Contingency Analysis for Assessing Line Losses in Nigeria 330-kV Power lines

Ademola Abdulkareem, Awosope C. O. A., Samuel I., Agbetuyi A. F

***Abstract:** Line losses in transmission lines constitute one of the major problems affecting power generation and distribution systems. Losses have been found to affect the overall efficiency of a system. Therefore, to increase the efficiency of any system, losses must be minimized. This paper carried out a comprehensive study and analysis of line losses associated with Nigeria 330-kV power transmission lines. The work includes the power-flow analysis carried out on the existing network using both the Newton-Raphson (N-R)written in code-based MATLAB and the model-based N-R in Power World Simulator (PWS) environment. The power-flow analysis was further subjected to contingency analysis and simulation using the N-R in PWS. Two load-flows were performed to reveal voltage violated buses.The results showed that the bus voltages outside the statutory limit of 0.95 – 1.05p.u(i.e 313.5 – 346.5kV) occurred at buses2-Birnin-Kebbi (0.9183pu), bus 9 Akangba (0.937pu), bus 18-Onitsha (0.935pu), bus 20-New-Haven (0.920pu), bus 25- Kaduna (0.9233pu), bus 26-Kano (0.776pu), bus 22-Jos (0.8192pu) and bus 28-Gombe (0.7247pu) under normal uncompensated condition. Capacitive shunt compensation was applied on these buses and the results recorded appreciable loss reduction (about 18.35%). The result of the single line contingency analysis for uncompensated and compensated indicates a total of 335 and 25 voltage bus violations respectively.*

***Keywords:** Line losses, power line, power-flow analysis, voltage violations, compensation, contingency analysis*

I. INTRODUCTION

The Nigerian power system network, like other networks elsewhere, is made up of a large interconnected network that spans the country nationwide. Power is usually generated at specific locations far from load centers before it is delivered to end-users through transmission and distribution systems. The purpose of an electrical power system is to generate and supply the real and reactive powersto consumers economically and reliably. However, the Nigeria 330-kV transmission network that connects the generation to distribution system is a “weak” linkcharacterized with high line losses and imbalance of reactive power between generation and load center. The voltage variation is due to imbalance in the generation and consumption of reactive power in the system. If the generated reactive power is less than the required consumption, the voltage level will dropand vise versa. However, it is difficult or practically impossible to have the two equal (i.e flat voltage profile), Because the reactive power in the system keeps varying with different types of loads.

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Too wide variation of the voltage causes excessive heating of distribution transformers thereby reducing the transformer capacity [1] [2]. The major goal of a power flow analysis is to obtain complete information about the voltage angle and magnitude for each bus in a power system for specified load and generator real and reactive powers and voltage condition [3].

The voltage drop in the line depends upon the resistance, inductance and capacitance. The resistance of transmission line conductors is the most important cause of power loss in the line and this determines the transmission efficiency [4].The present power situation in Nigeria is in a terrible state and there is high transmission loss due to the radial nature of the line and its lengthiness. So, there is a continuous voltage drop on the power lines and this gives cause for concern as it contributes to the constant power cut in the Nigeria power system. The main objective of this study is to carry out power-flow analysis of the existing 330-kV power network to determine the status of voltage angle and magnitude of each of the buses, to identify the weakest bus(e)s in the network and to come up with recommendations to mitigate losses with respect to specific improvement to the existing system. This work therefore, evaluates individual buses to ensure that the statutory voltage limit of ±5% is maintained based on the demand imposed on it and also provides compensation on the problem buses to reduce the power losses and high voltage drops associated with the Nigeria 330-kV power lines network in order to improve the system efficiency.

II. METHODOLOGY ADOPTED FOR THE WORK

The one-line diagram of existing 28-busNigerian 330-kV transmission system was redrawn for the purpose ofload-flow study performed under MATLAB environment. Data collection from PHCN includes Line data, bus data, generator data and other system components. This is followed by two load-flows analysis performed on the existing network to evaluate individual buses using (i) N-R code-based in Power World Simulator and (ii) model-based PWS software. Single-line contingency analysis was carried out on the existing network to further assess the reliability of the system. The weak area in the network wasthen identified with a view to mitigating power losses and increase reliability using capacitive shunt compensation method. The resulting network after compensation was analysed to ascertain its performance under normal and contingency conditions.

A. Nigeria 330-kV 28 Bus Transmission Network

The single-line diagram of the existing 330-kV Nigeria transmission network used as the case study is as shown in Fig.1. It has 28 buses with nine generating station. Egbin

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power station bus was chosen as the slack bus among other power generating stations because, Egbin bus as a slack bus brought about the lowest power mismatch in the network, hence, the generator with the largest power should be used as slack bus [5].

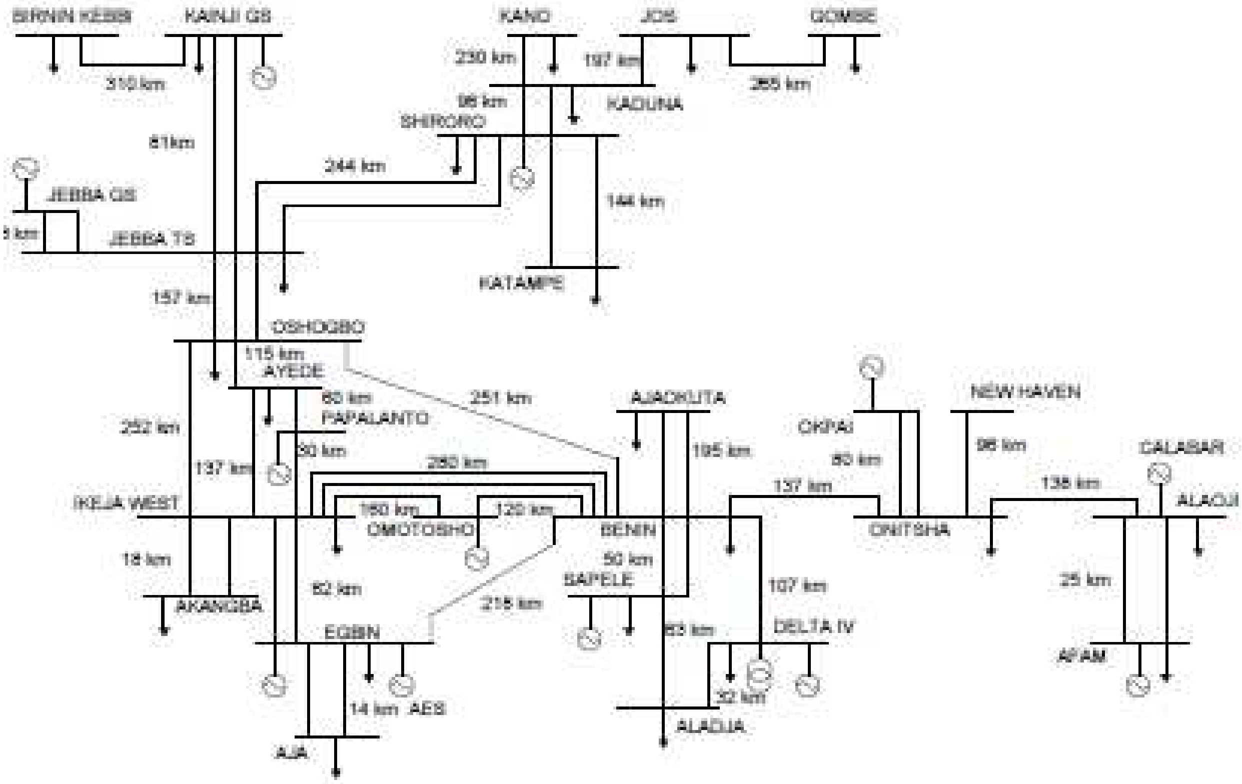

Figure 1: Single-Line Diagram of the existing 28 bus 330kv Nigerian transmission grid

III. RESULTS AND DISCUSSION

A. Power-Flow Solution based on the N-R Method.

The algorithm was developed and the Newton-Rap son's solution method was used to carry out the analysis using the relevant data as obtained from Power Holding Company of Nigeria(PHCN).MATLAB m-file program was developed and used for the simulation analysis. A summarized result of active power, reactive power and complex power flow at each bus and the line flow is presented in table I. The total active power loss from the power flow program solutions by Newton Raphson methodis 203.620 MW and that of the reactive power loss is - 1556.448 Mvar.

Table I: Summary of load-flow results of N-R

From Bus	To Bus	Active Power flow (MW)	Reactive Power flow (Mvar)	Complex Power flow (MVA)	Active Power loss (MW)	Reactive Power loss (Mvar)
1	2	115.9879	-30.7254	119.9885	1.4879	-116.625
1	3	501.7121	-55.2062	504.7403	6.633	-11.5062
2	1	-114.5	-85.9	143.14	1.4879	-116.625
3	1	-495.079	43.7	497.0041	6.633	-11.5062
3	4	-494.329	-38.5246	495.8279	0.671	-2.3843
3	5	321.8366	13.46	322.1179	5.6016	-78.1002
3	23	656.5715	-26.8354	657.1197	26.6503	75.2551
4	3	495	36.1403	496.3176	0.671	-2.3843
5	3	-316.235	-91.5602	329.2231	5.6016	-78.1002
5	6	177.026	42.3656	182.0249	1.5765	-71.7504
5	8	128.921	11.3987	129.4239	1.0055	-93.4136
5	13	-190.912	-113.1042	221.9008	3.238	-172.5968
6	5	-175.4496	-114.116	209.2965	1.5765	-71.7504
6	7	-80.9763	-36.6775	88.8954	0.1617	-34.9959

6	8	-19.3741	-56.0066	59.2629	0.0222	-98.1078
7	6	81.138	1.6816	81.1554	0.1617	-34.9959
7	8	73.662	-1.6816	73.6812	0.0577	-17.1578
8	5	-127.9155	-104.8124	165.3723	1.0055	-93.4136
8	6	19.3963	-42.1012	46.3544	0.0222	-98.1078
8	7	-73.6044	-15.4763	75.2138	0.0577	-17.1578
8	9	247.6955	235.7035	341.9199	2.9955	-22.7965
8	10	-403.8922	-362.0502	542.4106	6.4373	2.3304
8	12	-44.8346	-59.1121	74.1915	1.2761	-96.9254
8	13	-250.0452	-126.1513	280.0656	6.7175	-147.3841
9	8	-244.7	-258.5	355.9499	2.9955	-22.7965
10	8	410.3295	364.3806	548.7654	6.4373	2.3304
10	11	276.706	169.1378	324.3051	2.306	-36.6622
10	13	-196.7158	18.1493	197.5513	2.8778	-27.954
11	10	-274.4	-205.8	343	2.306	-36.6622
12	8	46.1107	-37.8133	59.6326	1.2761	-96.9254
12	13	54.4893	37.8133	66.3244	0.3626	-83.348
13	5	194.15	-59.4926	203.0606	3.238	-172.5968
13	8	256.7627	-21.2328	257.6391	6.7175	-147.3841
13	10	199.5937	-46.1033	204.8491	2.8778	-27.954
13	12	-54.1266	-121.1613	132.7018	0.3626	-83.348
13	14	14.1681	-155.6499	156.2934	0.3681	-165.9499
13	15	-262.4152	-26.9578	263.7962	1.1368	-36.8382
13	16	-473.9006	20.0871	474.3261	4.7811	-12.9197
13	18	-257.5321	123.0107	285.4022	4.4327	-70.3566
14	13	-13.8	-10.3	17.22	0.3681	-165.9499
15	13	263.552	-9.8805	263.7372	1.1368	-36.8382
15	17	-93.852	3.7389	93.9265	0.2026	-50.8631
16	13	478.6817	-33.0068	479.8183	4.7811	-12.9197
16	17	191.3183	-28.4304	193.4192	0.7637	-46.2284
17	15	94.0547	-54.602	108.755	0.2026	-50.8631
17	16	-190.5547	-17.798	191.384	0.7637	-46.2284
18	13	261.9648	-193.3673	325.6017	4.4327	-70.3566
18	19	-703.8188	82.449	708.6316	46.1812	14.2387
18	20	178.7979	112.9396	211.4806	1.7979	-20.4604
18	22	78.4561	-140.4214	160.8525	7.0193	-97.1128
19	18	750	-68.2103	753.0954	46.1812	14.2387
20	18	-177	-133.4	221.6406	1.7979	-20.4604
21	22	378.5	359.6307	522.1077	22.9367	-3.8779
22	18	-71.4367	43.3086	83.5394	7.0193	-97.1128
22	21	-355.5633	-363.5086	508.4916	22.9367	-3.8779
23	3	-629.9212	102.0904	638.1404	26.6503	75.2551
23	24	294.9635	64.7522	301.9873	4.8635	-80.2478
23	25	653.5577	486.4913	814.7463	21.1085	145.1124
24	23	-290.1	-145	324.3193	4.8635	-80.2478
25	23	-632.4492	-341.3789	718.7013	21.1085	145.1124
25	26	230.5674	155.9158	278.3362	9.9674	13.0158
25	27	208.8818	40.7631	212.8221	4.8743	-25.2542
26	25	-220.6	-142.9	262.8398	9.9674	13.0158

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27	25	-204.0075	-66.0173	214.4233	4.8743	-25.2542
				Total	**203.62**	**-1556.45**

B. Power-Flow Study Analysisusing PWS

Using the same data (i.e bus, transmission line and generator data) in MATLAB simulation, the power-flow analysis of the 330-kV power line network was eared out using the N.R method in the Power World Simulator run mode (Power World Cooperation Version 18, 2014). Power-flow problem solution starts with a single-line diagram of the power line system shown in figure 1. This network system is redrawn for model-based PWS using Edit Mode in the power simulator as hown in figure 2. The load-flow analysis is carried out to determine the bus voltages, phase angles, real and reactive power flows and line losses using the run mode of power world simulator as presented in figure 3. The results of bus voltages, line flows and power losses are as presented; in Tables II and III. The load-flow is performed on the existing system hence the results are obtained under normal condition.

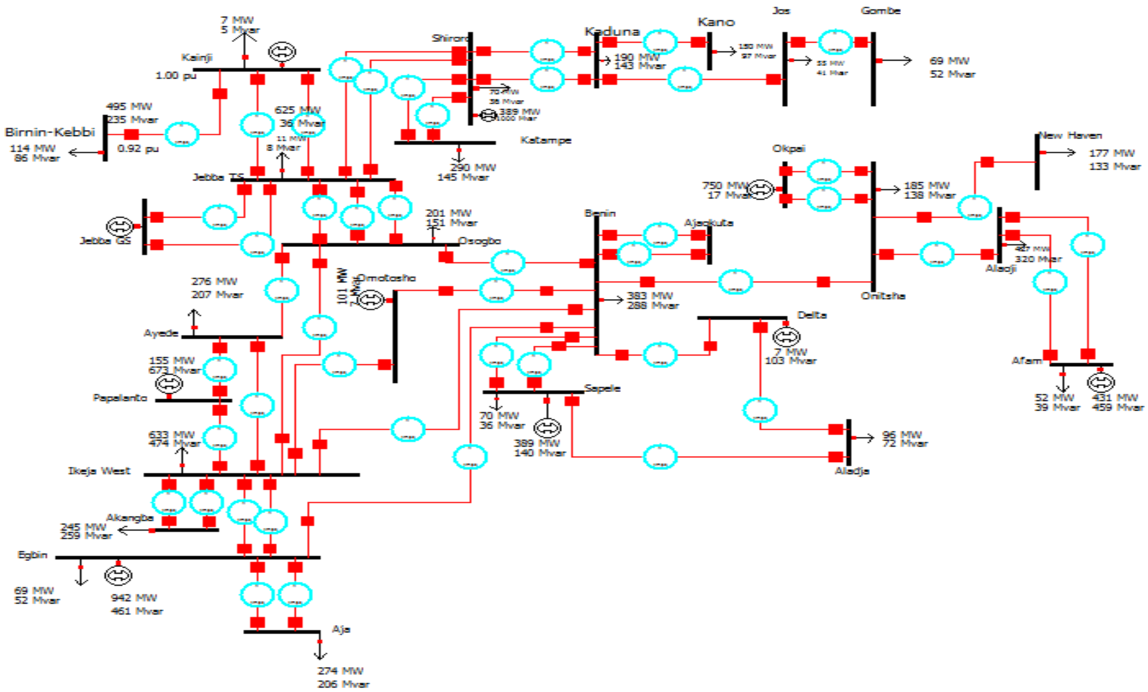

Figure 2: The Edit Mode Model of Existing Nigerian 330-kV Transmission Network

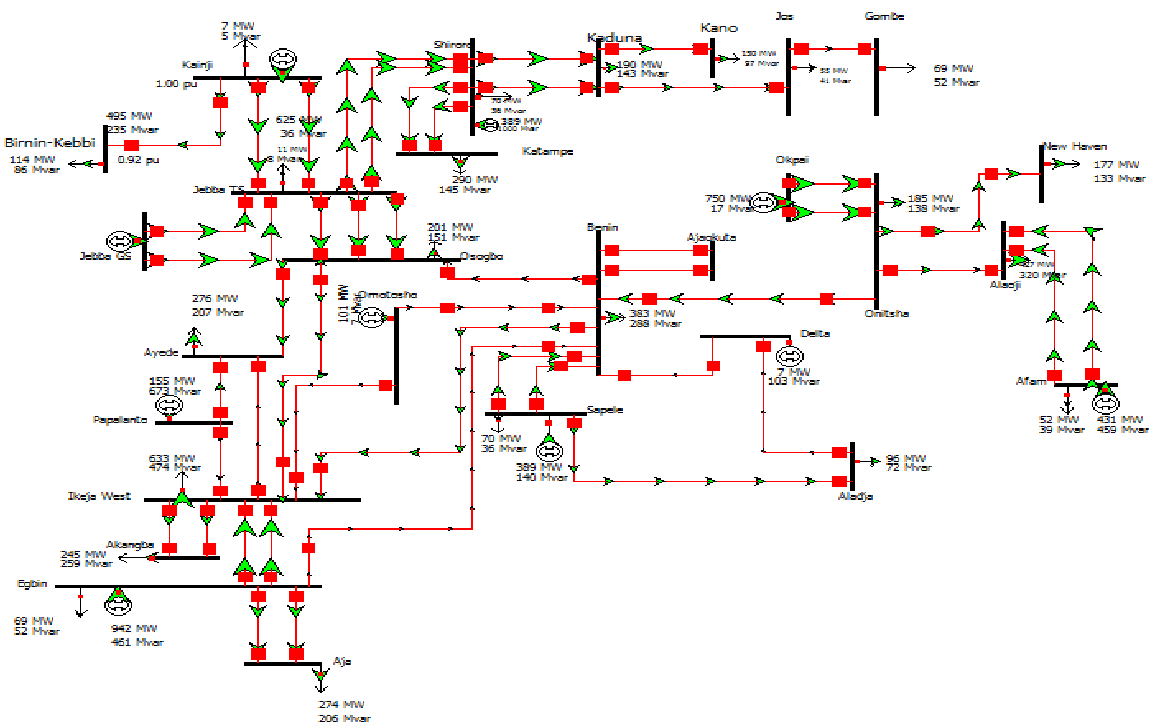

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Figure 3: The Simulation Mode of Existing Nigerian 330-kV Transmission Network

Table II: Bus Voltage Records of the Network before Compensation

Bus No	Name	PU Volt	Volt (kV)	Angle (Deg)
1	Kainji	1	330	8.53
2	Birnin-Kebbi	0.91829	303.04	2.21
3	Jebba TS	0.99991	329.97	4.96
4	Jebba GS	1	330	5.25
5	Oshogbo	0.98576	325.3	1.79
6	Ayede	0.97134	320.54	-2.17
7	Papalanto	1	330	-1.6
8	Ikeja-West	0.9711	320.46	-1.86
9	Akangba	0.93667	309.21	-3.01
10	Egbin	1	330	0
11	Aja	0.98081	323.67	-1.26
12	Omotosho	1	330	10.96
13	Benin	0.99098	327.03	9.82
14	Ajaokuta	1.00867	332.86	9.47

Bus No	Name	PU Volt	Volt (kV)	Angle (Deg)
15	Sapele	1	330	10.94
16	Delta	1	330	14.75
17	Aladja	0.99363	327.9	12.35
18	Onitsha	0.93457	308.55	17.38
19	Okpai	1	330	18.79
20	New Haven	0.91994	303.58	14.27
21	Afam	1	330	12.86
22	Alaoji	0.96948	319.93	13.1
23	Shiroro	1	330	-7.81
24	Katampe	0.97166	320.65	-11.1
25	Kaduna	0.92328	304.68	-13.15
26	Kano	0.77591	256.05	-24.8
27	Jos	0.81917	270.33	-21.94
28	Gombe	0.7247	239.15	-29.71

Table III: Line Flows and Power Losses of the Network before Compensation

From Bus No	From Name	To Bus No	To Name	Circuit	MW Flow	Mvar Flow	MVA Flow	MW Loss	Mvar Loss
1	Kainji	2	Birnin-Kebbi	1	116.7	48.5	126.4	2.2	-37.42
1	Kainji	3	Jebba TS	1	250.5	-36.7	253.2	1.83	-15.25
1	Kainji	3	Jebba TS	2	250.5	-36.7	253.2	1.83	-15.25
3	Jebba TS	4	Jebba GS	1	-247.3	31.8	249.4	0.19	-2.07
3	Jebba TS	4	Jebba GS	2	-247.3	31.8	249.4	0.19	-2.07
3	Jebba TS	5	Oshogbo	1	116.7	-10.7	117.2	0.78	-52.18
3	Jebba TS	5	Oshogbo	2	116.7	-10.7	117.2	0.78	-52.18
3	Jebba TS	5	Oshogbo	3	116.7	-10.7	117.2	0.78	-52.18
3	Jebba TS	23	Shiroro	1	315.5	-41.3	318.1	6.67	-22.81
3	Jebba TS	23	Shiroro	2	315.5	-41.3	318.1	6.67	-22.81
5	Oshogbo	6	Ayede	1	192.3	3.5	192.3	1.59	-28.35
5	Oshogbo	8	Ikeja-West	1	130	-9.9	130.4	1	-48.67
5	Oshogbo	13	Benin	1	-175.8	-20	176.9	2.89	-68.38
6	Ayede	7	Papalanto	1	-70.7	-153.2	168.7	0.6	-13.71
6	Ayede	8	Ikeja-West	1	-14.4	-21.8	26.1	0.01	-49.07
7	Papalanto	8	Ikeja-West	1	83.5	303.9	315.1	1.02	0.24
8	Ikeja-West	9	Akangba	1	123.1	111.1	165.8	0.71	-18.1
8	Ikeja-West	9	Akangba	2	123.1	111.1	165.8	0.71	-18.1
8	Ikeja-West	10	Egbin	1	-195.9	-144.2	243.3	1.3	-14.55
8	Ikeja-West	10	Egbin	2	-195.9	-144.2	243.3	1.3	-14.55
12	Omotosho	8	Ikeja-West	1	44.5	-15.2	47	0.12	-39.71
8	Ikeja-West	13	Benin	1	-246	-13.8	246.4	6.53	-43.48
10	Egbin	11	Aja	1	137.6	82.5	160.5	0.62	-20.39

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10	Egbin	11	Aja	2	137.6	82.5	160.5	0.62	-20.39
10	Egbin	13	Benin	1	-247.3	52.6	252.8	5.1	19.63
10	Egbin	29	AES	1	0	0	0	0	0
12	Omotosho	13	Benin	1	56.1	-0.6	56.1	0.15	-36.88
13	Benin	14	Ajaokuta	1	7	-68.7	69.1	0.08	-73.86
13	Benin	14	Ajaokuta	2	7	-68.7	69.1	0.08	-73.86
13	Benin	15	Sapele	1	-145.6	-54.3	155.4	0.42	-17.34
13	Benin	15	Sapele	2	-145.6	-54.3	155.4	0.42	-17.34
13	Benin	16	Delta	1	-445	14.4	445.3	4.65	14.76
13	Benin	18	Onitsha	1	-288.7	91.3	302.8	4.84	-8.72
15	Sapele	17	Aladja	1	-122.3	38	128.1	0.4	-20.43
16	Delta	17	Aladja	1	220.3	-0.5	220.3	1.12	-14.5
19	Okpai	18	Onitsha	1	375	23	375.7	12.73	-0.14
19	Okpai	18	Onitsha	2	375	23	375.7	12.73	-0.14
18	Onitsha	20	New Haven	1	178.6	116.6	213.3	1.6	-16.81
18	Onitsha	22	Alaoji	1	67.8	-108.8	128.2	6.17	-43.72
22	Alaoji	21	Afam	1	-182.7	-192.6	265.5	6.57	-4.98
22	Alaoji	21	Afam	2	-182.7	-192.6	265.5	6.57	-4.98
23	Shiroro	24	Katampe	1	146.3	27.5	148.9	1.27	-44.99
23	Shiroro	24	Katampe	2	146.3	27.5	148.9	1.27	-44.99
23	Shiroro	25	Kaduna	1	321.8	220.8	390.2	5.46	13.19
23	Shiroro	25	Kaduna	2	321.8	220.8	390.2	5.46	13.19
25	Kaduna	26	Kano	1	229.1	151.6	274.7	8.48	8.72
25	Kaduna	27	Jos	1	210.5	118.8	241.7	5.5	-9.88
27	Jos	28	Gombe	1	134.7	76	154.7	4.12	-21.87
								136.13	**-1057.4**

The results of table II obtained for PWS showed low voltage values at the following buses: bus-2-Birnin-Kebbi(0.9183pu), bus 9-Akangba (0.937pu), bus 18-Onitsha (0.935pu), bus 20-New-Haven(0.920pu), bus 25-Kaduna(0.9233pu), bus 26-Kano(0.7759pu), bus 27-Jos(0.8192pu)and. Bus 28-Gombe(0.7247pu). The total active power loss and the reactive power loss, from table III, are **136.13MW** and **-1057.40Mvar** respectively. In the two cases of load-flow, the voltage-violated buses are the same.

IV. LOSS MITIGATION MEASURE

Mitigation is the method employed to reduce energy loss in order to improve the system efficiency. Based on the above findings, the study moves further to explore loss mitigation measures that include appropriate solutions and suggestions. Line losses identification and Loss reduction that are necessary to ensure stability and reliability of the 330-kV power lines are the two cases employed for mitigation in this work.

A. Capacitive Compensation for Loss Reduction

The results of load-flow of N-R and PWS presented low voltage violations (-5%) at buses 2, 9, 18, 20, 25, 26, 27 and 28 as shown in table 2. It is obvious from table IIthat Gombe has the highest voltage dip due to its distance from the grid. This is closely followed by Kano, Jos, B/Kebbi, New-Haven, Kaduna, Onitsha and Akangba. Capacitive shunt compensation method was applied at these buses (because of its merits such as higher speed of response and absence of fault in-feed to the test system)and the results recorded appreciable voltage profile improvement and a reasonable reduction in the power loss.

The capacitive shunt compensation is applied at the identified low voltage violated buses shown in figure 4 in order to ensure that they are within the acceptable limits. Based on the Power Holding Company of Nigeria (PHCN) lagging power factor (pf) of 0.85 for transmission lines, the MVar capacities of the various capacitors needed to carry out full compensation of the violated buses are determined as follows:

Let the overall power factor be improved from0.85 lagging to 0.95 lagging.

Reactive MVar of Load corresponding to PHCN pf = Load $\times \tan(\cos^{-1}(0.85)$ (1)

Reactive MVar of Load corresponding to 0.95 pf =Load $\times\tan(\cos^{-1}(0.95))$ (2)

Rating of Capacitor Bank (Q_c) = Reactive Mvar of Load corresponding to 0.85pf – Reactive Mvar of Load corresponding to 0.95pf (3)

Equation 3 can be rewritten as:

$Q_c = \frac{P}{pf_1} \times \sin(cos^{-1}(pf_1)) - \frac{P}{pf_2} \times \sin(cos^{-1}$ (4)

where

P is the real power or load (MW) from PHCN bus data that was used under the uncompensated condition.

pf_1 and pf_2 are the power factors of PHCN for transmission (0.85) and the desired improved pf (0.95) respectively.The value of capacitance required is given by

$$C = \frac{Q_c}{\omega V^2} = \frac{Q_c}{2\pi f V^2};\ f = 50\text{Hz and } V = 330\text{kV} \quad (5)$$

Therefore, the ratings of the shunt capacitors (i.e compensation values) placed at each voltage violated bus and their capacitances in farads are calculated using equation (4) and (5) as follows:

Akangba Bus

Total load = 245MW

$$Q_c = \frac{245}{0.85} \times \sin(\cos^{-1}(0.85)) - \frac{245}{0.95} \times \sin(\cos^{-1}(0.95))$$

=151.837- 80.5276 = 71.309MVar

∴The value of capacitance required is

$$C = \frac{71.309}{2(3.142)(50)(330^2)} = \frac{71.309}{34216380} = 20.8\mu F$$

Birnin-KebbiBus

Total load = 427MW

$$Q_c = \frac{114.5}{0.85} \times \sin(\cos^{-1}(0.85)) - \frac{114.5}{0.95} \times \sin(\cos^{-1}(0.95)) =$$

70.9607-37.6343 = 33.33MVar

∴The value of capacitance required is

C = 33.33/34216380 = 9.74 μF

Onitsha Bus

Total load = 184.6

$$Q_c = \frac{184.6}{0.85} \times \sin(\cos^{-1}(0.85)) - \frac{184.6}{0.95} \times \sin(\cos^{-1}(0.95)) =$$

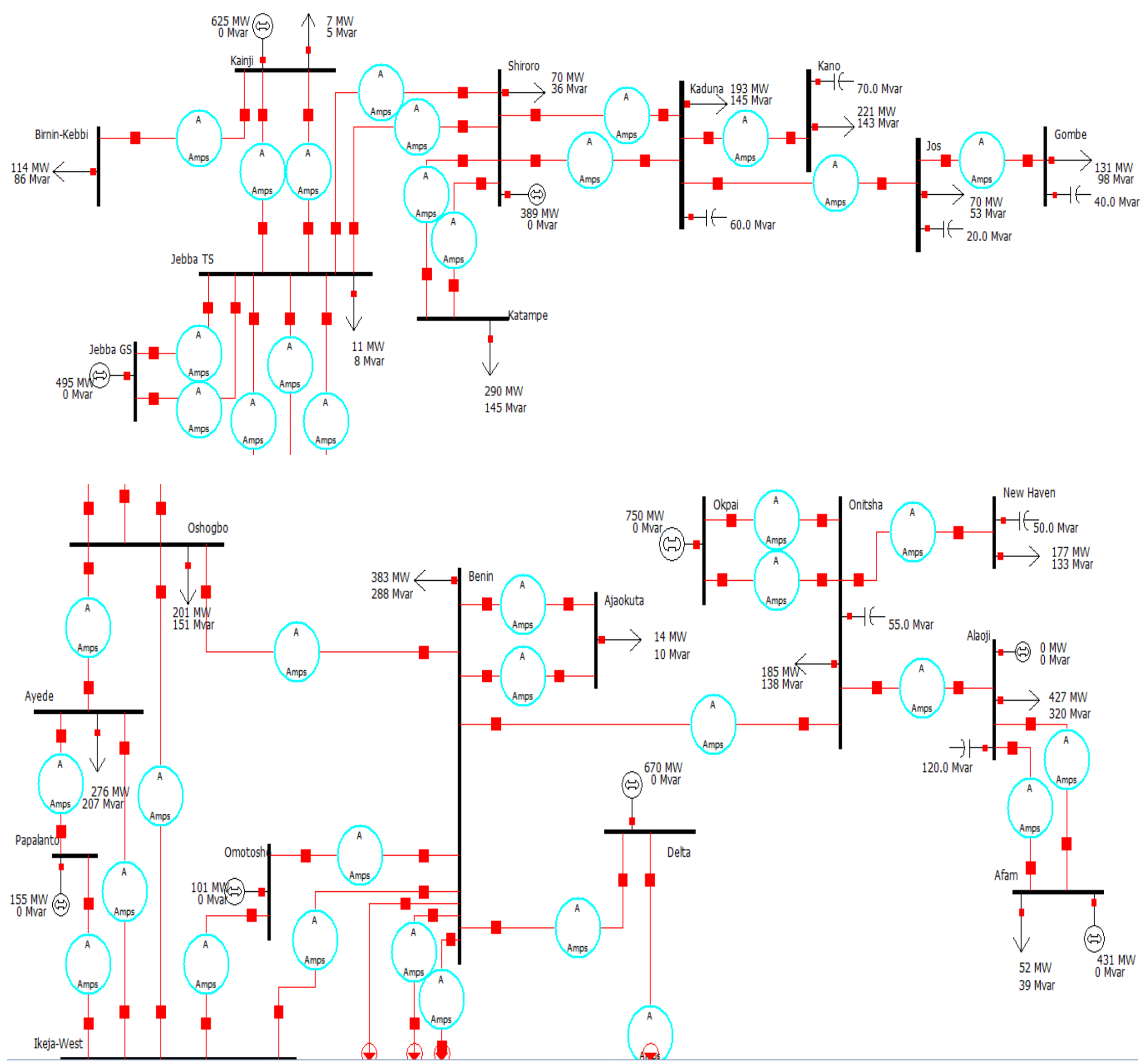
114.4049 – 60.6749 = 53.73Mvar

∴The value of capacitance required is

C = 53.73/34216380 = 15.7 μF

The following capacitor sizes are selected for the various power lines:

Akangba bus (75Mvar, 21μF), Onitsha bus (55Mvar, 16μF), New-Haven bus (50Mvar, 15μF), Birnin-Kebbi bus (40Mvar, 10μF), Kaduna bus (60Mvar, 18μF), Kano bus (70Mvar, 20μF), Jos bus (20Mvar, 6μF) and Gombe bus (40Mvar, 12μF). These are injected in the modelled test systemwith the capacitors placed at the voltage violated buses in the “Edit mode” of the Power World simulator as shown in figure 4. Newton-Raphson solution under the tools button of the Power World Simulator in the “Run mode” was used to generate the values of the reactive and real power losses on each line.



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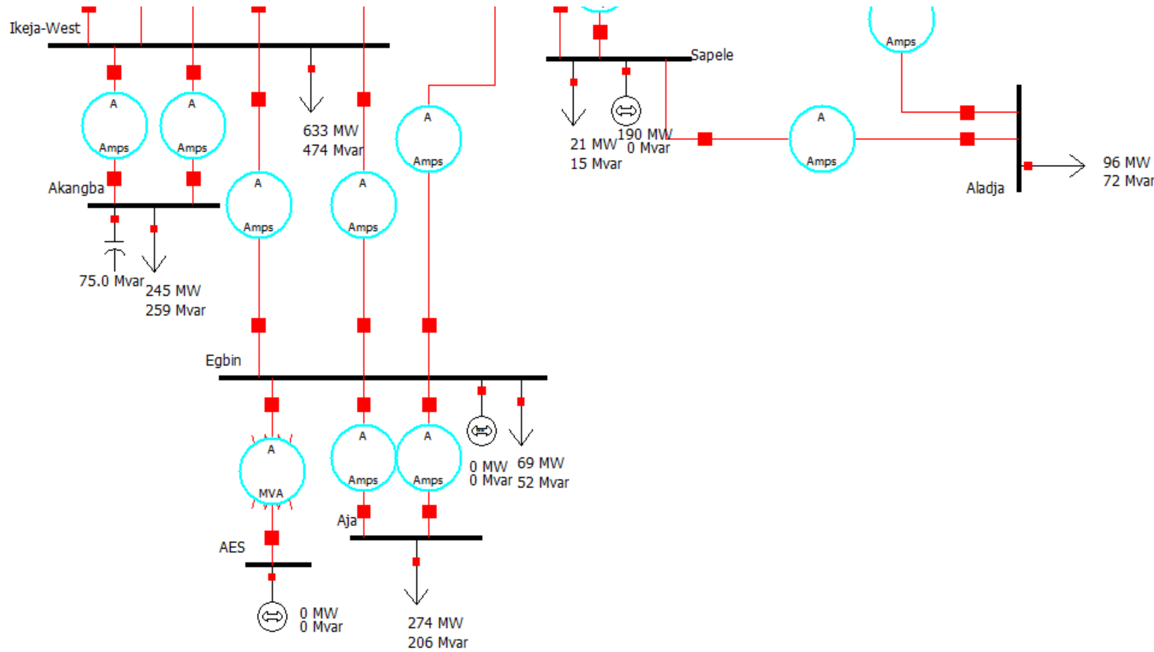

Figure 4: The model of injected capacitive shunt compensation on the affected buses

Voltages at all the 28 buses after compensation are shown in table 4 while the reactive and real power losses are presented in table V. All the buses' voltages are within the specified limit of 0.95-1.05puand from the values recorded in table IV, it could be seen that the values of the angles are improved upon after compensation. The smaller the phase angle the better the power factor.

Table IV: Bus voltage magnitudes and angles after compensation

Bus No	Bus Name	Voltage (kV)	Voltage (PU)	Angle (Deg)
15	Sapele	330	1	11.05
16	Delta	330	1	14.85
17	Aladja	327.897	0.99363	12.45
18	Onitsha	319.276	0.9675	17.48
19	Okpai	330	1	19.1
20	New Haven	313.856	0.95108	14.32
21	Afam	330	1	13.21
22	Alaoji	320.012	0.96973	13.44
23	Shiroro	330	1	-7.17
24	Katampe	320.646	0.97166	-10.46
25	Kaduna	326.764	0.99019	-12.48
26	Kano	318.71	0.96579	-21.81
27	Jos	331.784	1.0054	-19.73
28	Gombe	327.495	0.99241	-24.79

Bus No	Bus Name	Voltage (kV)	Voltage (PU)	Angle (Deg)
1	Kainji	330	1	8.9
2	Birnin-Kebbi	314.459	0.95291	2.59
3	Jebba TS	329.99	0.99997	5.33
4	Jebba GS	330	1	5.62
5	Oshogbo	325.509	0.98639	2.02
6	Ayede	320.824	0.97219	-2.05
7	Papalanto	330	1	-1.51
8	Ikeja-West	321.343	0.97377	-1.81
9	Akangba	315.297	0.95545	-2.99
10	Egbin	330	1	0
11	Aja	323.667	0.98081	-1.26
12	Omotosho	330	1	11.05
13	Benin	327.153	0.99137	9.92
14	Ajaokuta	332.991	1.00906	9.57

Table V: Real and Reactive power losses after compensation

From No	From Name	To No	To Name	Line flow, P (MW)	Line flow, Q (Mvar)	Complex power |S| (MVA)	MW Loss	Mvar Loss
1	Kainji	2	B/Kebbi	116.2	12	116.8	1.7	-43.67
1	Kainji	3	Jebba TS	250.8	-36.9	253.5	1.84	-15.22

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3	Jebba TS	4	Jebba GS	-247.3	34.6	249.7	0.19	-2.07
3	Jebba TS	5	Oshogbo	121.4	-12.2	122.1	0.84	-51.71
3	Jebba TS	5	Oshogbo	121.4	-12.2	122.1	0.84	-51.71
3	Jebba TS	23	Shiroro	308.6	-42.1	311.4	6.38	-25.84
5	Oshogbo	6	Ayede	197.8	2.6	197.8	1.67	-27.68
5	Oshogbo	8	Ikeja-West	136.1	-14.4	136.8	1.08	-48.17
5	Oshogbo	13	Benin	-173.2	-20.6	174.4	2.81	-69.26
6	Ayede	7	Papalanto	-67.6	-149.2	163.8	0.56	-14.04
6	Ayede	8	Ikeja-West	-12.2	-27.3	29.9	0.01	-49.27
7	Papalanto	8	Ikeja-West	86.7	274.1	287.5	0.85	-1.32
8	Ikeja-West	9	Akangba	122.9	77	145	0.53	-19.73
8	Ikeja-West	10	Egbin	-189.2	-130.9	230	1.16	-15.78
12	Omotosho	8	Ikeja-West	44.7	-15.8	47.4	0.12	-39.78
8	Ikeja-West	13	Benin	-247.4	-11	247.6	6.59	-43.33
10	Egbin	11	Aja	137.6	82.5	160.5	0.62	-20.39
10	Egbin	13	Benin	-250.1	52.6	255.6	5.2	20.53
12	Omotosho	13	Benin	55.9	-2	55.9	0.15	-36.93
13	Benin	14	Ajaokuta	7	-68.8	69.1	0.08	-73.94
13	Benin	15	Sapele	-145.5	-50.6	154.1	0.42	-17.4
13	Benin	16	Delta	-445.1	17.1	445.4	4.65	14.75
13	Benin	18	Onitsha	-290.6	82	301.9	4.79	-9.44
15	Sapele	17	Aladja	-122.2	38	128	0.4	-20.44
16	Delta	17	Aladja	220.3	-0.5	220.3	1.12	-14.51
19	Okpai	18	Onitsha	375	-39.7	377.1	12.76	-0.16
18	Onitsha	20	New Haven	178.1	23.4	179.6	1.07	-23.34
18	Onitsha	22	Alaoji	66.4	-98.8	119.1	5.18	-44.83
22	Alaoji	21	Afam	-182.9	-187.1	261.6	6.38	-5.13
23	Shiroro	24	Katampe	146.3	27.5	148.9	1.27	-44.99
23	Shiroro	25	Kaduna	315.2	-6.8	315.2	3.38	-7
25	Kaduna	26	Kano	224.9	-16.6	225.5	4.29	-47.06
25	Kaduna	27	Jos	205.7	-72.5	218.1	3.11	-47.85
27	Jos	28	Gombe	132.2	-36.5	137.2	1.65	-73.3
							119.54	**-1269.37**

As a result of shunt capacitive compensation applied at these voltage-violated buses, voltages of most of the problem buses came up to tolerable range and the real and reactive power losses significantly dropped from 203.63 or 136.13 MW (as shown in tables I and III) to 119.54MW and from -1057.4 MVAR to -1268 MVAR. This is an appreciable loss reduction (about 18.35%). The incorporation of system compensation leads to many benefits such as increasing transmission lines' efficiency and reliability which enable electrical company to transmit more power with the existing transmission lines. More customers can also be absorbed without increasing the number or output of generators. All the compensated buses are interconnected in the grid network by single circuit lines with inability to ensure the continued delivery of power in case of problems in a link between two buses or substations. It was also noticed that the violated buses from the Northern part of the country (Nigeria) are as a result of their very long distances from the generating stations.

B. *Contingency analysis in assessing system security and power line flow*

Contingencies are disturbances that can cause failure of the component of a power system. However, system security can be assessed using contingency analysis to ensure the continuity of power supply. In this research work, loss of a single line contingency analysis is performed on using the uncompensated and compensated load-flow analyses carried out in section 3B as revealed in the previous tables II and IV respectively.

C. Analysis of the results of uncompensated and compensated load-flows

Contingency analysis of the test power line 330-kV network is evaluated on the 28-bus system by subjecting the various lines to a single contingency analysis to examine the effect

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of loss of any single line on the network. The analysis is performed using the uncompensated and compensated results of tables II and IV respectively. The result of the single line contingency analysis for uncompensated and compensated indicates a total of ***335***and ***25*** violations as shown in tables VI and VII respectively. There is no line in the power line network that does not result in at least 4 violations outside the statutory limits of ±5% for the uncompensated as shown in table VI. The affected buses and the values of voltage violations are as indicated in table VI. Out of the 25 affected violations recorded after compensation, Shiroro-Kaduna has the highest violations of 4, Alaoji-Afam and Okpai-Aladja has 2 each while about 9 lines have 1 violation each. The affected lines are as indicated in table VII with their voltage magnitude violations.

Table VI: Contingency records of uncompensated load-flow result of table II

Label	Skip	Processed	Solved	No of violation	Bus No and Voltage magnitude Violation (pu)
L_000001Kainji-000002Birnin-KebbiC1	NO	YES	YES	6	9(0.95), 20(0.92), 25(0.92), 26(0.78), 27(0.82),28(0.72)
L_000001Kainji-000003JebbaTSC1	NO	YES	YES	7	2(0.92z0 9(0.95), 20(0.92), 25(0.92), 26(0.78), 7(0.82), 28(0.72)
L_000001Kainji-000003JebbaTSC2	NO	YES	YES	7	2(0.92z0 9(0.95), 20(0.92), 25(0.92), 26(0.78), 27(0.82), 28(0.72)
L_000003JebbaTS-000004JebbaGSC1	NO	YES	YES	7	2(0.92z0 9(0.95), 20(0.92), 25(0.92), 26(0.78), 27(0.82), 28(0.72)
L_000003JebbaTS-000004JebbaGSC2	NO	YES	YES	7	2(0.92z0 9(0.95), 20(0.92), 25(0.92), 26(0.78), 27(0.82), 28(0.72)
L_000003JebbaTS-000005OshogboC1	NO	YES	YES	7	2(0.92z0 9(0.95), 20(0.92), 25(0.92), 26(0.78), 27(0.82), 28(0.72)
L_000003JebbaTS-000005OshogboC2	NO	YES	YES	7	2(0.92z0 9(0.95), 20(0.92), 25(0.92), 26(0.78), 27(0.82), 28(0.72)
L_000003JebbaTS-000005OshogboC3	NO	YES	YES	7	2(0.92z0 9(0.95), 20(0.92), 25(0.92), 26(0.78), 27(0.82), 28(0.72)
L_000003JebbaTS-000023ShiroroC1	NO	YES	YES	7	2(0.92z0 9(0.95), 20(0.92), 25(0.92), 26(0.78), 27(0.82), 28(0.72)
L_000003JebbaTS-000023ShiroroC2	NO	YES	YES	7	2(0.92z0 9(0.95), 20(0.92), 25(0.92), 26(0.78), 27(0.82), 28(0.72)
L_000005Oshogbo-000006AyedeC1	NO	YES	YES	7	2(0.92z0 9(0.95), 20(0.92), 25(0.92), 26(0.78), 27(0.82), 28(0.72)
L_000005Oshogbo-000008Ikeja-WestC1	NO	YES	YES	7	2(0.92z0 9(0.95), 20(0.92), 25(0.92), 26(0.78), 27(0.82), 28(0.72)
L_000005Oshogbo-000013BeninC1	NO	YES	YES	7	2(0.92z0 9(0.95), 20(0.92), 25(0.92), 26(0.78), 27(0.82), 28(0.72)
L_000006Ayede-000007PapalantoC1	NO	YES	YES	8	2(0.92), 6(0.93), 9(0.94), 20(0.92), 25(0.92), 26(0.78), 27(0.82), 28(0.72)
L_000006Ayede-000008Ikeja-WestC1	NO	YES	YES	7	2(0.92), 9(0.95), 20(0.92), 25(0.92), 26(0.78), 27(0.82), 28(0.72)
L_000007Papalanto-000008Ikeja-WestC1	NO	YES	YES	8	2(0.92), 8(0.95), 9(0.92), 20(0.92), 25(0.92), 26(0.78),

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					27(0.82), 28(0.72)),
L_000008Ikeja-West-000009AkangbaC1	NO	YES	YES	7	2(0.92) 9(0.92), 20(0.92), 25(0.92), 26(0.78), 27(0.82), 28(0.72)
L_000008Ikeja-West-000009AkangbaC2	NO	YES	YES	7	Same buses and values as above
L_000008Ikeja-West-000010EgbinC1	NO	YES	YES	7	===== do======
L_000008Ikeja-West-000010EgbinC2	NO	YES	YES	7	===== do======
L_000012Omotosho-000008Ikeja-WestC1	NO	YES	YES	7	===== do======
L_000008Ikeja-West-000013BeninC1	NO	YES	YES	7	===== do======
L_000010Egbin-000011AjaC1	NO	YES	YES	7	===== do======
L_000010Egbin-000011AjaC2	NO	YES	YES	7	===== do======
L_000010Egbin-000013BeninC1	NO	YES	YES	7	===== do======
T_000010Egbin-000029AESC1	NO	YES	YES	7	===== do======
L_000012Omotosho-000013BeninC1	NO	YES	YES	7	===== do======
L_000013Benin-000014AjaokutaC1	NO	YES	YES	7	===== do======
L_000013Benin-000014AjaokutaC2	NO	YES	YES	7	===== do======
L_000013Benin-000015SapeleC1	NO	YES	YES	7	===== do======
L_000013Benin-000015SapeleC2	NO	YES	YES	7	===== do======
L_000013Benin-000016DeltaC1	NO	YES	YES	7	===== do======
L_000013Benin-000018OnitshaC1	NO	YES	YES	7	===== do======
L_000015Sapele-000017AladjaC1	NO	YES	YES	7	===== do======
L_000016Delta-000017AladjaC1	NO	YES	YES	7	===== do======
L_000019Okpai-000018OnitshaC1	NO	YES	YES	8	2(0.92), 9(0.92), 18(0.940), 20(0.89), 25(0.92), 26(0.78), 27(0.82), 28(0.72)
L_000019Okpai-000018OnitshaC2	NO	YES	YES	8	===== do======
L_000018Onitsha-000020NewHavenC1	NO	YES	YES	6	2(0.92), 9(0.95), 25(0.92), 26(0.78), 27(0.82), 28(0.72)
L_000018Onitsha-000022AlaojiC1	NO	YES	YES	7	2(0.92), 9(0.95), 20(0.92) `25(0.92), 26(0.78), 27(0.82), 28(0.72)
L_000022Alaoji-000021AfamC1	NO	YES	YES	8	2(0.92), 9(0.95), 20(0.92), 22(0.94) `25(0.92), 26(0.78), 27(0.82), 28(0.72)
L_000022Alaoji-000021AfamC2	NO	YES	YES	8	===== do======
L_000023Shiroro-000024KatampeC1	NO	YES	YES	8	===== do======
L_000023Shiroro-000024KatampeC2	NO	YES	YES	8	===== do======
L_000023Shiroro-000025KadunaC1	NO	YES	YES	7	2(0.92), 9(0.95), 20(0.92), `25(0.75), 26(0.54), 27(0.58), 28(0.46)
L_000023Shiroro-000025KadunaC2	NO	YES	YES	7	2(0.92), 9(0.95), 20(0.92), `25(0.75), 26(0.54), 27(0.58), 28(0.46)
L_000025Kaduna-000026KanoC1	NO	YES	YES	5	2(0.92), 9(0.95), 20(0.92), ` 27(0.88), 28(0.80)
L_000025Kaduna-000027JosC1	NO	YES	YES	4	2(0.92), 9(0.95), 20(0.92), 26(0.82)
L_000027Jos-000028GombeC1	NO	YES	YES	5	2(0.92), 9(0.95), 20(0.92), 26(0.82) 27(0.93)

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Table VII: Contingency Records of Compensated Load-Flow Results of Table IV

Label	Skip	Processed	Solved	No of Violation	Bus no & Voltage Magnitude Violation (pu)
L_000001Kainji-000002Birnin-KebbiC1	NO	YES	YES	0	None
L_000001Kainji-000003JebbaTSC1	NO	YES	YES	0	None
L_000001Kainji-000003JebbaTSC2	NO	YES	YES	0	None
L_000003JebbaTS-000004JebbaGSC1	NO	YES	YES	0	None
L_000003JebbaTS-000004JebbaGSC2	NO	YES	YES	0	None
L_000003JebbaTS-000005OshogboC1	NO	YES	YES	0	None
L_000003JebbaTS-000005OshogboC2	NO	YES	YES	0	None
L_000003JebbaTS-000005OshogboC3	NO	YES	YES	0	None
L_000003JebbaTS-000023ShiroroC1	NO	YES	YES	0	None
L_000003JebbaTS-000023ShiroroC2	NO	YES	YES	0	None
L_000005Oshogbo-000006AyedeC1	NO	YES	YES	0	None
L_000005Oshogbo-000008Ikeja-WestC1	NO	YES	YES	0	None
L_000005Oshogbo-000013BeninC1	NO	YES	YES	0	None
L_000006Ayede-000007PapalantoC1	NO	YES	YES	1	6(0.934)
L_000006Ayede-000008Ikeja-WestC1	NO	YES	YES	0	None
L_000007Papalanto-000008Ikeja-WestC1	NO	YES	YES	1	9(0.935)
L_000008Ikeja-West-000009AkangbaC1	NO	YES	YES	1	9(0.931)
L_000008Ikeja-West-000009AkangbaC2	NO	YES	YES	1	9(0.931)
L_000008Ikeja-West-000010EgbinC1	NO	YES	YES	1	9(0.947)
L_000008Ikeja-West-000010EgbinC2	NO	YES	YES	1	9(0.947)
L_000012Omotosho-000008Ikeja-WestC1	NO	YES	YES	0	None
L_000008Ikeja-West-000013BeninC1	NO	YES	YES	0	None
L_000010Egbin-000011AjaC1	NO	YES	YES	0	None
L_000010Egbin-000011AjaC2	NO	YES	YES	0	None
L_000010Egbin-000013BeninC1	NO	YES	YES	0	None
T_000010Egbin-000029AESC1	NO	YES	YES	0	None
L_000012Omotosho-000013BeninC1	NO	YES	YES	0	None
L_000013Benin-000014AjaokutaC1	NO	YES	YES	0	None
L_000013Benin-000014AjaokutaC2	NO	YES	YES	0	None
L_000013Benin-000015SapeleC1	NO	YES	YES	0	None
L_000013Benin-000015SapeleC2	NO	YES	YES	0	None
L_000013Benin-000016DeltaC1	NO	YES	YES	0	None
L_000013Benin-000018OnitshaC1	NO	YES	YES	0	None
L_000015Sapele-000017AladjaC1	NO	YES	YES	0	None
L_000016Delta-000017AladjaC1	NO	YES	YES	0	None
L_000019Okpai-000018OnitshaC1	NO	YES	YES	2	18(0.94), 20(0.923)
L_000019Okpai-000018OnitshaC2	NO	YES	YES	2	18(0.923), 20(0.923)
L_000018Onitsha-000020NewHavenC1	NO	YES	YES	0	None
L_000018Onitsha-000022AlaojiC1	NO	YES	YES	1	20(0.947)

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L_000022Alaoji-000021AfamC1	NO	YES	YES	2	20(0.95), 22(0.942)
L_000022Alaoji-000021AfamC2	NO	YES	YES	2	20(0.95), 22(0.942)
L_000023Shiroro-000024KatampeC1	NO	YES	YES	1	24(0.924)
L_000023Shiroro-000024KatampeC2	NO	YES	YES	1	24(0.924)
L_000023Shiroro-000025KadunaC1	NO	YES	YES	4	25(0.94), 26(0.891), 27(0.93), 28(0.90)
L_000023Shiroro-000025KadunaC2	NO	YES	YES	4	25(0.94), 26(0.891), 27(0.93), 29(0.90)
L_000025Kaduna-000026KanoC1	NO	YES	YES	0	None
L_000025Kaduna-000027JosC1	NO	YES	YES	0	None
L_000027Jos-000028GombeC1	NO	YES	YES	0	None

V. CONCLUTION

The Nigerian 330-kV power line network is bedeviled with various problems; one of these is the voltage instability which is due to voltage profile violations, nature of transmission lines, problem of long transmission lines and poor power quality. All these resultin to incessant power outages. In this work, the power-flows analysis for the Nigeria 330-kV grid system was carried out using both the numerical technique of Newton-Rap son iterative method and the model-based Newton-Raphsonin power World Simulator .Through this study, the voltage drop, the active and reactive power losses in the line were identified. Capacitive shunt compensation was used to regulate the voltage angle and magnitude. The results of the power flow analysis after compensation showa significant reduction in the total system real power loss by 18.5%with all the buses' voltages given within the specified limit of 0.95-1.05pu.The voltage angles were correspondingly improved upon. The smaller the phase angle the better the power factor. Further analysis of the results revealed that the compensated network performed better when subjected to contingency analysis. Based on the major findings of this work, it is recommended that more substations and additional lines between Jos and Kano and the much needed link between Southern and Northern parts of the grid should be introduced. This provides more loops to the existing 330-kV lines with minimal compensatory work to achieve higher and reduction of long lines to improve the voltage profile of the network. It is recommended that two double-circuit transmission lines should be introduced to interconnect all the compensated buses since all these buses are single circuit lines.

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