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Voltage Instability in Electrical Network: A Case Study of the Nigerian 330 kV Transmission Grid

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Abstract: In this study, various aspects of voltage instability in electrical power network using the Nigeria 330 kV transmission network as a case study were analysed. The study considered various causes of voltage instability such as loss of generators or lines, 3 phase faults, load increases which were simulated on the network using the Power World Simulator. The study revealed that the present 330 kV trasmission grid is highly unstable and require remedial measures to improve the voltage stability. Thus, shunt compensation, load shedding and strengthening of the network by incoporating additional lines into the grid showed greater improvment on the network. The study therefore, proposed a modified network that will improve the voltage stability in the network.

Key words: Voltage instability, buses, power world simulator, transmission, load flow analysis, faults

INTRODUCTION

The Nigeria 330 kV transmission grid is characterized by voltage instability. The electrical engineer who works in this industry will encounter challenging problems in designing future power systems to deliver increasing amounts of electrical energy in a safe, clean and economical manner (Glover and Sharma, 2002). Various factors such as loads and faults contribute to voltage instability in power systems. Voltage instability can be classified based on the severity of disturbance, into large disturbance voltage stability and small disturbance voltage stability (Anderson and Ajjirapu, 2007), or the time scale involved, into short term voltage stability and long term voltage stability. Large disturbances typically include system faults, loss of generation or circuit contingencies while small scale refer to small perturbations such as incremental change in system loads. In terms of time scales, voltage instability incidents may last from few seconds to several minutes. The various causes of voltage instability considered in this study include loss of generation, loss of lines, three phase balanced faults and load increases at some major buses. Suggestions to improve voltage stability such as shunt compensation, load shedding and introduction of loop systems and additional lines were also considered. The objective of this study therefore, was to examine the various causes of voltage instability using the Nigerian 330 kV as a case study and proffer suggestions to minimize their effects, thus improving the voltage stability of the network.

MATERIALS AND METHODS

The methodology adopted for this study is as follows;

- Overview of the Nigeria power network used as the test system.
- Simulation of various causes of voltage instability into the network to examine their effects using the Power World Simulator (PWS, 2000).
- Modifications of the existing network to reduce the effect of voltage instability in the system.

The Nigerian power network used as the test system: The Nigerian power network used for this study is a 28 bus network. The power stations summed up to 6200MW out of which 1920 MW is hydro and 4280 MW thermal-mainly gas fired (Ohohebi, 2006). The Nigerian electricity network comprises 11,000 km transmission lines (330 and 132 kV), 24000 km of sub-transmission lines (33 kV), 19000 km of distribution line (11 kV) and 22,500 substations (Sadoh, 2005). It has only one major loop system involving Benin-Ikeja West-Ayede-Oshogbo and Benin. The absence of loops accounts mainly for the weak and unreliable power system in the country. The single line diagram of the existing 330 kV Nigerian transmission network used as the test system for the case study is shown in Fig. 1 while Table 1 shows the bus indentifications.

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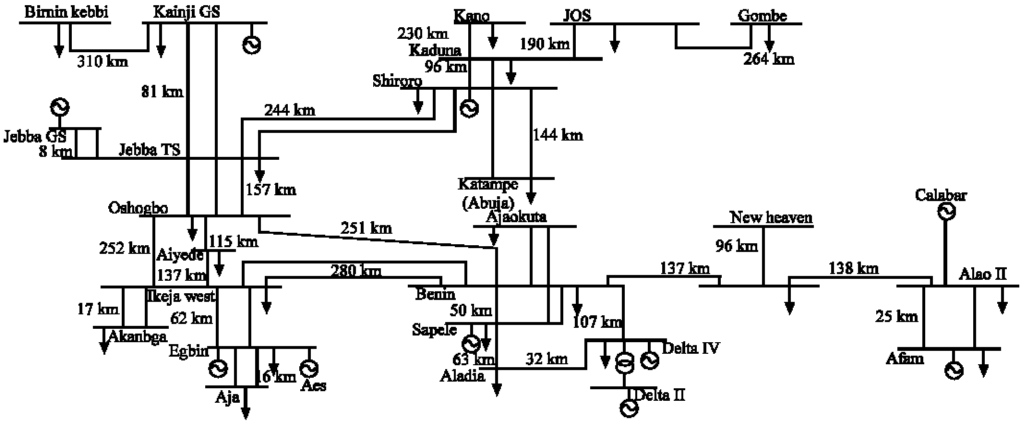

Fig. 1: The Nigerian 330 kV transmission grid used for the case study

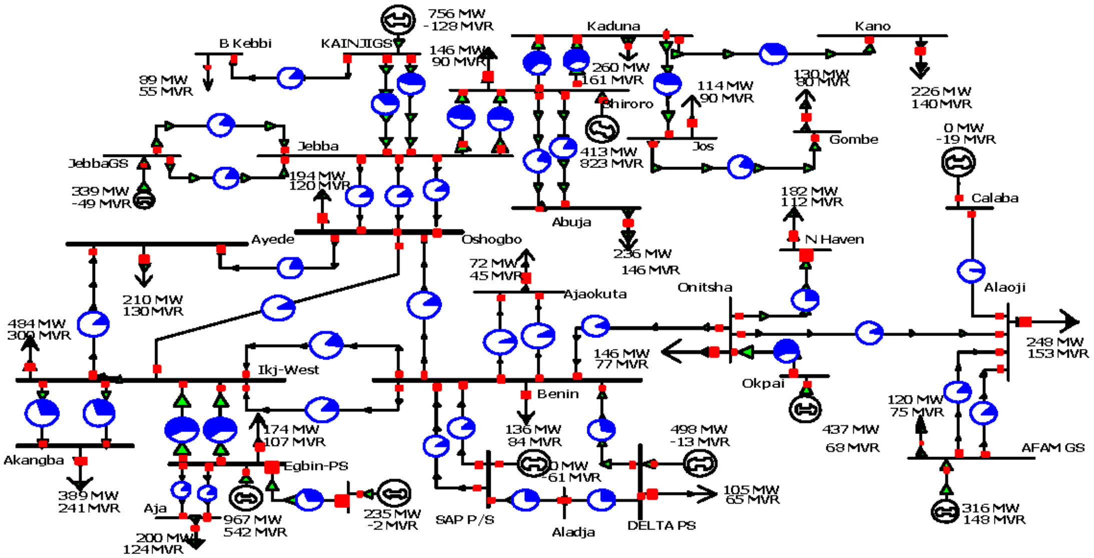

Fig. 2: Existing 330 kV transmission network (simulated in the run mode)

Table 1: Bus identification

Bus number	Bus name	Bus number	Bus name
1	Oshogbo	15	Aladja
2	Benin	16	Kano
3	Ikj-West	17	SAP P/S
4	Ayede	18	Aja
5	Jos	19	Ajaokuta
6	Onitsha	20	N Haven
7	Akangba	21	Alaoji
8	Gombe	22	AFAMGS
9	Abuja	23	Jebba
10	Egbin-PS	24	JebbaGS
11	DELTA PS	25	KAINJIGS
12	AES	26	B Kebbi
13	Okpai	27	Shiroro
14	Calabar	28	Kaduna

Table 2: Location and installed capacities of power stations in Nigeria as at 2005 in MW (PHCN, 2006)

Power station	Kanji	Jebba	Shiroro	Sapele	Afam	Egbin	Delta	Ijora	Total
Installed Capacity	760	578.4	600	1020	969.6	1320	912	40	6200

Table 3: Bus voltages under normal and shunt compensation operating conditions

	Normal condition			Compensated network		
Nr	PU Volt	Volt (kV)	Angle (Deg)	PU Volt	Volt (kV)	Angle (Deg)
1	0.98986	326.654	-6.85	0.98992	326.673	-6.67
2	1.0018	330.593	-3.32	1.0018	330.595	-3.14
3	0.9637	318.021	-6.87	0.96371	318.025	-6.7
4	0.95534	315.263	-9.04	0.95538	315.277	-8.86
*5	0.76078	251.056	-39.42	1.0264	338.711	-35.47
6	0.98046	323.553	-1.95	0.98046	323.553	-1.78
7	0.95589	315.444	-7.46	0.9559	315.447	-7.28
*8	0.65964	217.681	-50.8	1.03472	341.459	-38.38
9	0.97119	320.492	-24.11	0.97119	320.492	-23.41
10	1	330	-2.85	1	330	-2.68
11	1	330	0.54	1	330	0.71
12	1	330	-2.85	1	330	-2.68
13	1	330	2.31	1	330	2.48
14	1	330	-5.19	1	330	-5.02
15	1.0008	330.265	-1.56	1.0008	330.265	-1.39
*16	0.74893	247.148	-40.36	0.97601	322.082	-31.43
17	1	330	-2.55	1	330	-2.37
18	0.99362	327.894	-3.36	0.99362	327.894	-3.19
19	1.00759	332.504	-4.52	1.00759	332.506	-4.35
20	0.95624	315.56	-5.1	0.95624	315.56	-4.92
21	0.96416	318.174	-5.17	0.96416	318.174	-4.99
22	1	330	-1.31	1	330	-1.13
23	1	330	-4.75	1.00009	330.028	-4.57
24	1	330	-4.53	1	330	-4.36
25	1	330	0	1	330	0
26	0.98364	324.603	-4.87	0.98364	324.603	-4.87
27	1	330	-21.2	1	330	-20.51
*28	0.90349	298.153	-27.68	0.99548	328.507	-26.81

The peak load of 3860 MW in December 2005 obtained under a maximum generation of 3960 MW from the installed capacities shown in Table 2 was used for the case study.

Power flow analysis of the test system: Load flow analysis to determine the bus voltage, active and reactive power flow and losses on the various lines under normal conditions was carried out. In carrying out this analysis, the Power World Simulator (PWS) software was used. Thus, the test system shown in Fig. 1 was redrawn using the edit mode in the PWS. The input data for the power flow analysis included the generator's output power, maximum and minimum reactive power limits of the generator, MW and MVAR peak loads, impedance of the lines, voltage and power ratings of the lines and transformer data. These were entered into the dialog box of PWS and simulated using the Newton Raphson iterative method available in the Run Mode as shown in Fig. 2 of the PWS. The bus voltages, line flows and power losses under normal operating condition are shown in Table 3 and 4, respectively. The voltages at buses 5, 8, 16 and 28 are low and in order to ensure that they are within acceptable limits, shunt compensations were injected into the buses. Based on Power Holding Company of Nigeria (PHCN) power factor of 0.85 for the transmission lines, the MVAr capacities of the various capacitors required to carry out full compensation of the network at the buses were determined as shown in Fig. 3.

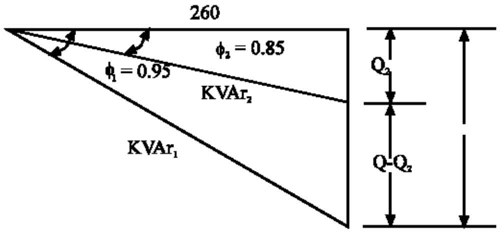

Fig. 3: Determination of capacity of shunt capacitors

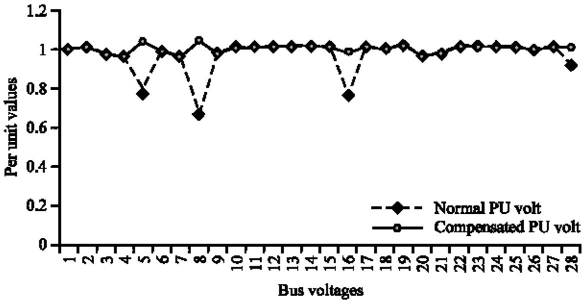

Fig. 4: Voltage profiles for the normal and compensated conditions on the network

Table 4: Line flows and power losses under normal operating condition

From Nr	To Nr	From MW	From Mvar	From MVA	Lim MVA	Max percent	MW loss	Mvar loss
28	16	235.4	160.1	284.7	760	37.5	9.42	20.09
28	27	-376.6	-249.8	451.9	760	63.2	8.21	37.43
28	5	257.8	178.6	313.6	760	41.3	9.45	28.68
28	27	-376.6	-249.8	451.9	760	63.2	8.21	37.43
27	9	118.9	27.1	121.9	760	18.3	0.89	-45.95
27	9	118.9	27.1	121.9	760	18.3	0.89	-45.95
27	23	-370.2	52.3	373.9	760	50.6	12.77	16.2
27	23	-370.2	52.3	373.9	760	50.6	12.77	16.2
26	25	-89	-55	104.6	760	13.8	0.91	-98.39
25	23	333.3	-42.1	335.9	760	44.2	3.35	-3.3
25	23	333.3	-42.1	335.9	1000	33.6	3.35	-3.3
24	23	169.5	-24.4	171.2	1000	17.1	0.09	-2.66
24	23	169.5	-24.4	171.2	1000	17.1	0.09	-2.66
23	1	77.6	-16.3	79.3	760	11.4	0.35	-56.14
23	1	77.6	-16.3	79.3	760	11.4	0.35	-56.14
23	1	77.6	-16.3	79.3	760	11.4	0.35	-56.14
21	22	-97	-38.6	104.4	760	13.8	1.02	-2.09
21	22	-97	-38.6	104.4	760	13.8	1.02	-2.09
20	21	0.5	-42.1	42.1	1000	4.2	0.02	-48.16
19	2	-36	-22.5	42.5	760	8.3	0.11	-74.36
15	17	187.7	-17.5	188.5	760	24.8	0.38	-8.55
15	11	-187.7	17.5	188.5	760	25.2	0.81	-17.8
14	21	0	-19.3	19.3	760	4.4	0	-53.05
10	18	100.1	52.8	113.2	760	15.5	0.13	-9.18
10	18	100.1	52.8	113.2	760	15.5	0.13	-9.18
10	12	-235	2.4	235	760	30.9	0	0.01
10	3	413.9	169.2	447.1	760	58.8	4.49	32.06
6	21	53.7	-10.4	54.7	760	8.5	0.16	-46.31
6	20	183.8	47.2	189.8	760	25.7	1.34	-22.69
6	13	-433.1	-56.3	436.7	760	58.2	3.95	12.05
5	8	134.3	59.9	147.1	760	20.1	4.34	-20.09
4	3	-97.1	-30.8	101.9	760	13.4	0.51	-44.21
4	1	-112.9	-99.2	150.3	760	19.8	0.85	-34.07
3	2	-74.1	-85.1	112.9	760	14.9	0.77	-106.3
3	10	-409.4	-147.9	435.3	760	58.3	4.49	9.76
3	7	194.8	122.9	230.4	760	30.3	0.34	2.42
3	7	194.8	122.9	230.4	760	30.3	0.34	2.42
3	2	-74.1	-85.1	112.9	760	14.9	0.77	-106.32
3	1	-4.3	-77.1	77.2	760	10.2	0.1	-92.33
2	19	36.1	-51.9	63.2	760	8.3	0.11	-74.36
2	17	-93.5	15.3	94.7	760	13.1	0.17	-19.54
2	17	-93.5	15.3	94.7	760	13.1	0.17	-19.54
2	11	-202.9	15.9	203.5	760	27.5	1.62	-27.22
2	6	-49.2	54.8	73.7	760	10	0.28	-2.73
1	2	-80.4	-50.4	94.9	760	12.5	0.59	-89.56

Kaduna bus:

$$\text{Total Load} = 260\text{MW}$$

$$\text{Reactive MVAr of load} = \frac{260}{0.85} \times \sin(\cos^{-1} 0.85)$$
$$= 161 \text{ MVAr lagging}$$

$$\begin{matrix}\text{Reactive MVAr of load} \\ \text{corresponding to 0.95 pf}\end{matrix} = \frac{260}{0.95} \times \sin(\cos^{-1} 0.95) = 95.5\text{MVAr}$$

$$\text{laggingRating of capacitor bank} = (161 - 95.50)\text{MVAR}$$
$$= 75.5 \text{ MVArMVAr}$$

This size corresponds to values obtained from BICC tables for determining sizes of capacitor in KVAr per KW of load of raising the power factors. Thus, using the table, the following capacitor sizes were selected for the various lines, taking into account the bus voltages and power losses on the lines. Kano Bus (40 MVAr), Jos bus (60 MVAr), Gombe bus (30 MVAr).These were injected into the network and the results were as shown in Table 3 and Fig. 4.

RESULTS AND DISCUSSION

Simulation of various causes of voltage instability into the network: The bulk power system is designed and operated to provide continuity of service in the case of

Table 5: Effect of generator outage on the network

Power Stations	Mva violations	Bus low-voltage violations	Power losses (MW)
Egbin	10-12 869.5 114.4%, 25-23 938.4 123.5%	1,3,4,5,7,8,16,28.	204
Delta	Nil	4,5,8,16,28	107
Aes	Nil	5,8,16,28	126
Okpai	Nil	4,5,6,8,13,16,20,21,28	128
Afam	Nil	4,5,6,8,16,20,21,22,28	134
Jebba	Nil	5,8,16,28	109
Sapele	Out of service at time investigation, December 2005		
Shiroro	Total voltage collapse, blackout		
Kainji	Used as slack bus in the analysis		

Table 6: Contigency analysis of the test system

Contingency records

Label	Skip	Processed	Solved	Violations	Max line %	Min volt
L00001Oshogbo-00002BeninC1	No	Yes	Yes	5		0.66
L00003Ikj-West-00001OshogboC1	No	Yes	Yes	5		0.66
L00004Ayede-00001OshogboC1	No	Yes	Yes	6		0.66
L00023Jebba-00001OshogboC1	No	Yes	Yes	4		0.66
L00023Jebba-00001OshogboC2	No	Yes	Yes	4		0.66
L00023Jebba-00001OshogboC3	No	Yes	Yes	4		0.66
L00003Ikj-West-00002BeninC1	No	Yes	Yes	5		0.66
L00003Ikj-West-00002BeninC2	No	Yes	Yes	5		0.66
L00002Benin-00006OnitshaC3	No	Yes	Yes	4		0.66
L00002Benin-00011DELTAPSC1	No	Yes	Yes	4		0.66
L00002Benin-00017SAPP/SC1	No	Yes	Yes	4		0.66
L00002Benin-00017SAPP/SC2	No	Yes	Yes	4		0.66
L00002Benin-00019AjaokutaC1	No	Yes	Yes	4		0.66
L00019Ajaokuta-00002BeninC2	No	Yes	Yes	4		0.66
L00004Ayede-00003Ikj-WestC1	No	Yes	Yes	5		0.66
L00003Ikj-West-00007AkangbaC1	No	Yes	Yes	5		0.66
L00003Ikj-West-00007AkangbaC2	No	Yes	Yes	5		0.66
L00003Ikj-West-00010Egbin-PSC1	No	Yes	Yes	8	117.2	0.66
L00010Egbin-PS-00003Ikj-WestC2	No	Yes	Yes	8	116.3	0.66
L00005Jos-00008GombeC1	No	Yes	Yes	3		0.795
L00028Kaduna-00005JosC1	No	Yes	Yes	2		0.81
L00006Onitsha-00013OkpaiC1	No	Yes	Yes	8		0.66
L00006Onitsha-00020NHavenC1	No	Yes	Yes	6		0.66
L00006Onitsha-00021AlaojiC1	No	Yes	Yes	5		0.66
L00027Shiroro-00009AbujaC1	No	Yes	Yes	5		0.66
L00027Shiroro-00009AbujaC2	No	Yes	Yes	5		0.66
L00010Egbin-PS-00012AESC1	No	Yes	Yes	4		0.66
L00010Egbin-PS-00018AjaC1	No	Yes	Yes	4		0.66
L00010Egbin-PS-00018AjaC2	No	Yes	Yes	4		0.66
L00015Aladja-00011DELTAPSC1	No	Yes	Yes	4		0.66
L00014Calaba-00021AlaojiC1	No	Yes	Yes	4		0.66
L00015Aladja-00017SAPP/SC1	No	Yes	Yes	4		0.66
L00028Kaduna-00016KanoC1	No	Yes	Yes	2		0.775
L00020NHaven-00021AlaojiC1	No	Yes	Yes	5		0.66
L00021Alaoji-00022AFAMGSC1	No	Yes	Yes	6		0.66
L00021Alaoji-00022AFAMGSC2	No	Yes	Yes	6		0.66
L00024JebbaGS-00023JebbaC1	No	Yes	Yes	4		0.66
L00024JebbaGS-00023JebbaC2	No	Yes	Yes	4		0.66
L00025KAINJIGS-00023JebbaC1	No	Yes	Yes	4		0.66
L00025KAINJIGS-00023JebbaC2	No	Yes	Yes	4		0.66
L00027Shiroro-00023JebbaC1	No	Yes	Yes	5	105.9	0.66
L00027Shiroro-00023JebbaC2	No	Yes	Yes	5	105.9	0.66
L00026BKebbi-00025KAINJIGSC1	No	Yes	Yes	4		0.66
L00028Kaduna-00027ShiroroC1	No	Yes	No	Unsolved		
L00028Kaduna-00027ShiroroC2	No	Yes	No	Unsolved		

possible contingencies such as loss of generation unit, loss of transmission line, or failure of any single component of the system (IEEE, 1997). The North America Electric Reliability Council (NERC) guidelines also recommend making it operational requirements that systems be able to handle any single contingency. Thus, the test system was subjected to single contingency analysis.

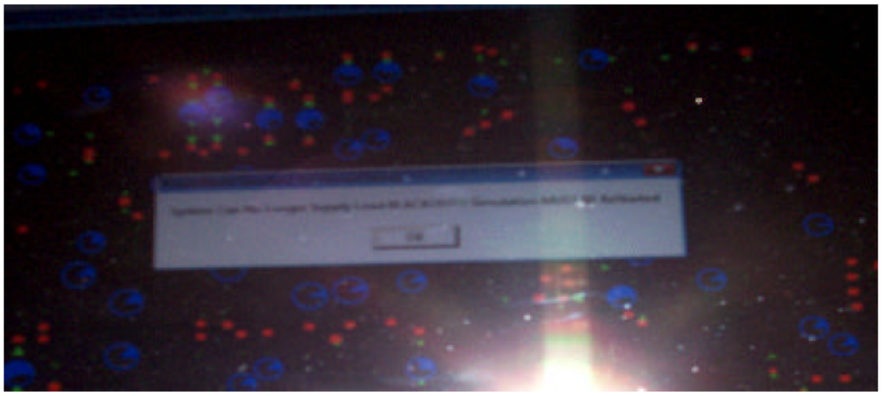

Fig. 5: Total voltage collapse (blackout) resulting from outage of shiroro power station

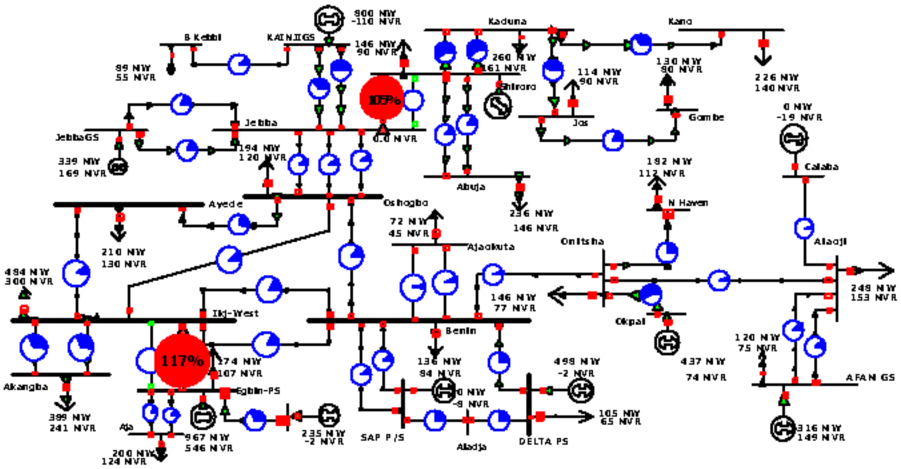

Fig. 6: State of network after loss of Egbin-ikeja West line

Loss of generation units i.e. generator tripping: This was caused by tripping or opening the circuit breaker linking the various power stations to their respective buses. The effect of outage on each of the power stations on the network is summarized in Table 5. The worst case recorded was the outage of shiroro power station that led to total voltage collapse (blackout) as shown in Fig. 5. The outage at Egbin power station caused some lines to be over loaded and this scenerio resulted in the highest power losses.

Loss of transmission lines: Power transfer capability is highly dependent on transmission network and thus transmission lines must be designed to have enough capacity to enhance voltage stability. The transmission lines were subjected to contingency analysis as recommended to show the effect of loss of any single line on the network as shown in Table 6. The system recorded a total of 200 violations. The worst case scenario was when one of the circuits in Egbin-Ikeja west was affected. Shiroro-Jebba and the second Egbin-Ikeja west lines were overloaded as shown in Fig. 6. The thermal limits of these lines were exceeded and this could result to overheating thus increasing the power losses in the network. It was also observed that low voltages occur at buses 3, 4, 5, 7, 8,16 and 28 as shown in Fig. 7 and Table 7. In order to restore the system to normal, load shedding was applied to the buses 3, 5 and 28 by tripping their loads. The voltages were restored to normal as shown in Fig. 8. Thus, the load shedding prevented the system from voltage collapse. This is the major control presently applied in the Nigerian power system by PHCN.

Load increase at some buses: In order to study the effects on load increase on the network, the loads in bus 1, 2 and 3 were increased in steps. This resulted in high

Table 7: Bus voltages recorded after loss of lines

Number	Name	Area name	PU volt	Volt (kV)
1	Oshogbo	1	0.98084	323.676
2	Benin	1	0.99822	329.412
*3	Ikj-West	1	0.93433	308.33
*4	Ayede	1	0.93552	308.723
*5	Jos	1	0.76078	251.056
6	Onitsha	1	0.97954	323.249
*7	Akangba	1	0.92627	305.669
*8	Gombe	1	0.65964	217.681
9	Abuja	1	0.97119	320.492
10	Egbin-PS	1	1	330
11	DELTA PS	1	1	330.001
12	AES	1	1	330
13	Okpai	1	1	330.001
14	Calaba	1	1	330.001
15	Aladja	1	1.0008	330.265
*16	Kano	1	0.74893	247.148
17	SAP P/S	1	1	330.001
18	Aja	1	0.99362	327.894
19	Ajaokuta	1	1.00387	331.279
20	N Haven	1	0.9555	315.313
21	Alaoji	1	0.96373	318.031
22	AFAM GS	1	1	330.001
23	Jebba	1	0.99946	329.822
24	JebbaGS	1	1	330
25	KAINJIGS	1	1	330
26	B Kebbi	1	0.98364	324.603
27	Shiroro	1	1	330
*28	Kaduna	1	0.90349	298.153

voltage drops in most of the lines while others experience overloading thus reducing their thermal capability. Buses 4, 6, 7, 20, 21 featured mostly prominently in addition to buses 5, 8, 16, 28 for low voltage values while lines 1-2, 3-10, 24-25 were overloaded. This suggested the need to introduce additional lines in the network to improve the voltage profiles.

Three-phase balanced faults: In order to simulate a large disturbance, a 3-phase fault was simulated at buses 1, 2 and 3. Bus 1 was selected because it is the major bus linking the southern and northern parts of the grid and also the location of the National Control Centre (NCC). Bus 2 represents the bus which links the eastern, western and northern parts of the network. Bus 3 is the highest loaded bus in the entire network and also tied to the highest generating stations located at Egbin and AES. The bus voltages after the simulation were shown in Table 8 for buses 1, 2 and 3 and compared with the normal condition as well as Fig. 9. The results showed low voltages at all the buses. Only one phase voltage was recorded for this analysis since the voltages were identical for all the three phases except the phase angles. The current also went up astronomically and recorded the highest value of 1068 amperes from line 1 and 2 when Oshogbo was short circuited, 987 amperes from line 1 to 2 for bus 2 and 814 amperes on line 1 to 4. The values obtained under normal condition for these lines were 168 amperes on the line 1 and 2 and 275 amperes for line 1-4.

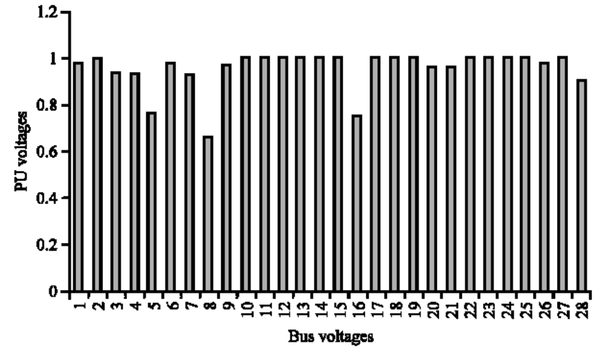

Fig. 7: Voltage profiles after loss of lines

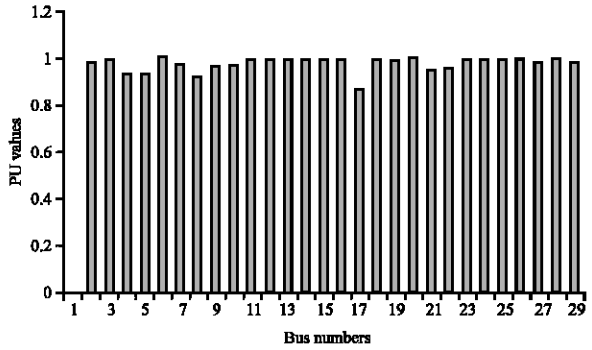

Fig. 8: Voltage profiles after load shedding

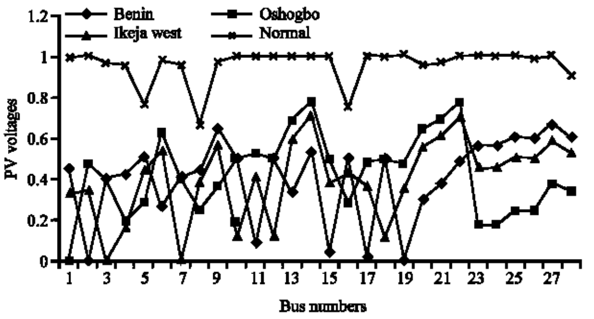

Fig. 9: Comparison of voltage profiles in the network under normal and fault conditions

In order to restore the system after this fault (Table 9), reactive power compensation was injected into the system at locations with low voltage values at buses 5, 8, 16 and 28.

The suggested network: Based on the analysis of the various causes of voltage instability in the network, the network shown in Fig. 10 is recommended. This network has additional lines between buses 1 and 4, 3 and 10, 5 and 8, 16 and 28, 27 and 28. This will provide enough transmission capability in the system and reduce the effect of overloads on the lines duirng contingencies.

Table 8: Bus voltages after simulation of faults

Number	Name	Bus 1	Bus 2	Bus 3	Normal
1	Oshogbo	0	0.44713	0.32224	0.98084
2	Benin	0.46879	0	0.35007	0.99822
3	Ikj-West	0.39939	0.40471	0	0.93433
4	Ayede	0.19148	0.41672	0.16061	0.93552
5	Jos	0.28591	0.50531	0.4418	0.76078
6	Onitsha	0.62658	0.25996	0.53502	0.97954
7	Akangba	0.39615	0.40143	0	0.92627
8	Gombe	0.24791	0.43813	0.38306	0.65964
9	Abuja	0.36499	0.64507	0.56399	0.97119
10	Egbin-PS	0.49722	0.4982	0.11808	1
11	DELTA PS	0.52324	0.08414	0.41108	1
12	AES	0.49723	0.49822	0.1181	1
13	Okpai	0.68222	0.3284	0.5944	1
14	Calaba	0.77021	0.52559	0.70799	1
15	Aladja	0.49372	0.03866	0.37798	1.0008
16	Kano	0.28146	0.49744	0.43492	0.74893
17	SAP P/S	0.4793	0.01705	0.36212	1
18	Aja	0.49404	0.49502	0.11733	0.99362
19	Ajaokuta	0.4715	0	0.3521	1.00387
20	N Haven	0.63933	0.30084	0.55495	0.9555
21	Alaoji	0.68826	0.37483	0.61049	0.96373
22	AFAM GS	0.77216	0.48256	0.70094	1
23	Jebba	0.17027	0.5587	0.45327	0.99946
24	JebbaGS	0.17335	0.56066	0.45565	1
25	KAINJIGS	0.24259	0.60307	0.50763	1
26	B Kebbi	0.23862	0.5932	0.49933	0.98364
27	Shiroro	0.37582	0.6642	0.58072	1
28	Kaduna	0.33955	0.6001	0.52467	-14.41

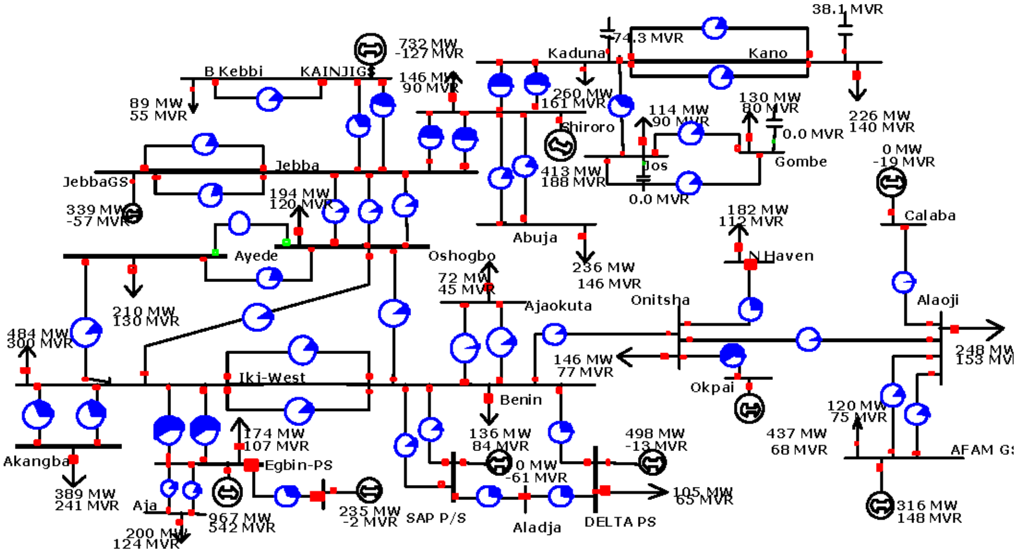

Fig. 10: Suggested 330 kV transmission network

The present 330 kV transmission network is highly unreliable due to frequent voltage instability in the system voltages as low as 217 kV in the network was recorded at bus 8 during this analysis. The contingency analysis also showed 200 voltage violations in the analysis. This does not augur well for a country which depends largely on constant and good quality power supply for its economic growth. Thus, shunt compensation using capacitors were used to restore the voltage to acceptable limits as shown in Table 3 and Fig. 4.

However, subjecting the network to further analysis under contingency, such as loss of generator, transmission line or 3 phase faults revealed that high power losses and voltage drops are frequent occurrences in the network. The estimated energy loss for 2005 was 337.5 GWA (Ohohaebi and Kuale, 2007). Total voltage

Table 9: Line flows after 3 phase faults

				Bus 1		Bus 2		Bus 3	
From number	To number	Circuit	Xfrmr	Phase cur A from	Phase cur A to	Phase cur A from	Phase cur A to	Phase cur A from	Phase cur A to
1	2	1	Yes	1067.7	1028.85	981.3	1018.4	135.72	113.43
3	1	1	No	854.43	888.31	135	64.89	716.72	689.39
4	1	1	No	946.05	953.32	172.2	141.79	812.47	794.31
23	1	1	No	611.44	620.27	381.1	432.11	454.04	494.13
23	1	2	No	611.44	620.27	381.1	432.11	454.04	494.13
23	1	3	No	611.44	620.27	381.1	432.11	454.04	494.13
3	2	1	Yes	186.1	108.13	781.4	822.2	711.2	675.93
3	2	2	Yes	186.1	108.13	781.4	822.2	711.2	675.93
2	6	3	No	674.19	669.23	1078	1076.9	781.04	777.02
2	11	1	No	390.25	365.87	449.8	446.85	405.36	384.93
2	17	1	No	171.06	158.81	212.8	212.51	181.14	171.04
2	17	2	No	171.06	158.81	212.8	212.51	181.14	171.04
2	19	1	No	51.64	34.49	0	0	38.56	25.76
19	2	2	No	34.49	51.64	0	0	25.76	38.56
4	3	1	No	1005.01	978.48	120	140.75	761.93	769.18
3	7	1	No	173.33	173.55	175.6	175.87	0	0
3	7	2	No	173.33	173.55	175.6	175.87	0	0
3	10	1	Yes	1021.3	1002.48	1013	995.01	1188.31	1185.68
10	3	2	Yes	1011.96	1013.84	1004	1005.9	1188.05	1188.31
5	8	1	No	127.13	152.15	224.7	268.9	196.44	235.1
28	5	1	No	228.23	250.71	403.4	443.08	352.66	387.39
6	13	1	No	748.26	730.99	778.4	768.81	753.87	737.86
6	20	1	No	329.66	315.7	310.2	294.73	316.96	299.99
6	21	1	No	192.21	152.77	228.3	200.91	200.57	161.03
27	9	1	No	80.17	93.94	141.7	166.02	123.88	145.16
27	9	2	No	80.17	93.94	141.7	166.02	123.88	145.16
10	12	1	No	375.1	375.1	380.7	380.71	425.61	425.61
10	18	1	No	98.48	103.01	98.68	103.22	23.39	24.46
10	18	2	No	98.48	103.01	98.68	103.22	23.39	24.46
15	11	1	No	358.72	343.77	414	411.4	372.64	359.93
14	21	1	No	42.33	79.4	60.12	93.3	45.59	83.21
15	17	1	No	358.72	365.49	414	414.58	372.64	378.2
28	16	1	No	207.18	233.4	366.2	412.49	320.14	360.65
20	21	1	No	252.31	194.69	326.7	295.85	272.64	221.09
21	22	1	No	221.97	209.76	273.2	265.7	235.17	223.97
21	22	2	No	221.97	209.76	273.2	265.7	235.17	223.97
24	23	1	No	288.21	288.96	275	276.45	275.31	276.82
24	23	2	No	288.21	288.96	275	276.45	275.31	276.82
25	23	1	No	640.92	648.84	606.4	619.01	615.01	628.38
25	23	2	No	640.92	648.84	606.4	619.01	615.01	628.38
27	23	1	No	636.5	671.41	671.8	716.91	675.12	718.76
27	23	2	No	636.5	671.41	671.8	716.91	675.12	718.76
26	25	1	No	45.14	42.37	112.2	105.33	94.46	88.66
28	27	1	No	328.9	315.75	581.3	558.03	508.21	487.89
28	27	2	No	328.9	315.75	581.3	558.03	508.21	487.89

collapse (blackout) was obtained when Shiroro Power Station was out of service. Load increases and loss of transmission lines also forced most of the lines to be overloaded above their thermal capabilities. In order to restore the system from total collapse, load shedding and shunt compensation were carried out. Thus, additional lines are required to create alternative routes in the network in the case of line failures or load increase at the buses.

The 3-phase faults simulated into buses 1, 2 and 3 resulted in very low voltages at all the buses and very high current flows on the lines. These considerations gave rise to the modified network of Fig. 10, which will ensure enough transmission capability and increase the power quality of the system.

RECOMMENDATIONS

In order to improve the voltage stability in the network, the following are recommended

- Need to construct additional lines between buses 1 and 4, 16 and 28, 5 and 8, 3 and 10, 27 and 28 profiles as shown in Fig. 10. This will enhance grid security and improve voltage.
- Generation output in the power stations should be improved by carrying out regular maintenance and replacing the overaged units. Constant supply of fuel to these stations must be ensured.
- Lines 3-10, 27-28, must be re-enforced to avoid possible system collapse that could result from tripping of any of the circuits.

- There is urgent need to plan all load sheddings in advance in order to react to any major line or generator outage.
- Thermal stability limits of the lines should be closely monitored especially during load increase on the network.
- Proper design of the power system layout taking into account the contigencies analysis should be carried out.
- Good system protection to provide rapid detection and isolation of faults in the network should be provided, taking into account the short circuit values in the sizing of the circuit breakers.
- Preventive maintenance programmes and inspection at regular intervals should be encouraged.

CONCLUSION

Voltage instability in the Nigerian 330 kV transmission grid is very high due to low generation, radial and fragile nature of the tranmssion lines and poor system protection. The strenghtening of the network by incorporating shunt compensation and additional lines will help in a great deal to improve voltage stability in the system. In addition, good maintenance schedule as well as proper outage planning must be put in place to ensure good and reliable voltage stability in the network.

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