdots\cdots Y_{ii} \cdots\cdots Y_{in} \\ \vdots & \vdots \\ I_{n1} & I_{n2} \cdots\cdots Y_{ni} \cdots\cdots Y_{nn} \end{bmatrix} \begin{bmatrix} V_1 \\ V_2 \\ \vdots \\ V_i \\ \vdots \\ V_n \end{bmatrix} \cdots (1)$$

$$\hat{I}_{bus} = Y_{bus} \hat{V}_{bus} \ldots\ldots\ldots\ldots (2)$$

Where I_{bus} is the vector of the injected bus currents (i.e. external current sources). The current is positive when flowing toward the bus and it is negative if flowing away from the bus. V_{bus} is the vector of bus voltages measured from the reference node (i.e. node voltage). Y_{bus} is known as the bus admittance matrix. The diagonal element of each node is the sum of admittances connected to it. It is known as the self admittance or driving point admittance i.e. $Y_{ii} = \sum_{k=o}^{n} y_{ik} \quad k \neq i \cdots\cdots (3)$

The off-diagonal element is equal to the negative of the admittance between the nodes. This is known as the mutual admittance or transfer admittance i.e. $Y_{ik} = Y_{ki} = -y_{ik} \cdots\cdots (4)$

3.1 POWER FLOW EQUATION

A typical bus of a power system network is shown in figure 2. The transmission lines are represented by their equivalent Π models where impedances have been converted to per unit admittance s on a common MVA base.

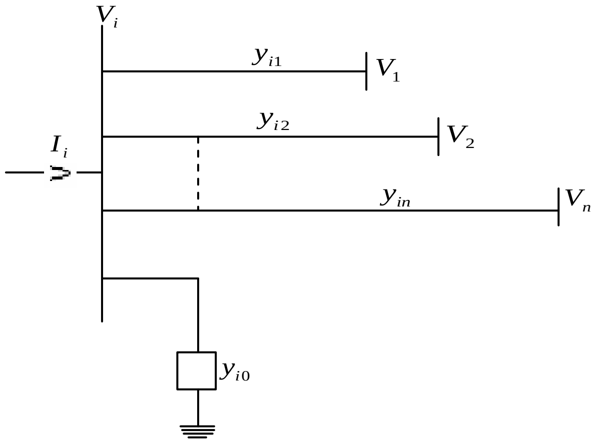

Fig. 2 Typical bus of a power system.

The current I_i entering bus i is evaluated thus:

$$I_i = y_{i0}V_i + y_{i1}(V_i - V_1) + y_{i2}(V_i - V_2) + \cdots + y_{in}(V_i - V_n)$$

$$= (y_{i0} + y_{i1} - y_{i2} \cdots + y_{in})V_i - y_{i1}V_1 - y_{i2}V_2 \cdots - y_{in}V_n \cdots\cdots (5)$$

$$= V_i \sum_{k=0}^{n} y_{ik} - \sum_{k=1}^{n} y_{ik} V_{kk \neq i} \cdots\cdots\cdots (6)$$

The real and reactive power at bus i is

$$P_i + jQ_i = V_i I_i^* \cdots\cdots\cdots\cdots (7)$$

$$I_i = \frac{P_i - jQ_i}{V_i^*} \cdots\cdots\cdots (8)$$

Substituting for I_i in equation (8) yields

$$\frac{P_i - jQ_i}{V_i^*} = V_i \sum_{k-0}^{n} y_{ik} - \sum_{k=1}^{n} y_{ik} V_k k \neq i \cdots (9)$$

Equation (9) can be rewritten in terms of bus admittance matrix as

$$I_i = \sum_{k=1}^{n} Y_{ik} V_k \cdots\cdots\cdots\cdots (10)$$

In (10), k includes bus i, n = number of buses and $Y_{ik} = G_{ik} + jB_{ik}$. Expressing (10) in polar from we have

$$I_i = \sum_{k=1}^{n} |Y_{ik}||V_k| \angle Q_{ik} + \delta_k \cdots\cdots (11)$$

The complex power at bus i is

$$P_i - jQ_i = V_i^* I_i \cdots\cdots\cdots\cdots\cdots\cdots (12)$$

Substituting the value of I_i in polar as in (11) into (12) we have,

$$P_i - Q_i = |V_i| \angle -\delta_i \sum_{k=1}^{n} |Y_{ik}||V_k| \angle \theta_{ik} + \delta_k \cdots\cdots\cdots (13)$$

Separating (13) into real and imaginary parts,

$$P_i = |V_i| \sum_{k=1}^{n} |V_k||Y_{ik}| \cos(\delta_k - \delta_i + \theta_{ik}) \cdots\cdots\cdots (14)$$

$$Q_i = |V_i| \sum_{k=1}^{n} |V_k||Y_{ik}| \sin(\delta_k - \delta_i + \theta_{ik}) \cdots\cdots\cdots (15)$$

Equations (14) and (15) constitute a set of non-linear algebraic equations in terms of the independent variables, voltage magnitude in per unit and phase angle in radians.

4 EVALUATION AND RESULT

The existing 330kV used in this analysis is shown in fig 1. The input data for this study includes the generated voltages from respective power station. The line parameters of various lines and the load allocations (reactive and real powers) at different buses [Appendixes 1and 2]

With the power base of this analysis at about 3309mw which is less than 30% of the expected generation by the year 2014, the performance of the national grid of 28 buses is very unsatisfactory. The details can be seen clearly in the detailed results of different generation levels.

Table 1: voltage profile for simulation

Bus No	Bus Name	Before Loss of Line			After Loss of Line		
		pu Volt	Volt (kV)	Angle (deg)	pu Volt	Volt (kV)	Angle (deg)
1	Kainji	1.05	346.500	0	1.05	346.500	0
2	Oshogbo	1.0402	343.266	-4.9953	1.0374	342.342	-4.9833
3	Benin	1.0278	339.174	-4.1873	1.0255	338.415	-4.1072
4	Ikeja-West	1.0139	334.587	-4.5499	1.01	333.300	-4.3473
5	Aiyede	1.0085	332.805	-6.5397	1.0051	331.683	-6.4526
6	Jos	1.033	340.890	-23.0722	1.033	340.890	-23.0743
7	Onitsha	0.9992	329.736	-2.0798	0.999	329.670	-2.01
8	Akangba	1.0092	333.036	-4.8028	1.0053	331.749	-4.6021
9	Gombe	0.9915	327.195	-29.39	0.9915	327.195	-29.3922
10	Abuja	1.0286	339.438	-14.1534	1.0286	339.438	-14.1556
11	Egbin PS	1.02	336.600	-2.502	1.02	336.600	-2.3193
12	Delta PS	1.05	346.500	-2.2937	1.05	346.500	-2.2265
13	AES	1	330.000	0	1	330.000	0
14	Okpai	1	330.000	-1.2678	1	330.000	-1.1989
15	Calabar	1	330.000	0	1	330.000	0
16	Aladja	1.0365	342.045	-2.8166	1.0365	342.045	-2.7496
17	Kano	1.0026	330.858	-19.9762	1.0026	330.858	-19.9784
18	Sapele PS	1.015	334.950	-3.0637	1.015	334.950	-2.997
19	Aja	1.0183	336.039	-2.6478	1.0183	336.039	-2.4651
20	Ajaokuta	1.0361	341.913	-5.3161	1.0338	341.154	-5.2403
21	New Haven	0.9947	328.251	-3.8825	0.9945	328.185	-3.8133
22	Alaoji	0.9969	328.977	-1.8745	0.9968	328.944	-1.81
23	Afam GS	1	330.000	-1.5143	1	330.000	-1.4503
24	Jebba TX	1.0506	346.698	-2.9016	1.0505	346.665	-2.902
25	Jebba PS	1.05	346.500	-2.7793	1.05	346.500	-2.7805
26	Birnin Kebbi	1.0469	345.477	-4.328	1.0469	345.477	-4.328
27	Shiroro	1.05	346.500	-11.8148	1.05	346.500	-11.8169
28	Kaduna	1.0406	343.398	-15.4371	1.0406	343.398	-15.4392

4.1 GENERATION LEVEL AT 3309MW

Result shown in table 1 and fig 3 shows the voltage profile and angle at each bus after the power flow analysis with generation standing at 3309MW. Details further show only one violation of voltage at bus 24 (Aiyede) with recorded voltage of 1.0506 p.u (346.698) which is slightly above the maximum allowable limit of 1.05p.u 346.50kV by 0.198kV. This violation can be remedied by using a voltage controlled device such as voltage condensers (svc). The thermal limitations on all the lines showed compliance to the limit of 760MVA. However the highest MVA loading of 526.51MVA was recorded on the line linking Shiroro-Kaduna

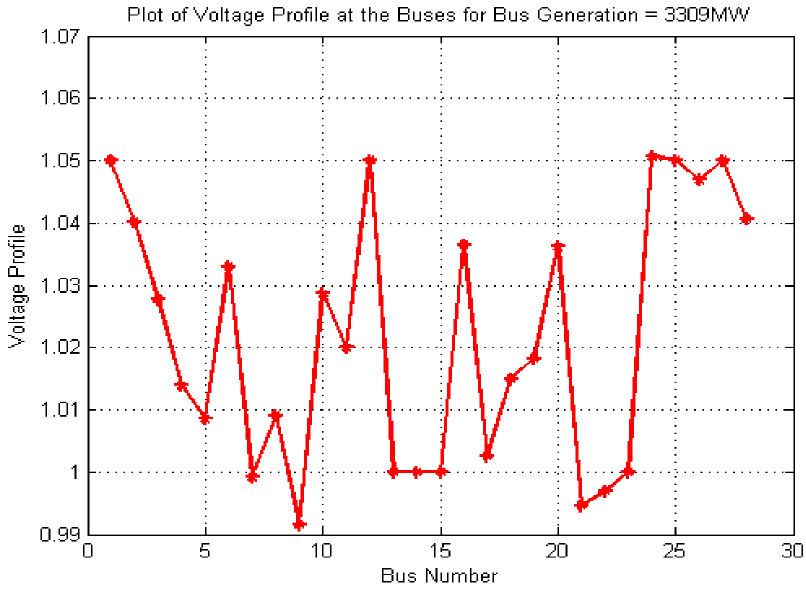

Fig 3: Voltage profiles at 3309MW generation level

4.2 LOSS OF DIFFERENT LINES

At this level of generation i.e 3309MW, the loss of line 20 (Oshogbo-Ikeja West line) showed same result as in section 4.1 as could be seen in table 1 and fig 4. The grid should be said to be stable at this level of generation with loss of Oshogbo-Ikeja West line, with one voltage violation and MVA compliance.

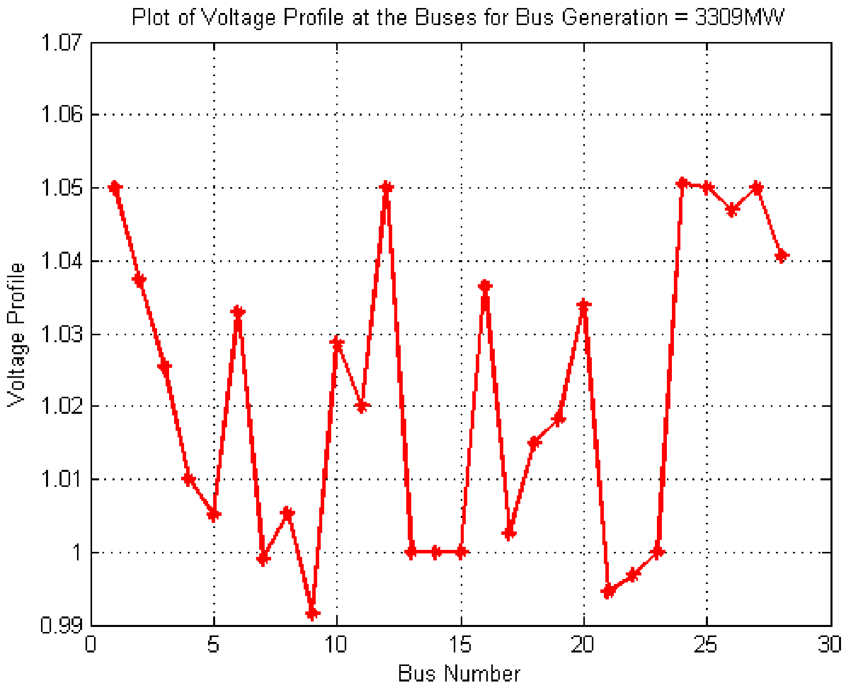

Fig 4: Voltage profiles at 3309MW generation level with loss of Oshogbo – Ikeja West

However, when he following lines, Jebba TX - Oshogbo (line 14) Shiroro – Jebba TX (line3), and Oshogbo- Benin (line22) were loss respectively grid showed serious instability and total collapse of the system.

4.30 RESULTS OBSERVED WHEN THE GRID WITH SIMULATED WITH SUPERIMPOSED GENERATION CAPACITY

The existing Nigeria 330kV was simulated with different levels of generation ranging from 4089.67MW, through 5522.45MW, 8312.3MW to 10,080MW. At the generation level of 4,089.67MW, there was a voltage violation at the same bus 24 of about tolerable limit of 0.165KV. At the generation level of 5522.45MW, no violation occurred as far as voltage is concerned but one thermal violation was registered.

However, at 8312.3MW and 10,080MW generation levels, series of both voltage and thermal limit violations were recorded. The results in tabular form are presented in table 4. including responses and violation when lines were removed at different levels represented by only Oshogbo-Ikeja west line. Fig 5 shows a family of curves for the bus voltage profile of all simulated generation levels.

Table 4: Simulation at different generation levels and corresponding violations observed.

No	Generation Level	Losses		Voltage Violations	MVA Violation
		P_L	Q_L		
1a	3309 MW	40.4176	286.7054	1	0
1b	Loss of Oshogbo – Ikeja West	40.5596	285.8784	1	0
2a	4089.6 MW	55.2857	352.1604	1	0
2b	Loss of Oshogbo – Ikeja West	56.2317	376.5887	1	0
3a	5,522.45 MW	203.3536	1272.1192	0	1
3b	Loss of Oshogbo – Ikeja West	224.8427	1538.1515	1	2
4a	8,312.3 MW	Total System Collapse			
4b	Loss of Oshogbo – Ikeja West				
5a	10,080MW				
5b	Loss of Oshogbo – Ikeja West				

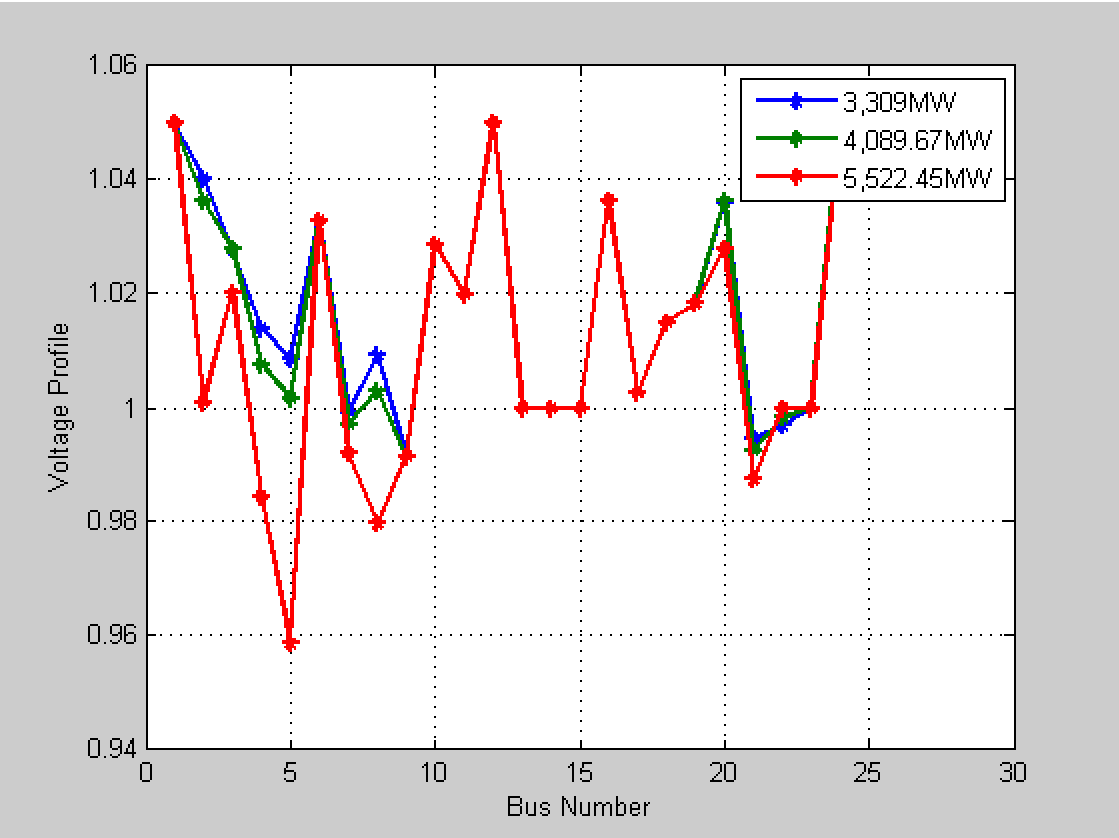

Fig 5: Bus voltages profiles for the different generation levels simulated

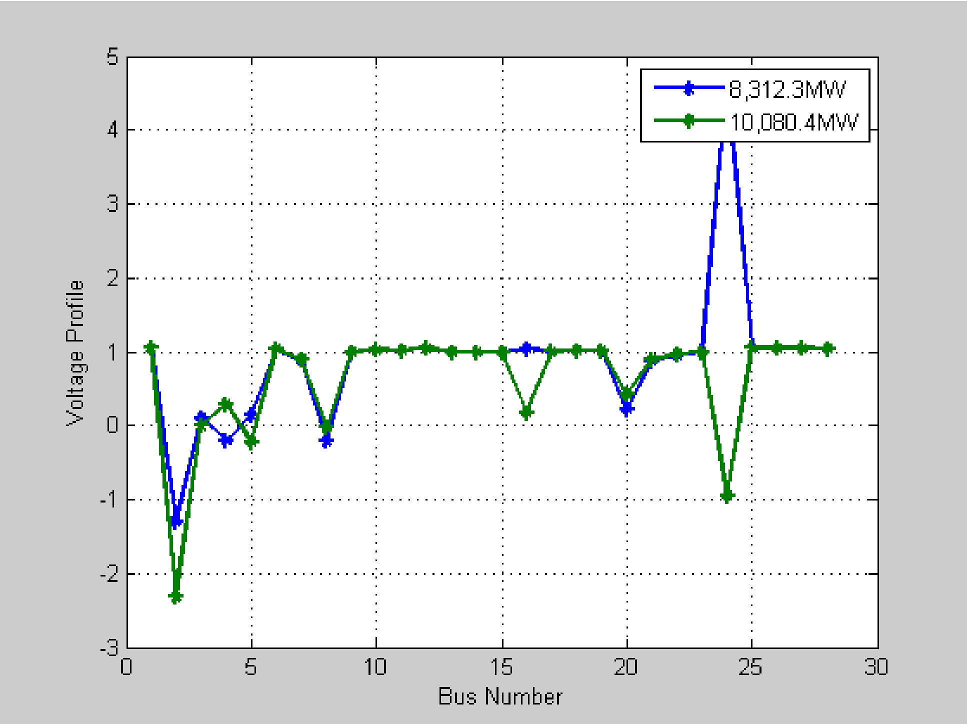

Fig 6: Bus voltages profiles for the different generation above tolerable limit

4.3 DISCUSSION/OBSERVATIONS

Table 4 shows violations of bus bar voltage, and thermal loading of line at various generation levels imposed on the 28 bus national grid. From the results, it was very evident that the existing national grid remains stable within the limit of 5522.45MW. It was noticed that at any level above 5522.45MW removal of any transmission line resulted in multiple intolerable voltage violations, thermal violations and even system collapse. The situations worsen with further increase in generation. This exposes the existing power grid's inability to cope beyond 5,522MW level.

Certain serious observations were made as regards the performance of the power grid among others are:

- Any fault in two out of the triple circuits linking Oshogbo and Jebba buses results in serious system failure or collapse.
- Any fault or failure in Shiroro bus results in complete collapse of the power grid.
- Any fault in either Benin, Ikeja-west or Oshogbo bus or all the three buses; results in serious failure of the grid network because it is observed that the line running from Benin-Ikeja West-Aiyede-Oshogbo-Benin is the only viable loop in the ensure grid.

These limitations can be attributed to the following [3]:

- Radial nature of the grid
- Single 330kV circuits
- Concentrated generation
- Fewer transmission substations to cope with the load and size of the country.
- Major weakness of the grid was observed with the simultaneous removal of Benin-Onitsha and Jebba Ts-Shiroro lines resultant effect is the islanding of the eastern state with removal of Onitsha-Benin line and landing of state in the north with removal of Shiroro-Jebba Ts line.

5.0 CONCLUSION AND RECOMMENDATION

CONCLUSION:

The existing 28bus Nigeria 330kV transmission network is associated with various problems. This work was targeted at examining or determining whether the existing network will be capable of withstand or coping with the proposed 10,080MW and above generation curve 2014.

The maximum allowable generation capacity of 5,522.45MW with tolerable violations was observed and further increase in generation resulted in grid collapse. These deficiencies can be ascribed to fragile radial network subjecting the system to failure, inefficiency, unreliability and poor performance.

RECOMMENDATIONS:

Consequent upon the results so obtained as in most figures (figs. 5 and 6), it is seriously recommended that

i. More double circuit lines even triple lines should dominate the proposed new lines even to replace these existing single lines in order to increase efficiency and reliability.
ii. More substations be constructed in order to reduce some of long transmission lines especially in the northern part of the country in-turn reduce line losses.
iii. Existing power stations injection substations, transmission lines should be rehabilitated for better service.
iv. PHCN or bodies responsible for generation, transmission and distribution in the country at all levels to keep records and make such available to research students on demand for research work purposes.

REFERENCES

[1] Stanley Opara. FG issues 20 Independent Power Project Licenses. The Punch Wed. 7th Dec. 2011 pg 19. vol. 17 no 20027
[2] Oscarline Onwuemenyi NERC Recommends Faster winding up of PHCN. Vanguard Tuesday 13th Dec. 2011 pg 28 vol. 25 No. 61516
[3] A.S.A. Bada (2012). “Transmission Evacuation and Constraints” National Power Retreat. www.nigeriaelectricityprivitisation.com/wp.../download.
[4] E.O. Okwu(2007) “Power Distribution in Developing Economy” “The Nigerian Perspective” Newsletter of the Nigerian Society of Engineers. Vol. 3 No. 2 pp4-5
[5] PHCN Power Report, 2008
[6] C.C. Okoro and Achugbu (2007). “Contingency assessment of the Nigerian 330kV Power Grid” Proceedings of International Conference and Exhibition on Power Systems, University of Lagos Nigeria.
[7] C.C. Okoro and K.C Achugbu (2008) “Performance Analysis and Indices for the existing Nigeria 330kV National Power Grid” paper presented at the International Conference on Power and Telecommunication by the Nigerian Institute of Electrical Electronic Engineers held at the international Conference Center Abuja.
[8] E. Hirst and B. Kirby (2000) “Bulk Power Basics: Reliability and Commerce” Consulting in Electric-Industry Restructuring, Oak Ridge, Tennessee 37830.
[9] A. Mazer (2007) “Electric Power Planning for Regulated and Deregulated Markets” John Wiley and sons Inc. Hoboken, new Jersey.
[10] C.C. Okoro (2003) “Emergent problems of power utilities in Developing Economics” Nigerian Society of Engineers Memorial Lecture delivered in honor of Engr. E.A. Adeleye, held at Lagos thermal station Egbin
[11] W. W. Hogan (1992) “Contract Network for Electric Power Transmission: Technical reference” John F. kennedy school of government, Havard University, Cambridge, Masseuse tts 02138
[12] A.G. Bhutad, S.V. Kulkani and S.A. Khaparde (2003). “Three-Phase Power Flow Methods for Radial Distribution Networks”, IEEE Transaction Power Delivery, vol. 3 Nov., 2003.
[13] I.J. Nagrath and D.P. Kethari (1994). “Power System Engineering” First Edition, Tenth Reprint, Tata Mc Graw-Hill (2007).
[14] C.L. Wadhwa (2005) “Electrical Power Systems” Fourth Edition New Age International (P) LTD New Delhi.

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