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Contingency Analysis of the Nigeria 330kv Grid System (post-reform) Using Power World Simulator

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Abstract:- With the Nigeria Power Sector going through reforms, it is very important to be able to predict the extent of violations that can occur in the network in the event of unprecedented contingencies. This is usually achieved through contingency analysis of the network in order to make for adequate provision of infrastructure to ensure system security in event of such contingencies. In this paper, single line contingency analysis for the Nigeria 330kv post-reform grid to determine violations in the network due to the individual contingencies were considered using power world simulator. The simulation result indicates that with generator contingency at KainjuI, there were four bus violations with a maximum per unit voltage of 1.154 from table 3. There were twenty one bus violations for Shiroro-Jebba, Jebba-Gamno, Shiroro-Mando, Mando-Jos, Jos-Gombe, Jos-Markudi, Damaturu-Gombe, Damaturu-Mambilla, Ikeja-Egbin and Nassarawa-Markud line with minimum per unit voltage of 0.315Pu representing Damaturu-Mambilla.

Keywords:- Contingency, Violations, Post-reform grid, Power world, System analysis

I. INTRODUCTION

The on-going reform in the Nigeria Power sector, among its numerous objectives, is to produce radical expansion of the existing grid network. It is expected that in the next few years, a much larger, more fortified and stable grid will replace the scanty, unstable and fragile grid that exists presently. This is a major objective of the on-going reform in the power sector. As a solution to the country's present power crisis, caused majorly by a weak grid network, the Nigerian government has mapped out a reform program for the power sector which has in its short term plan the objective of expanding the grid to a total generation capacity of 10,000MW by the year 2011.

Power system network consist of equipment like generators, transformers, transmission lines, circuit breakers etc. Failure of any of this equipment during its operation harms the reliability of the system and hence leading to outages. Therefore, one of the major aim of power system planning and its operation is to study the effect of outages in terms of its severity [1]. All over the world, countries are expanding their power system networks in other to meet up with developmental challenges and this is accompanied by increased Contingencies referring to disturbances such as transmission element outages or generator outages which may always cause sudden and large changes in both the configuration and the state of the system. Contingencies may result in severe violations of the operating constraints. Consequently, planning for contingencies forms an important aspect of secure operation [2].

The rapid increase in the demand for electricity as a result of population growth, industrial development and rise in consumer electrical appliances have necessitated the stepping up of generation and transmission capabilities of the grid network to deliver quality power supply to the consumers. Various researches have shown that the existing grid network is inadequate and lacks the capacity to provide the right quantity and quality of power for the whole country [3][4][5][6]. It must be noted however that most of the solutions proffered by these researchers demand moderate expansion and changes in the grid network. The detailed load flow study of the emerging grid was carried out on the Nigerian power grid with focus on the 330kV power transmission lines, all generating stations and 330kV substations.

A look at the reform in Nigeria so far shows that the government is pursuing a plan of unbundling the power sector, establishing an independent regulator and eventually privatizing its assets (KP) The focus is on how to privatize distribution companies to bring the pricing of wholesale and retail power to cost recovery level, to improve collections of bills and to enforce the disconnections of non- paying customers. The unbundling had led to establishment of 18 successor companies from NEPA comprising 6 generation companies, one Transmission company and 11 Distribution companies. The sector has also been deregulated leading to private sector participation in the generation sector and a number of Independent Power Producers (IPPs) are in operation in the country today. Each of the 18 companies has its own management that is self-accounting and not dependent on government funding.

The purpose of contingency analysis is to analyze the power system in order to identify the overloads and problems that can occur due to a "contingency". This is an abnormal condition in electrical network. It puts the whole system or a part of the system under stress. It occurs due to sudden opening of a transmission line, generator tripping, sudden change in generation and load values. Contingency analysis provides tools for managing, creating, analyzing, and reporting lists of contingencies and associated violations in a power system [7]

II. MATERIALS AND METHODS

The software used for the analysis and simulation of the 330kv grid to achieve the solution of the power flow problem is Power World Simulator version 16.0 (Educational version).
Contingencies referring to disturbances such as transmission element outages or generator outages may cause sudden and large changes in both the configuration and the state (parameters) of the system. Contingencies may result in severe violations of the system operating constraints. Consequently, planning for contingencies is an important aspect of the secure power grid operation in the presence of emerging Nigerian power market deregulation [8].

Power flow analysis is a tool used to perform, investigate the magnitude and phase angle of the voltage at each bus including the real and reactive power flows in the system components.

Variables of Power Flow Study

At each bus two of four quantities δ, │V│, P and Q are specified and the remaining two are calculated. Where; δ is the line angle: V is the line or system voltage. P and Q are the active and reactive powers, respectively

Table 1. Power Flow variables

Bus Type	*Known Variables*	*Unknown Variables*
Swing/ Slack/ reference bus	V , δ	P , Q
PV/ Generator/ Voltage Control Bus	P , V	Q , δ
PQ/ Load Bus	P , Q	V , δ

Developing Power Relation

$\mathbf{I}_{\mathbf{BUS}} = \mathbf{Y}_{BUS}\mathbf{V}_{BUS}$ **(1)**

When the bus currents are known, equation (7) for any ***n*** buses can be solved for bus voltage as

$\mathbf{V}_{BUS} = \mathbf{Y}^{-1}{}_{BUS}\, \mathbf{I}_{BUS}$ **(2)**

$\mathbf{Y}^{-1}{}_{BUS}$ (*which is the inverse of the bus admittance matrix*) is known as bus impedance matrix $\mathbf{Z}_{BUS}$.

Derivation of Power Flow Equations

The expression for the apparent power injected into any ***i*** named bus is given

$\mathbf{S}_i = \mathbf{P}_i + j\mathbf{Q}_i$ **(3)**

$\mathbf{S}_i = \mathbf{V}_i\mathbf{I}_i^*$ **(4)**

Where

$\mathbf{P}_i$ is real power component of power in bus *i*

$\mathbf{Q}_i$ is reactive power component of power in bus *i*

$\mathbf{V}_i$ is bus Voltage at bus *i*

$\mathbf{I}_i$ is bus current at bus *i*

$\mathbf{P}_i + j\mathbf{Q}_i = \mathbf{V}_i\mathbf{I}_i^*$ **(5)**

$\mathbf{P}_i - j\mathbf{Q}_i = \mathbf{V}_i^*\mathbf{I}_i$ **(6)**

$$\mathbf{I}_i = \sum_{k}^{n} \mathbf{Y}_{ik}\mathbf{V}_k \quad \textbf{(7)}$$

For i ,*k* = 1,2,3,... **n**

Where $\mathbf{Y}_{ik}$ is the admittance for the transmission line between buses i and k

The substitution of (7) into (6) gives

$$\mathbf{P}_i - j\mathbf{Q}_i = \mathbf{V}_i^* \sum_{k}^{n} \mathbf{Y}_{ik}\mathbf{V}_k \qquad (8)$$

Comparing terms;

$\mathbf{P}_i$ represents the real part while $\mathbf{Q}_i$ represents the negative imaginary part of the RHS of equation (8). Mathematicallythis becomes,

$$\mathbf{P}_i = \text{real part of } \mathbf{V}_i^* \sum_{k}^{n} \mathbf{Y}_{ik}\mathbf{V}_k. \qquad (\mathbf{9})$$

$$\mathbf{Q}_i = -\text{ imaginary part of } \mathbf{V}_i^* \sum_{k}^{n} \mathbf{Y}_{ik}\mathbf{V}_k \qquad (\mathbf{10})$$

With $\mathbf{Y}_{ik}=\mathbf{G}_{ik} + \mathbf{B}_{ik}$ recall that in their polar forms $\mathbf{Y}_{ik}$, $\mathbf{V}_i^*$ and $\mathbf{V}_k$ are given as

$$\mathbf{Y}_{ik} = |Y_{ik}|e^{j\theta_{ik}} = |Y_{ik}| \angle \theta_{ik} \qquad (11a)$$

$$\mathbf{V}_i^* = |V_i|e^{-j\delta_i} = |V_i| \angle -\delta_i \qquad (\mathbf{11b})$$

$$\mathbf{V}_k = |V_k|e^{j\delta_k} = |V_k| \angle \delta_k \qquad (12)$$

Where θ_{ik} andδ are the phase angle of the admittance and the bus voltage respectively.

Sustituting for $\mathbf{Y}_{ik}$, $\mathbf{V}_i^*$ and $\mathbf{V}_k$in equation (8) **(13)**

$$\mathbf{P}_i - j\mathbf{Q}_i = |V_i|e^{-j\delta_i} \sum_{k}^{n} |Y_{ik}|e^{j\theta_{ik}}|V_k|e^{j\delta_k}$$

$$\mathbf{P}_i - j\mathbf{Q}_i = |V_i| \sum_{k}^{n} |Y_{ik}||V_k|e^{j(\theta_{ik}+\delta_k-\delta_i)}$$

This implies that

$$\mathbf{P}_i - j\mathbf{Q}_i = |V_i| \sum_{k}^{n} |Y_{ik}||V_k|e^{j(\theta_{ik}-\delta_i+\delta_k)} \qquad (14)$$

For ***i, k*** *= 1,2,3,...**n***

$$\mathbf{P}_i = |V_i| \sum_{k}^{n} |Y_{ik}||V_k|\cos(\theta_{ik} - \delta_i + \delta_k) \qquad (\mathbf{15})$$

$$\mathbf{Q}_i = -|V_i| \sum_{k}^{n} |Y_{ik}||V_k|\sin(\theta_{ik} - \delta_i + \delta_k) \qquad (\mathbf{16})$$

For ***i, k*** *= 1,2,3,...**n.***

$$\mathbf{P}_i = |V_i|^2|Y_{ii}|\cos\theta_{ii} + |V_i| \sum_{k\neq i}^{n} |Y_{ik}||V_k|\cos(\theta_{ik} - \delta_i + \delta_k) \qquad (\mathbf{17})$$

$$\mathbf{Q}_i = -|V_i|^2|Y_{ii}|\sin\theta_{ii} - |V_i| \sum_{k\neq i}^{n} |Y_{ik}||V_k|\sin(\theta_{ik} - \delta_i + \delta_k) (\mathbf{18})$$

Contingency Analysis

Many possible outage conditions could happen to a power system. Thus, there is a need to have a means to study a large number of them, so that load dispatchers can be warned ahead of time if one or more outages will cause serious overload on other equipment. The problem of studying all possible outages becomes very difficult to solve since it is required to

Present the results quickly so that corrective actions could be taken. To meet this requirement, a special type of analysing program is designed named Contingency analysis that model failure events, one after the other in sequence until all credible outages have been studied. [9]

III. RESULTS AND DISCUSSION

The run mode of the power world simlator software is the mode where the actual power flow or load flow simulation and the voltage stability analysis was done. This mode allowed in performing a load flow analysis in other to produce some unknown variables such as the active and the reactive power for the slack bus, the reactive power for the generator buses, the voltages in the load buses and the angles for all the buses in the network as shown. The result of the plots of the simulations are shown in figures 2 to 9.

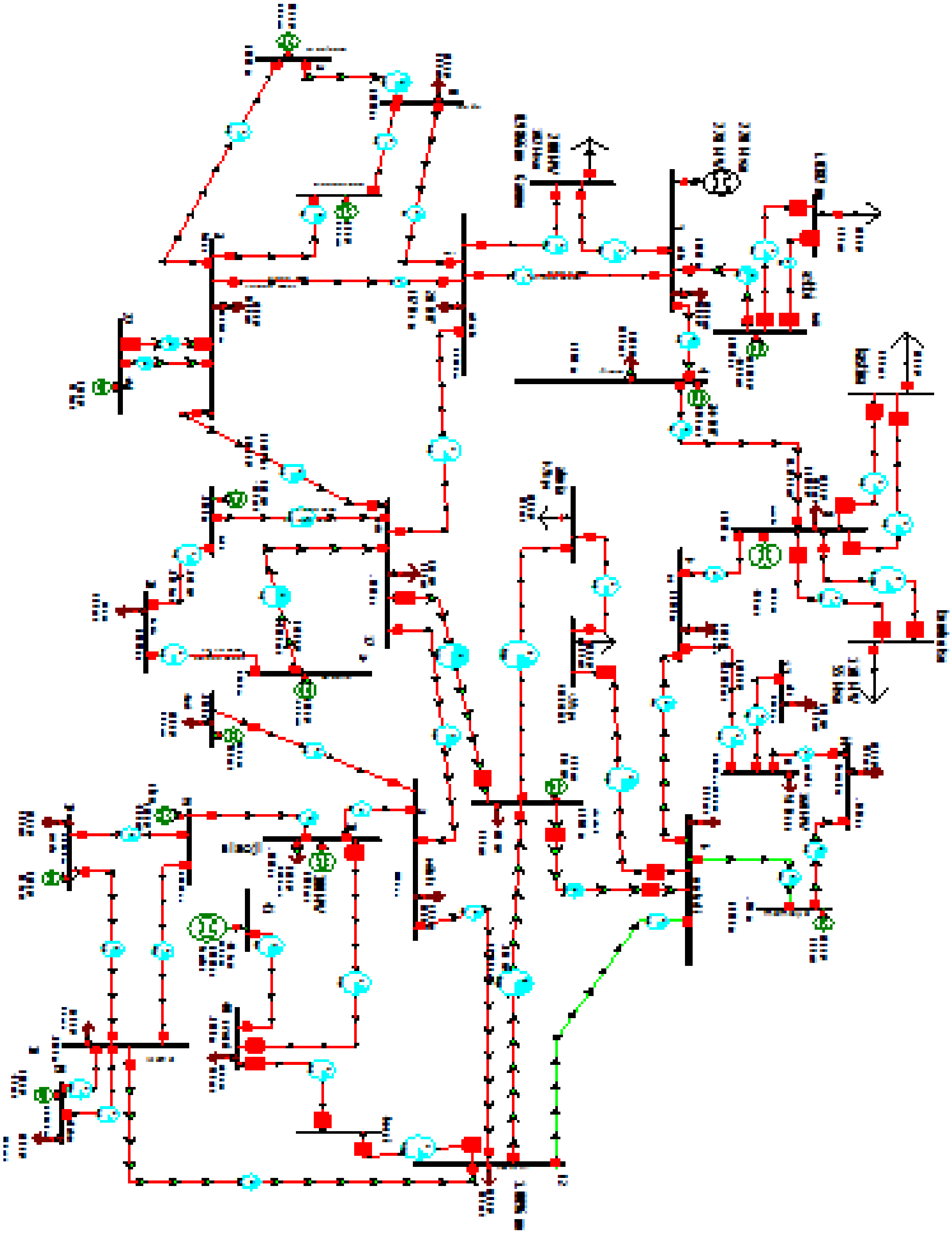

Figure 1: The simulated Nigeria 330kv grid on the power world platform

In the same run mode, the power world simulation software was used to perform a set of single line contingencies. Load flow analysis are applied during simulation of lines and generators outages. Some violations were noticed when the actual power flow simulation was conducted on the forty one bus interconnected network. The summary of various contingencies are shown in tables 2 – 7. While tables 8 and 9 show number of outages that lead to bus and line violations.

Table 2 Summary of generator contingencies

Label	Violations	Max Branch %	Min Volt	Max Volt
kanjiU1	4	103.3		1.154
jebbaU1	1		0.94	
shiroroU1	0			
olunrunsogoU1	0			
gereguU1	0			
sapelleU1	0			
deltaU1	0			
papalantoU1	0			
egbinU1	1	203.9		
afamU1	0			
alaojiU1	0			
okpaiU1	0			
mambiyaU1	3		0.923	
guararaU1	0			
omokuU1	0			
calabarU1	0			
egbemaU1	0			

Table 3 bus violation summary

shutdown element	affected element	Value	limit
Kanji	Kanji	1.11	1.05
	Kebbi	1.15	1.05
Jebba	Ganmo	0.94	0.95
Mambiya	Gombe	0.93	0.95
	Yola	0.92	0.95
	Damaturu	0.93	0.95

Table 4. Line violation summary

shutdown element	affected element	Value (MVA)	limit	percent
Kanji	egbin - ikeja.w	802.77	777.34	103.3
	egbin - ikeja.w	802.77	777.34	103.3
Egbin	kanji –Jebba	1585.06	777.34	203.9

Table 5.The contingency record for the lines is shown below.

Label	Violations	Max Branch %	Min Volt	Max Volt
kanji-jebba	0			
kebbi-kanji	0			
kebbi-kanji	0			
shiroro-jebba	1	111		
jebba-oshogbo	0			
jebba-Ganmo	1		0.934	
shiroro-mando	1	105		
oshogbo-benin	0			
oshogbo-ikeja.w	0			

oshogbo-ayede	0			
Ganmo-oshogbo	0			
mando-jos	3		0.928	
mando-kumbotso	0			
mando-kumbotso	0			
mando-kastina	0			
kastina-mando	0			
jos-gombe	3		0.921	
jos-markurdi	1		0.949	
yola-gombe	0			
damaturu-gombe	3		0.735	
olunrunsogo-ikeja.w	0			
ayede-olunrunsogo	0			
damaturu-mambiya	4		0.315	
ajaokuta-benin	0			
benin-sapelle	0			
benin-onitcha	0			
benin-delta	0			
ikeja.w-benin	0			
ajaokuta-new.h	0			
markurdi-ajaokuta	0			
abuja-ajaokuta	0			
aladja-sapelle	0			
onitcha-alaoji	0			
onitcha-okpai	0			
onitcha-new.h	0			
delta-aladja	0			
papalanto-ikeja.w	0			
ikeja.w-egbin	1	127.2		
ikeja.w-egbin	1	127.2		
ayede-papalanto	0			
alaoji-afam	0			
afam-omoku	0			
afam-ikot.e	0			
alaoji-owerri	0			
markurdi-new.h	0			
new.h-ikote	0			
ebonyi-new.h	0			
markurdi-mambiya	0			
nasarawa-markurdi	2		0.884	
omoku-ikot.e	0			
ikot.e-calabar	0			
ikote-calabar	0			
bayelsa-owerri	0			
owerri-ebonyi	0			
abuja-nasarawa	0			

Table 6 showing the bus violation

shutdown element	affected element	Value	limit
jeba - Ganmo	Ganmo	0.93	0.95
jos - mando	Jos	0.93	0.95
	Gombe	0.95	0.95
	Yola	0.94	0.95

jos - Gombe	Gombe	0.93	0.95
	Yola	0.92	0.95
	damaturu	0.94	0.95
jos - markurdi	Yola	0.945	0.95
damaturu - Gombe	Jos	0.9	0.95
	Gombe	0.77	0.95
	Yola	0.74	0.95
nasarawa - Markurdi	Abuja	0.92	0.95
	Nasarawa	0.88	0.95

Table 7 showing the line violation

shutdown element	affected element	Value	limit	percent
jeba - shirroro	ajaokuta - markurdi	862.97	777.34	111.02
shiroro - mando	ajaokuta–markurdi	816.17	777.34	104.99
ikeja.w - egbin	egbin - ikeja.w	988.72	777.34	127.19

Determinations of the Network Weaknesses

Generally, the result of contingency analysis obtained from this network has helped to determine weakness in some elements on the network. The weak elements found in the network are the buses and transmission line. Network weaknesses is observed when a particular line or lines repeatedly becomes overloaded, when there is an occurrence of different outages and also when a particular bus repeatedly tend to rise above or below it acceptable values and when there is also an occurrence of different outages as showing in tables 8 and 9. The most violated element that led to bus violations was Yola and the number of outages that led to bus violation were five namely Mambilla, Jos-Mando, Jos-Gombe, Jos-Makurdi and Damaturu-Gombe

Table 8 showing number of outages that lead to bus violation

violated elements	number of outages that lead to bus violation	name of the outage elements	over voltage	under voltage
ganmo	2	Jebba	Nil	0.94
		jeba - Ganmo	Nil	0.93
Gombe	4	Mambiya	Nil	0.93
		jos - mando	Nil	0.945
		jos - Gombe	Nil	0.93
		damaturu - Gombe	Nil	0.77
Yola	5	Mambiya	Nil	0.92
		jos - mando	Nil	0.94
		jos - Gombe	Nil	0.92
		jos - markurdi	Nil	0.945
		damaturu - Gombe	Nil	0.74
Damaturu	2	Mambiya	Nil	0.93
		jos - Gombe	Nil	0.94
Jos	2	jos - mando	Nil	0.93
		damaturu - Gombe	Nil	0.9
kebbi	1	Kanji	1.15	Nil
Abuja	1	nasarawa - Markurdi	Nil	0.88

violated elements	number of outages that lead to line violation	name of the outage elements	MVA loadinf of the line
egbin - ikeja.w	2	egbin - ikeja.w	988.72
		Kanji	802.77
ajaokuta - markurdi	2	jeba - shirroro	862.97
		shiroro - mando	816.17

Table 9 showing the number of outages that lead to line violation

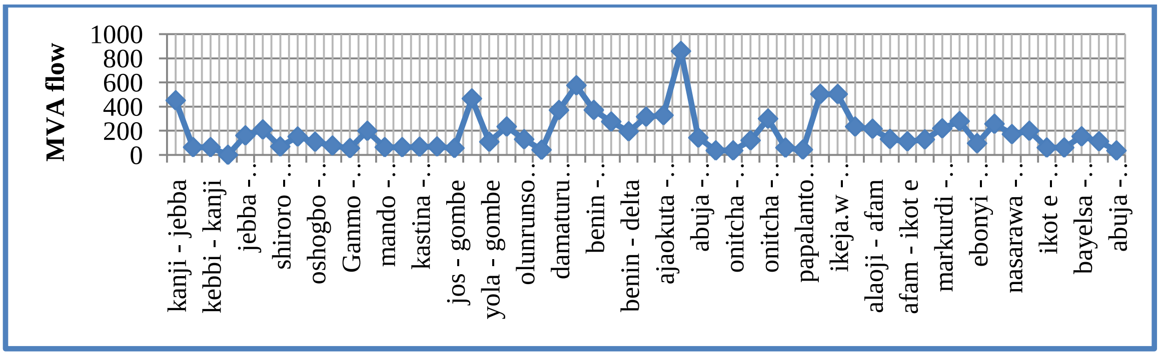

Fig 2 Graph showing violation when Jeba - Shirroro was shut down

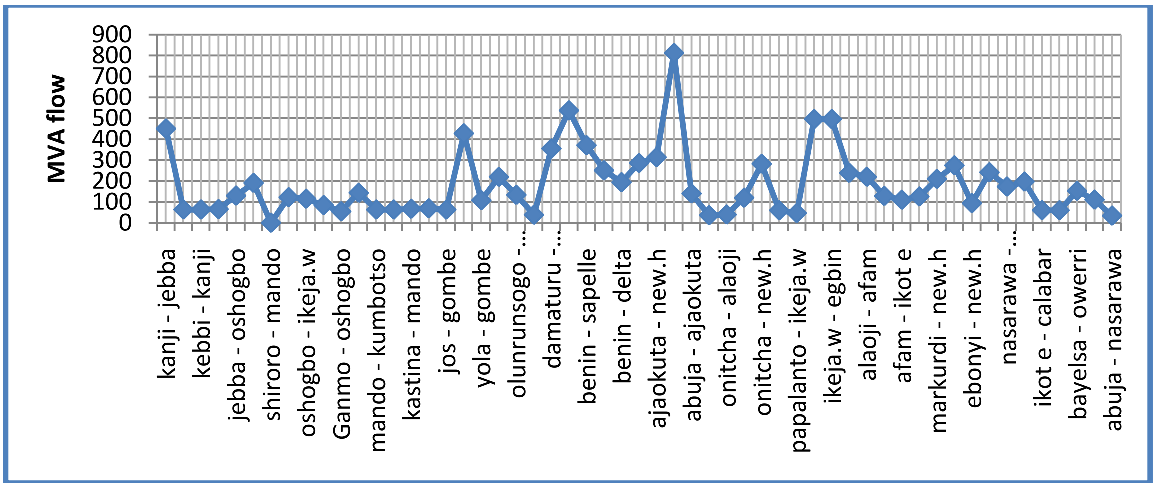

Fig 3showing when shiroro - mando was shut down

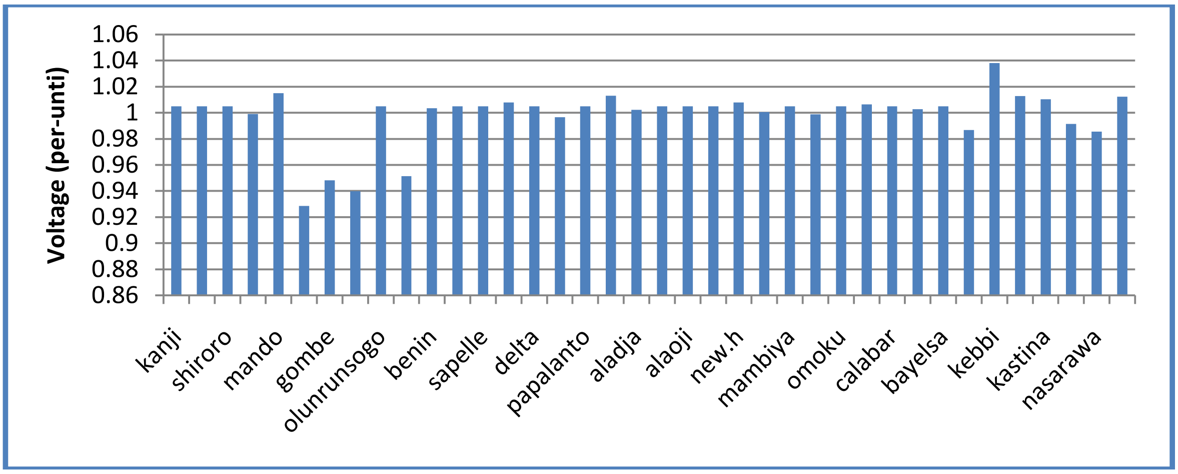

Fig 4 showing violation sumary of when jos - mando was shut down

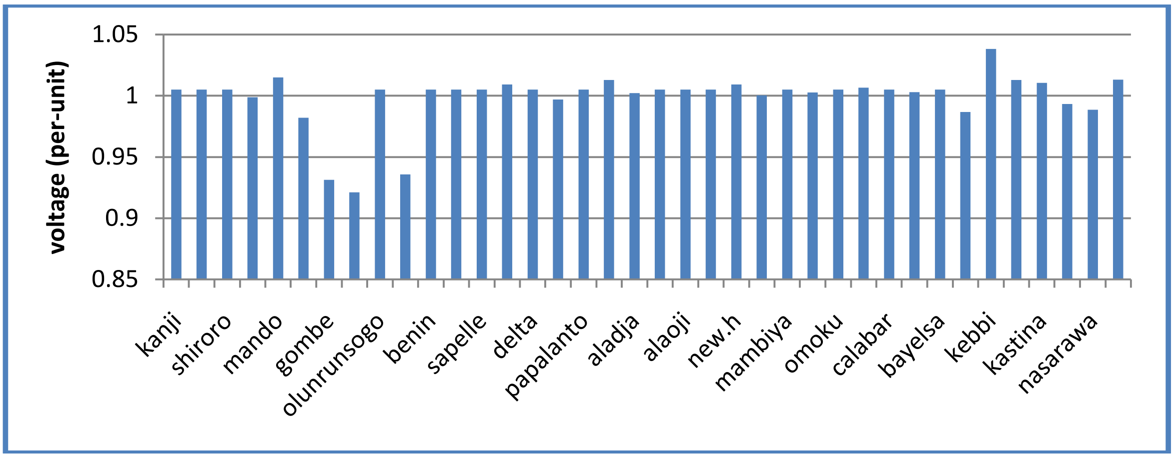

Fig 5showing the violation when jos - Gombe was shut down

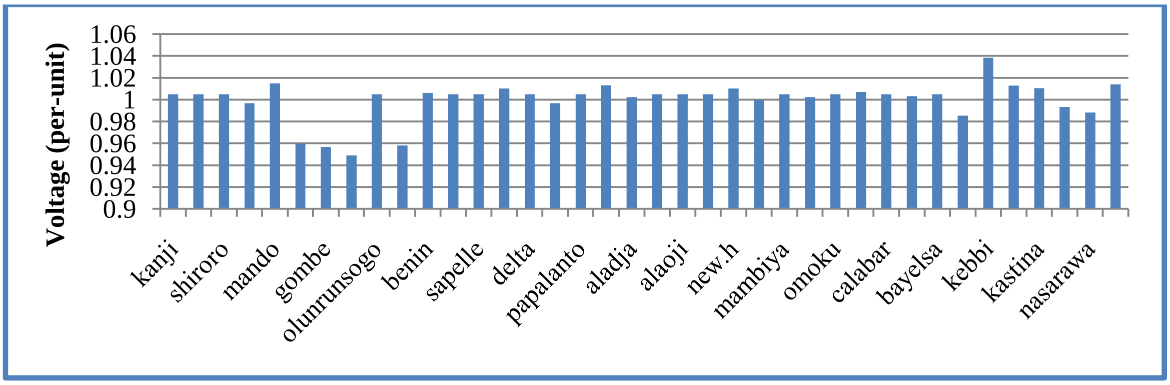

Fig 6 graph showing the violation when jos - markurdi was shut down

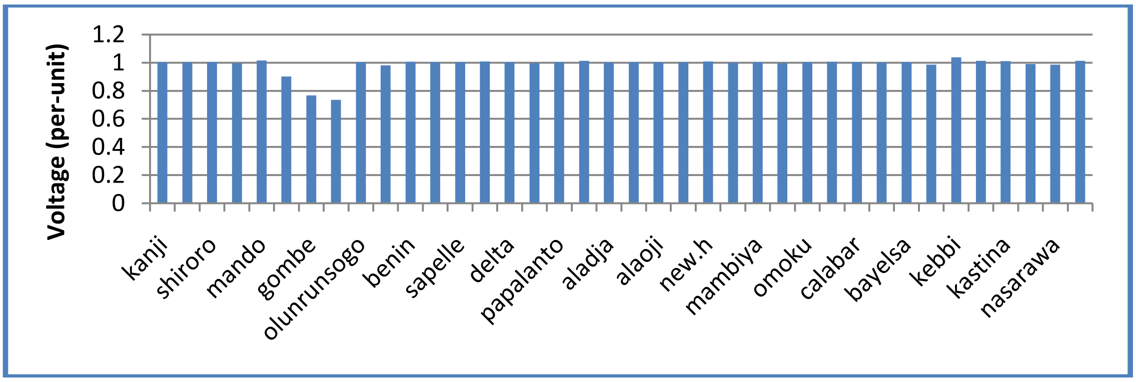

Fig7 showing the violation when damaturu - Gombe was shut down

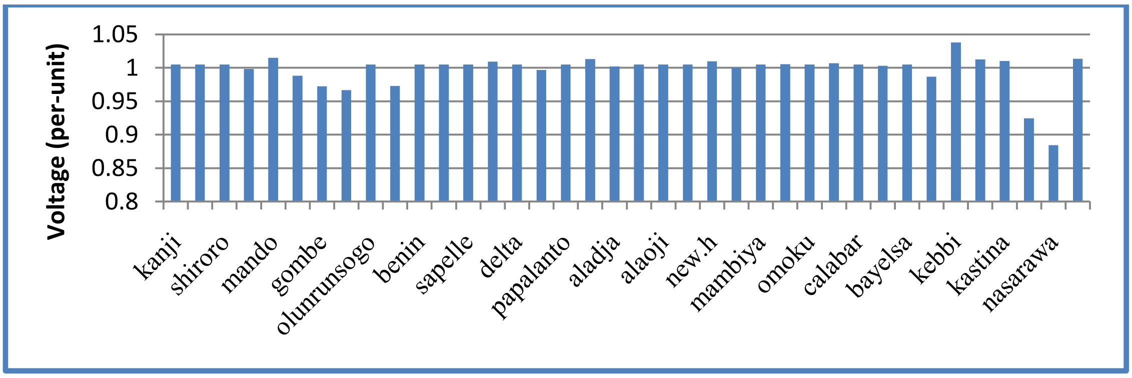

Fig 8 Showing whenNasarawa - Markurdi was shut down

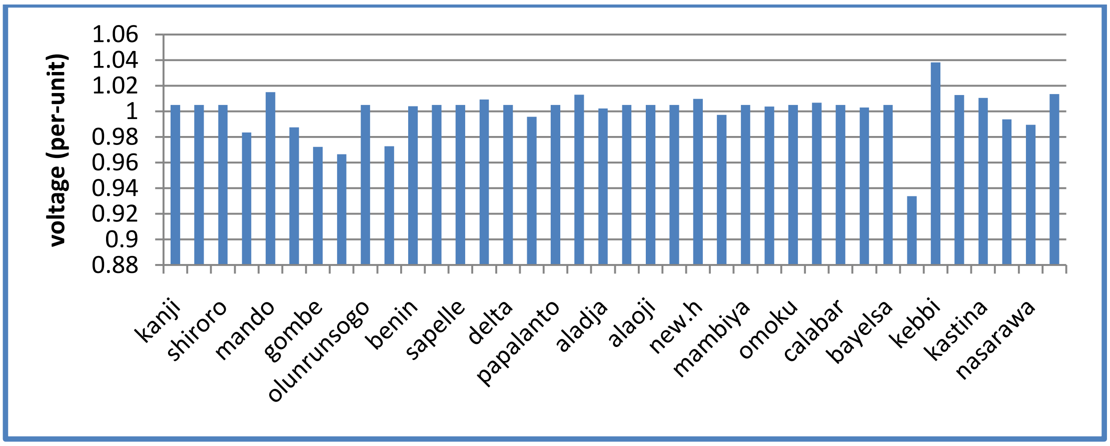

Fig 9 showing when Jebba-Ganmo was shut down

V. CONCLUSION

In the post-reform grid, Nigeria has a power network which unlike the pre-reform (existing) network, offers higher power generation capacity, stability, efficiency and reliability. It also has a higher percentage of double circuit and short transmission lines with more loops thereby reducing transmission losses and improving the reliability and efficiency of the network. With these observations, direct corrective actions can always be planned for the system.

The simulation result indicates that with generator contingency at Kainj uI, there were four bus violations with a maximum per unit voltage of 1.154 from table 3. There were twenty one bus violations for Shiroro-Jebba,Jebba-Gamno, Shiroro-Mando,Mando-Jos,Jos-Gombe,Jos-Markudi,Damaturu-Gombe, Damaturu- Mambilla,Ikeja-Egbin and Nassarawa-Markud line with minimum per unit voltage of 0.315Pu representing Damaturu-Mambilla.

REFERENCES

[1]. Ahmad, S., Zakria, N. M., Elahi, A. -U., &Biswas, G. A. K. (2011). *Contingency Analysis and Reliability Evaluation of Bangladesh Power System*.Thesis Report, BRAC University, Dhaka, Bangladesh.
[2]. Bakar, A. H. A, Ng, Y. Y., & Tan, C. K. (2014).Analysis of Overload Conditions on Generator Loss of Excitation Relay under Severe Contingencies.*AORC Technical meeting, C4-1013*
[3]. A.O Balogun: Impact Sector Reforms on Nigeria Electricity, Conference proceedings of the International Conference and Exhibition in Power Systems, Nigeria, July 2007, pp 123-128.
[4]. C.C. Okoro and K.C Achugbu: Contingency Evaluation of the 330kV National Grid, Proceedings of the International Conference and Exhibition in Power Systems, Lagos, Nigeria, July 2007, pp 137-146.
[5]. Transmission Company of Nigeria: Grid Network for the Evacuation of the Proposed 10, 000MW Power Generation, 2003.
[6]. Archive of Course Presentation on Power System Design and Protection: Grid Distant Protection Training Course Organized by ENERGO Nigeria Limited for PHCN Staff, 2004.
[7]. KPMG Handbook. (2013, December).*A guide to Nigeria power sector*.
[8]. Izuegbunam, F. I., Duruibe, S. I., &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*(6), 1002-1008.
[9]. Nonyelu, C. J., &Madueme, T. C. (2013). Power System Contingency Analysis: A Study of Nigeria's 330KV Transmission Grid. In proceeding of *Energy Source for Power Generation, At Electrical Engineering, University of Nigeria, Nsukka*, (Volume4).
[10]. Sadiq, A.A.; and Nwohu, M.N.2013. Evaluation of inter-area available transfer capacity of Nigeria 330kv network international journal of Engineering and Technology 3(2): 148-58.