Contingency Analysis of the Nigeria 330kv Post-Reform Integrated Power System 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 mambilla, there were six bus violations with a maximum per unit voltage of 1.166. There were also seven bus violations for Jos-Gombe and Damaturu-Mambilla line contingencies with minimum per unit voltages of 0.921 and 0.399 respectively.

Keywords: Contingency, Violations, Post-reform grid, Power world, Analysis

INTRODUCTION

A reliable, continuous supply of electrical energy is an essential part of today's complex societies. 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 (Roy, 2011). 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 (Chary, 2013).

The Nigerian Power Sector Privatisation is reputed to be one of the boldest privatization initiatives in the global power sector over the last decade, with transaction cost of about $3.0bn (KPMG Handbook, 2013). There are currently 20 grid-connected generating plants in operation in the Nigerian Electricity Supply Industry (NESI) with a total installed capacity of 10,396.0 MW and available capacity of 6,056 MW. Most generation is thermal based, with an installed capacity of 8,457.6 MW (81% of the total) and an available capacity of 4,996 MW (83% of the total). Hydropower from three major plants accounts for 1,938.4 MW of total installed capacity (and an available capacity of 1,060 MW).

Successor Generation Companies (Gencos): There are 6 successor Gencos in Nigeria.

Independent Power Producers (IPPs): IPPs are power plants owned and managed by the private sector. . The existing IPPs include Shell – Afam VI (642MW), Agip – Okpai (480MW) and AES Barges (270MW).

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National Integrated Power Projects: The National Integrated Power Project ('NIPP') is an integral part of Federal Government's efforts to combat the power shortages in the country. It was conceived as a fast-track public sector funded initiative to add significant new generation capacity to Nigeria's electricity supply system along with the electricity transmission, distribution and natural gas supply infrastructure required to deliver the additional capacity to consumers throughout the country. There are 10 National Integrated Power Projects (NIPPs), with combined capacity of 5,455 MW.

The Transmission Company of Nigeria (TCN) is a successor company of PHCN, following the unbundling of the sector, and is currently being managed by a Management Contractor, Manitoba Hydro International (Canada). Manitoba is responsible for revamping TCN to achieve technical and financial adequacy in addition to providing stable transmission of power without system failure. Currently, the transmission capacity of the Nigerian Electricity Transmission system is made up of about 5,523.8 km of 330 KV lines and 6,801.49 km of 132 KV lines.

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 sudden change in load value. Contingency analysis provides tools for managing, creating, analyzing, and reporting lists of contingencies and associated violations in a power system (Bakar, 2014; Izuegbunam, Duruibe and Ojukwu, 2011).

In the year 2014, Nigeria witnessed a lot of activities in the electric power sector, with reforms being at the core of such activities, but the national grid has remained a weak link along the value chain due to constant obstructions like failure of equipments which do cause overloads to other equipments and this has been complicated with transmission line expansions not being adequately planned (Business day magazine, 2014). There is need to establish a proper study on the probable contingencies in the system, as a tool for power system planners and operation engineers thereby breeching the gap in the knowledge of power system contingency and reliability planning of the pre reform era and current post reform era. This research was aimed at analysing the probable contingencies on the Nigeria 330kv post reform integrated power system in order to explore uncertainties and effects of alternative internal and external changes in the power systems and to identify limitations that can affect the power reliability and security operations.

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). The existing 330kv grid has a total of 17 generators. The generating units at Afam - iv-v and Afam vi, Sapelle G.S. and sapelle NIPP, Olorunshogo phase 1 and Olorunshogo NIPP were combined respectively during the analysis. The network has a total of 25 load buses.

Power Flow Study for Contingency Analysis

Contingency analysis is the study of the outage of elements such as transmission lines, transformers and generators, and investigation of the resulting effects on line power flows and bus voltages of the remaining system. It represents an important tool to study the effect of elements outages in power system security during operation and planning (Nonyelu & Madueme, 2013).

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Power flow analysis is probably the most important of all network calculations. It is performed to investigate the magnitude and phase angle of the voltage at each bus and 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.

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

$$I = \frac{V}{Z} = YV$$

$$I_{BUS} = Y_{BUS} \ V_{BUS}$$

$$I = \sum_{K=1}^{N} Y_{ik} \ V_k \text{ .... (1)}$$

$$V = |V| \ e^{J<V}$$

$$I = |I| \ e^{J<I}$$

$$I^* = |I| \ e^{-J<I}$$

$$S = V I^* = |V| \ |I|_e^{-J(<V - <1)}$$

$$= |V| \ |I|_e^{J(\theta)}$$

$$= |V| \ |I|^{(\cos\theta + j\sin\theta)}$$

$$= P + jQ$$

$$S = (VI^*)^* = V^*I = P - jQ$$

$$I_i = \frac{P_i - jQ_i}{V^*_i} \text{ .... (2)}$$

Using equation (1) replace I_i from (2)

$$\frac{P_i - jQ_i}{V^*_i} = \sum_{K=1}^{N} Y_{ik} \ V_k \text{ .... (3)}$$

$$Y_{ii} V_i + \sum_{K=1}^{N} Y_{ik} \ V_k \ (k \neq i)$$

$$V_i = \frac{1}{Y_{ii}} \left[\frac{P_i - jQ_i}{V_i^*} - \sum_{K=1}^{N} Y_{ik} V_k \right] \quad (k = i) \text{ .... (A)}$$

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Equation (3) can be written as,

$$P_i - jQ_i = V_i^* \sum_{K=1}^{N} Y_{ik} V_k$$

$$= V_i^* \left[Y_{ii} V_i + \sum_{K=1}^{N} Y_{ik} V_k \right] \quad (k \neq i)$$

$$Q_i = -Im \left[V_i^* (Y_{ii} V_i + \sum_{K=1}^{N} Y_{ik} V_k) \right] \quad (k \neq i) \text{ .... (B)}$$

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 operation personnel 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. (Ahmad, Zakria, Elahi & Biswas, 2011)

Contingency Analysis Procedure

How contingency analysis can be performed is described in a simple way in the following flowchart:

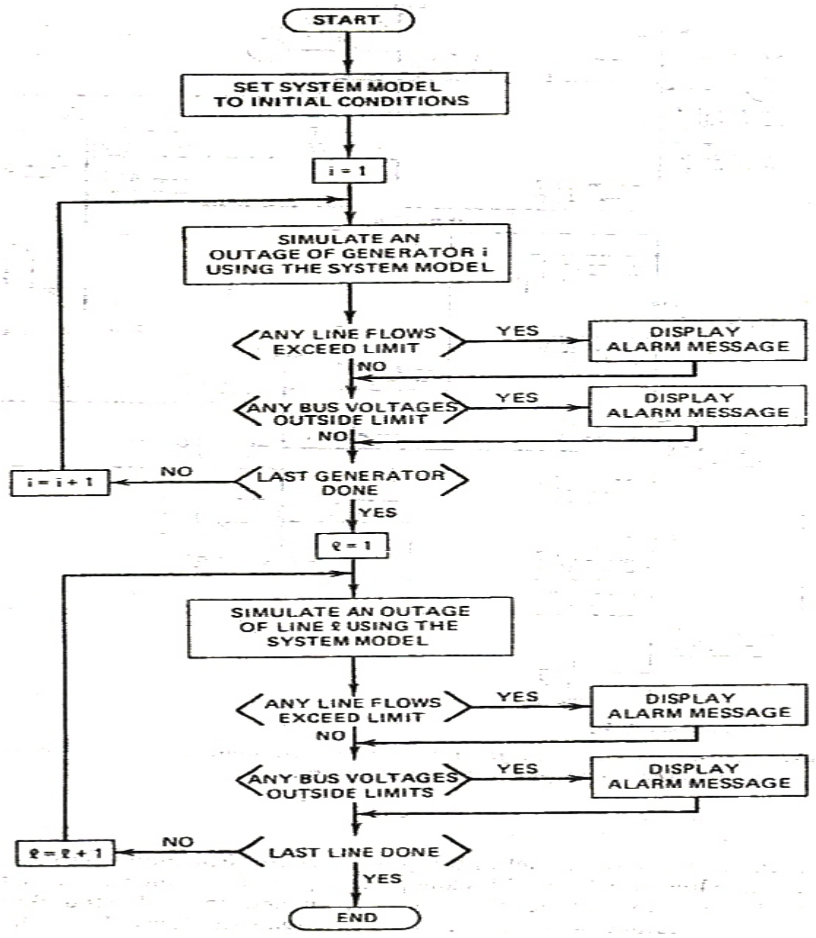

Figure 1. System flow chart

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RESULTS AND DISCUSSION

The run mode of the power world simulator 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 in figure 2. The result is shown in table 2 and figure 3.

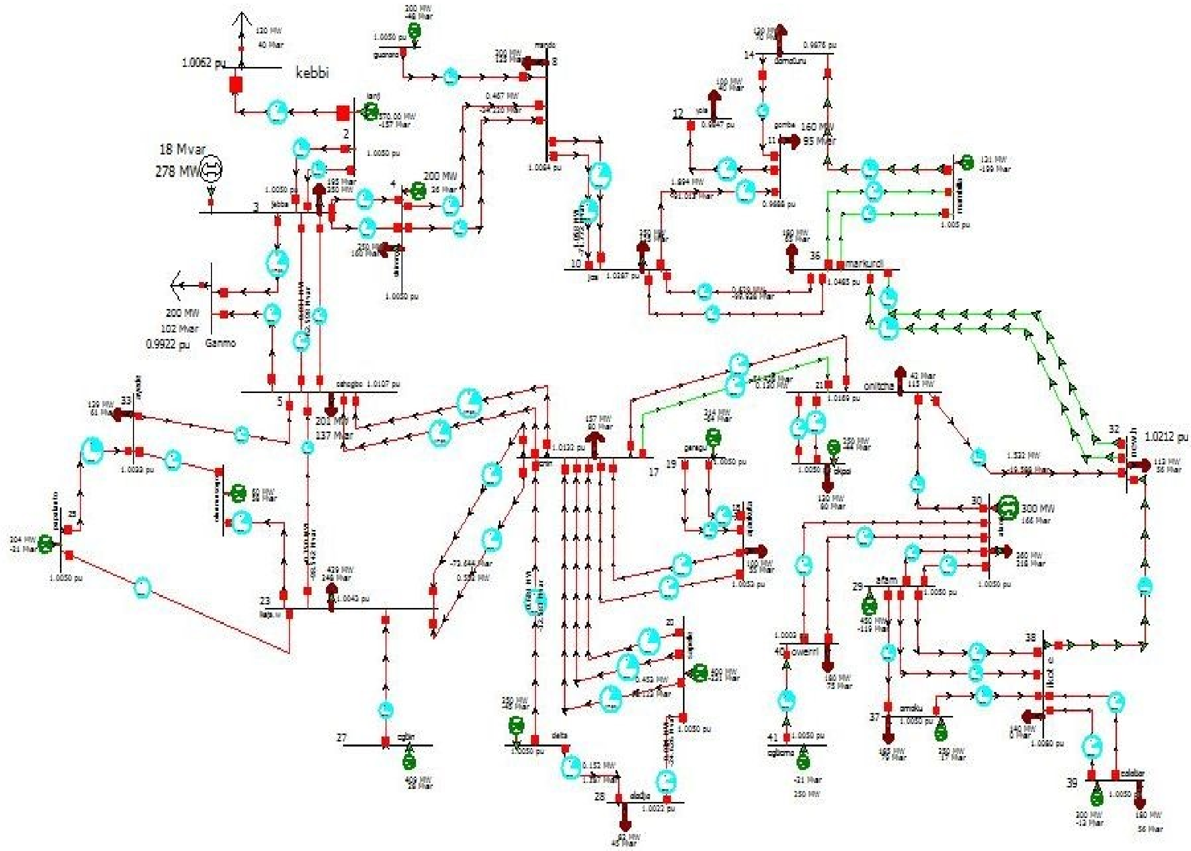

Figure 2. The simulated Nigeria 330kv grid on the Power world Platform

Table 2(Part-I). Network Data Table

No	Name	Nom kV	PU Volt	Volt (kV)	Angle (Deg)	Load MW	Load Mvar	Gen MW	Gen Mvar
1	kanji	330	1.005	331.65	-58.99			570	-157.26
2	jebba	330	1.005	331.65	-64.43	350	195	278	18
3	shiroro	330	1.005	331.65	-70.38	250	160	200	25.62
4	oshogbo	330	1.01067	333.521	-64.23	201	137		
5	mando	330	1.00839	332.77	-72.32	200	125		
6	jos	330	1.02866	339.457	-76.22	250	125		
7	gombe	330	0.98881	326.307	-82.16	160	95		

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Table 2 Part-II). Network Data Table

No	*Name*	*Nom kV*	*PU Volt*	*Volt (kV)*	*Angle (Deg)*	*Load MW*	*Load Mvar*	*Gen MW*	*Gen Mvar*
8	yola	330	0.98472	324.959	-86.9	100	40		
9	olunrunsogo	330	1.005	331.65	-64.06	130	70	60	58.25
10	damaturu	330	0.9876	325.907	-81.79	130	70		
11	benin	330	1.01316	334.343	-58.93	157	80		
12	ajaokuta	330	1.00528	331.743	-56.97	100	55		
13	geregu	330	1.005	331.65	-56.88			214	-64.39
14	sapelle	330	1.005	331.65	-57.63			400	-231.46
15	onitcha	330	1.01686	335.565	-60.08	115	42		
16	delta	330	1.005	331.65	-56.63			250	-44.64
17	ikeja.w	330	1.00427	331.41	-61.82	429	248		
18	papalanto	330	1.005	331.65	-61.81			204	-20.98
19	egbin	330	1.013	334.29	-59.68			409.16	28.21
20	aladja	330	1.00223	330.736	-57.25	82	45		
21	afam	330	1.005	331.65	-56.69			450	-118.87
22	alaoji	330	1.005	331.65	-56.87	360	218	300	166.49
23	okpai	330	1.005	331.65	-58.59	130	80	250	-44.26
24	new.h	330	1.02119	336.992	-63.25	113	56		
25	ayede	330	1.00333	331.1	-63.93	139	61		
26	mambilla	330	1.005	331.649	-76.38			130.88	-198.59
27	guarara	330	1.005	331.65	-69.34			200	-48.35
28	markurdi	330	1.04847	345.997	-73.12	180	65		
29	omoku	330	1.005	331.65	-57.39	185	79	250	17.45
30	ikot e	330	1.00799	332.637	-58.13	140.32	0		
31	calabar	330	1.005	331.65	-57.36	180	56	300	-13.3
32	owerri	330	1.00027	330.088	-56.3	180	75		
33	egbema	330	1.005	331.65	-52.44			250	-21.03
34	Ganmo	330	0.99223	327.437	-66.44	200	102		
35	kebbi	330	1.00624	332.06	-65.43	120	40		

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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 thirty five bus interconnected network. The summary of various contingencies are shown in tables 3 – 7.

Table 3. Summary of Generator Contingencies

Generator	*Violations*	*Max Branch %*	*Min Volt*	*Max Volt*
kanji	0			
jebba	0			
shiroro	0			
olunrunsogo	0			
geregu	0			
sapelle	1			1.05
delta	0			
papalanto	0			
egbin	1			1.051
afam	1			1.052
alaoji	1			1.051
okpai	1			1.05
mambilla	6			1.166
guarara	0			
omoku	1			1.051
calabar	1			1.051
egbema	1			1.051

Table 4. Violation summary when the generator at Mambilla was shutdown

Bus	*Value*	*Limit*	*Percentage*
jos	1.09	1.05	
gombe	1.13	1.05	
yola	1.14	1.05	
damaturu	1.14	1.05	
mambilla	1.17	1.05	
markurdi	1.12	1.05	

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Table 5. Summary of Line contingencies

No	*Line*	*Islanded load*	*Islanded Gen*	*Violations*	*Max Branch %*	*Min Volt*	*Max Volt*
1.	kanji-jebbaC1			0			
2.	kanji-jebbaC2			0			
3.	kebbi-kanjiC1	120		0			
4.	shiroro-jebbaC3			0			
5.	Jebba-shiroroC5			0			
6.	jebba-oshogboC1			0			
7.	jebba-oshogboC2			0			
8.	jebba-GanmoC1			0			
9.	shiroro-mandoC1			0			
10.	shiroro-mandoC2			0			
11.	oshogbo-beninC1			0			
12.	oshogbo-beninC2			0			
13.	oshogbo-ikeja.wC1			0			
14.	oshogbo-ayedeC1			0			
15.	Ganmo-oshogboC1			0			
16.	mando-josC1			0			
17.	mando-josC2			0			
18.	guarara-mandoC1		200	0			
19.	jos-gombeC1			3		0.921	
20.	jos-markurdiC1			0			
21.	jos-markurdiC2			0			
22.	yola-gombeC2	100		1			1.051
23.	damaturu-gombeC1			0			
24.	olunrunsogo-ikeja.wC1			0			
25.	ayede-olunrunsogoC1			0			
26.	damaturu-mambillaC2			4		0.399	
27.	ajaokuta-beninC2			0			
28.	benin-ajaokutaC3			0			
29.	benin-sapelleC1			0			
30.	benin-sapelleC2			0			
31.	benin-sapelleC3			0			

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32.	benin-onitchaC1		0	
33.	benin-onitchaC2		0	
34.	benin-deltaC1		0	
35.	ikeja.w-beninC1		0	
36.	ikeja.w-beninC2		0	
37.	geregu-ajaokutaC3		0	
38.	geregu-ajaokutaC4		0	
39.	aladja-sapelleC1		0	
40.	onitcha-alaojiC1		0	
41.	onitcha-okpaiC1		0	
42.	onitcha-okpaiC2		0	
43.	onitcha-new.hC1		1	1.05
44.	delta-aladjaC1		0	
45.	papalanto-ikeja.wC2		0	
46.	ikeja.w-egbinC1		0	
47.	ikeja.w-egbinC2		0	
48.	ayede-papalantoC1		0	
49.	alaoji-afamC1		0	
50.	alaoji-afamC2		0	
51.	afam-omokuC1		0	
52.	afam-ikoteC1		0	
53.	afam-0ikoteC2		0	
54.	alaoji-owerriC1		0	
55.	alaoji-owerriC2		0	
56.	markurdi-new.hC1		0	
57.	markurdi-new.hC2		0	
58.	new.h-ikoteC1		1	1.051
59.	markurdi-mambillaC1		0	
60.	markurdi-mambillaC2		0	
61.	omoku-ikoteC2		0	
62.	ikote-calabarC2		0	
63.	ikote-calabarC3		0	
64.	owerri-egbemaC1	250	1	1.051

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Table 6. Violation summary when Jos – Gombe line was opened

Bus	*Value*	*Limit*	*Percentage*
Gombe	0.93	0.95	
Yola	0.92	0.95	
Damaturu	0.94	0.95	

Table 7. Violation summary when Damaturu – Mambilla line was opened

Bus	*Value*	*Limit*	*Percentage*
Jos	0.87	0.95	
Gombe	0.46	0.95	
Yola	0.40	0.95	
Damaturu	0.45	0.95	

On shutting down the generators and opening the lines were large violations were noticed, then running the simulation to note the effect of these contingencies on the network the results in figures 4 – 6 were gotten.

Generator contingency: When the generator at mambilla was shut down, about six number violations were recorded at various buses. All these were bus violations, as shown in table 3 and Fig 3 which shows that voltage values at the buses went beyond 1.05pu. These buses are Jos, Gombe, Yola, Damature, mambilla and makurdi.

Line Contingency: When the line connecting Jos and Gombe was shut down, (i.e. Opened), three number violations were recorded and they were low voltage violations. They occurred at gombe, Yola and Damaturu.

Also when the line connecting damaturu and mambilla was shut down, (i.e. Opened), four number violations occurred at Jos, Gombe, Yola and damaturu.

CONCLUSION

From the network and from the results obtained, it was noted that, though the post-reform Nigeria 330kv grid system is more complex and difficult to analyse, there are fewer violations in the system during contingencies when compared to previous works done on the pre-reform grid. This is as a result of the availability of more than one transmission link between most stations (buses) in the system. This accounts for the absence of line overloading and less bus voltage violations during contingency events.

Also it was noted that even though parameter changes were always noted at lines and buses during contingencies, most severe violations were noted in areas with single circuit transmission line between the buses.

With these observations, direct corrective actions can always be planned for the system.

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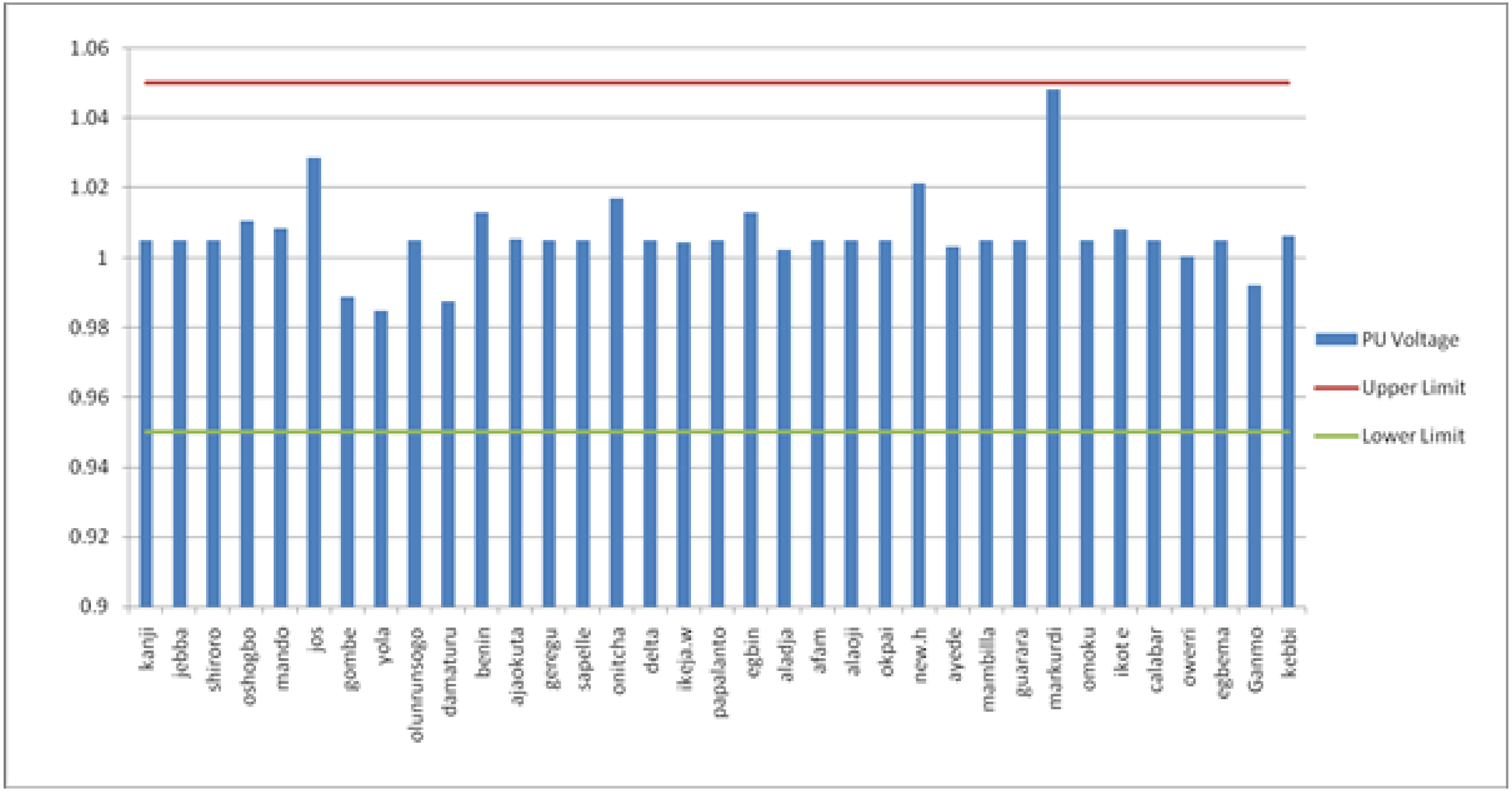

Figure 3. Network PU Voltage profile

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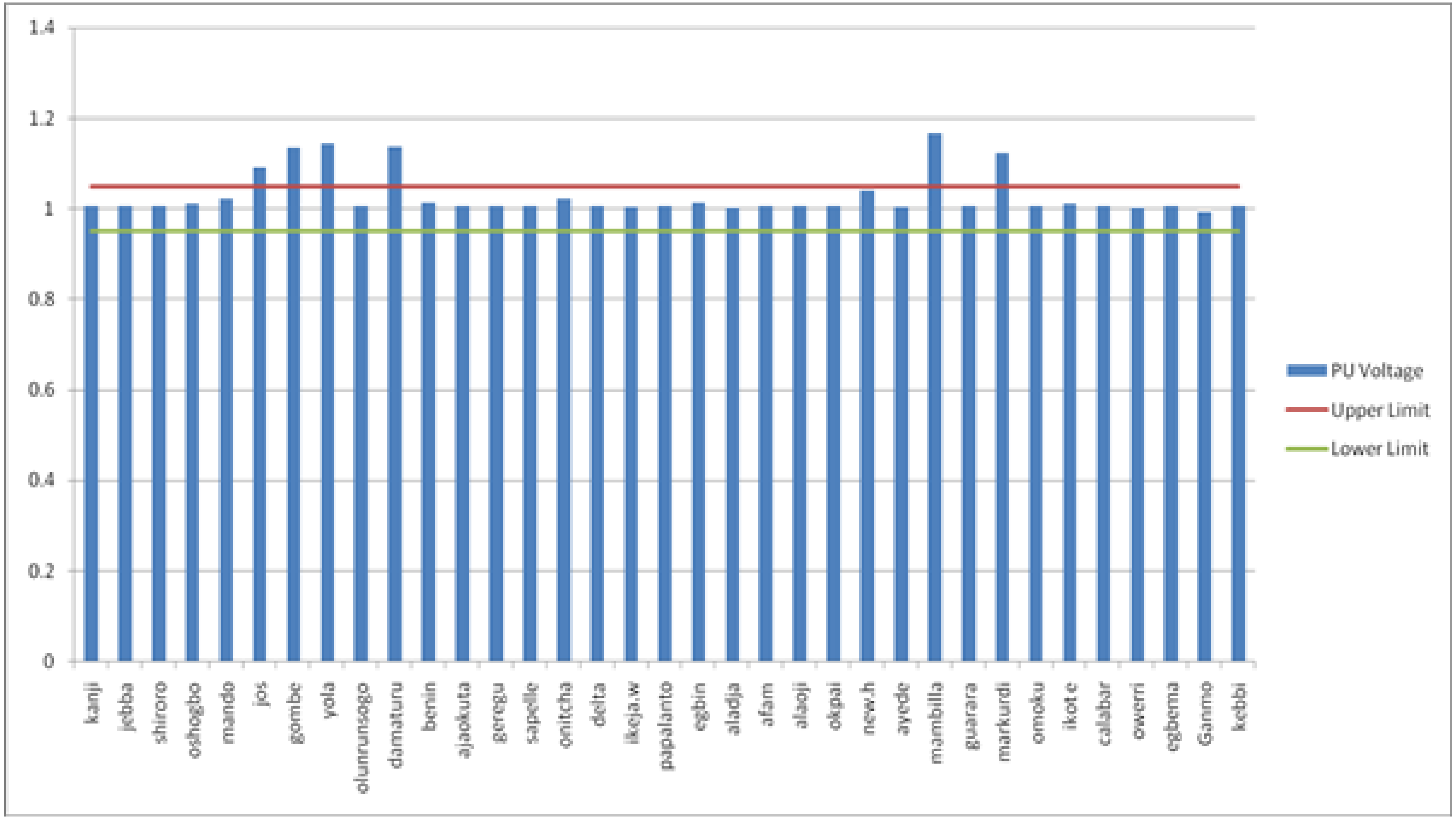

Figure 4. PU voltage when the generator at Mambilla was shutdown

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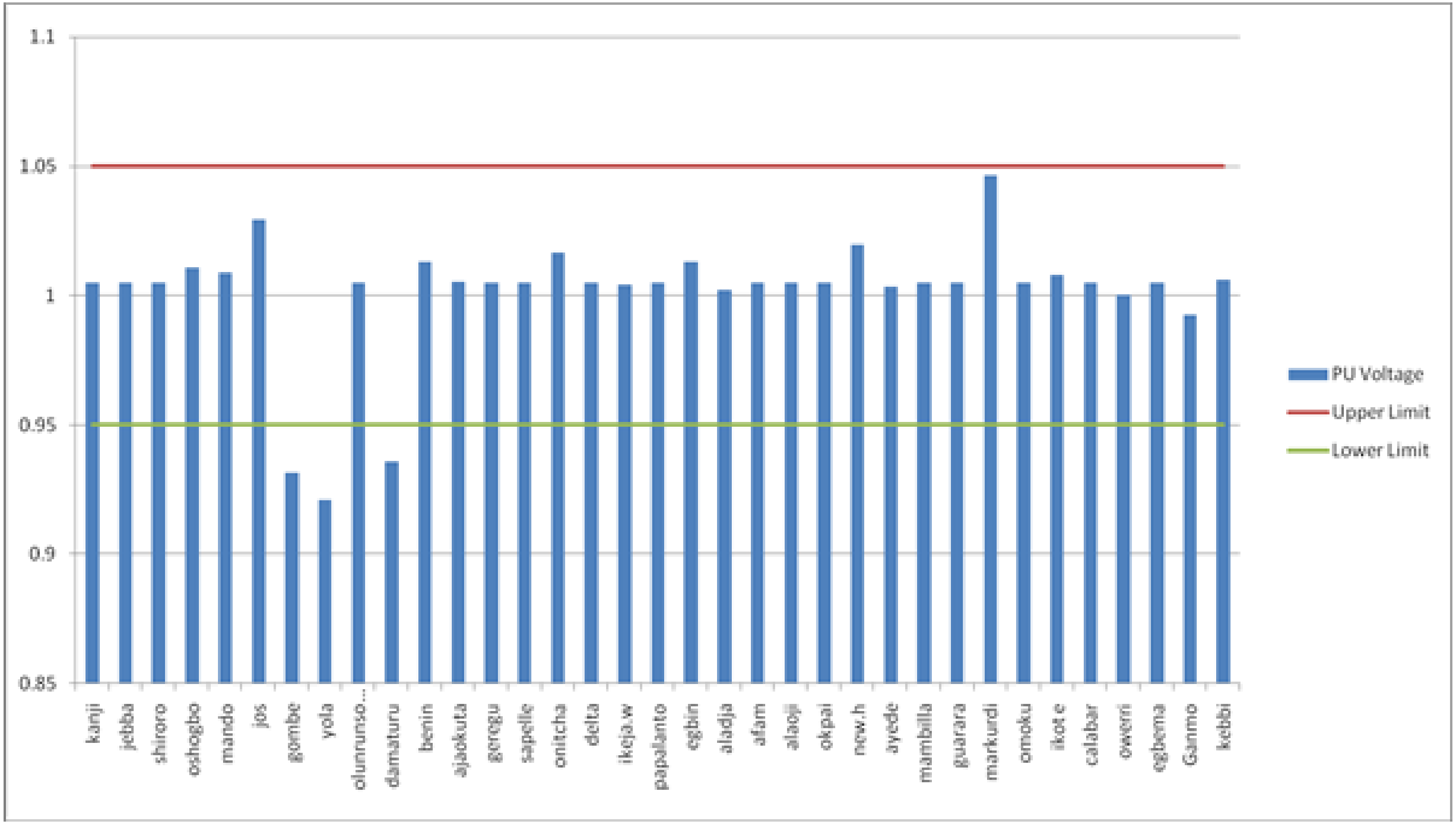

Figure 5. PU voltage When Jos – Gombe line was opened

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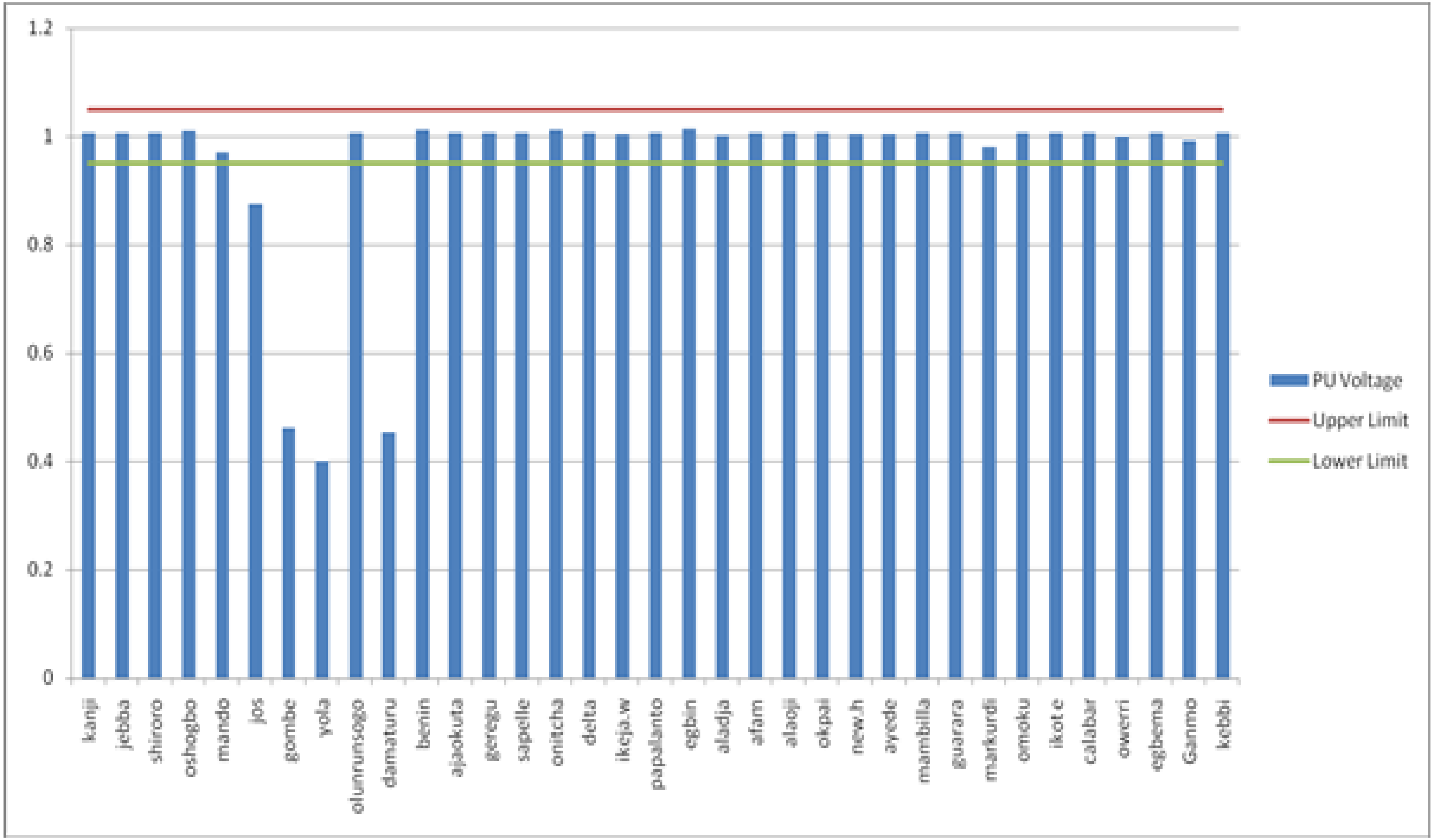

Figure 6. PU voltage when Damaturu – Mambilla line was opened

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RECOMMENDATIONS

The technical information provided in this paper forms a veritable database for future work towards improved Nigeria power system operation. The following are recommended to ensure efficient operation of the Nigeria grid system:

1. The existing transmission lines and substations should be upgraded to improve voltage profile of vulnerable buses like Jos, Gombe, Yola, Damaturu, mambilla and makurdi buses.and makurdi buses.
2. Provision of double circuit transmission lines to connect kebbi - kanji, jos - gombe, yola – gombe and damaturu - mambilla will greatly enhance the efficient operation of the grid.
3. The Transmission Company of Nigeria (TCN) should adopt the use of (Flexible AC Transmission), FACT devices as they can improve the lines reactive power transfer capability in any contingency event, as they have faster switching than the traditional compensation devices.

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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] Chary, V. M. D. (2013). *Contingency analysis in power systems, transfer capability computation and enhancement using facts devices in deregulated power system*. PhD thesis, Jawaharlal Nehru technological university Hyderabad kukatpally, Hyderabad – 500 085 India

[4] Electric power for Nigeria. (2014, July 15). Business day magazine. [Online]. Available: http://businessdayonline.com/2014/01/electric-power-for-nigeria-in.

[5] 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.

[6] Jan-E-Alam, Md., & Hasib, C. A. (2010). Voltage collapse constrained loadability analysis of Bangladesh power system network. *Presented at Power and Energy system (AsiaPes2010), Phuket, Thailand*, November 24 – 26.

[7] KPMG Handbook. (2013, December). *A guide to Nigeria power sector*.

[8] Mishra, V. J., & Khardenvis, M. D. (2012). Contingency Analysis of Power System. *Presented at the International Conference on Emerging Frontiers in Technology for Rural Area (EFITRA).*

[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,* (Volume 4).

[10] Roy, A. K. (2011). *Contingency analysis in power system.* Masters' Dissertation Thapar University, Patiala – 147004 India.

[11] Sadiq, A. A., Nwohu, M. N., Ambafi, J. G., & Olatomiwa, L. J. (2013). Effect of Contingency on Available Transfer Capability of Nigerian 330-kV Network. *AU Journal of Technology, 16*(4), 241-246.

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