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Analysis of the Effects of Geopolitical Zone - Based Generator Outages on the Performance of the Nigerian 330 kV – 132 kV Transmission Network

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ABSTRACT

Power systems are very prone to disturbances and the effect of these disturbances can be quite severe if the network is not secure. Having an idea of the effect of some of these unforeseen disturbances will go a long way in enhancing the system security by putting the necessary mechanisms in place to avoid such occurrences. This study is therefore aimed at determining how the line losses and the voltage profile of the Nigerian 330 kV-132 kV transmission system will be affected when the largest generating stations in each geopolitical zone is knocked out of supply. The transmission system was modeled in ETAP 19.0 software environment and power flow analysis was carried out using Newton-Raphson iteration technique. The generating stations were then divided into their various geopolitical zones and the highest in each zone knocked off and the power flow analysis carried out in each case. A comparison of the results obtained with that of the original network showed that the highest value of line losses increment of 25% was recorded when Jebba PS, representing North-Central (NC) zone was knocked. For the voltage profile, Dandikowa PS outage (representing North-East (NE) zone) led to 31.4% of the buses violating the voltage limit, which happens to be the highest, while Jebba PS (NC), Egbi PS (SW), Ihovbor PS/Azura PS (SS), and Alaoji PS (SE) led to bus voltage violations of 30%, 30%, 14.5% and 13% respectively as against the 11.8% recorded for the original network. Molai TS and Yenagoa TS buses recorded the lowest and highest values of bus voltages in all the cases.

1. Introduction

The electricity situation in Nigeria is quite pathetic as it has been very epileptic and unstable for the past three decades. The electricity supply to various homes is about six hours on the average in a day [1]. The efficiency of a power supply system is a reflection of the number of power outages per year in a place, with high level of outages mostly linked to consumer dissatisfaction with electricity service [2,3]. Just like other power system networks, the Nigerian power system network consists of a large network connected together that covers the entire nation. With the aid of transmission and distribution system networks, the power, which is normally generated very far away from load centres, is conveyed to the areas where it will be utilized. The ability to reliably and economically deliver the generated real and reactive power to the final consumers is what makes a good power system. It is a known fact that the Nigerian transmission system is quite weak and fragile, with high system losses associated with it. The reactive power between the load centre and the point of generation is not balanced. This mismatch in the generation and utilization of reactive power in the system leads to variations in the system voltage. A drop in the system's voltage level is as a result of generated reactive power of the system being less than the utilization required and vice versa.

Hence, due to the fact that the system's reactive power changes continuously with various types of loads, it will be difficult or almost impossible to have a voltage profile that is flat [4]. When the system's voltage fluctuation is large, the capacity of the transformer in the system will reduce due to the excess heating in it as a result of the wide voltage variation [5,6]. Acquiring a complete and comprehensive information about the magnitude and angle of the voltages in the various buses in the system for a given load and generator real and reactive power, as well as voltage condition, is the main purpose of power flow analysis [7]. The transmission line's resistance, inductance and capacitance are the determinants of its voltage drop. The major parameter that determines the magnitude of power loss in a line is its resistance and this is what determines the transmission system's efficiency [8]. The Nigerian power system is presently in a very terrible state and it is characterized with high system losses primarily due to the lines being lengthy and radial in nature. This brings about a continuous drop in voltage in the lines [4]. This scenario is unwanted and is of great concern as it is part of the reasons for the constant cut in power in the Nigerian power system. There is thus the need to improve on the security of the country's power system so as to have a better voltage profile and reduced line losses.

When a power system is free from risks or danger, then such a power system is said to be secure. Power system security simply has to do with activities designed to maintain system operation even at the event of one or more system component's failure [9]. The ability of a power system to adequately deal with any contingencies without any consequences is what determines the power system's security [10]. Contingency simply refers to malfunctioning or failure of any of the equipment in the power system as a result of issues related to the power system [11,12]. It represents unplanned occurrences like outage of transmission lines, load or generators, as well as control actions brought about by transient conditions. This can lead to instability in the system [13]. Congestion of transmission lines (which degenerates to line outage) as well as failure of any of the system's component are the major causes of the failure. When the transmission system is overloaded or underloaded, it can lead to transmission line congestion, which can as well lead to failure of the system's components. It is thus very important to carry out contingency analysis on the system to ensure it operates effectively as well as securing it from unforeseen occurrence [10].

Contingencies can lead to serious violations of the operating constraints of the system. It is thus necessary to adequately plan for contingencies as it goes a long way in determining the secure operation of the power system. All equipment in a power system are designed to operate within certain limits without violation. In the event that there is a violation of this limit, it can lead to cascading failures, which may lead to the complete collapse of a large section of the system [14].

Nigeria is made up of six (6) geopolitical zones. It is necessary that the generating stations should be spread across the various geopolitical zones so as to ensure, to a large extent, a balance in the system. In the event of a generating station outage in a particular zone, how will the entire transmission system be affected?

The aim of this study is therefore, to determine how the transmission system losses and voltage profile will be affected in the event of a generating station outage on each of the geopolitical zones, with the largest generating unit of each zone being taken out in each scenario.

2. Modeling of Components Outage

Contingency analysis in a power system simply entails the comprehensive study of the loss of system components like transformers, generators, transmission lines, etc as well as investigating its effects on the overall performance of the system.

Contingency analysis ensures adequate system operation in a defensive manner. Problems occurring in power systems if not swiftly corrected by the systems operator, can degenerate into more serious issues. Thus, contingency analysis programs are normally incorporated into modern computers. These programs model the power system as well as study the outages occurring so as to notify system operators in the events of overloads and violation of voltage limits [15].

2.1 Simulation of Line Outage

In order to effectively simulate transmission line outages, a corresponding bus admittance matrix is formulated [16]. If it is assumed that the line experiencing outage is the line connected between buses m and n, then the admittance matrix $[Y]$ elements that will be affected are Y_{mm}, Y_{nn}, Y_{mn} and Y_{nm}. From the π method of representing transmission lines, the new values of the admittances will now be:

$$Y'_{mm} = Y_{mn} - \frac{1}{(R_{mn}+jX_{mn})} - \frac{jB_{mn}}{2} \tag{1}$$

$$Y'_{nn} = Y_{nn} - \frac{1}{(R_{nm}+jX_{nm})} - \frac{jB_{nm}}{2} \tag{2}$$

$$Y'_{mn} = Y_{mn} - \frac{1}{(R_{mn}+jX_{mn})} = 0.0 \tag{3}$$

$$Y'_{nm} = Y_{nm} - \frac{1}{(R_{nm}+jX_{nm})} = 0.0 \tag{4}$$

Where:

Y'_{mm} , Y_{mm} --- Self admittance at bus m post and pre-contingency
Y'_{nn} , Y_{nn} --- Self admittance at bus n post and pre-contingency
$Y'_{mn} = Y'_{nm}$ --- Mutual admittance between bus m and n post-contingency
$Y_{mn} = Y_{nm}$ --- Mutual admittance between bus m and n pre-contingency [17].

2.2 Simulation of Generating Unit Outage

This model helps in simulating a scenario where one or more generating units is out. If it is assumed that the total generation at bus (m) for the station is P_{gm}, and also, that there are (g) units that are identical, then:

$$P'_{gm} = P_{gm} - n\frac{P_{gm}}{g} \tag{5}$$

Where:

P'_{gm} --- Active power generated at bus m post-outage
P_{gm} --- Active power generated at bus m before the outage
n --- Number of outage generation units in the station
$\frac{P_{gm}}{g}$ --- Active power generated at bus m per a generator unit [17].

For the purpose of this study, only generating unit outage will be considered and this will be done based on the one with the largest value in the various geopolitical zones in Nigeria.

3. Methodology

The Nigerian 330 kV-132 kV transmission network was modeled in ETAP 19.0 software environment. This was done after relevant data was collected from the Transmission Company of Nigeria, National Control Centre, Osogbo. The data collected include transmission lines parameters, route lengths, bus loadings, generating stations ratings, etc. These served as the input data for the modeled network in the ETAP 19.0 software environment. Load flow analysis was then carried out on the modeled network using Newton-Raphson iteration technique. From the load flow analysis, the transmission lines losses as well as the various bus voltages were noted. The network diagram on ETAP 19.0 software environment is shown in figure 1.

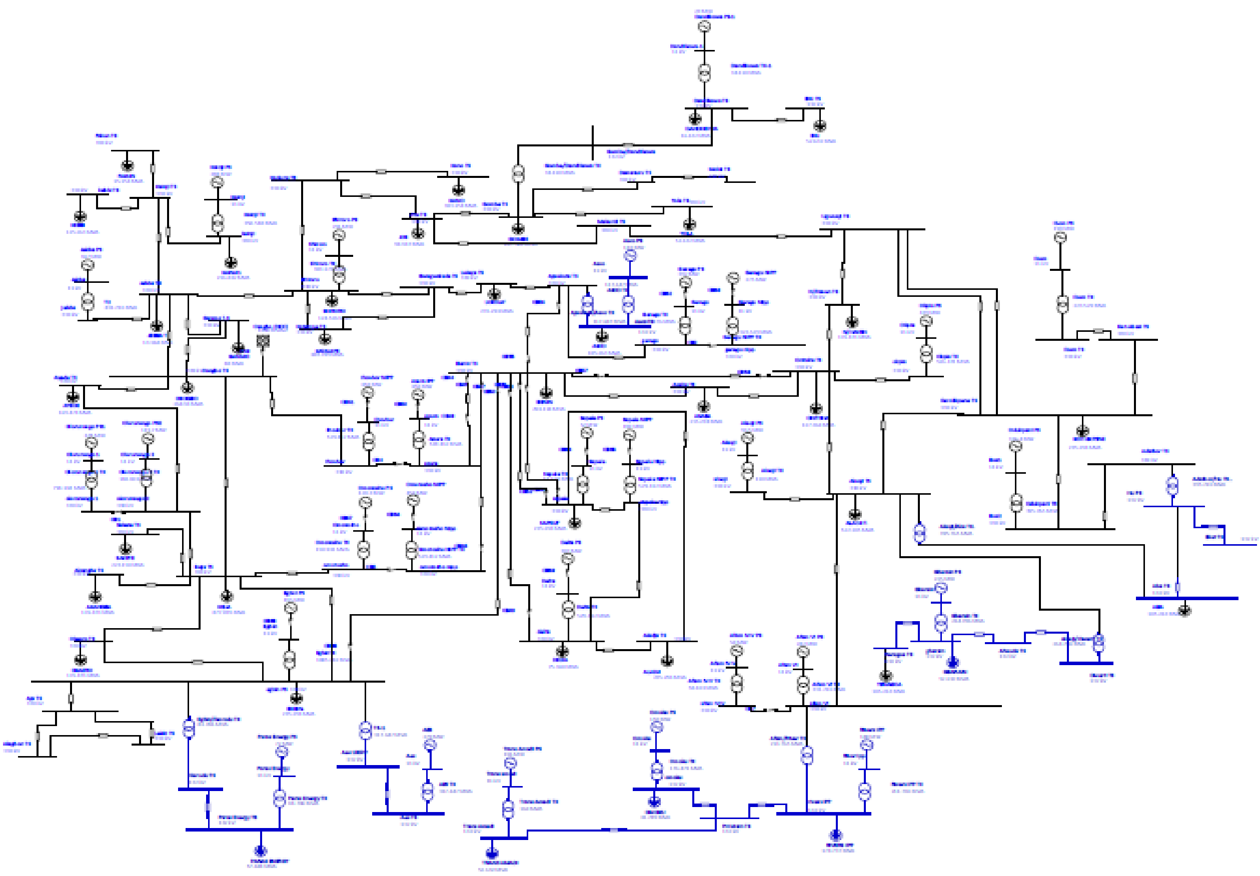

Figure 1: Nigerian 330 kV-132 kV Network Diagram on ETAP Edit Mode

Contingency analysis was then carried out on the modeled network. This was done by categorizing the various generating stations into their different geopolitical zones and the largest generator in each zone was knocked off one at a time. Table 1 shows the various generating stations and their different geopolitical zones.

Table 1: Generating Stations Along with their Geopolitical Zones

S/N	ID	State	Rating (MW)	Zones
1	Asco PS	Kogi	110	NC
2	Geregu NIPP	Kogi	275	NC
3	Geregu PS	Kogi	392	NC
4	Jebba PS	Niger	367	NC
5	Kainji PS	Niger	298	NC
6	Shiroro PS	Niger	256	NC
7	Dandikowa PS-1	Gombe	29	NE
8	Alaoji PS	Abia	93.5	SE
9	Afam IV-V PS	Rivers	50	SS
10	Afam VI PS	Rivers	282	SS
11	Azura IPP	Edo	450	SS
12	Delta PS	Delta	383	SS
13	Gbarain PS	Bayelsa	225	SS
14	Ibom PS	Akwa Ibom	190	SS
15	Ihovbor NIPP	Edo	450	SS

16	Odukpani PS	Cross River	336.4	SS
17	Okpai PS	Delta	439	SS
18	Omoku PS	Rivers	150	SS
19	Rivers IPP	Rivers	180	SS
20	Sapele NIPP	Delta	450	SS
21	Sapele PS	Delta	52	SS
22	Trans Amadi PS	Rivers	136	SS
23	AES	Lagos	270	SW
24	Egbin PS	Lagos	855	SW
25	Olorunsogo PS1	Ogun	675	SW
26	Olorunsogo PS2	Ogun	119.7	SW
27	Omotosho NIPP	Ondo	450	SW
28	Omotosho PS	Ondo	128.3	SW
29	Paras Energy PS	Lagos	72	SW

As seen from table 1, North-Central (NC) has 6 generating stations with Jebba PS being the largest. It will be knocked off for the purpose of this study. For North-East, only Dandikowa PS 1 is present so it will be knocked off. The same applies to the South-East zone having only Alaoji PS. For the South-South zone, the largest rating there is 450 MW which corresponds to the capacities of Azura PS and Ihovbor PS. These two generating stations are very close to each other as they almost located in the same place. As a result of their proximity, they will be taken as a single generating station, so both of them, amounting to 900 MW will be knocked off. For the South-West zone, Egbin has the largest value so it will be knocked off. It will be observed that the North-West geopolitical zone has no generating station. In the ETAP 19.0 software environment, this analysis was done by putting the relevant generating station out of service (knock off) and then the load flow analysis carried out. This procedure was repeated for each scenario and the results obtained exported from the software for analysis.

4. Results and Discussion

The load flow analysis of the original network was done and the results showing the losses and the voltage profile are shown in tables 2 and 3. For the various geopolitical zones, the largest generating station in each case was knocked off as shown in table 1. The results for the line losses and bus voltages for North-Central, North-East, South-East, South-South and South-West geopolitical zones are shown in tables 4 and 5 respectively. Their corresponding network diagrams on ETAP run mode are shown in figures 2 to 6 respectively.

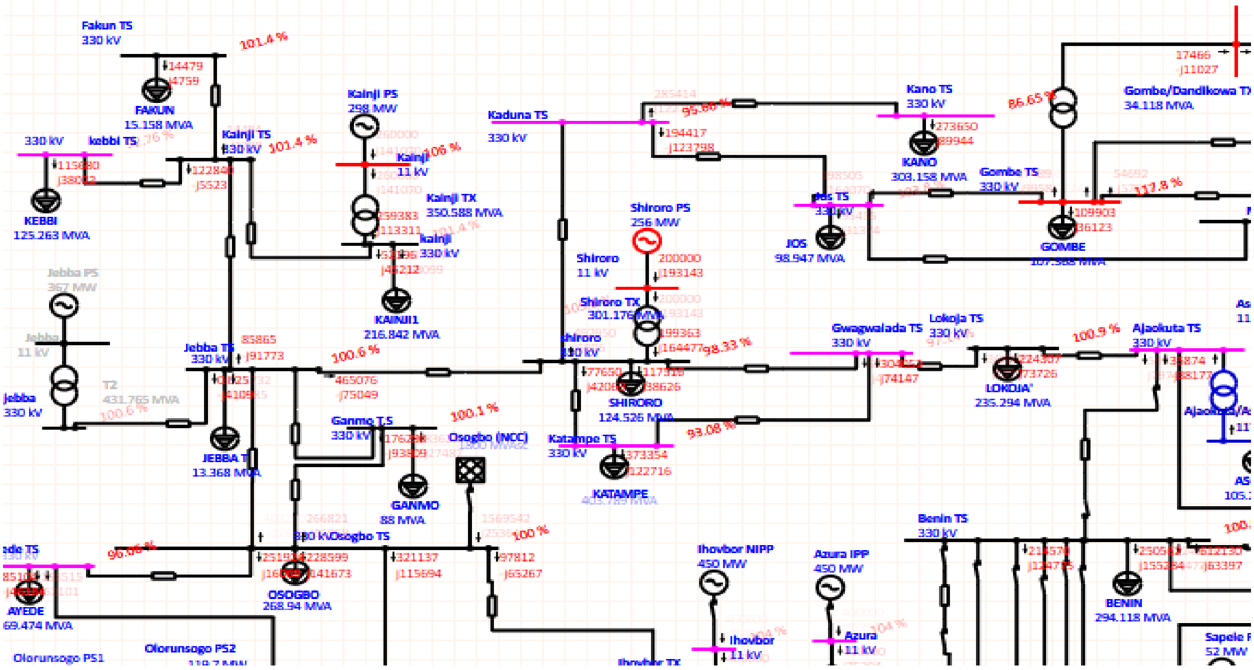

Figure 2: Network Diagram on ETAP Run Mode with Jabba PS (NC) knocked off

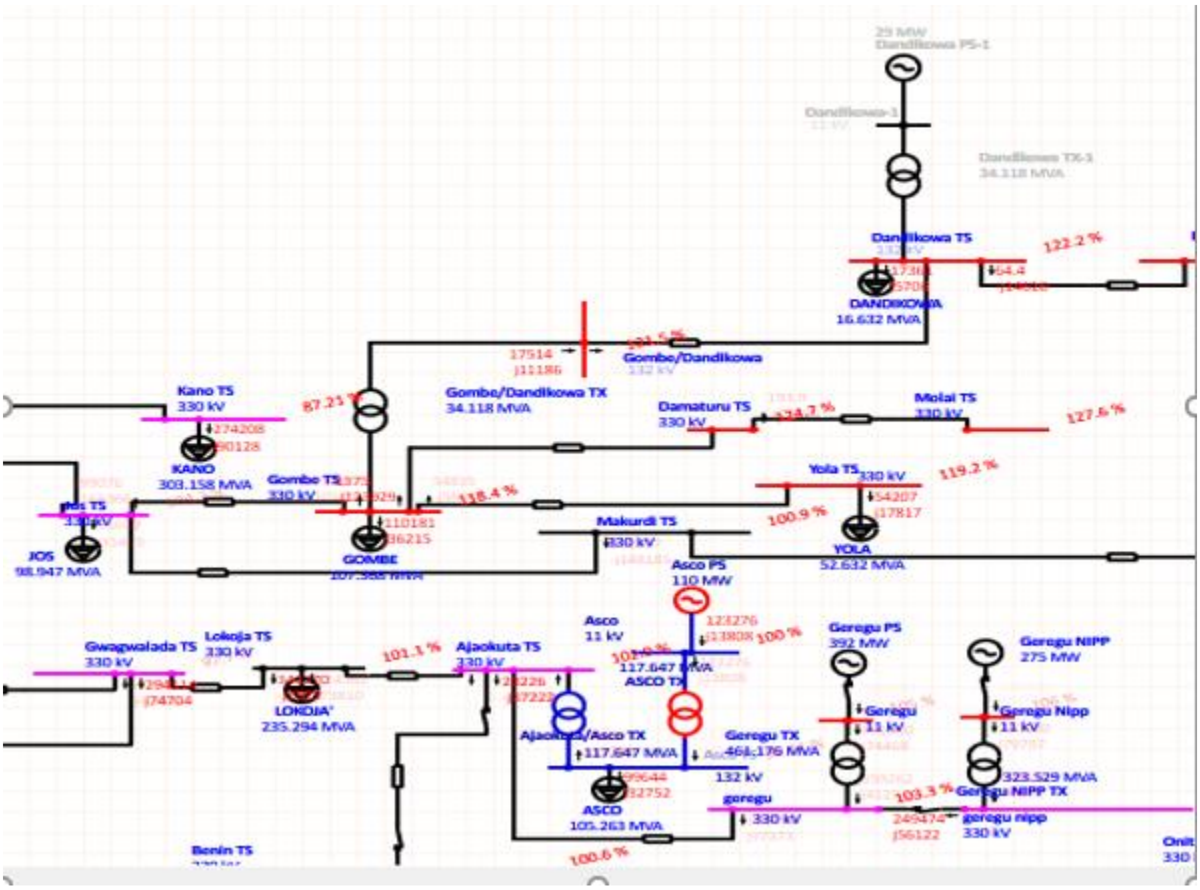

Figure 3: Network Diagram on ETAP Run Mode with Dandikowa PS 1 (NE) knocked off

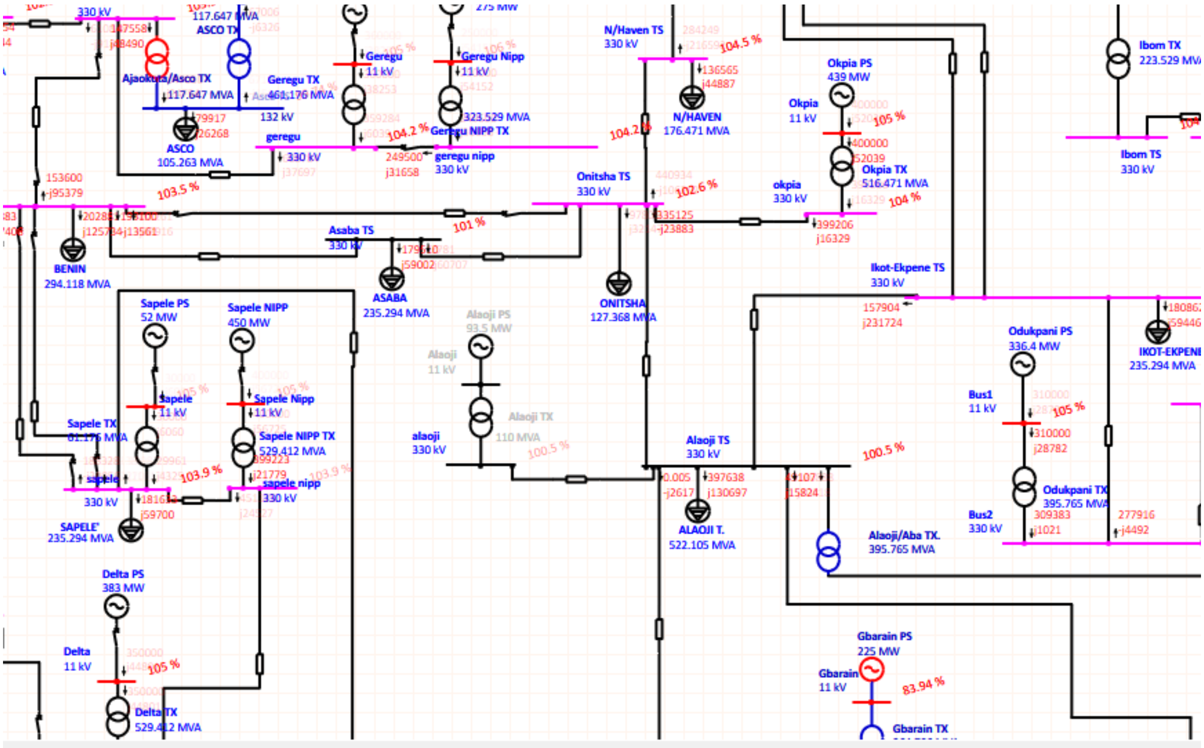

Figure 4: Network Diagram on ETAP Run Mode with Alaoji PS (SE) knocked off

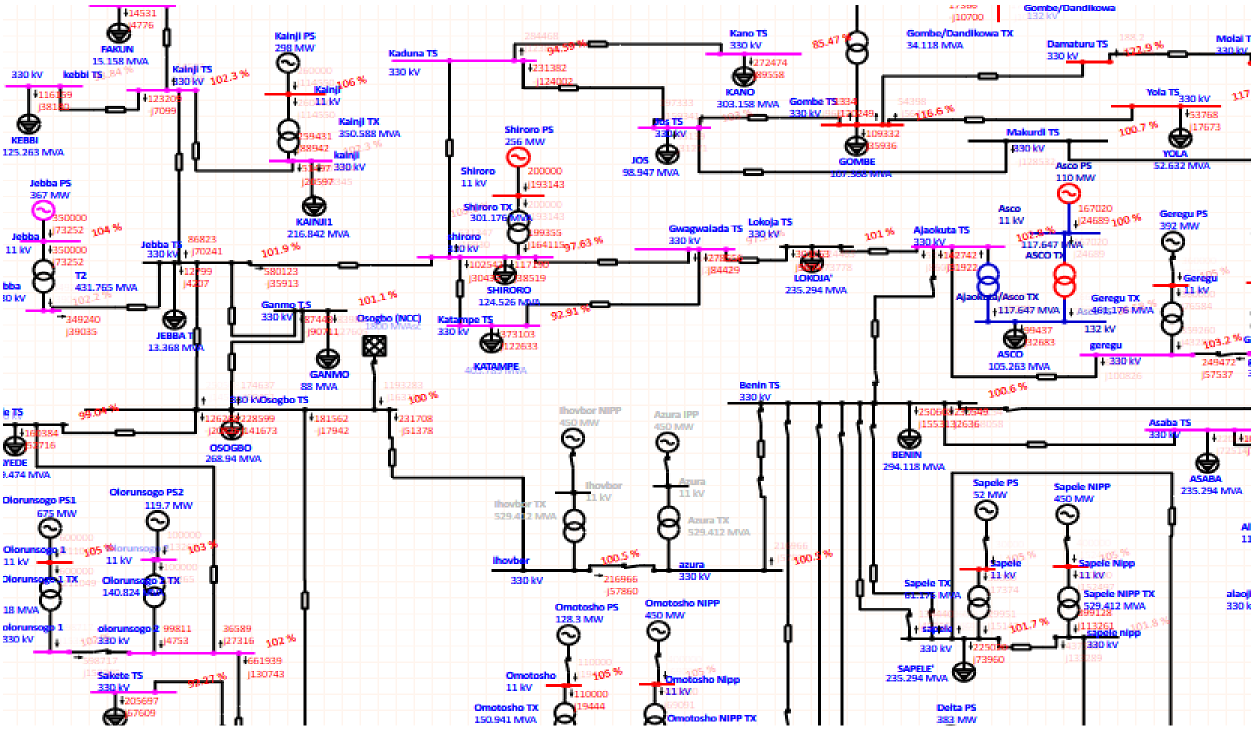

Figure 5: Network Diagram on ETAP Run Mode with Azura PS and Ihovbor PS (SS) knocked off

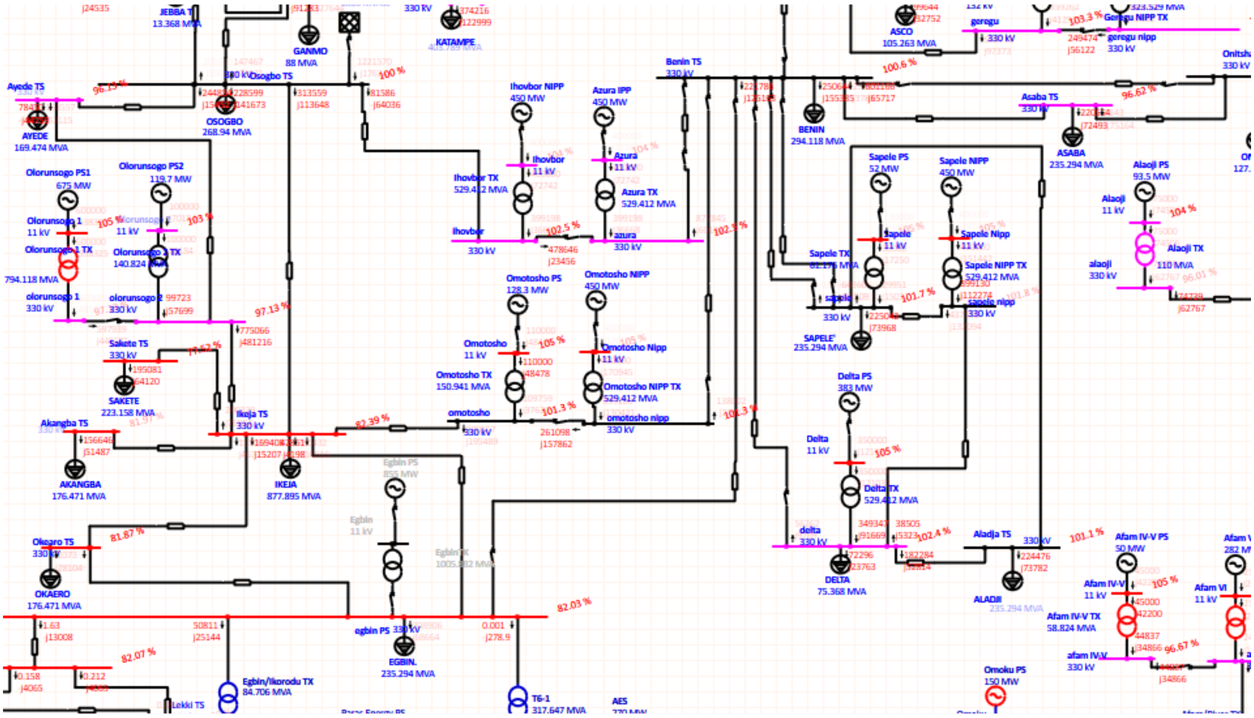

Figure 6: Network Diagram on ETAP Run Mode with Egbin PS (SW) knocked off

Table 2: Line Losses for Original Network

S/ N	Lines		kW Losses	kvar Losses
	From Bus	To Bus		
1	Aba TS	Itu PS	584.00	-815.30
2	Adaibor TS	Odukpani PS	9.37	-2533.40
3	Adiabor TS	Itu PS	6.17	277.50
4	AES 132kV	AES TS	0.00	-427.80
5	Afam VI PS	Rivers IPP PS	637.80	28700.70
6	Ahaoda TS	Gbarain PS	2348.40	7342.00
7	Aja TS	Alagbon TS	0.26	-6294.90
8	Aja TS	Lekki TS	0.18	-1330.80
9	Ajaokuta TS	Lokoja TS	7211.90	8286.40
10	Ajaokuta TS	Geregu PS	2485.90	1552.60
11	Ajaokuta TS	Benin TS	4931.90	-96879.20
12	Ajaokuta TS	Asco TS	599.20	26964.60
13	Alaoji TS	Alaoji PS	415.69	-2603.00
14	Alaoji TS	Afam VI PS	127.30	-14858.70
15	Alaoji TS	Aba TS	519.32	869.40
16	Alaoji TS	Owerri TS	199.40	8974.80
17	Asaba TS	Benin TS	5065.60	-15385.10
18	Ayede TS	Olorunsogo PS 2	13178.70	28887.60
19	Benin TS	Azura PS	4388.90	15056.70
20	Benin TS	Omotosho NIPP PS	5361.20	-6632.00
21	Benin TS	Egbin PS	702.10	-50692.00
22	Benin TS	Sapele PS	3366.50	-36331.00
23	Benin TS	Delta PS	634.90	-24258.50

Table 3: Bus Voltages for Original Network

S/ N	Bus ID	Voltage p.u.
1	Aba TS	1.01
2	Adiabor TS	1.05
3	AES 132kV	1.02
4	AES TS	1.02
5	Afam IV-V	1.02
6	Afam VI	1.02
7	Ahaoda TS	0.89
8	Aja TS	1.02
9	Ajaokuta TS	1.04
10	Akangba TS	0.98
11	Aladja TS	1.03
12	Alagbon TS	1.02
13	Alaoji PS	1.01
14	Alaoji TS	1.01
15	Asaba TS	1.01
16	Asco TS	1.00
17	Ayede TS	0.99
18	Azura PS	1.04
19	Benin TS	1.04
20	BIU TS	1.03
21	Damaturu TS	1.40
22	Dandikowa TS	1.20
23	Delta PS	1.04
24	Egbin PS	1.02

24	BIU TS	Dandikowa TS	2799.20	329.60
25	Damaturu TS	Gombe TS	2210.30	-58771.90
26	Dandikowa TS	Gombe/Dandikowa	801.30	894.00
27	Delta PS	Aladja TS	817.60	-3924.10
28	Egbin PS	Okearo TS	3612.80	-1091.80
29	Egbin PS	Aja TS	2311.93	-7479.20
30	Egbin PS	Ikorodu TS	5171.01	3195.70
31	Egbin PS	AES 132kV	0.00	0.07
32	Fakun TS	Kainji TS	3453.43	-6389.40
33	Ganmo T.S	Osogbo TS	510.90	-18735.30
34	Gbarain PS	Yenagoa TS	860.60	1837.70
35	Gombe TS	Jos TS	17653.70	-14385.50
36	Gombe/Dandikowa	Gombe TS	197.60	8892.80
37	Gwagwalada TS	Katampe TS	5624.00	10884.90
38	Ikeja TS	Akangba TS	194.60	-8250.00
39	Ikeja TS	Okearo TS	1947.00	-8420.70
40	Ikeja TS	Egbin PS	2272.10	-4449.50
41	Ikorodu TS	Paras Energy TS	191.50	378.60
42	Ikot-Abasi TS	Ikot-Ekpene TS	127.30	-44378.70
43	Ikot-Abasi TS	Ibom TS	8.62	-34015.70
44	Ikot-Ekpene TS	Odukpani PS	3396.90	-36000.80
45	Ikot-Ekpene TS	Alaoji TS	1348.20	-15215.70
46	Itu PS	Eket TS	1.11	-3080.60
47	Jebba TS	Jebba PS	669.10	-2383.40
48	Jebba TS	Osogbo TS	1596.20	-78374.50
49	Jebba TS	Ganmo T.S	524.20	-36810.70
50	Jos TS	Kaduna TS	3646.20	-38241.70
51	Kaduna TS	Shiroro PS	4819.00	-34256.80
52	Kainji TS	Kebbi TS	4173.40	-60622.70
53	Kainji TS	Kainji PS	5.90	-98.58
54	Kainji TS	Jebba TS	53.67	-44632.50
55	Kano TS	Kaduna TS	18493.20	29203.10
56	Lekki TS	Alagbon TS	0.13	-4843.30
57	Lokoja TS	Gwagwalada TS	35047.20	-25346.80
58	Makurdi TS	Jos TS	20356.10	-137399.00
59	Molai TS	Damaturu TS	550.80	-121004.00
60	N/Haven TS	Onitsha TS	18108.60	56186.30
61	Okpai PS	Onitsha TS	4448.50	-13131.50
62	Olorunsogo PS 2	Ikeja TS	7947.40	23492.60
63	Omotosho PS	Ikeja TS	14368.20	25210.70
64	Onitsha TS	Benin TS	13864.10	-19510.10
65	Onitsha TS	Alaoji TS	13046.00	24234.60
66	Onitsha TS	Asaba TS	3193.90	-15261.70
67	Osogbo TS	Ikeja TS	8405.10	-17137.90
68	Osogbo TS	Ihovbor PS	23156.20	41775.40
69	Osogbo TS	Ayede TS	4506.00	-7515.30
70	Owerri TS	Ahaoda TS	4939.70	14595.60
71	PH Main TS	Omoku PS	2571.80	296.80
72	PH Main TS	Trans Amadi	2101.80	-783.00
73	Rivers IPP PS	PH Main TS	1409.20	1476.60
74	Sakete TS	Ikeja TS	2497.50	-4336.50

25	Eket TS	1.05
26	Fakun TS	1.05
27	Ganmo T.S	1.03
28	Gbarain PS	0.85
29	Geregu NIPP PS	1.04
30	Geregu PS	1.04
31	Gombe TS	1.31
32	Gombe/Dandikow a	1.24
33	Gwagwalada TS	1.02
34	Ibom TS	1.05
35	Ihovbor NIPP PS	1.04
36	Ikeja TS	0.99
37	Ikorodu TS	0.99
38	Ikot-Abasi TS	1.05
39	Ikot-Ekpene TS	1.04
40	Itu PS	1.05
41	Jebba PS	1.04
42	Jebba TS	1.04
43	Jos TS	1.13
44	Kaduna TS	1.04
45	Kainji PS	1.05
46	Kainji TS	1.05
47	Kano TS	0.86
48	Katampe TS	0.99
49	kebbi TS	1.00
50	Lekki TS	1.02
51	Lokoja TS	1.03
52	Makurdi TS	1.07
53	Molai TS	1.45
54	N/Haven TS	1.05
55	Odukpani PS	1.05
56	Okearo TS	1.00
57	Okpai PS	1.04
58	Olorunsogo PS1	1.03
59	Olorunsogo PS2	1.03
60	Omoku PS	0.91
61	Omotosho NIPP	1.05
62	Omotosho PS	1.05
63	Onitsha TS	1.03
64	Osogbo TS	1.00
65	Owerri TS	0.98
66	Paras Energy TS	0.98
67	PH Main TS	0.95
68	Rivers IPP	0.96
69	Sakete TS	0.95
70	Sapele NIPP	1.04
71	Sapele PS	1.04
72	Shiroro PS	1.04
73	Trans Amadi PS	0.95
74	Ugwuaji TS	1.05
75	Yenagoa TS	0.83

75	Sapele NIPP PS	Sapele PS	2204.60	657.10
76	Sapele NIPP PS	Delta PS	2168.70	-14802.00
77	Sapele PS	Aladja TS	1049.17	-15187.20
78	Shiroro PS	Jebba TS	1694.30	-130511.00
79	Shiroro PS	Katampe TS	831.60	-31204.20
80	Shiroro PS	Gwagwalada TS	2556.10	-24356.90
81	Ugwuaji TS	Makurdi TS	2714.80	-18253.60
82	Ugwuaji TS	N/Haven TS	2361.70	-2264.80
83	Ugwuaji TS	Ikot-Ekpene TS	3243.10	-79931.30
84	Ugwuaji TS	Ikot-Ekpene TS	3243.10	-79931.30
85	Yola TS	Gombe TS	2488.90	-95624.70
	Total		**347341.56**	**-1306933.11**

76	Yola TS	1.33

Table 4: Line Losses for Various Geopolitical Zones Generator Outage

S/N	Lines		NC		NE		SE		SS		SW	
	From Bus	**To Bus**	**kW Losses**	**kvar Losses**	**kW Losses**	**kvar Losses**	**kW Losses**	**kvar Losses**	**kW Losses**	**kvar Losses**	**kW Losses**	**kvar Losses**
1	Aba TS	Itu PS	778.2	762.2	777.9	753.9	535.4	-544.7	784.9	786.5	777.9	753.9
2	Adaibor TS	Odukpani PS	14.77	-2338.7	14.79	-2343.6	300.087	-2504	14.94	-2341.3	14.79	-2343.6
3	AES 132kV	AES TS	0.0005	-278.5	0.0005	-278.9	3546.87	-428	0.0007	-414.8	0.0005	-278.9
4	Ahaoda TS	Gbarain PS	5675.5	21688	5615.4	21428.6	2398.3	7603.7	5622.6	21459.8	5615.4	21428.6
5	Aja TS	Alagbon TS	0.169	-4098.9	0.17	-4104.8	0.26	-6298.3	0.252	-6104.2	0.17	-4104.8
6	Aja TS	Lekki TS	0.117	-866.5	0.117	-867.8	2000.68	-1331.5	0.174	-1290.4	0.117	-867.8
7	Ajaokuta TS	Lokoja TS	7180.4	8788.3	6506.3	5958.1	7115.7	7892.2	5678.1	2625.7	6506.3	5958.1
8	Ajaokuta TS	Geregu PS	1558.8	1946	1545.8	1879.3	1485.3	1548.8	1550.3	1902.3	1545.8	1879.3
9	Ajaokuta TS	Benin TS	353	-102898	492.3	-102594	2492.7	-98535.3	2082.7	-96031.7	492.3	-102594
10	Alaoji TS	Alaoji PS	28.96	-2260	28.44	-2269.7	0.0046	-2617.3	28.5	-2268.5	28.44	-2269.7
11	Alaoji TS	Afam VI PS	227	-12870.9	214.3	-12963	4567.98	-14551.6	215.8	-12951.5	214.3	-12962.7
12	Asaba TS	Benin TS	9599	7710.2	9336.1	6454.1	5809.1	-11856.1	8834.7	4210	9336.1	6454.1
13	Ayede TS	Olorunsogo PS 2	1220.4	-21890.6	1045.6	-22701	12399.9	25380.1	410.2	-27787.8	1045.6	-22700.8
14	Benin TS	Azura PS	14650	60928.2	14134	58627	4760.1	16716.8	953	46.38	14134	58627
15	Benin TS	Omotosho NIPP	2670.6	-16772.7	2433.7	-17853	5869.7	-4325.8	15589	40049	2433.7	-17853.3
16	Benin TS	Egbin PS	16063	28499	16802	31720.2	3654.53	-51770.5	2919.1	-38423.3	16802	31720.2
17	Benin TS	Sapele PS	602	-25451.2	593.4	-25524	945.8	-25509.8	597.1	-25492.6	593.4	-25524.3
18	Benin TS	Sapele PS	266.9	-10787.1	263	-10821	4328.87	-10733.6	264.7	-10806	263	-10820.5
19	Benin TS	Delta PS	413	-23977.3	408.3	-24029	634.5	-24207.4	410.3	-24006.7	408.3	-24029.3
20	Biu TS	Dandikowa TS	63.73	-14467.5	64.38	-14616	2867.4	1011.5	62.38	-14162.7	64.38	-14615.8
21	Damaturu TS	Gombe TS	1169.8	-49686.3	1181.2	-50174	2170.9	-57724.4	1146.2	-48684.1	1181.2	-50174
22	Dandikowa TS	Gombe/Dandikowa	88.89	-2250.3	89	-2276.7	3652.98	1035.7	88.68	-2195.9	89	-2276.7
23	Delta PS	Aladja TS	1131.7	-2232.6	1129.7	-2247.7	819.7	-3904.3	1130.6	-2241.1	1129.7	-2247.7
24	Egbin PS	Okearo TS	21.55	-10332.6	16.25	-10370	3496.6	-1574.6	2449.4	-5283.9	16.25	-10370.1
25	Egbin PS	Aja TS	1.26	-4870	1.26	-4877	1.93	-7483.2	1.87	-7252.5	1.26	-4877
26	Fakun TS	Kainji TS	5.61	-5997.3	5.53	-6141.1	3.43	-6385.7	5.55	-6104.6	5.53	-6141.1
27	Ganmo T.S	Osogbo TS	6913.2	10363.7	2429.6	-9881.7	469.8	-18912.8	3208.1	-6345.4	2429.6	-9881.7
28	Gbarain PS	Yenagoa TS	2109.5	7617.2	2086.3	7510.6	879.2	1960.6	2089	7523.4	2086.3	7510.6
29	Gombe TS	Jos TS	15059	-9513.5	15147	-9796.2	17335.1	-14347.2	14878.8	-8922	15147	-9796.2
30	Gwagwalada TS	Katampe TS	6823.9	17646.3	6347.5	15370	5583.3	10732.9	5917.9	13632.9	6347.5	15370
31	Ikeja TS	Akangba TS	390.6	-4698.6	390.1	-4711.7	3098.23	-8260.4	314.3	-7360.2	390.1	-4711.7
32	Ikeja TS	Okearo TS	782.2	-7983.6	744	-8157.5	1860.7	-8786.9	972.5	-11716.1	744	-8157.5

33	Ikeja TS	Egbin PS	200.1	-8914	182	-9010.3	2187	-4839.9	1331.9	-8097.8	182	-9010.3
34	Ikorodu TS	Paras Energy TS	422.1	1589.3	421.6	1586.4	4965.45	378	309.7	928.7	421.6	1586.4
35	Ikot-Abasi TS	Ikot-Ekpene TS	114.1	-39772.2	114.5	-39907	3098.54	-43696.6	114.4	-39862.9	114.5	-39906.6
36	Ikot-Abasi TS	Ibom TS	7.72	-30484.9	7.75	-30588	8.49	-33492.9	7.74	-30554.4	7.75	-30587.9
37	Ikot-Ekpene TS	Odukpani PS	4057.1	-29104.4	4016.1	-29394	3419.9	-35283.9	4023.4	-29324.2	4016.1	-29393.7
38	Ikot-Ekpene TS	Alaoji TS	2029.3	-10247.9	2071.6	-10136	3854.45	-13734.1	2091.4	-10042.2	2071.6	-10136.4
39	Itu PS	Eket TS	1.03	-2860.4	1.03	-2866.7	3987.76	-3047.6	1.03	-2864.9	1.03	-2866.7
40	Jebba TS	Jebba PS	0.0247	-4108.8	688.9	-2169.7	4098.7	-2379.9	700.1	-2100.1	688.9	-2169.7
41	Jebba TS	Osogbo TS	14464	-23055.1	4624.8	-64485	1419.4	-79056	6268.5	-57436.9	4624.8	-64485.1
42	Jebba TS	Ganmo T.S	1393.2	-30854.5	330.8	-36333	462.2	-37035.6	476.5	-35449.5	330.8	-36333.1
43	Jos TS	Kaduna TS	11284	4228.6	12401	8788.8	4294.1	-34786.9	15330.1	23094.9	12401	8788.8
44	Kaduna TS	Shiroro PS	13119	6521.3	13746	8546.5	5463	-31318	15497.1	17034.6	13746	8546.5
45	Kainji TS	kebbi TS	7159.3	-43545	7013.2	-45865	4175	-60571.2	7049.4	-45278.4	7013.2	-45864.8
46	Kainji TS	kainji PS	3.23	-100.5	1.83	-107.7	4908.67	-98.6	2.04	-106.4	1.83	-107.7
47	Kainji TS	Jebba TS	733.9	-39699.6	531.4	-41549	4098.56	-44594.7	572.2	-41110.4	531.4	-41548.6
48	Kano TS	Kaduna TS	11764	32838.9	11660	32146.8	18668.2	30504.5	11994.1	34339.5	11660	32146.8
49	Lekki TS	Alagbon TS	0.0842	-3153.6	0.0843	-3158.2	2000.9	-4845.9	0.125	-4696.5	0.0843	-3158.2
50	Lokoja TS	Gwagwalada TS	11686	-33768.1	9971	-41428	14756.9	-26458.2	7925.5	-49222.2	9971	-41428.3
51	Makurdi TS	Jos TS	2776.2	-143049	2370.5	-145710	8964.4	-14069.1	1361.5	-14755.8	2370.5	-145710
52	Molai TS	Damaturu TS	192	-73038.1	193.9	-73755	4045.87	-11884.8	188.2	-71564.9	193.9	-73755
53	N/Haven TS	Onitsha TS	24522	87168.6	23618	83052.5	20120.3	65442.9	21773	74850.4	23618	83052.5
54	Okpai PS	Onitsha TS	5265.8	-7624.6	5218.6	-7897.6	4498.9	-12661.8	5196.8	-8024.5	5218.6	-7897.6
55	Olorunsogo PS 2	Ikeja TS	48798	207695	48131	204716	8294.3	25025.9	23794.2	94354.7	48131	204716
56	Omotosho PS	Ikeja TS	30219	102539	31017	106065	13435.5	21043.1	4442	-17801.2	31017	106065
57	Onitsha TS	Benin TS	27559	41599.8	26549	37316.2	16685.4	-7554.6	24588.1	29319.1	26549	37316.2
58	Onitsha TS	Alaoji TS	23715	74988.4	23092	72116.8	15981.5	37779.1	21994.7	67212.1	23092	72116.8
59	Onitsha TS	Asaba TS	365.1	-13048.2	357	-13134	2509.87	-15079.4	341.4	-13226.5	357	-13134.2
60	Osogbo TS	Ikeja TS	31647	94460	30267	88286.3	7364.8	-21796.8	8459.3	-15720.7	30267	88286.3
61	Osogbo TS	Ihovbor PS	2953.6	-47156.8	2137.8	-50824	20047	27966	14742.5	6482.2	2137.8	-50824.1
62	Osogbo TS	Ayede TS	8304.9	10151.7	7847	8095.6	4062.1	-9519.7	2063.3	-18437.6	7847	8095.6
63	Owerri TS	Ahaoda TS	12026	44780.9	11898	44230.8	5046.3	15153	11913.2	44297.1	11898	44230.8
64	PH Main TS	Omoku PS	1043.4	2791.5	1040.6	2772.3	2000.77	370.2	1040.9	2774.7	1040.6	2772.3
65	PH Main TS	Trans Amadi PS	179.2	-277	178.7	-282.1	1500.88	-757.3	178.8	-281.5	178.7	-282.1
66	Rivers IPP PS	PH Main TS	734.4	2976.4	732.6	2967.3	1600.67	1504.8	732.8	2968.4	732.6	2967.3
67	Sakete TS	Ikeja TS	5256.6	12918.2	5248.8	12863.8	2495.6	-4362	4099.7	3635.8	5248.8	12863.8
68	Sapele NIPP PS	Sapele PS	219.6	735.3	130.5	-14168	2000.89	-15168.8	130.2	-14162.6	130.5	-14167.9
69	Sapele NIPP PS	Delta PS	105.3	-14479.2	218.6	730.5	4975.98	660.2	219.1	732.6	218.6	730.5
70	Sapele PS	Aladja TS	129.9	-14155.6	104.4	-14497	3869.45	-14779.2	104.8	-14489.4	104.4	-14497.2
71	Shiroro PS	Jebba TS	28256	-10260.2	32826	5348.2	2471	-12700.9	42930.7	48575.1	32826	5348.2
72	Shiroro PS	Katampe TS	1524	-24151.3	1754.1	-23509	801.2	-31221	2077	-21402.2	1754.1	-23508.8
73	Shiroro PS	Gwagwalada TS	579	-29658.2	326	-31161	3000.87	-24746.1	50.41	-31788	326	-31161.2
74	Ugwuaji TS	Makurdi TS	1036.5	-21663.2	966.7	-22079	2452.5	-18910.2	698.1	-23066.4	966.7	-22078.9
75	Ugwuaji TS	N/Haven TS	446.3	-1494.8	425.4	-1595.5	2000.76	-2016.5	378	-1780	425.4	-1595.5
76	Ugwuaji TS	Ikot-Ekpene TS	580.4	-69741.5	612.5	-69905	3000.56	-78587.4	661.2	-69573.6	612.5	-69905.3
77	Ugwuaji TS	Ikot-Ekpene TS	580.4	-69741.5	612.5	-69905	5000.7	-78587.4	661.2	-69573.6	612.5	-69905.3

78	Yola TS	Gombe TS	628.6	-75767.6	628	-76558	1500.9	-938717	630.1	-741431	628	-76557.5
	Total		433943	-357567	416129	-452245	360681	-1354291	347368	-794092	416129	-452245

From table 2, the total line losses in the network is 347 MW. From table 3, it can be observed that 9 of the 76 buses (which represents 11.8%) violated the statutory voltage limit of 0.85 to 1.05 p.u. with the highest voltage of 1.45 p.u. recorded at Molai TS while the lowest voltage of 0.83 p.u. was recorded at Yenagoa TS. For the line losses, when considering scenario one, with Jebba PS (representing North-Central) knocked off, as can be seen from table 4, the line losses increased to 434 MW, which represents an increase of 25%. For North-East, South-East, South-South and South-West scenarios, the losses changed to 416 MW, 361 MW 347 MW and 416 MW respectively, representing about 20%,4%, 0% and 20% increase respectively when compared to the original network.

For the voltage profile, as can be seen from table 5, for the North-Central zone, 23 of the 76 buses, representing about 30%, violated the statutory voltage limit with the lowest value of 0.62 p.u. recorded at Yenagoa TS while the highest value being 1.27 p.u. recorded at Molai TS. Of the 23 violating buses, 16 fell below the statutory limit while 7 were above it. For the North-East scenario, 15 buses fell below the statutory voltage limit while 7 were above it, making a total of 22 buses (representing about 31.4 %) that fell outside the statutory voltage limit. The lowest value of 0.63 p.u. was recorded at Yenagoa TS while the highest value of 1.28 p.u. was recorded at Molai TS. When the South-East outage is taken into consideration, as can also be seen from table 5, it was discovered that 2 buses (Yenagoa TS, 0.82 p.u. and Gbarain PS, 0.84 p.u.) fell below the statutory limit while 8 buses were above the statutory limit, making a total of 10 buses (representing about 13%) falling outside the statutory limit. Yenagoa TS had the lowest value of 0.82 p.u. while Molai TS had the highest value of 1.44 p.u. For the South-South zone, 4 buses fell below the statutory limit while 7 buses were above, making a total of 11 buses (representing about 14.5%) that were outside the limit. The lowest value of 0.83 p.u. was recorded at Yenagoa TS while the highest value of 1.26 p.u. was recorded at Molai TS. For the South-West zone, 16 buses fell below the statutory limit while 7 buses were above it, making a total of 23 buses (about 30%). The lowest value of 0.63 p.u. was recorded at Yenagoa TS while the highest value of 1.28 p.u. was recorded at Molai TS. The results are summarized in table 6.

Table 6: Summary of Results

	Original Network	**Jebba PS (NC) Outage**	**Dandikowa PS (NE) Outage**	**Alaoji PS (SE) Outage**	**Azura/ Ihovbor PS (SS) Outage**	**Egbin PS (SW) Outage**
Percentage increase in losses from original network	0%	25%	20%	4%	0%	20%
Total no of buses below statutory limit	1	16	15	2	4	16
Total no of buses above statutory limit	8	7	7	8	7	7

Percentage of buses outside limit	11.80%	30%	31.40%	13%	14.50%	30%
Bus with lowest voltage/value	Yenagoa TS/0.83 p.u.	Yenagoa TS/0.62	Yenagoa TS/0.63 p.u	Yenagoa TS/0.82 p.u.	Yenagoa TS/0.83 p.u.	Yenagoa TS/0.63 p.u
Bus with highest voltage/value	Molai TS /1.45 p.u.	Molai TS /1.27 p.u.	Molai TS /1.28 p.u.	Molai TS /1.44 p.u.	Molai TS /1.26 p.u.	Molai TS /1.28 p.u.

5. Conclusion and Recommendations

An analysis of the effect of generating stations outages based on geopolitical zones of the Nigerian 330 kV-132 kV transmission network has been carried out. From the analysis carried out, it can be deduced that Molai TS and Yenagoa TS, each always have the highest and lowest values respectively of bus voltages for all scenarios. These buses are quite vulnerable. The Jebba PS outage (representing North-Central geopolitical zone) registered the highest increase in line losses of about 25% while the highest bus voltage violation of 31.4% occurred in Dandikowa PS (North-East) outage. The original network has some deficiencies, with about 12% bus voltage violation and this value increased when the various power stations in each zone were knocked off. It is thus recommended that the Nigerian 330 kV-132 kV transmission network should be improved upon and a scenario where there will be outages of these generating stations should be avoided.

The various generating stations in Nigeria have been categorized into various geopolitical zones and it was discovered that North-East and South-East geopolitical zones have only one generating station each, while the North-West geopolitical zone has none. This is not supposed to be. It is therefore recommended that more generating stations should be added to the network in these geopolitical zones so that there will be a sort of balance of generating stations based on geopolitical zones, as it is believed that this will go a long way in improving the overall performance of the network.

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