Uniport Journal of Engineering and Scientific Research (UJESR)

Vol. 8, Issue 2, 2024, Page 07-18
ISSN: 2616-1192

(www.ujesr.org)

Simulation and Analysis of Nigeria 330kV Network

Emmanuel, A.U
Department of Electrical and Electronic Engineering, Federal University Otuoke, Nigeria
Corresponding author's email: amasaeu@fuotuoke.edu.ng

Abstract
Modern power systems are expanding continually in size and complexity. This is due to the increasing power generation and load demand. In view of the anticipated increase in power generation in the Nigeria electricity sector, there is need to assess the performance state of the Nigeria power system. This work examined the performance efficiency of the Nigeria 330kV power network under different operating conditions. The network under study consists of nine old existing generating stations together with an additional generating station at Alaoji, 40 generator and load buses, and 29 transmission lines. The network was modelled and simulated using ERACS software tool. The power flow was ran using the Gauss Seidel load flow algorithm. Low voltage violations were discovered at buses-08(Kano), 09(Jos), 10(Gombe), and 12(Ayede). Shunt compensators were placed at these weak buses location to keep the voltage at a minimum value of 0.9pu. Also, the Alaoji - Onitsha single circuit transmission line (Line-26) was able to accommodate additional power generation of 150MW For better network efficiency, this research proposed that new power generation stations should be built at the north –eastern part of the country to compensate for the shortfalls in power supply to that region. Flexible Alternating Circuit Transmission Systems should be placed at strategic locations in the grid. In addition, the on-going double circuit transmission line project from Alaoji Substation to Onitsha Substation should be speedily completed for optimal transmission of power across the network.

Keywords: *Load flow, ERACS, Bus voltage, Flexible alternating circuit transmission systems*

Received: 19th January, 2024 *Accepted: 1st March, 2024*

1. Introduction

An electric power system is an integration of components designed to efficiently transmit and distribute electric energy produced by generators to consumer load centres (Chapman, 2002). The system consists of three basic components: the generating plant, the transmission network and the distribution. These components are integrated to supply electrical energy, meet the demand of reactive and real power of consumers with a high quality of supply (Putrus, 2013). The power stations (generators) are usually sited at some faraway distance from the load terminals. Extensive power supply network are therefore established between the generating stations and the load centres.

Power network engineers are faced with the challenge of maintaining the voltage profile of a network within defined limits for high quality of services to consumers. Changes in generation and load profiles during steady and fault operating conditions of a power system may adversely affect the voltage profile of the network (Bakare, 2005). Over-voltages on the network lead to protection failures. Meanwhile, under-voltage occurrences deteriorate the voltage stability margin and bulk power transfer capacity of transmission lines. Reactive power control devices are sometimes introduced into the network to stabilize the voltage profile and improve system efficiency.

Power transfer capability of a transmission system defines the efficiency of the associated system segments to reliably move power from one area to another over defined system conditions without compromising system security (Hojabi and Hizam, 2011). Transmission systems efficiency is determined by the network voltage stability limit, short circuit level, surge impedance loading (SIL) and thermal limit of the transmission lines (Eseosa and Ogujor, 2012).

The transmission subsystem of electric utilities in Nigeria is interconnected into a large power grid. The 330 kV national grid, which is the highest in the country, is designed to transport electric energy generated from generating stations at various locations in the country to the distribution networks which feed the load centres. However, the Nigeria transmission 330 kV grid has a radial topology, with fragile and very long transmission lines of about 5650km in length. The Nigeria's power transmission infrastructure continues to be a challenge as it still remains a weak link in the country's electricity supply chain (PTFP, 2014).

The rising demand for electricity in Nigeria is higher than the present generation capacity (PTFP, 2014). This results in the associated transmission systems being over congested and stressed beyond their allowable limit. Since a good number of the generating stations are situated far from the load centres, there is a tendency of experiencing voltage and frequency fluctuations in the network (Eseosa and Ogujor, 2012). This makes the stability of the network to be weak under fault conditions, resulting to frequent power outages on the grid (Onohaebi, 2009). Thus, there is need to investigate the capacity of the existing Nigeria 330kV network. This is in order to identify possible constraints on the grid. Load flow analysis is to be carried out for a network structure of nine (9) generating stations, 40 generator and load buses, and 29 transmission lines (NIPP, 2007). For the network infrastructures to be fully utilized, appropriate voltage compensation schemes need to be incorporated into the network. Some of these schemes include VAr compensation technologies such as shunt compensators and FACTS controllers.

Furthermore, there would be an integration of further generation on the network to observe its response. This added generation is from the constructed Alaoji power plant. The Alaoji power plant phase1, is a 3x126MW gas turbine plan (NIPP, 2007). Power from this plant is expected to be transmitted through a proposed double circuit transmission line running from Alaoji station to Onitsha transmission substation (NIPP, 2007). Presently, the transmission line project is yet to be completed, despite the fact that the new power plant is operational.

However, there is an existing single circuit line that runs from the Alaoji transmission substation to Onitsha transmission substation. Considering the surge impedance loading limit and thermal limit of the line, there is need to investigate the capability of the existing line to accommodate the further power from the Alaoji power plant.

2. Materials and methods

The grid system was modelled in accordance with network diagram obtained from National Integrated Power Project (NIPP) study report(NIPP, 2007).The network for this study consisted of nine (9) generating stations as well as a new generating stations, thirty eight (38) buses and twenty eight (29) transmission lines.

2.1 Data collection

The data used in this analysis and assessment were collected from the National Integrated Power Project (NIPP) grid study report of 2007 (NIPP, 2007). Information used for the simulation included data for generator and load buses, transmission lines data, and generators and transformers data .The network was modelled and simulated in ERACS in other to determine the following: active and reactive power flows in all the branches of the network, active and reactive power contributed by each generator, active and reactive power losses in each component in the network, bus voltages magnitudes and angles throughout the network.

2.2 Network load flow studies

The load/power flow study gives the steady state conditions of the power system network (Weedy et al., 2012). This includes the network voltage profile, current, real and reactive power flows. According to Saadat (1999), and Maruf and Garba (2013), there are basically four types of buses in the power network. They are: PV bus (generator bus), PQ bus (load bus), Slack bus (reference bus), and Disconnected bus (de-energized bus).

2.3 Load flow equation

Agreeing with Maruf and Garba (2013), the net complex power injected in the ιth bus for a power system is given as

$$S_i = P_i + jQ_i \tag{1}$$

$$= (PG_i - P_{Di}) + (QG_i - Q_{Di})$$

For a system with n - number of buses,

$$S_i = P_i + jQ_i \tag{2}$$

$$= V_i I_i^*$$

i= 1, 2.3…n

V_i is the n - bus voltage matrix, I_i^* is the complex conjugate of source current, and I_i injected into the ιth bus.

Using Kirchhoff's current law (KCL), the power flow equation for n - bus in a power system can be expressed in admittance form as

$$I = Y_{bus} V \tag{3}$$

Y_{bus} is the bus admittance matrix.
Taking the conjugate of S in Equation (2),

$$S^* = P_i - jQ_i \qquad (4)$$
$$= V_i^* I_{ii}$$

Therefore, the current flowing across the ith bus is expressed as

$$I_i = \frac{P_i - jQ_i}{V_i^*} \qquad (5)$$

The Gauss Seidel method of load flow is used to express voltage V_i for a ith bus in terms of real power P_i and reactive power Q_i.

This is given as:

$$V_i = \frac{1}{Y_{ii}}\left[\frac{P_i - jQ_i}{V_i^*} - \sum_{\substack{k=1 \\ k\neq i}}^{n} Y_{ik}V_k\right] \qquad (6)$$

The solutions of this load flow equation for the n buses are achieved using Gauss –Siedel numerical iterative method. The Nigeria 330kV network is an interconnection of several of these buses being linked through various transmission lines. The single line diagram of the Nigeria 330kV is shown in Fig. 1. To understand the power transfer capability and stability of the Nigeria 330kV grid, it was essential to study and evaluate how the network performs under different generation and loading conditions. The power flow analysis was realized in ERACS by the reading of system data and using Gauss Seidel iterative technique to solve the load flow. The load flow study was conducted for six different scenarios listed below:

1. Normal generation versus base load
2. Normal generation versus shedded base load
3. Normal generation versus shedded base load with VAr compensation.
4. Maximum generation versus minimum load (60% 0f base load).
5. New generation versus shedded base load
6. New generation versus shedded base load with reactor

2.4 Input data used for the analysis of 330kvintegrated network

The input data for the network analysis were generators assigned output real power and reactive power, substations MW loads transmission line sizes and impedance values, and the voltage level of each bus. Fig. 1 shows the single line diagram of the Nigeria 330kV under study. The study base values used for the load flow were S_{base} = 100MVA, V_{base} = 330kV, while the bus voltage tolerance was ±10%. (NIPP, 2007). The surge impedance loading (SIL) of the existing single circuit Alaoji- Onitsha transmission line is 363MW, while the thermal rating is 760MVA (NIPP, 2007). The length of the transmission lines when computed in the ERACS software were divided by the value, 10. This was to ensure conformity to the standard value of line impedance for 330kV transmission lines as stated in Weedy et al. (2012).

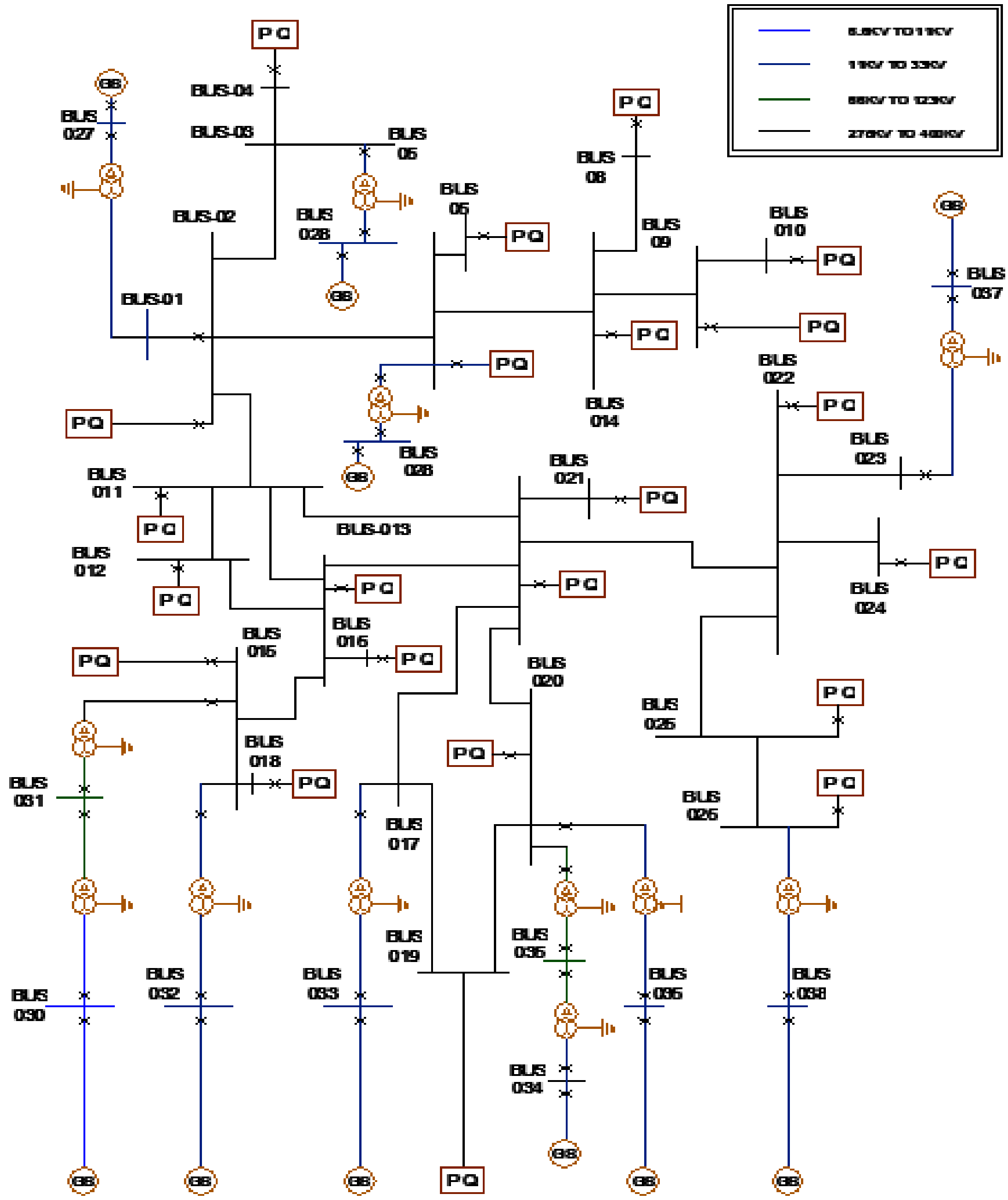

Fig. 1: Single line diagram of the Nigeria 330kV power network.

3. Results and discussion

The results of the load flow study for the different scenarios are presented below.

3.1 Base case generation versus base load (Scenario 1)

The base load used for this simulation is 3416.60MW, with an assigned power generation of 3774.10MW. The results presented in Tab. 1 show a voltage violation at buses-05, 06, 07, 08,09,10,12 and 29, as the allowable voltage limit is 0.90pu-1.10pu. Considerably amount of the power transmitted to these buses is lost along the transmission lines linking these buses due to their long distance. The total active and reactive power loss in the network is found to be 64.78MVAr and 679.61 MVAr respectively. Also, there is insufficient power supply (from Jebba, Kainji, and Shiroro generation stations) to meet the loads at buses-06, 07, 08, 09, and 10. The Shiroro generation station is stretched beyond its generation limit.

Table 1: Load flow study results for scenario 1

Busbar ID	Bus Name	pV (pu)	V (kV)	AV (deg)	PG (MW)	QG (MVAr)	PL (MW)	QL (MVAr)
BUS-01	Jebba TS	0.964886	318.412	-0.6599	0	0	0	0
BUS-02	Jebba SS	0.959654	316.686	-0.996	0	0	12	7.437
BUS-03	Kainji SS	0.995893	328.645	0.3962	0	0	0	0
BUS-04	Birnin	0.932992	307.887	-4.5401	0	0	85	52.678
BUS-05	Shiroro SS	0.800385	264.127	-5.8331	0	0	120	74.369
BUS-06	Katampe	0.761021	251.137	-9.6157	0	0	167.411	103.752
BUS-07	Kaduna SS	0.717354	236.727	-11.8661	0	0	184.933	114.611
BUS-08	Kano SS	0.577023	190.417	-24.984	0	0	135.263	83.828
BUS-09	Jos SS	0.643286	212.284	-19.0275	0	0	51.727	32.058
BUS-010	Gombe SS	0.597566	197.197	-24.3892	0	0	44.636	27.663
BUS-011	Osogbo SS	0.919402	303.403	-5.1696	0	0	180	111.554
BUS-012	Ayede SS	0.871906	287.729	-10.0384	0	0	240	148.739
BUS-013	Ikeja West	0.904025	298.328	-8.7103	0	0	550	340.859
BUS-014	Benin SS	0.963984	318.115	-3.2655	0	0	120	74.369
BUS-015	Egbin SS	0.979991	323.397	-3.6937	0	0	260	161.134
BUS-016	Akangba	0.894747	295.267	-9.4796	0	0	400	247.898
BUS-017	Sapele SS	0.976569	322.268	-2.3707	0	0	0	0
BUS-018	Aja SS	0.976484	322.24	-3.9728	0	0	200	123.949
BUS-019	Aladja SS	0.99093	327.007	-1.2321	0	0	43	26.649
BUS-020	Delta SS	1.001438	330.475	-0.4267	0	0	44	27.269
BUS-021	Ajaokuta	0.962756	317.71	-3.5523	0	0	15	9.296
BUS-022	Onitsha SS	0.965158	318.502	-2.4829	0	0	152	94.201
BUS-023	Okpai TS	0.992749	327.607	-0.1106	0	0	0	0
BUS-024	New	0.932787	307.82	-4.9866	0	0	135.6	84.037
BUS-025	Alaoji SS	0.973061	321.11	-1.9462	0	0	250	154.936
BUS-026	Afam SS	0.981606	323.93	-1.2688	0	0	64	39.664
BUS-027	Jebba GS	0.943527	15.096	1.0102	414.999	350	0	0
BUS-028	Kainji GS	1	16	1.1845	289.999	319.496	0	0
BUS-029	Shiroro GS	0.804473	12.228	-1.2623	530	350	0	0
BUS-030	AES GS	0.899302	9.443	-1.044	237	53	0	0
BUS-031	AES TS	0.94113	124.229	-1.7499	0	0	0	0
BUS-032	Egbin GS	1	16	0	997.361	1029.519	0	0
BUS-033	Sapele GS	0.919731	14.486	-0.4073	77	70	0	0
BUS-034	Delta II GS	1	11.5	3.0158	100	26.501	0	0
BUS-035	Delta II TS	0.999872	131.983	1.8326	0	0	0	0
BUS-036	Delta IV	0.96047	11.045	0.52	237.998	200	0	0
BUS-037	Okpai GS	1	15.75	1.5557	297.997	186.793	0	0
BUS-038	Afam GS	0.927656	10.668	1.5884	336.996	235.251	0	0
Total					3,519.35	2,820.56	3,454.57	2,140.95

3.2 Base case generation versus shedded base load (Scenario 2)

Due to the insufficient power supply to the loads connected at buses-06, 07, 08, 09, and 10 in scenario 1, the loads at these buses are reduced to match with available power generation. The simulation was conducted for an assigned power generation of 3462.649MW against a shedded base load of 3416.6MW. The results shown in Tab. 2 show an improvement compared to scenario 1. However, there are still voltage violations at buses-08, 09, 10, and 12. This is as a result of the long distance of the transmission lines that consume some of the transported reactive power along the different axis. The active power loss at the network is 46.049MW, while the reactive power loss is 442.235MVAr.

3.3 Base case generation versus shedded base load with var compensation (Scenario 3)

The incorporation of reactive (VAr) compensation to the network of scenario 3 is to compensate for the loss in reactive power along the concerned lines. Shunt load compensators are connected to bus 7 and bus 12. The shunt load acts as a capacitor, producing additional reactive power along the transmission lines. The shunt compensator connected at Bus-07 compensate for the reactive power loss along the line from Jebba TS (Bus- 01) to Gombe SS (Bus-010). While the shunt compensator connected at BUS-012 compensate for the reactive power loss along the line from Ayede SS (BUS-012) to Ikeja West SS (BUS-013). The supply voltages along these lines are improved, thereby keeping the voltage at the buses within the statutory limits as shown in Tab. 3. The active power loss at the network is found to be 39.50 MW, while the reactive power loss is 243.68 MVAr. This shows a considerable improvement in the network efficiency.

Table 2: Load flow study results for scenario 2

Busbar ID	Bus Name	pV (pu)	V (kV)	AV (deg)	PG (MW)	QG (MVAr)	PL (MW)	QL (MVAr)
BUS-01	Jebba TS	0.964886	318.412	-0.6599	0	0	0	0
BUS-02	Jebba SS	0.959654	316.686	-0.996	0	0	12	7.437
BUS-03	Kainji GS	0.995893	328.645	0.3962	0	0	0	0
BUS-04	Birnin kebbi	0.932992	307.887	-4.5401	0	0	85	52.678
BUS-05	Shiroro SS	0.800385	264.127	-5.8331	0	0	120	74.369
BUS-06	Katampe SS	0.761021	251.137	-9.6157	0	0	185	114.653
BUS-07	Kaduna SS	0.717354	236.727	-11.8661	0	0	161	99.779
BUS-08	Kano SS	0.577023	190.417	-24.984	0	0	104	64.453
BUS-09	Jos SS	0.643286	212.284	-19.0275	0	0	48	29.748
BUS-010	Gombe SS	0.597566	197.197	-24.3892	0	0	48	29.748
BUS-011	Osogbo SS	0.919402	303.403	-5.1696	0	0	180	111.554
BUS-012	Ayede SS	0.871906	287.729	-10.0384	0	0	240	148.739
BUS-013	Ikeja West SS	0.904025	298.328	-8.7103	0	0	550	340.859
BUS-014	Benin SS	0.963984	318.115	-3.2655	0	0	120	74.369
BUS-015	Egbin SS	0.979991	323.397	-3.6937	0	0	260	161.134
BUS-016	Akangba SS	0.894747	295.267	-9.4796	0	0	400	247.898
BUS-017	Sapele SS	0.976569	322.268	-2.3707	0	0	0	0
BUS-018	Aja SS	0.976484	322.24	-3.9728	0	0	200	123.949
BUS-019	Aladja SS	0.99093	327.007	-1.2321	0	0	43	26.649
BUS-020	Delta SS	1.001438	330.475	-0.4267	0	0	44	27.269
BUS-021	Ajaokuta SS	0.962756	317.71	-3.5523	0	0	15	9.296
BUS-022	Onitsha SS	0.965158	318.502	-2.4829	0	0	152	94.201
BUS-023	Okpai TS	0.992749	327.607	-0.1106	0	0	0	0
BUS-024	New Haven SS	0.932787	307.82	-4.9866	0	0	135.6	84.037
BUS-025	Alaoji SS	0.973061	321.11	-1.9462	0	0	250	154.936
BUS-026	Afam SS	0.981606	323.93	-1.2688	0	0	64	39.664
BUS-027	Jebba GS	0.943527	15.096	1.0102	414.999	379.609	0	0
BUS-028	Kainji GS	1	16	1.1845	289.999	61.339	0	0
BUS-029	Shiroro GS	0.804473	12.228	-1.2623	530	400	0	0
BUS-030	AES GS	0.899302	9.443	-1.044	237	52.999	0	0
BUS-031	AES TS	0.94113	124.229	-1.7499	0	0	0	0
BUS-032	Egbin GS	1	16	0	997.361	970.407	0	0
BUS-033	Sapele GS	0.919731	14.486	-0.4073	77	70	0	0
BUS-034	Delta II GS	1	11.5	3.0158	100	16.461	0	0
BUS-035	Delta II TS	0.999872	131.983	1.8326	0	0	0	0
BUS-036	Delta IV GS	0.96047	11.045	0.52	237.998	199.999	0	0
BUS-037	Okpai GS	1	15.75	1.5557	297.997	173.592	0	0
BUS-038	Afam GS	0.927656	10.668	1.5884	336.996	235.248	0	0
Total					3462.649	2559.654	3416.6	2117.419

3.4 Maximum generation versus minimum load (Scenario 4)

In this scenario, the generators are running at 90% of their rated capacity. The minimum load condition is 60% of the base load. The minimum load used for this simulation is 3,978.692 MW, with an assigned maximum power generation of 2,223.36MW. The results displayed in Tab. 4 show a voltage violation at buses-08, 09,10,12,13, and 16; due to shortfall in reactive power supply. The voltage violation at buses-08, 09, and 10 is owing to the loss in reactive power supply along the lines from bus-05 to bus-10. Similarly, the voltage drop at buses 12, 13, and 14 is due to the fall in reactive power supply to these buses as the slack generator (Egbin GS) at bus 32 is seriously absorbing reactive power. Thus, operating the network at this condition will involve providing reactive power compensators at the concerned buses location which will be much more cost ineffective.

Table 3: Load flow study results for scenario 3

Busbar ID	Bus Name	pV (pu)	V (kV)	AV (deg)	PG (MW)	QG (MVAr)	PL (MW)	QL (MVAr)
BUS-01	Jebba TS	0.964886	318.412	-0.6599	0	0	0	0
BUS-02	Jebba SS	0.959654	316.686	-0.996	0	0	12	7.437
BUS-03	Kainji GS	0.995893	328.645	0.3962	0	0	0	0
BUS-04	Birnin kebbi	0.932992	307.887	-4.5401	0	0	85	52.678
BUS-05	Shiroro SS	0.800385	264.127	-5.8331	0	0	120	74.369
BUS-06	Katampe SS	0.761021	251.137	-9.6157	0	0	185	114.653
BUS-07	Kaduna SS	0.717354	236.727	-11.8661	0	0	161.1	53.221
BUS-08	Kano SS	0.577023	190.417	-24.984	0	0	104	64.453
BUS-09	Jos SS	0.643286	212.284	-19.0275	0	0	48	29.748
BUS-010	Gombe SS	0.597566	197.197	-24.3892	0	0	48	29.748
BUS-011	Osogbo SS	0.919402	303.403	-5.1696	0	0	180	111.554
BUS-012	Ayede SS	0.871906	287.729	-10.0384	0	0	240.1	4.261
BUS-013	Ikeja West SS	0.904025	298.328	-8.7103	0	0	550	340.859
BUS-014	Benin SS	0.963984	318.115	-3.2655	0	0	120	74.369
BUS-015	Egbin SS	0.979991	323.397	-3.6937	0	0	260	161.134
BUS-016	Akangba SS	0.894747	295.267	-9.4796	0	0	400	247.898
BUS-017	Sapele SS	0.976569	322.268	-2.3707	0	0	0	0
BUS-018	Aja SS	0.976484	322.24	-3.9728	0	0	200	123.949
BUS-019	Aladja SS	0.99093	327.007	-1.2321	0	0	43	26.649
BUS-020	Delta SS	1.001438	330.475	-0.4267	0	0	44	27.269
BUS-021	Ajaokuta SS	0.962756	317.71	-3.5523	0	0	15	9.296
BUS-022	Onitsha SS	0.965158	318.502	-2.4829	0	0	152	94.201
BUS-023	Okpai TS	0.992749	327.607	-0.1106	0	0	0	0
BUS-024	New Haven SS	0.932787	307.82	-4.9866	0	0	135.6	84.037
BUS-025	Alaoji SS	0.973061	321.11	-1.9462	0	0	250	154.936
BUS-026	Afam SS	0.981606	323.93	-1.2688	0	0	64	39.664
BUS-027	Jebba GS	0.943527	15.096	1.0102	414.999	139.082	0	0
BUS-028	Kainji GS	1	16	1.1845	289.999	23.306	0	0
BUS-029	Shiroro GS	0.804473	12.228	-1.2623	530	400	0	0
BUS-030	AES GS	0.899302	9.443	-1.044	237	53	0	0
BUS-031	AES TS	0.94113	124.229	-1.7499	0	0	0	0
BUS-032	Egbin GS	1	16	0	997.361	878.44	0	0
BUS-033	Sapele GS	0.919731	14.486	-0.4073	77	70	0	0
BUS-034	Delta II GS	1	11.5	3.0158	100	7.825	0	0
BUS-035	Delta II TS	0.999872	131.983	1.8326	0	0	0	0
BUS-036	Delta IV GS	0.96047	11.045	0.52	237.998	199.999	0	0
BUS-037	Okpai GS	1	15.75	1.5557	297.997	163.179	0	0
BUS-038	Afam GS	0.927656	10.668	1.5884	336.996	235.25	0	0
Total					3,456.3	2,170.08	3,416.8	1,926.4

Table 4: Load flow study results for scenario 4.

Busbar ID	Bus Name	pV (pu)	V (kV)	AV (deg)	PG (MW)	QG (MVAr)	PL (MW)	QL (MVAr)
BUS-01	Jebba TS	0.995005	328.352	30.8104	0	0	0	0
BUS-02	Jebba SS	0.988542	326.219	30.4203	0	0	7.2	4.462
BUS-03	Kainji GS	0.985087	325.079	30.0434	0	0	0	0
BUS-04	Birnin kebbi	0.951297	313.928	27.0961	0	0	51	31.607
BUS-05	Shiroro SS	0.980415	323.537	29.4323	0	0	72	44.622
BUS-06	Katampe SS	0.961116	317.168	27.8081	0	0	111	68.792
BUS-07	Kaduna SS	0.928042	306.254	25.8617	0	0	138	85.525
BUS-08	Kano SS	0.821184	270.991	17.6816	0	0	156	96.68
BUS-09	Jos SS	0.881603	290.929	21.8236	0	0	48	29.748
BUS-010	Gombe SS	0.849684	280.396	18.8572	0	0	48	29.748
BUS-011	Osogbo SS	0.917292	302.706	26.4855	0	0	108	66.932
BUS-012	Ayede SS	0.863333	284.9	17.2244	0	0	144	89.243
BUS-013	Ikeja West SS	0.870356	287.217	10.1768	0	0	330	204.516
BUS-014	Benin SS	0.918014	302.945	46.3655	0	0	72	44.622
BUS-015	Egbin SS	0.956435	315.624	3.4031	0	0	156	96.68
BUS-016	Akangba SS	0.864619	285.324	9.6807	0	0	240	148.739
BUS-017	Sapele SS	0.94992	313.474	49.1313	0	0	0	0
BUS-018	Aja SS	0.95429	314.916	3.2275	0	0	120	74.369
BUS-019	Aladja SS	0.982038	324.073	51.2291	0	0	25.8	15.989
BUS-020	Delta SS	1.000665	330.219	52.388	0	0	26.4	16.361
BUS-021	Ajaokuta SS	0.917973	302.931	46.172	0	0	9	5.578
BUS-022	Onitsha SS	0.954261	314.906	64.9865	0	0	91.2	56.521
BUS-023	Okpai TS	0.994553	328.203	68.8737	0	0	0	0
BUS-024	New Haven SS	0.93532	308.656	63.4704	0	0	81.36	50.422
BUS-025	Alaoji SS	0.982239	324.139	74.3203	0	0	150	92.962
BUS-026	Afam SS	0.990775	326.956	75.5771	0	0	38.4	23.798
BUS-027	Jebba GS	1.025417	16.407	32.6471	513.002	449.999	0	0
BUS-028	Kainji GS	0	0	0	0	0	0	0
BUS-029	Shiroro GS	1	15.2	32.4641	540	432.432	0	0
BUS-030	AES GS	1	10.5	6.0636	243	86.478	0	0
BUS-031	AES TS	0.94567	124.829	5.4201	0	0	0	0
BUS-032	Egbin GS	1	16	0	796.686	-1093.281	0	0
BUS-033	Sapele GS	0.919981	14.49	51.2842	324.002	199.999	0	0
BUS-034	Delta II GS	0	0	0	0	0	0	0
BUS-035	Delta II TS	0	0	0	0	0	0	0
BUS-036	Delta IV GS	1	11.5	54.4563	540.001	437.454	0	0
BUS-037	Okpai GS	1	15.75	71.5684	482	291.271	0	0
BUS-038	Afam GS	1	11.5	77.7144	540.001	204.76	0	0
Total					3,978.692	1,009.112	2,223.360	1,377.916

3.5 New generation versus shedded base load (Scenario 5)

A new generation station (Alaoji GS) was connected to the network of scenario 3 at bus-25. The new generator was assigned an output active and reactive power of 150MW and 8 MVAr respectively. The results of the network simulation in Tab. 5 show that the network was stable without any thermal failure or voltage violation. The single circuit transmission line, (Line 26) connecting bus -

22 and bus-25 has a thermal rating of 760MVA, with a surge impedance loading of 363MW, while the total maximum power being transmitted along the line from the simulation is 517.735MW. This result confirms that the line has the capacity to accommodate additional power generation from the Alaoji GS (bus-39) considering the surge impedance loading limit and the increase generation at Afam GS (at bus-38). However, at an assigned output reactive power of 8MVAr from the Alaoji GS (bus-39), the generator at bus-37(Okpai GS) is constrained to increase its reactive power output, thus operating at a very low power factor of 0.71. Thus, to address this problem, the assigned reactive power output of the Alaoji GS needs to be increased, but for the network to be stabilized under this condition, a reactor needs to be connected at bus-25(Alaoji SS) so as to stabilize any voltage increase at the bus. This leads to scenario 6.

Table 5: Load flow study results for scenario 5

Busbar ID	Bus Name	pV (pu)	V (kV)	AV (deg)	PG (MW)	QG (MVAr)	PL (MW)	QL (MVAr)
BUS-01	Jebba TS	0.990546	326.88	10.0377	0	0	0	0
BUS-02	Jebba SS	0.988485	326.2	9.7056	0	0	12	7.437
BUS-03	Kainji TS	0.995006	328.352	11.2232	0	0	0	0
BUS-04	Birnin kebbi	0.932021	307.567	6.2774	0	0	85	52.678
BUS-05	Shiroro SS	1.020115	336.638	6.312	0	0	120	74.369
BUS-06	Katampe SS	0.987598	325.907	3.7834	0	0	185	114.653
BUS-07	Kaduna SS	1.003391	331.119	3.2432	0	0	161.1	-53.221
BUS-08	Kano SS	0.945578	312.041	-1.1348	0	0	104	64.453
BUS-09	Jos SS	0.962991	317.787	-0.1826	0	0	48	29.748
BUS-010	Gombe SS	0.934856	308.502	-2.6546	0	0	48	29.748
BUS-011	Osogbo SS	0.942716	311.096	5.1807	0	0	180	111.554
BUS-012	Ayede SS	0.920984	303.925	-1.7384	0	0	240.1	-4.261
BUS-013	Ikeja West SS	0.910371	300.422	-3.0272	0	0	550	340.859
BUS-014	Benin SS	0.94672	312.418	13.9222	0	0	120	74.369
BUS-015	Egbin SS	0.984201	324.786	-1.6623	0	0	260	161.134
BUS-016	Akangba SS	0.901161	297.383	-3.7857	0	0	400	247.898
BUS-017	Sapele SS	0.961548	317.311	14.8362	0	0	0	0
BUS-018	Aja SS	0.98071	323.634	-1.939	0	0	200	123.949
BUS-019	Aladja SS	0.980885	323.692	15.9747	0	0	43	26.649
BUS-020	Delta SS	0.993957	328.006	16.7798	0	0	44	27.269
BUS-021	Ajaokuta SS	0.945387	311.978	13.6253	0	0	15	9.296
BUS-022	Onitsha SS	0.951632	314.038	28.3224	0	0	152	94.201
BUS-023	Okpai TS	0.99413	328.063	30.6515	0	0	0	0
BUS-024	New Haven SS	0.918722	303.178	25.7443	0	0	135.6	84.037
BUS-025	Alaoji SS	0.976813	322.348	42.3836	0	0	250	154.936
BUS-026	Afam SS	0.989122	326.41	43.9424	0	0	64	39.664
BUS-027	Jebba GS	1	16	11.6138	415.001	126.687	0	0
BUS-028	Kainji GS	1	16	12.0456	290.002	87.442	0	0
BUS-029	Shiroro GS	1.072189	16.297	8.9848	530.002	400	0	0
BUS-030	AES GS	0.997882	10.478	0.8985	237	53	0	0
BUS-031	AES TS	0.945153	124.76	0.2649	0	0	0	0
BUS-032	Egbin GS	1	16	0	476.165	968.21	0	0
BUS-033	Sapele GS	0.906472	14.277	16.8595	77	70	0	0
BUS-034	Delta II GS	1	11.5	20.1376	100	81.584	0	0
BUS-035	Delta II TS	1.001409	132.186	18.9896	0	0	0	0
BUS-036	Delta IV GS	0.942054	10.834	17.7525	238.002	199.999	0	0
BUS-037	Okpai GS	1	15.75	32.2839	298	297.739	0	0

BUS-038	Afam GS	1	11.5	45.9723	685.002	305.051	0	0
BUS-039	Alaoji GS	1.004673	15.07	44.1939	150.001	8	0	0
BUS-040	Alaoji TS	0.976924	322.385	42.4464	0	0	0	0
Total					3496.175	2597.712	3416.8	1811.419

3.6 New generation versus shedded base load with reactor (Scenario 6)

With the connection of a 25MVAr reactor at bus 23-(Alaoji SS), the assigned reactive power output from the new generation at bus-39 is increased from 8MVAr to 76MVAr, while the reactive power output from the Okpai GS (at bus 37) is reduced to 292.49MVAr which is an improvement of scenario 1. The results displayed in Table show that the network performance is stable; having no violation in bus voltage.

Table 6: Load flow study results for scenario 6

Busbar ID	Bus Name	pV (pu)	V (kV)	AV (deg)	PG (MW)	QG (MVAr)	PL (MW)	QL (MVAr)
BUS-01	Jebba TS	0.99058	326.89	10.0364	0	0	0	0
BUS-02	Jebba SS	0.98852	326.212	9.7043	0	0	12	7.437
BUS-03	Kainji TS	0.99502	328.355	11.222	0	0	0	0
BUS-04	Birnin kebbi	0.93203	307.57	6.2763	0	0	85	52.678
BUS-05	Shiroro SS	1.02015	336.651	6.3109	0	0	120	74.369
BUS-06	Katampe SS	0.98764	325.921	3.7826	0	0	185	114.653
BUS-07	Kaduna SS	1.00343	331.132	3.2423	0	0	161.1	-53.221
BUS-08	Kano SS	0.94562	312.055	-1.1352	0	0	104	64.453
BUS-09	Jos SS	0.96303	317.801	-0.1832	0	0	48	29.748
BUS-010	Gombe SS	0.9349	308.517	-2.6549	0	0	48	29.748
BUS-011	Osogbo SS	0.94286	311.142	5.1796	0	0	180	111.554
BUS-012	Ayede SS	0.92114	303.976	-1.7374	0	0	240.1	-4.261
BUS-013	Ikeja West SS	0.91054	300.477	-3.0258	0	0	550	340.859
BUS-014	Benin SS	0.94726	312.596	13.9124	0	0	120	74.369
BUS-015	Egbin SS	0.98427	324.808	-1.6619	0	0	260	161.134
BUS-016	Akangba SS	0.90133	297.438	-3.7841	0	0	400	247.898
BUS-017	Sapele SS	0.96206	317.479	14.8255	0	0	0	0
BUS-018	Aja SS	0.98078	323.656	-1.9385	0	0	200	123.949
BUS-019	Aladja SS	0.98133	323.839	15.9633	0	0	43	26.649
BUS-020	Delta SS	0.99437	328.141	16.7679	0	0	44	27.269
BUS-021	Ajaokuta SS	0.94593	312.157	13.6159	0	0	15	9.296
BUS-022	Onitsha SS	0.95288	314.449	28.2836	0	0	152	94.201
BUS-023	Okpai TS	0.99466	328.236	30.6119	0	0	0	0
BUS-024	New Haven SS	0.92002	303.605	25.7125	0	0	135.6	84.037
BUS-025	Alaoji SS	0.98053	323.575	42.2571	0	0	250.1	179.936
BUS-026	Afam SS	0.99115	327.08	43.8147	0	0	64	39.664
BUS-027	Jebba GS	1	16	11.6125	415	126.255	0	0
BUS-028	Kainji GS	1	16	12.0444	290.001	87.244	0	0
BUS-029	Shiroro GS	1.07223	16.298	8.9835	530.002	400	0	0
BUS-030	AES GS	0.99795	10.478	0.8986	237	52.999	0	0
BUS-031	AES TS	0.94522	124.768	0.2651	0	0	0	0

BUS-032	Egbin GS	1	16	0	476.02	967.228	0	0
BUS-033	Sapele GS	0.90692	14.284	16.8468	77	70	0	0
BUS-034	Delta II GS	1	11.5	20.1255	100	80.909	0	0
BUS-035	Delta II TS	1.00155	132.205	18.9773	0	0	0	0
BUS-036	Delta IV GS	0.94243	10.838	17.7398	238.002	199.999	0	0
BUS-037	Okpai GS	1	15.75	32.245	298	292.494	0	0
BUS-038	Afam GS	1	11.5	45.8462	685.002	266.295	0	0
BUS-039	Alaoji GS	1.0226	15.339	43.9878	150.002	76	0	0
BUS-040	Alaoji TS	0.98112	323.769	42.3171	0	0	0	0
Total					3496.029	2619.423	3416.9	1836.419

4. Conclusion

This study presents a power system analysis of the Nigeria 330kv electricity network. The load flow study of the network at different generation and loading scenarios revealed that there is voltage violation at bus - Kano, Jos, Gombe and Ayede. The violation of voltage statutory limits at these buses without reactive power compensation confirms the reality of the poor electric power supply across the northern geographical region of the country. This is even evident in spite of the minimum loading condition of the network. Therefore, to improve the efficiency of the network, reactive power compensators are added to the weak bus locations. The integration of 150MW additional power from the newly built Alaoji generation station to the network at Alaoji substation did not exceed the transfer capacity of the old Alaoji-Onitsha single circuit transmission line. The balanced three - phase fault study results show that the network can be operated safely during short circuit condition since the short circuit level of the buses are not exceeded during the fault condition.

References

Adebayo, I.G., Aborisade, and Oyesina, K.A. (2013). Steady State Voltage Stability Enhancement Using Static Synchronous Series Compensator (SSSC); A Case Study of Nigerian 330kv Grid System. Research Journal in Engineering and Applied Sciences,2 :54-61.

Adebayo, I.G., Adejumobi, I.A. and Olajire, O.S. (2013). Power Flow Analysis and Voltage Stability Enhancement Using Thyristor Controlled Series Capacitor (TCSC) FACTS Controlle. International Journal of Engineering and Advanced Technology (IJEAT), 2 : 100-104.

Adepoju, G.A., Tijani, M.A., Sanusi, M.A. and Olatunji, D.O. (2013). Three-Phase Fault Currents Evaluation For Nigerian 28-Bus 330kV Transmission System. International Journal of Engineering Research and Applications (IJERA),3: 125-132.

Ariyo, F.K. (2013). Investigation of Nigerian 330 kV Electrical Network With Distributed Generation Penetration – Part III: Deterministic And Probabilistic Analyses. American Journal of Electrical Power and Energy Systems, 2 : 7-22.

Chapman, S.J. (2002). Electric Machinery and Power System Fundamentals. Boston: McGraw/Hill, 2002.

Bakare, G.A.,Venayagamoorthy, G.K., and Aliyu, U.O (2005). Reactive power and voltage control of the Nigerian grid system using micro-genetic algorithm. IEEE Power Engineering Society General Meeting, 2: 1916-1922.

Eseosa, O. and Ogujor,E.A. (2012). Determination of Bus Voltages, Power Losses and Flows in the Nigeria 330kV Integrated Power System. International Journal of Advances in Engineering & Technology, IJAET, 4: 94-106.

Hassan, M.O., Cheng, S.J. and Zakaria, Z.A. (2009) . Steady-State Modeling of SVC and TCSC for Power Flow Analysis. Proceedings of the International MultiConference of Engineers and Computer Scientists, Hong Kong.

Hojabi, M. and Hizam, H. (2011). Available Transfer Capability Calculation. Applications of MATLAB in Science and Engineering. [Online]. Available: https://www.researchgate.net/publication/221915923_Available_Transfer_Capability_Calculation

Ibe, A.O. and Okedu, E.K. (2009). A Critical Review of Grid Operations in Nigeria. The Pacific Journal of Science and Technology,10 : 486-490.

Ibe, A.O. and A. Odia, A. (2011). Transient Stability Assessment of the Nigerian 330kV Network. International Journal of Engineering (IJE), 4: 357-367.

Ifeanyi, O.P and John,O.K. (2012). Power Flow and Contingency Assessment of the Existing

330kV Nigeria Power Grid to Cope With the Proposed Increase In Power Generation. International Journal of Engineering Research & Technology (IJERT), 1: 1-9.

Izuegbunam, F.I., Duruibe, S.I. and Ojukwu, G.G. (2011). Power flow and Contingency Assessment Simulation of the expanding 330KV Nigeria Grid Using Power World Simulator. Journal of Emerging Trends in Engineering and Applied Sciences (JETEAS) 2: 1002-1008.

Kour, G., Brar, G.S. and Jaswanti . (2012). Static VAR Controller based Power Flow Control in Distribution System by GA. International Journal of Engineering Research and Applications (IJERA), 2: 1857-1862.

Liangzhong, Y., Cartwright, P., Schmitt, L. and Xiao-Ping, Z. (2005). Congestion Management of Transmission Systems Using FACTS. Transmission and Distribution Conference and Exhibition: Asia and Pacific, IEEE/PES : 1-5.

Maruf, A.A. and Garba, K.U. (2013). Determination of Bus Voltages, Power Losses and Load Flow in The Norhtern Nigeria 330kv Transmission Sub-Grid. International Journal of Advancements in Research & Technology, 2:1-9.

Murali, D. and Rajaram, M. (2010). Active and Reactive Power Flow Control using FACTS Devices. International Journal of Computer Applications, 9: 45-50.

National Integrated Power Project (NIPP).(2007). Integration and Evacuation Study for National Integrated Power Projects(NIPP) Nigeria (1 ed.). [Online]. Available: http://www.scribd.com/doc/108682364/NIPP-Grid-Study-Final-Report-April-2007-Executive-Summary-and-Background-Report http://cdn.intechopen.com/pdfs-wm/18561.pdf.

Onohaebi,O.S. (2009). Power Outages in the Nigeria Transmission Grid. Research Journal of Applied Sciences, 4: 1-9.

Presidential Task Force on Power (PTFP). (2014). Nigeria Generation Report. [Online]. Available: http://www.nigeriapowerreform.org/

Saadat, H.(1999). Power System Analysis. NY: WCB/McGRAW-Hill.

Sadiq, A. A.and Nwohu, M.N. (2013). Evaluation of Inter – Area Available Transfer Capability of Nigeria 330kV Network. International Journal of Engineering and Technology, 3: 148-158.

Song, Y. H. and Johns, A.T. (2011). Investigation of Reactive Power Control and Compensation for HVDC System. Electrical and Computer Engineering. The University of Manitoba, Canada.

Tamimi, B., Canizares, C.A. and Vaez-Zadeh, S. (2010). Effect of Reactive Power Limit Modeling on Maximum System Loading and Active and Reactive Power Markets. Power Systems, IEEE Transactions,25: 1106-1116.

Weedy, B.M., Cory, B.J., Jenkins, J.B. and Ekanayake, S. (2012). Electric power systems, 5th ed. ed. West Sussex, UK: John Wiley & Sons, Ltd .

Yousefi, A., Nguyen, T.T., Zareipour, H. and Malik, O.P. (2012). Congestion Management Using Demand Response and FACTS Devices. Electrical Power and Energy Systems 37: 78-85.

Zeraatzade, M. (2010).Transmission Congestion Management by Optimal Placement of FACTS Devices. School of Engineering and Design Brunel University,United Kingdom.