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Voltage Dips Reduction in the Nigeria 330 kV Transmission Grid

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Abstract: This study carried out an in-depth study and analysis of voltage dips associated with Nigerian 330 kV transmission network. The research methodology involved the power flow analysis of the 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 have voltages as low as 217 kV at some buses. 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%, have positive impact on voltage dips and enhance reliability and security of the transmission grid.

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

INTRODUCTION

The transmission grid system in Nigeria is predominantly characterised 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) (Sadoh, 2005). These lines experience high voltages under light load conditions and very low voltages under high loading conditions. Onohaebi (2006) presented a detailed analysis on the effects of low voltages on the network as well as the consumers'. The present network have only one major loop system involving Benin-Ikeja West-Ayede-Oshogbo and Benin. Glover *et al.* (2002) BICC (1965) recommend that low voltage problems can be remedied by possible changes in transformer tap positions, increase in generator schedule voltage, system reconfiguration to shift load to less heavily loaded lines, addition of capacitors and FACTS devices, disconnection of shunt reactors and addition of lines or transformers. Thus, it became imperative to strengthen the network by the introduction of additional lines and compensating devices.

The objective of this study was to analyse the voltage dips associated with the 330 kV network in order to assess its performance with a view to examine where further modifications are needed to ensure better efficiency and security of the network.

MATERIALS AND METHODS

The materials and methods used for this study include:

- Review of the 330 kV transmission network in Nigeria.
- Data collated based on Power Holding Company of Nigeria (PHCN) logbooks, reports for 2004 and 2005, visitation to transmission stations. 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 based on ± 5% of nominal value.
- 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 voltage dips and increase reliability of supply voltage within acceptable limits.
- Analysing the resulting network to ascertain the performance under normal and contingency conditions.

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RESULTS

The single line diagram of the existing 28 bus 330 kV Nigerian transmission network as at December 2005 used as the test system for the case study is shown in Fig. 1 and the bus identifications are shown in Table 1.

Power flow analysis of the existing 330 kv transmission network: The test system shown in Fig. 2 was redrawn using the edit mode in the Power World Simulator (PWS) (Power World Co-operation, 1996-2000, version 8.0) as shown in Fig. 2. The input data for the power flow analysis include the generator's output power, maximum and minimum reactive power limits of the generators, MW and MVAR peak loads, impedance of the lines, voltage and power ratings of the lines and transformer data (PHCN, 2005). These were entered into the dialog box of PWS and simulated using the Newton Raphson method available in the Run Mode of the PWS to determine the bus voltages. The bus information for voltages resulting from the simulations are shown in Table 2 and Fig. 3.

Contingency analysis of the existing network: IEEE Standards Board (1997) states that bulk power system is normally 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. 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.

The proposed modifications to the existing network: Based on the report of the (NEPA Technical Committee, 2004), the following lines were under construction to improve the existing network:

- Second Benin-Onitsha 330 kV line and Substation.
- Gombe-Yola-Jalingo 330 kV single circuit line and substation.
- Alaoji-Calabar 330 kV line.
- The NEPA Technical Committee report also proposed the following lines.
- Gombe-Damaturu 330 kV line and Substation.
- Damaturu-Maiduguri 330 kV line and substation.
- Jos-Makurdi 330 kV single circuit line.
- Alaoji-Enugu 330 kV single circuit line.

In this study, the above lines were incorporated into the network and simulated, but some of the resulting bus voltages were still out of tolerance. A closer study of the network showed that enough provision was not made to have closed loops in the Nigeria power system. Further investigations on the network indicated that when these

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	AFAM GS
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

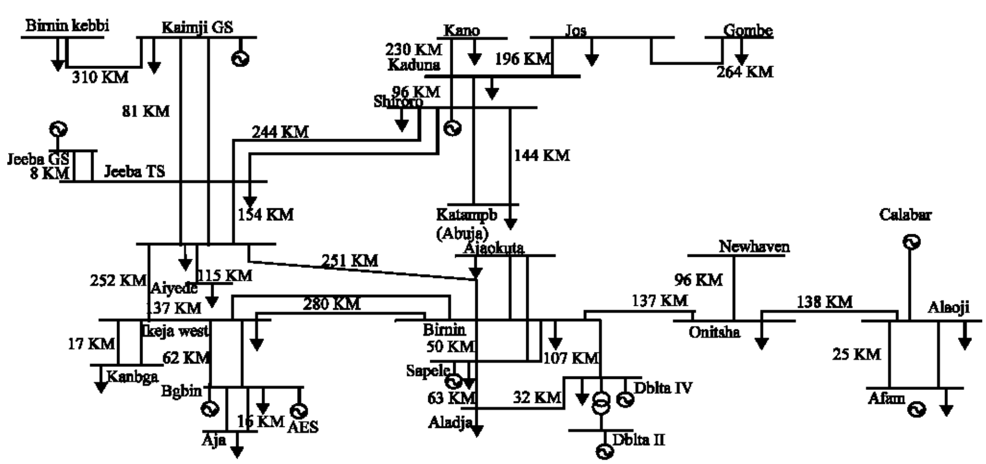

Fig. 1: The Nigerian 330 kV transmission grid used for the case study

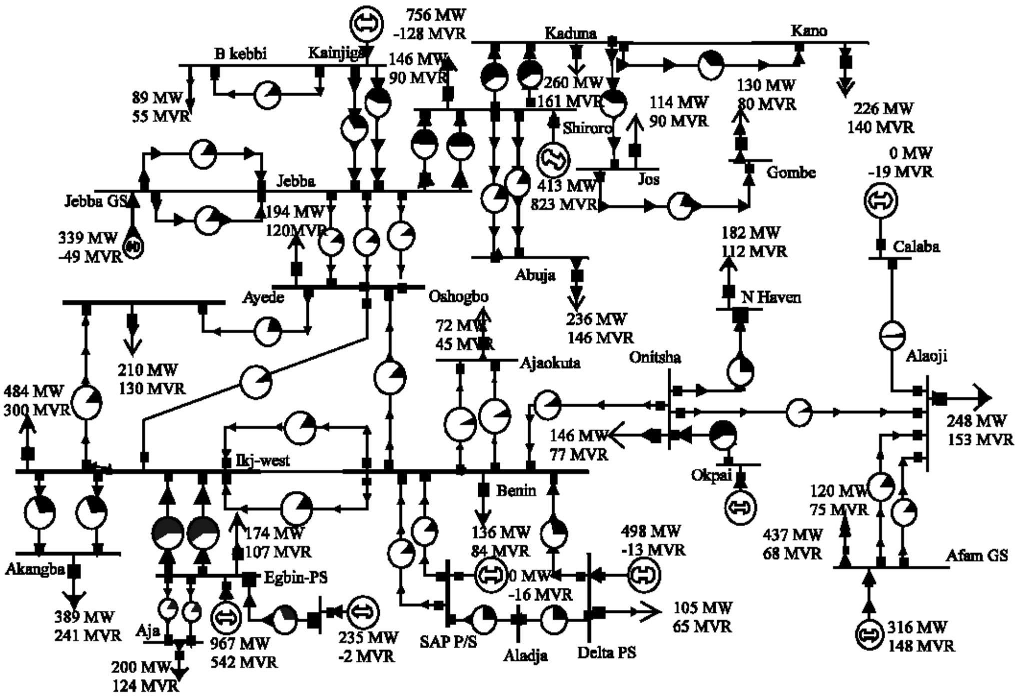

Fig. 2: The Nigeria 330 kV transmission network (simulated in the run mode)

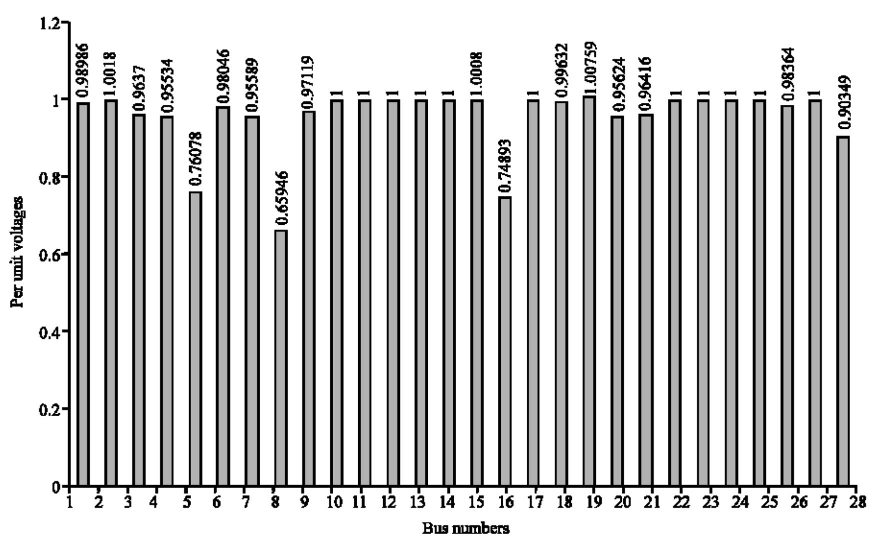

Fig. 3: Voltage profiles under normal operating conditions

are completed, it will reduce line congestions but have not provided the much needed alternative routes to link the Southern and Northern parts of the Grid to enhance grid security. In view of the above and the contingency analysis carried out for the existing condition, the following lines are suggested by the author of this study in addition, to provide more loops as well as providing the necessary alternative links in the Grid:

- Makurdi-New Haven 330 kV line to form a loop in the Network.
- Abuja-Ajaokuta 330 kV line to form another loop in the system.
- Additional circuits on the Ayede-Oshogbo and Kaduna-Kano line to improve the bus voltages lines under contingencies.
- Additional line suggested between Egbin-Ikeja West to decongest the existing double circuit under

contingency and also reduce the line loading under normal condition.

- Additional line between Shiroro-Kaduna to decongest the existing double circuit and improve the voltage profile of the line.

It was also necessary to carry out minimal compensation to improve the network performance. Thus, compensating devices were determined as shown in Fig. 4.

Kaduna bus: Total Load = 260MW

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

$$=161 \text{ MVAr lagging}$$

Reactive MVAr of load corresponding to 0.95 pf =

$$\frac{260}{0.95}\times\sin(\cos^{-1}0.95)=95.5\text{MVAr lagging}$$

Rating of capacitor bank = 161-95.5MVAR
= 75.5 MVAr ≈ 75 MVAr

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

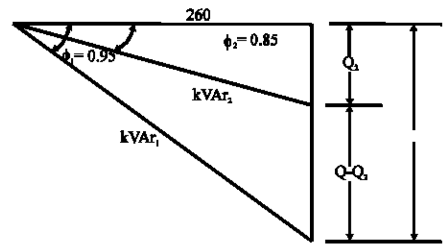

Fig 4: Determination of capacity of shunt capacitors

Table 2: Bus records under normal operating conditions

Nr	PU Volt	Volt (kV)	Angle (Deg)
1	0.98986	326.654	-6.85
2	1.0018	330.593	-3.32
3	0.9637	318.021	-6.87
4	0.95534	315.263	-9.04
5	0.76078	251.056	-39.42
6	0.98046	323.553	-1.95
7	0.95589	315.444	-7.46
8	0.65964	217.681	-50.8
9	0.97119	320.492	-24.11
10	1	330	-2.85
11	1	330	0.54
12	1	330	-2.85
13	1	330	2.31
14	1	330	-5.19
15	1.0008	330.265	-1.56
16	0.74893	247.148	-40.36
17	1	330	-2.55
18	0.99362	327.894	-3.36
19	1.00759	332.504	-4.52
20	0.95624	315.56	-5.1
21	0.96416	318.174	-5.17
22	1	330	-1.31
23	1	330	-4.75
24	1	330	-4.53
25	1	330	0
26	0.98364	324.603	-4.87
27	1	330	-21.2
28	0.90349	298.153	-27.68

Table 3: Summary of voltage violations for the existing network

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	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

Table 3: Continued

Label	Skip	Processed	Solved	Violations	Max line (%)	Min volt
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

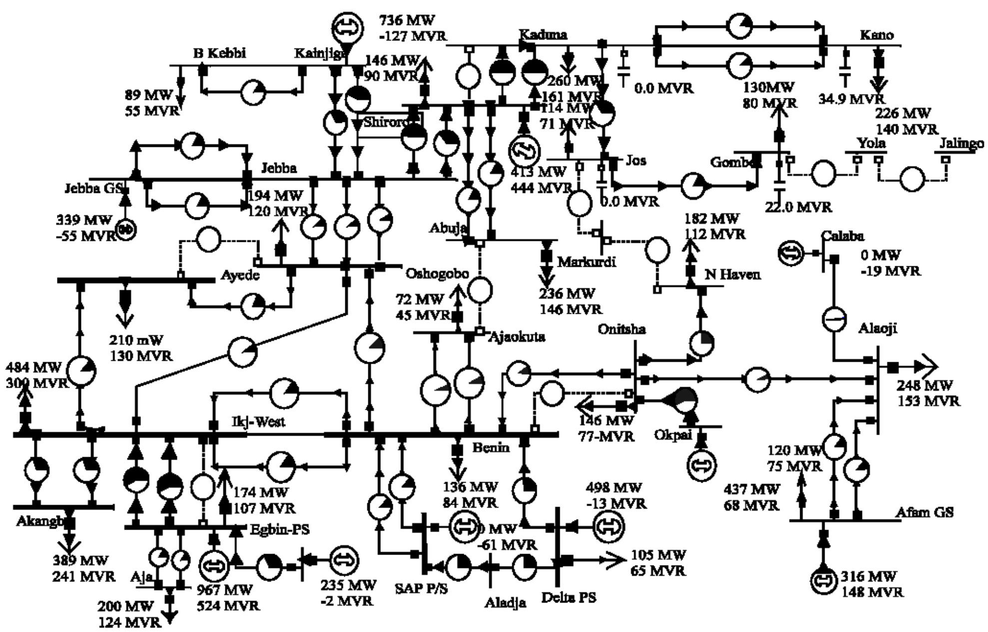

Fig. 5: The proposed Nigerian 330 kV transmission network (simulated in the run mode)

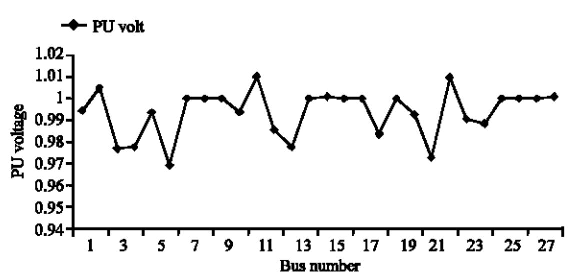

Fig. 6: Bus voltages in PU values in the proposed 330 kV transmission network

A total of 8 various combinations were obtained resulting in 8 case studies which were tested and the results are shown in Table 4. The best combination of shunt capacitors occurred at Kano and Gombe buses. The implementation of the above on-going and proposed projects by PHCN and those suggested in this study, by the authors to close the new loops resulted in the new network of Fig. 5. The proposed network was then simulated in the Run Mode of PWS and the resulting bus voltages are shown in Table 4 and Fig. 6. The network was also subjected to contingency analysis and the results are shown in Table 5.

Table 4: Bus information for the proposed 330kV transmission network

Number	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	-10.3
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

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

Label	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Proposed 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
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

Table 5: Continued

Label	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Proposed network
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

DISCUSSION

Voltage profiles of the networks: All the bus voltages in the proposed network are within the acceptable limits of ±5% as shown in Fig. 6, while the existing network recorded voltage violations as shown in Fig. 2. Voltages as low as 251 kV (0.76 pu) at bus 5, 217.6 kV (0.66 pu), 247 kV (0.74) at bus 16 were recorded under normal operating conditions of the network. These high voltage drops also have corresponding effect on the voltages at he consumers' destination. According to voltages as low as 40 V as against the 230 V required at utilization level are recorded in some areas in the network. The on-going modifications to the Nigeria 330 kV network will not achieve the desired results as shown in this study. Thus, there is need to strengthen the network as reflected in the proposed modified network of Fig. 5. Thus, the proposed network have greatly minimised the voltage dips associated with Nigerian 330 kV network.

Contingency analysis: The contingencies analysis showed a total of 208 voltage violations outside the statutory limits of ±5% in the existing network. This shows that the existing network cannot cope with contingences in case of faults, leading to poor voltage profiles and poor power quality in the network. However, there is no line in the network that does not result in at least 2 voltage violations. The highest voltage violation was recorded when line 3-10 was affected resulting in 8 voltage violations in the network. The proposed network recorded voltages that were within acceptable limits as shown in Table 5. Thus, this network will provide better power supply to the citizenry.

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

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.

CONCLUSION

In this study, the analysis of the voltage dips in the Nigerian 330 kV transmission network was carried out. The Newton-Raphson method in Power World Simulator environment was used in the study. The study showed that the present state of the Nigerian 330 kV National Grid is unsatisfactory and require lot of modifications. The study further revealed that the planned modifications of the existing network will not have the desired positive impact on voltage dips in the network except further strengthening is carried out to enhance the voltage profiles. The number of voltage dips that will be experienced after implementation of the strengthening of the network will reduce drastically, thus minimizing the effects of unbalanced faults on quality of supply.

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