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Reduction of the High Technical Power Losses Associated with the Nigerian 330KV Transmission Network

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Abstract: This study carried out an in-depth study and analysis of power losses associated with the Nigerian 330 kV and proposed modifications to the existing network to improve the efficiency, reliability, security and ensure good quality power for the citizenry. The research methodology involved the power flow analysis of the existing network and subjecting it to contingency analysis and simulation using Newton-Raphson method in Power World Simulator (PWS) environment. The study revealed that the existing network cannot cope with contingencies leading to very low performance and even blackout at emergencies. The proposed modifications to the 330 kV transmission network which incorporated some additional lines to form more loops and minimal compensation, meet the acceptable voltage limits of ±5%. It also reduces the energy losses from 337.5-189.9 MWH, representing 45% improvement over existing network and enhances reliability and security of the transmission grid.

Key words: Power losses, power flow analysis, contingency analysis, compensation, power world simulator, transmission

INTRODUCTION

The Nigeria power system is characterized by high power losses estimated at 44.5% of sent-out generation. (Hon. Minister of Power and Steel, 2004). Based on the Power Holding Company of Nigeria, (PHCN) annual reports for 2004 and 2005, the transmission line losses alone was estimated at 9.2% of the total losses in the network while the remaining was due to distribution network comprising technical and non-technical losses (PHCN, Oshogbo, 2004 and 2005). The annual energy loss for 2005 was estimated to be 337.5 GWH (Onohaebi and Kuale, 2007). This amounted to over two billion, six hundred thousand Naira (Onohaebi and Kuale, 2007). based on the prevailing tariff rates in Nigeria (PHCN, 2002 and 2006). Thus, there is need to increase the efficiency of the 330KV transmission network and improve the present state of the network. The existing Nigerian electricity network comprises 11,000 km Transmission lines (330 and 132kV), 24000 km of sub-transmission lines (33kV), 19000 km of distribution line (11kV) and 22,500 substations (Sadoh, 2005). The transmission grid system in Nigeria is predominantly characterized by radial, fragile and very long transmission lines, some of which risk total or partial system collapse in the event of major fault occurrence and make voltage control difficult. These lines include Benin-Ikeja West (280 km), Oshogbo-Benin (251 km), Oshogbo-Jebba (249 km), Jebba-Shiroro (244 km), Birnin Kebbi-Kainji (310 km), Jos-Gombe (265 km) and Kaduna-Kano (230 km) (Onohaebi, 2006). These lines experience high voltages under light load conditions and thus they increase the power losses and reduce the maximum power transfer of the line. The present network have only one major loop system involving Benin-Ikeja West-Ayede-Oshogbo and Benin. The objective of this paper was to analyse the existing 330KV network to determine the weak areas resulting in high technical losses with a view to strengthen and improve the efficiency and reliability of the system. This study therefore, proposed a network that will reduce the power losses and high voltages drops associated with in the 330KV transmission network in Nigeria.

MATERIALS AND METHODS

The materials and methods used for this study include:

- The 330 kV transmission network in Nigeria with emphasis on the schematic diagrams of the entire network, line impedances and the associated lengths.
- Data collated based on Power Holding Company of Nigeria (PHCN) logbooks, reports for 2004 and 2005, visitation to transmission stations in Benin, Oshogbo, Ikeja West and Kainji and Jebba, line surveys and interaction with PHCN staff. The data employed in the analysis was based on the maximum loading and generation for December 2005.

- Load flow analysis using Power World Simulator software (Version 8.0) (Power World Corporation, 1996-2000). The maximum load and generation were used as the operating condition. The base case represented realistic conditions and then abnormal/worst case scenarios were applied to the system to ascertain the various flow configurations and determine areas on the network with high or low bus voltage values and power losses based on ± 5% of nominal value with a view to ascertain areas where compensatory work is required.
- Contingency analysis was carried out on the existing network to further assess the effects of line failures/components on the system under emergency or fault conditions
- Strengthening of the identified weak areas in the network with a view to reduce power losses and increase reliability of supply voltage within acceptable limits.
- Analysing the resulting network to ascertain the performance under normal and contingency conditions.

RESULTS AND DISCUSSION

The Nigerian power grid: The existing Nigeria transmission network as at December 2005 used for the case study was drawn in the Edit mode of the PWS and simulated as shown in Fig. 1.

Power flow analysis of the existing 330KV transmission network: The input data for the power flow analysis include 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 (Glover and Sarma, 2002). These were entered into the dialog box of PWS and simulated using the Newton Raphson method available in the Run Mode of the PWS. Table 1 and Fig. 2 showed the bus Information for voltages, while the line flows/loading and power losses for the existing condition of the 330kV Nigeria Transmission Network is shown in Table 2.

Contingency analysis of the existing network: Normally, the bulk power system is designed and operated to provide continuity of service in the case of possible contingencies such as loss of generation unit, loss of transmission line, or failure of any single component of the system (IEEE Standards Board, 1997). The North America Electric Reliability Council (NERC) guidelines recommend making it operational requirements that systems be able to handle any single contingency. The Nigerian 330 kV transmission network was subjected to single contingency analysis to examine the effect of loss of any single line on the network and it resulted in 45 different contingencies. The summary of the voltage tolerance violations are shown in Table 3.

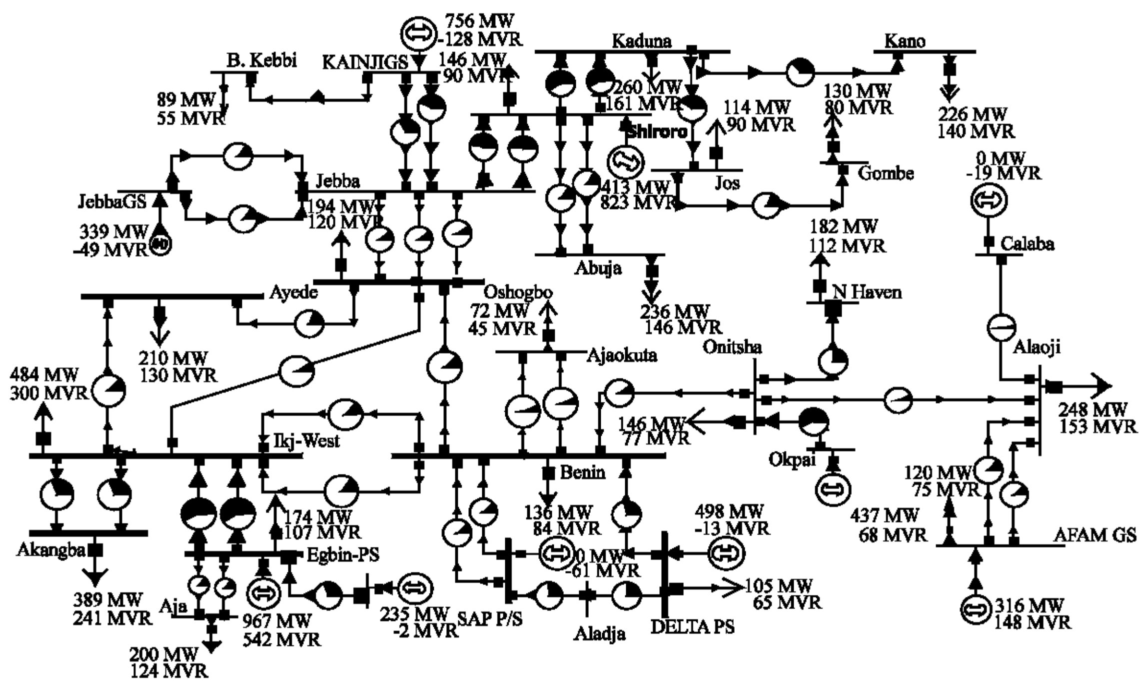

Fig. 1: Existing 330 kV transmission network (Simulated in the run mode)

Introduction of additional lines to the existing 330KV network: Based on the load flow analysis, it became necessary to introduce additional circuits to add more loop systems to the network and minimal compensatory works to achieve higher efficiency and stability in the system. Various transmission lines are under construction and others are proposed by PHCN (Hon. Minister of Power and Steel, 2004). However, a closer study of these lines showed that enough provision was not made to have closed loops in the Nigeria power system. Further investigations/simulation on the network indicated that when the additional lines are completed, they will reduce line congestions but will not provide the much needed alternative routes to link the Southern and Northern parts of the Grid. In view of the above and the contingency analysis carried out for the existing condition, more lines were suggested by the author of this study in addition, to provide more loops as well as providing the necessary alternative links in the Grid. Simulated results however showed that there is still need for compensatory works on the buses at Kaduna, Kano, Jos and Gombe. Based on 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 were determined as shown in Fig. 3.

Kaduna Bus

Total load = 260MW

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

=161MVAr lagging

Reactive MVAr of load corresponding to 0.95pf

$$= \frac{260}{0.95} \times \sin(\cos^{-1} 0.95)$$

=95.5MVAr lagging

Rating of capacitor bank = 161-95.5MVAR

= 75.5 MVAr MVAr

This size corresponds to values obtained from tables (BICC, I965) 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

A total of 8 various combinations were obtained resulting in 8 case studies which were tested and the results are as shown in Table 4 and 5. The best combination of shunt capacitors occurred at Kano and Gombe buses.

Table 1: Bus voltages of the existing network

No.	Name	PU Volt	Volt (kV)	Angle (Deg)
1	Oshogbo	0.98986	326.653	-6.85
2	Benin	1.0018	330.593	-3.32
3	Ikj-West	0.9637	318.021	-6.87
4	Ayede	0.95535	315.265	-9.04
5	Jos	0.76079	251.059	-39.42
6	Onitsha	0.98046	323.553	-1.95
7	Akangba	0.95589	315.444	-7.46
8	Gombe	0.65965	217.686	-50.80
9	Abuja	0.97119	320.492	-24.11
10	Egbin-PS	1	330	-2.85
11	Delta PS	1	330	0.54
12	AES	1	330	-2.85
13	Okpai	1	330	2.31
14	Calaba	1	330	-5.19
15	Aladja	1.0008	330.265	-1.56
16	Kano	0.74894	247.149	-40.36
17	SAP P/S	1	330	-2.55
18	Aja	0.99362	327.894	-3.36
19	Ajaokuta	1.00759	332.504	-4.52
20	N Haven	0.95624	315.56	-5.10
21	Alaoji	0.96416	318.174	-5.17
22	AFAM GS	1	330	-1.31
23	Jebba	1	330	-4.75
24	JebbaGS	1	330	-4.53
25	KAINJIGS	1	330	0.00
26	B Kebbi	0.98364	324.603	-4.87
27	Shiroro	1	330	-21.20
28	Kaduna	0.9035	298.154	-27.68

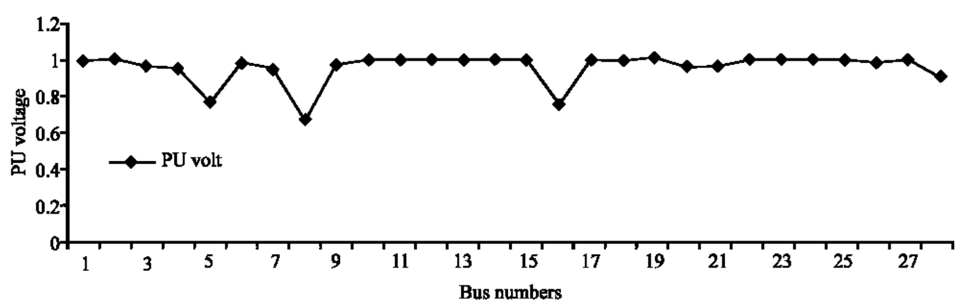

Fig. 2: Bus voltages in PU values in the existing 330 kV transmission network

Table 2: Bus information for line loading and losses for the existing condition of 330kVNigeria transmission network

From Nr	From Name	To Nr	To Name	Circuit	Status	Xfrmr	From MW	From Mvar	From MVA	Lim MVA	Max (%)	MW Loss	Mvar Loss
28	Kaduna	16	Kano	1	Closed	No	235.4	160.1	284.7	760	37.5	9.42	20.09
28	Kaduna	27	Shiroro	2	Closed	No	-376.6	-249.8	451.9	760	63.2	8.21	37.43
28	Kaduna	5	Jos	1	Closed	No	257.8	178.6	313.6	760	41.3	9.45	28.67
28	Kaduna	27	Shiroro	1	Closed	No	-376.6	-249.8	451.9	760	63.2	8.21	37.43
27	Shiroro	9	Abuja	2	Closed	No	118.9	27.1	121.9	760	18.3	0.89	-45.95
27	Shiroro	9	Abuja	1	Closed	No	118.9	27.1	121.9	760	18.3	0.89	-45.95
27	Shiroro	23	Jebba	1	Closed	No	-370.2	52.3	373.9	760	50.6	12.77	16.20
27	Shiroro	23	Jebba	2	Closed	No	-370.2	52.3	373.9	760	50.6	12.77	16.20
26	B Kebbi	25	KAINJIGS	1	Closed	No	-89.0	-55.0	104.6	760	13.8	0.91	-98.39
25	KAINJIGS	23	Jebba	2	Closed	No	333.3	-42.1	335.9	760	44.2	3.35	-3.30
25	KAINJIGS	23	Jebba	1	Closed	No	333.3	-42.1	335.9	760	33.6	3.35	-3.30
24	JebbaGS	23	Jebba	1	Closed	No	169.5	-24.4	171.2	760	17.1	0.09	-2.66
24	JebbaGS	23	Jebba	2	Closed	No	169.5	-24.4	171.2	760	17.1	0.09	-2.66
23	Jebba	1	Oshogbo	3	Closed	No	77.6	-16.3	79.3	760	11.4	0.35	-56.14
23	Jebba	1	Oshogbo	2	Closed	No	77.6	-16.3	79.3	760	11.4	0.35	-56.14
23	Jebba	1	Oshogbo	1	Closed	No	77.6	-16.3	79.3	760	11.4	0.35	-56.14
21	Alaoji	22	AFAM GS	1	Closed	No	-97.0	-38.6	104.4	760	13.8	1.02	-2.09
21	Alaoji	22	AFAM GS	2	Closed	No	-97.0	-38.6	104.4	760	13.8	1.02	-2.09
20	N Haven	21	Alaoji	1	Closed	No	0.5	-42.1	42.1	760	4.2	0.02	-48.16
19	Ajaokuta	2	Benin	2	Closed	No	-36.0	-22.5	42.5	760	8.3	0.11	-74.36
15	Aladja	17	SAP P/S	1	Closed	No	187.7	-17.5	188.5	760	24.8	0.38	-8.55
15	Aladja	11	Delta PS	1	Closed	No	-187.7	17.5	188.5	760	25.2	0.81	-17.80
14	Calaba	21	Alaoji	1	Closed	No	0.0	-19.3	19.3	760	4.4	0.00	-53.05
10	Egbin-PS	18	Aja	2	Closed	No	100.1	52.8	113.2	760	15.5	0.13	-9.18
10	Egbin-PS	18	Aja	1	Closed	No	100.1	52.8	113.2	760	15.5	0.13	-9.18
10	Egbin-PS	12	AES	1	Closed	No	-235.0	2.4	235.0	760	30.9	0.00	0.01
10	Egbin-PS	3	Ikj-West	2	Closed	Yes	413.9	169.2	447.1	760	58.8	4.49	32.06
6	Onitsha	21	Alaoji	1	Closed	No	53.7	-10.4	54.7	760	8.5	0.16	-46.31
6	Onitsha	20	N Haven	1	Closed	No	183.8	47.2	189.8	760	25.7	1.34	-22.69
6	Onitsha	13	Okpai	1	Closed	No	-433.1	-56.3	436.7	760	58.2	3.95	12.05
5	Jos	8	Gombe	1	Closed	No	134.3	59.9	147.1	760	20.1	4.34	-20.09
4	Ayede	3	Ikj-West	1	Closed	No	-97.1	-30.8	101.9	760	13.4	0.51	-44.21
4	Ayede	1	Oshogbo	1	Closed	No	-112.9	-99.2	150.3	760	19.8	0.85	-34.08
3	Ikj-West	2	Benin	1	Closed	Yes	-74.1	-85.1	112.9	760	14.9	0.77	-106.32
3	Ikj-West	10	Egbin-PS	1	Closed	Yes	-409.4	-147.9	435.3	760	58.3	4.49	9.76

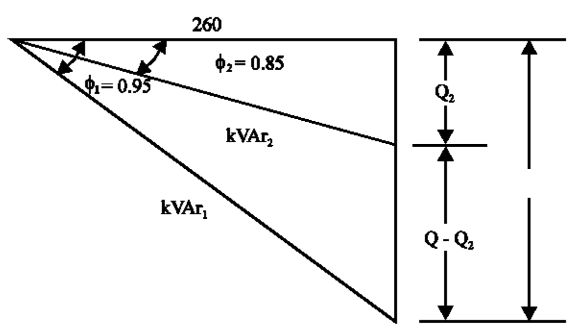

Fig. 3: Determination of capacity of shunt capacitors

The proposed 330KV transmission network: Based on the analysis so far, the network of Fig. 4 shows the modified future Grid system indicating the proposed lines and the associated compensating devices. The network has additional circuits at Ayede-Oshogbo, Egbin-Ikeja west and Kaduna-Shiroro introduced. Table 6 and Fig. 5 showed the simulated bus voltages, while Table 7 shows the line loadings and losses information for the proposed 330kV transmission network. To further ensure that the network satisfy the standards of NERC relating to contingency, it was subjected to the contingency analysis and the results are shown in Table 8.

Estimation of annual energy loss for the network: From the results obtained in the simulation of peak loads under peak generation for December 2005, the total energy loss was obtained using the annual load factor as (Onohaebi and Kuale, 2007).

$LF_A = LF_D \times R_{WM} \times R_{MA} = 0.681 \times 0.721 \times 0.992 = 0.487$

The Load Loss Factor (LLF) = C (LF) + 1 – C (LF)^2

where C = 0.3 for transmission lines

$= 0.3 \times 0.487 + 0.7 \times 0.487^2 = 0.383$

Annual MWH Loss = LLF × Peak Loss in MW × 8,760

Using the peak power loss under maximum generation and peak loading, i.e., 100.6 MW, the total energy loss for 2005 was 0.383 × 100.6 × 8,760 = 337,521 MWH

The proposed network recorded a peak loss of 56.6 MW in December, a saving of 44 MW. Using the load

Table 3: Summary of voltage violations for the existing condition

Contingency records label	Skip	Processed	Solved	Violations	Max Line %	Min volt	Max volt
L00001Oshogbo-00002BeninC1	No	Yes	Yes	5		0.66	
L00003Ikj-West-00001OshogboC1	No	Yes	Yes	6		0.66	
L00004Ayede-00001OshogboC1	No	Yes	Yes	6		0.66	
L00023Jebba-00001OshogboC1	No	Yes	Yes	5		0.66	
L00023Jebba-00001OshogboC2	No	Yes	Yes	5		0.66	
L00023Jebba-00001OshogboC3	No	Yes	Yes	5		0.66	
L00003Ikj-West-00002BeninC1	No	Yes	Yes	6		0.66	
L00003Ikj-West-00002BeninC2	No	Yes	Yes	6		0.66	
L00002Benin-00006OnitshaC3	No	Yes	Yes	5		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	117.3	0.66	
L00010Egbin-PS-00003Ikj-WestC2	No	Yes	Yes	8	116.4	0.66	
L00006Onitsha-00020NHavenC1	No	Yes	Yes	6		0.66	
L00006Onitsha-00021AlaojiC1	No	Yes	Yes	5		0.66	
L00006Onitsha-00034OkpaiC1	No	Yes	Yes	8		0.66	
L00010Egbin-PS-00018AjaC1	No	Yes	Yes	4		0.66	
L00010Egbin-PS-00018AjaC2	No	Yes	Yes	4		0.66	
L00010Egbin-PS-00033AESC1	No	Yes	Yes	4		0.66	
L00036Aladja-00011DELTAPSC1	No	Yes	Yes	4		0.66	
L00036Aladja-00017SAPP/SC1	No	Yes	Yes	4		0.66	
L00020NHaven-00021AlaojiC1	No	Yes	Yes	5		0.66	
L00021Alaoji-00022AFAMGSC1	No	Yes	Yes	6		0.66	
L00021Alaoji-00022AFAMGSC2	No	Yes	Yes	6		0.66	
L00035Calaba-00021AlaojiC1	No	Yes	Yes	4		0.66	
L00024JebbaGS-00023JebbaC1	No	Yes	Yes	4		0.66	
L00024JebbaGS-00023JebbaC2	No	Yes	Yes	4		0.66	
L00025KAINJIGS-00023JebbaC1	No	Yes	Yes	5	105.9	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			
L00027Shiroro-00032AbujaC1	No	Yes	Yes	5	0.66		
L00027Shiroro-00032AbujaC2	No	Yes	Yes	5	0.66		
L00028Kaduna-00029KanoC1	No	Yes	Yes	2	0.775		
L00028Kaduna-00030JosC1	No	Yes	Yes	2	0.81		
L00030Jos-00031GombeC1	No	Yes	Yes	3	0.795		

Table 4: Simulated results of real power losses of the compensated and modified 330 kV transmission networks

BUS From name	Bus To name	Case-1 MW loss	Case 2 MW loss	Case 3 MW loss	Case 4 MW loss	Case 5 MW loss	Case 6 MW loss	Case 7 MW loss	Case 8 MW loss	Mod.network MW loss
Yola	Jalingo	0	0	0	0	0	0	0	0	0
Calaba	Alaoji	0	0	0	0	0	0	0	0	0
Oshogbo	Benin	0.59	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.07
Abuja	Ajaokuta	0	0.85	0.84	0.85	0.85	0.85	0.84	0.84	0.99
Ajaokuta	Benin	0.11	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.63
Aladja	SAP P/S	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38	0.38
Aladja	DELTA PS	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81	0.81
Alaoji	AFAM GS	0.99	0.91	0.91	0.92	0.92	0.92	0.91	0.91	0.91
Alaoji	AFAM GS	0.99	0.91	0.91	0.92	0.92	0.92	0.91	0.91	0.91
Ayede	Oshogbo	0.85	1.47	1.47	1.47	1.47	1.47	1.47	1.47	0.46
Ayede	Ikj-West	0.51	0.11	0.12	0.12	0.12	0.12	0.11	0.12	0.01
Ayede	Oshogbo	0	0	0	0	0	0	0	0	0.46
B Kebbi	KAINJIGS	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91	0.91
Benin	Ajaokuta	0.11	0.57	0.57	0.57	0.57	0.57	0.57	0.57	0.63
Benin	SAP P/S	0.17	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.19
Benin	Onitsha	0.1	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.07
Benin	DELTA PS	1.62	1.63	1.63	1.63	1.63	1.63	1.63	1.63	1.64

Table 4: Continued

Bus From name	Bus To name	Case-1 MW loss	Case 2 MW loss	Case 3 MW loss	Case 4 MW loss	Case 5 MW loss	Case 6 MW loss	Case 7 MW loss	Case 8 MW loss	Mod.network MW loss
Benin	Onitsha	0.1	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.07
Benin	SAP P/S	0.17	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.19
Egbin-PS	AES	0	0	0	0	0	0	0	0	0
Egbin-PS	Ikj-West	0	0	0	0	0	0	0	0	1.95
Egbin-PS	Aja	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Egbin-PS	Aja	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Egbin-PS	Ikj-West	4.49	4.47	4.47	4.47	4.47	4.47	4.47	4.47	1.95
Egbin-PS	Ikj-West	4.49	4.47	4.47	4.47	4.47	4.47	4.47	4.47	1.95
Gombe	Yola	0	0	0	0	0	0	0	0	0
Ikj-West	Akangba	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.33
Ikj-West	Oshogbo	0.1	0.36	0.35	0.35	0.35	0.35	0.36	0.35	0.16
Ikj-West	Benin	0.78	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.13
Ikj-West	Akangba	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.34	0.33
Ikj-West	Benin	0.78	0.26	0.26	0.26	0.26	0.26	0.26	0.26	0.13
Jebba	Oshogbo	0.35	1.32	1.31	1.31	1.31	1.31	1.31	1.31	1.28
Jebba	Oshogbo	0.35	1.32	1.31	1.31	1.31	1.31	1.31	1.31	1.28
Jebba	Oshogbo	0.35	1.32	1.31	1.31	1.31	1.31	1.31	1.31	1.28
JebbaGS	Jebba	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.1
JebbaGS	Jebba	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.1
Jos	Markurdi	0	1.33	1.29	1.35	1.33	1.34	1.32	1.29	1.13
Jos	Gombe	0	0	0	0	0	0	0	0	0
Jos	Gombe	2.16	1.64	1.56	1.7	1.9	1.92	1.63	1.56	1.64
Kaduna	Jos	5.13	1.54	1.49	1.4	1.34	1.35	1.54	1.49	1.52
Kaduna	Kano	0	0	1.09	1.28	1.24	1.14	1.26	1.09	1.12
Kaduna	Kano	6.54	5.95	1.09	1.28	1.24	1.14	1.26	1.09	1.12
Kaduna	Shiroro	0	0	0	0	0	0	0	0	1.52
Kaduna	Shiroro	5.48	3.47	3.36	3.46	3.37	3.41	3.41	3.36	1.52
Kaduna	Shiroro	5.48	3.47	3.36	3.46	3.37	3.41	3.41	3.36	1.52
KAINJIGS	Jebba	3.19	3.04	3	3	3	3	3	3	2.93
KAINJIGS	Jebba	3.19	3.04	3	3	3	3	3	3	2.93
Markurdi	N Haven	0	1.07	1.17	0.99	1.01	0.99	1.08	1.17	0.95
N Haven	Alaoji	0.01	0.04	0.05	0.03	0.03	0.03	0.04	0.05	0.04
Onitsha	Okpai	3.85	3.82	3.82	3.82	3.82	3.82	3.82	3.82	3.82
Onitsha	Alaoji	0.16	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.27
Onitsha	N Haven	1.35	2.77	2.75	2.76	2.75	2.75	2.76	2.75	2.61
Shiroro	Abuja	0.89	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.22
Shiroro	Abuja	0.89	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.22
Shiroro	Jebba	12.24	5.61	5.54	5.55	5.55	5.55	5.54	5.54	5.48
Shiroro	Jebba	12.24	5.61	5.54	5.55	5.55	5.55	5.54	5.54	5.48
Total		84.02	67.9	63.54	63.73	63.97	63.09	64.09	63.81	

Table 5: Bus voltage violations arising from contingency analysis of the compensated and modified 330kV transmission networks

Label	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Modified network
L00001Oshogbo-00002BeninC1	4	2	1	1	1	2	2	1	0
L00003Ikj-West-00001OshogboC1	4	2	1	1	1	2	2	1	0
L00004Ayede-00001OshogboC1	5	3	2	2	2	3	3	2	0
L00004Ayede-00001OshogboC2	3	1	0	0	0	1	1	0	0
L00023Jebba-00001OshogboC1	3	2	1	1	1	2	2	1	0
L00023Jebba-00001OshogboC2	3	2	1	1	1	2	2	1	0
L00023Jebba-00001OshogboC3	3	2	1	1	1	2	2	1	0
L00003Ikj-West-00002BeninC1	4	3	2	2	2	3	3	2	0
L00003Ikj-West-00002BeninC2	4	3	2	2	2	3	3	2	0
L00002Benin-00006OnitshaC3	3	1	0	0	0	1	1	0	0
L00002Benin-00006OnitshaC4	3	1	0	0	1	1	1	0	0
L00002Benin-00011DELTAPSC1	3	1	0	0	0	1	1	0	0
L00002Benin-00017SAPP/SC1	3	1	0	0	0	1	1	0	0
L00002Benin-00017SAPP/SC2	3	1	0	0	0	1	1	0	0
L00002Benin-00019AjaokutaC1	3	1	0	0	0	1	1	0	0
L00019Ajaokuta-00002BeninC2	3	1	0	0	0	1	1	0	0
L00004Ayede-00003Ikj-WestC1	4	2	1	1	1	2	2	1	0
L00003Ikj-West-00007AkangbaC1	4	2	1	1	1	2	2	1	0
L00003Ikj-West-00007AkangbaC2	4	2	1	1	1	2	2	1	0
L00010Egbin-PS-00003Ikj-WestC1	7	5	4	4	4	5	5	4	0
L00010Egbin-PS-00003Ikj-WestC2	3	1	0	0	0	1	1	0	0
L00010Egbin-PS-00003Ikj-WestC3	7	5	4	4	4	5	5	4	0

Table 5:Continued

Label	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Modified network
L00006Onitsha-00020NHavenC1	5	1	0	1	3	2	1	0	0
L00006Onitsha-00021AlaojiC1	3	1	0	0	1	1	1	0	0
L00006Onitsha-00034OkpaiC1	5	2	1	1	3	2	2	1	0
L00010Egbin-PS-00018AjaC1	3	1	0	0	0	1	1	0	0
L00010Egbin-PS-00018AjaC2	3	1	0	0	0	1	1	0	0
L00010Egbin-PS-00033AESC1	3	1	0	0	0	1	1	0	0
L00036Aladja-00011DELTAPSC1	3	1	0	0	0	1	1	0	0
L00036Aladja-00017SAPP/SC1	3	1	0	0	0	1	1	0	0
L00032Abuja-00019AjaokutaC1	3	1	0	0	1	1	1	0	0
L00020NHaven-00021AlaojiC1	4	1	0	0	1	1	1	0	0
L00037Markurdi-00020NHavenC1	3	2	3	1	1	1	2	3	1
L00021Alaoji-00022AFAMGSC1	4	1	0	0	1	1	1	0	0
L00021Alaoji-00022AFAMGSC2	4	1	0	0	1	1	1	0	0
L00035Calaba-00021AlaojiC1	3	1	0	0	1	1	1	0	0
L00024JebbaGS-00023JebbaC1	3	1	0	0	0	1	1	0	0
L00024JebbaGS-00023JebbaC2	3	1	0	0	0	1	1	0	0
L00025KAINJIGS-00023JebbaC1	3	1	0	0	0	1	1	0	0
L00025KAINJIGS-00023JebbaC2	3	1	0	0	0	1	1	0	0
L00027Shiroro-00023JebbaC1	3	1	0	0	1	1	1	0	0
L00027Shiroro-00023JebbaC2	4	1	0	0	1	1	1	0	0
L00026BKebbi-00025KAINJIGSC1	3	1	0	0	0	1	1	0	0
L00028Kaduna-00027ShiroroC1	Unsolved	3	0	2	2	3	3	0	0
L00028Kaduna-00027ShiroroC2	Unsolved	3	0	2	2	3	3	0	0
L00028Kaduna-00027ShiroroC3	3	1	0	0	0	1	1	0	0
L00027Shiroro-00032AbujaC1	4	1	0	0	0	1	1	0	0
L00027Shiroro-00032AbujaC2	4	1	0	0	0	1	1	0	0
L00028Kaduna-00029KanoC1	1	0	1	1	2	2	1	1	1
L00028Kaduna-00029KanoC2	3	1	1	1	2	2	1	1	1
L00028Kaduna-00030JosC1	1	Unsolved	Unsolved	Unsolved	Unsolved	Unsolved	Unsolved	Unsolved	1
L00030Jos-00031GombeC1	2	1	0	0	0	0	1	0	0
L00030Jos-00031GombeC2	3	1	0	0	0	1	1	0	0
L00030Jos-00037MarkurdiC1	3	3	2	3	3	3	3	2	2
L00031Gombe-00038YolaC1	3	1	0	0	0	1	1	0	0

Table 6: Bus information for the proposed 330kV transmission network

No.	Name	PU Volt	Volt (kV)	Angle (Deg)
1	Oshogbo	0.9944	328.152	-8.59
2	Benin	1.00472	331.557	-9.65
3	Ikj-West	0.9769	322.378	-10.19
4	Ayede	0.97769	322.639	-10.52
6	Onitsha	0.99358	327.882	-10.30
7	Akangba	0.9692	319.837	-10.76
10	Egbin-PS	1	330	-7.54
11	DELTA PS	1	330	-5.78
17	SAP P/S	1	330	-8.86
18	Aja	0.99362	327.894	-8.05
19	Ajaokuta	1.00992	333.274	-12.67
20	N Haven	0.98549	325.213	-14.99
21	Alaoji	0.97753	322.585	-14.49
22	AFAM GS	1	330	-10.59
23	Jebba	1.00077	330.254	-4.44
24	JebbaGS	1	330	-4.22
25	KAINJIGS	1	330	0
26	B Kebbi	0.98364	324.603	-4.87
27	Shiroro	1	330	-15.19
28	Kaduna	0.99242	327.5	-18.74
29	Kano	0.97264	320.97	-23.39
30	Jos	1.00947	333.124	-23.73
31	Gombe	0.99057	326.888	-29.77
32	Abuja	0.98825	326.123	-16.71
33	AES	1	330	-7.54
34	Okpai	1	330	-6.01
35	Calaba	1	330	-14.51
36	Aladja	1.0008	330.265	-7.87
37	Markurdi	1.02153	337.106	-18.59
38	Yola	0	0	0
39	Jalingo	0	0	0

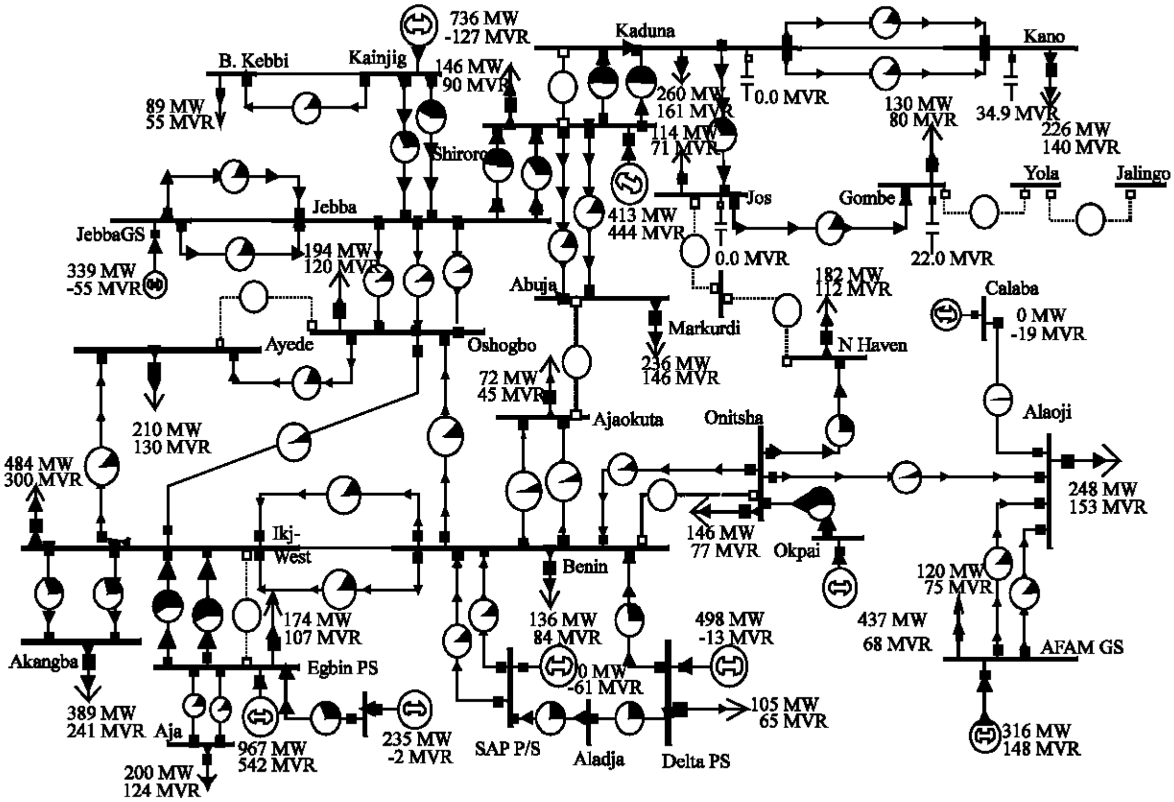

Fig. 4: Proposed 330 kV transmission network with additional circuits shown in dashed lines and compensating devices

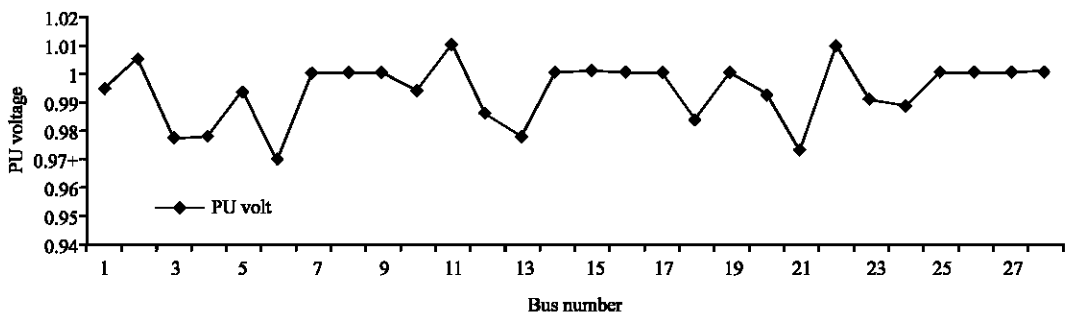

Fig. 5: Bus voltages in PU values in the proposed 330 kV transmission network

Table 7: Bus information for line loading and losses for the proposed 330kV Nigeria transmission network

From Nr	From Name	To Nr	To Name	Circuit	Status	Xfrmr	From MW	From Mvar	From MVA	Lim MVA	Max %()	MW Loss	Mvar Loss
38	Yola	39	Jalingo	1	Open	No	0.0	0	0	760	0	0	0
35	Calaba	21	Alaoji	1	Closed	No	0.0	-22	22.4	760	4.2	0	-53.95
1	Oshogbo	2	Benin	1	Closed	Yes	22.3	-63	66.8	760	8.8	0.07	-94.74
32	Abuja	19	Ajaokuta	1	Closed	No	-112.0	-56	125.1	760	16.5	0.99	-71.48
19	Ajaokuta	2	Benin	2	Closed	No	-92.6	-15	93.7	760	14.3	0.63	-70.59
36	Aladja	17	SAP P/S	1	Closed	No	187.0	-17	188.2	760	24.8	0.38	-8.56
36	Aladja	11	DELTA PS	1	Closed	No	-187.0	17.4	188.2	760	25.2	0.81	-17.82
21	Alaoji	22	AFAM GS	1	Closed	No	-97.1	-21	99.3	760	13.1	0.91	-3.08
21	Alaoji	22	AFAM GS	2	Closed	No	-97.1	-21	99.3	760	13.1	0.91	-3.08
4	Ayede	1	Oshogbo	1	Closed	No	-97.7	-55	112	760	14.7	0.46	-38.59
4	Ayede	3	Ikj-West	1	Closed	No	-14.5	-21	25.3	760	4.3	0.01	-49.67

Table 7: Continued

From Nr	From Name	To Nr	To Name	Circuit	Status	Xfrmr	From MW	From Mvar	From MVA	Lim MVA	Max %()	MW Loss	Mvar Loss
4	Ayede	1	Oshogbo	2	Closed	No	-97.7	-55	112	760	14.7	0.46	-38.59
26	B Kebbi	25	KAINJIGS	1	Closed	No	-89.0	-55	104.6	760	13.8	0.91	-98.39
2	Benin	19	Ajaokuta	1	Closed	No	93.2	-56	108.7	760	14.3	0.63	-70.59
2	Benin	17	SAP P/S	2	Closed	No	-93.3	36.4	100.2	760	14.3	0.19	-19.4
2	Benin	6	Onitsha	4	Closed	No	29.9	-2.9	30.1	760	7.5	0.07	-51.41
2	Benin	11	DELTA PS	1	Closed	No	-203.0	24.9	204.7	760	27.8	1.64	-27.14
2	Benin	6	Onitsha	3	Closed	No	29.9	20.7	36.4	760	5.2	0.07	-4.6
2	Benin	17	SAP P/S	1	Closed	No	-93.3	36.4	100.2	760	14.3	0.19	-19.4
10	Egbin-PS	33	AES	1	Closed	No	-235.0	2.4	235	760	30.9	0	0.01
10	Egbin-PS	3	Ikj-West	2	Closed	Yes	276.0	103	294.5	760	38.7	1.95	12.48
10	Egbin-PS	18	Aja	1	Closed	No	100	52.8	113.2	760	15.5	0.13	-9.18
10	Egbin-PS	18	Aja	2	Closed	No	100	52.8	113.2	760	15.5	0.13	-9.18
10	Egbin-PS	3	Ikj-West	3	Closed	No	276	103	294.5	760	38.7	1.95	12.48
10	Egbin-PS	3	Ikj-West	1	Closed	Yes	276	91.4	290.7	760	38.4	1.95	-10.12
31	Gombe	38	Yola	1	Open	No	0	0	0	760	0	0	0
3	Ikj-West	7	Akangba	2	Closed	No	195	123	230.3	760	30.3	0.33	2.33
3	Ikj-West	1	Oshogbo	1	Closed	No	-36.8	-64	73.5	760	9.7	0.16	-93.54
3	Ikj-West	2	Benin	2	Closed	Yes	-14.8	-85	86.6	760	11.4	0.13	-113.1
3	Ikj-West	7	Akangba	1	Closed	No	195	123	230.3	760	30.3	0.33	2.33
3	Ikj-West	2	Benin	1	Closed	Yes	-14.8	-85	86.6	760	11.4	0.13	-113.1
23	Jebba	1	Oshogbo	3	Closed	No	151	-29	153.9	1000	15.4	1.28	-48.53
23	Jebba	1	Oshogbo	2	Closed	No	151	-29	153.9	760	20.2	1.28	-48.53
23	Jebba	1	Oshogbo	1	Closed	No	151	-29	153.9	760	20.2	1.28	-48.53
24	JebbaGS	23	Jebba	2	Closed	No	170	-59	179.6	1000	18	0.1	-2.6
24	JebbaGS	23	Jebba	1	Closed	No	170	-59	179.6	1000	18	0.1	-2.6
30	Jos	37	Markurdi	1	Closed	No	-106	-48	116.3	760	15.3	1.13	-93.59
30	Jos	31	Gombe	2	Open	No	0	0	0	760	0	0	0
30	Jos	31	Gombe	1	Closed	No	132	-37	136.6	760	18.4	1.64	-87.06
28	Kaduna	30	Jos	1	Closed	No	141	-75	159.9	760	21	1.52	-61.94
28	Kaduna	29	Kano	2	Closed	No	114	-24	116.6	760	16.3	1.12	-74.88
28	Kaduna	29	Kano	1	Closed	No	114	-24	116.6	1000	12.4	1.12	-74.88
28	Kaduna	27	Shiroro	3	Closed	No	-210	-13	210.2	760	27.8	1.52	-23.07
28	Kaduna	27	Shiroro	2	Closed	No	-210	-13	210.2	760	27.8	1.52	-23.07
28	Kaduna	27	Shiroro	1	Closed	No	-210	-13	210.2	760	27.8	1.52	-23.07
25	KAINJIGS	23	Jebba	2	Closed	No	311	-44	314.5	760	41.4	2.93	-6.77
25	KAINJIGS	23	Jebba	1	Closed	No	311	-44	314.5	1000	31.4	2.93	-6.77
37	Markurdi	20	N Haven	1	Closed	No	-107	45.8	116.6	760	19.9	0.95	-59.57
20	N Haven	21	Alaoji	1	Closed	No	-17.6	-4.6	18.2	1000	4.9	0.04	-50.16
6	Onitsha	34	Okpai	1	Closed	No	-433	19	433.6	760	57.5	3.82	10.69
6	Onitsha	21	Alaoji	1	Closed	No	71.7	-11	72.6	760	10.5	0.27	-45.46
6	Onitsha	20	N Haven	1	Closed	No	275	-11	275.4	760	36.2	2.61	-13.34
27	Shiroro	32	Abuja	2	Closed	No	62.2	-7.3	62.6	760	10.1	0.22	-52.49
27	Shiroro	32	Abuja	1	Closed	No	62.2	-7.3	62.6	760	10.1	0.22	-52.49
27	Shiroro	23	Jebba	2	Closed	No	-246	5.1	245.6	1000	25.6	5.48	-46.05
27	Shiroro	23	Jebba	1	Closed	No	-246	5.1	245.6	760	33.7	5.48	-46.05

Table 8: Contingency records for the proposed network

Label	Skip	Processed	Solved	Violations
L00001Oshogbo-00002BeninC1	No	Yes	Yes	0
L00003Ikj-West-00001OshogboC1	No	Yes	Yes	0
L00004Ayede-00001OshogboC1	No	Yes	Yes	0
L00004Ayede-00001OshogboC2	No	Yes	Yes	0
L00023Jebba-00001OshogboC1	No	Yes	Yes	0
L00023Jebba-00001OshogboC2	No	Yes	Yes	0
L00023Jebba-00001OshogboC3	No	Yes	Yes	0
L00003Ikj-West-00002BeninC1	No	Yes	Yes	0
L00003Ikj-West-00002BeninC2	No	Yes	Yes	0
L00002Benin-00006OnitshaC3	No	Yes	Yes	0
L00002Benin-00006OnitshaC4	No	Yes	Yes	0
L00002Benin-00011DELTAPSC1	No	Yes	Yes	0
L00002Benin-00017SAPP/SC1	No	Yes	Yes	0
L00002Benin-00017SAPP/SC2	No	Yes	Yes	0
L00002Benin-00019AjaokutaC1	No	Yes	Yes	0
L00019Ajaokuta-00002BeninC2	No	Yes	Yes	0
L00004Ayede-00003Ikj-WestC1	No	Yes	Yes	0
L00003Ikj-West-00007AkangbaC1	No	Yes	Yes	0

Table 8: Continued

Label	Skip	Processed	Solved	Violations
L00003Ikj-West-00007AkangbaC2	No	Yes	Yes	0
L00010Egbin-PS-00003Ikj-WestC1	No	Yes	Yes	0
L00010Egbin-PS-00003Ikj-WestC2	No	Yes	Yes	0
L00010Egbin-PS-00003Ikj-WestC3	No	Yes	Yes	0
L00006Onitsha-00020NHavenC1	No	Yes	Yes	0
L00006Onitsha-00021AlaojiC1	No	Yes	Yes	0
L00006Onitsha-00034OkpaiC1	No	Yes	Yes	0
L00010Egbin-PS-00018AjaC1	No	Yes	Yes	0
L00010Egbin-PS-00018AjaC2	No	Yes	Yes	0
L00010Egbin-PS-00033AESC1	No	Yes	Yes	0
L00036Aladja-00011DELTAPSC1	No	Yes	Yes	0
L00036Aladja-00017SAPP/SC1	No	Yes	Yes	0
L00032Abuja-00019AjaokutaC1	No	Yes	Yes	0
L00020NHaven-00021AlaojiC1	No	Yes	Yes	0
L00037Markurdi-00020NHavenC1	No	Yes	Yes	1
L00021Alaoji-00022AFAMGSC1	No	Yes	Yes	0
L00021Alaoji-00022AFAMGSC2	No	Yes	Yes	0
L00035Calaba-00021AlaojiC1	No	Yes	Yes	0
L00024JebbaGS-00023JebbaC1	No	Yes	Yes	0
L00024JebbaGS-00023JebbaC2	No	Yes	Yes	0
L00025KAINJIGS-00023JebbaC1	No	Yes	Yes	0
L00025KAINJIGS-00023JebbaC2	No	Yes	Yes	0
L00027Shiroro-00023JebbaC1	No	Yes	Yes	0
L00027Shiroro-00023JebbaC2	No	Yes	Yes	0
L00026BKebbi-00025KAINJIGSC1	No	Yes	Yes	0
L00028Kaduna-00027ShiroroC1	No	Yes	Yes	0
L00028Kaduna-00027ShiroroC2	No	Yes	Yes	0
L00028Kaduna-00027ShiroroC3	No	Yes	Yes	0
L00027Shiroro-00032AbujaC1	No	Yes	Yes	0
L00027Shiroro-00032AbujaC2	No	Yes	Yes	0
L00028Kaduna-00029KanoC1	No	Yes	Yes	1
L00028Kaduna-00029KanoC2	No	Yes	Yes	1
L00028Kaduna-00030JosC1	No	Yes	No	Unsolved
L00030Jos-00031GombeC1	No	Yes	Yes	0
L00030Jos-00031GombeC2	No	Yes	Yes	0
L00030Jos-00037MarkurdiC1	No	Yes	Yes	2
L00031Gombe-00038YolaC1	No	Yes	Yes	0
L00038Yola-00039JalingoC1	No	Yes	Yes	0

loss factor of 0.383, the annual MWH loss for this network if operated over the same period (2005) was $0.383\times56.6\times8760 = 189{,}897$MWH Gain in annual energy = 337,521 - 189897 = 147,624 MWH.

The financial loss due to transmission losses in 330 kV in 2005 on the existing network was estimated based on PHCN new tariff structure and PHCN monthly revenue analysis by tariff amounted to 2.6 billion Naira in the existing network (Onohaebi and Kuale, 2007)compared to 1.4 billion Naira in the proposed 330kV transmission network (a saving of 1.2 billion Naira).

DISCUSSION OF SIGNIFICANT FINDINGS ARISING FROM THE EXISTING AND PROPOSED NETWORKS IN THIS RESEARCH

Power losses in the network: The existing network recorded a total energy loss of 337.5 GWH in 2005. Simulation of the proposed network under the same loading and generating conditions for the same period resulted in total energy loss of 189.9 GWH, a savings of 147.6 GWH representing 45% improvement. This is enormous considering the poor electric power generation in Nigeria.

Voltage profiles of the networks: All the bus voltages in the proposed network are within the acceptable limits of ±5% as shown in Fig. 5 while the existing network recorded voltage violations as shown in Fig. 2.

Contingency analysis: The contingencies analysis showed a total of 208 voltage violation outside the statutory limits of ±5% in the existing circuits as against the proposed network whose voltages were within acceptable limits.

Line losses: Line losses in the existing network were high with Shiroro recording 12.7 MW under a laod 260 MW. The highest value obtained in the proposed network was 5.48 MW under the same loading condition.

Line loading: Some lines were overloaded up 117% in the existing network which could result in overheating loading of the lines which could affect the thermal capability of such lines. However, no line was over loaded in the proposed network.

Financial losses: The financial losses due to transmission losses in 330kV in 2005 on the existing network amounted to 2.6 billion Naira in the existing network compared to 1.4 billion Naira in the proposed 330kV transmission network (a saving of 1.2 billion Naira).

Loop systems: More loops systems were provided to enhance better efficiency and reliability of the network, thus creating alternative routes in case of faults as compared to the existing network that was characterised by radial, long and fragile lines. Thus, the alternative routes provided for the buses and lines that experienced low voltages and high power losses in the network will help to improve the voltage profiles and minimise the high technical losses in the network.

In summary, the available generated power in Nigeria is grossly inadequate to meet the power demand of the citizens. Thus, this research have greatly reduced the power losses and maintained acceptable voltage levels which will foster better efficiency in the power network, good power quality, higher efficiency, reliability and security in the Nigerian 330kV transmission grid as against the existing network that is epileptic and unreliable. This constitute a unique benefit.

CONCLUSION

In this study, the analysis of the power losses and voltage drops in the Nigerian 330kV transmission network. The Newton-Raphson method in Power World Simulator environment was used in the study. The study showed that the present state of the Nigerian National Grid is unsatisfactory and require lot of modifications. This study, thus proposed a modified network that will ensure minimal losses, enhances power security, efficiency and reliability, thus reducing the huge financial losses as against the existing network that is epileptic and unreliable. Further analysis of the results revealed that the proposed network performed satisfactorily even when subjected to contingency analysis.

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