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A Power Flow Analysis of the Nigerian 330 KV Electric Power System

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Abstract: *Management of reactive power and voltage control constitute part of the major challenge in power system industry. Adequate reactive power control solves power quality problems like voltage profile maintenance at all power transmission levels, transmission efficiency and system stability. Power demand increases steadily while the expansion of power generation and transmission has been severely limited due to the inadequate resources and environmental forces. These give cause for concern as they contribute to the constant power failure in the Nigeria power system. In this work the Nigeria 330KV network, 30 bus system is considered. To alleviate/eradicate some of these problems mentioned, compensation in power system becomes very essential. Compensation reduces generating MVA and MVAR. The reduction in MVAR helps electrical companies to transmit more power and absorbing more customers without expanding their power networks. Newton-Raphson's solution method was used to carry out the analysis because of its sparsity, fast convergence and simplicity attribute as compared to other solution methods using the relevant data as obtained from power holding company of Nigeria (PHCN). MAT LAB/SIMULINK software was used to carry out the simulation analysis. The results obtained showed that the bus voltages outside the statutory limit of 0.95 – 1.05p.u that is 313.5 – 346.5KV were buses 14(Jos) with value 0.8171pu, bus 17(Gombe) 0.8144p.u bus 18(Abuja) 0.9402pu, bus 19(Maiduguri) 0.8268pu, bus 22(Kano) 0.7609pu, bus 29(Kaduna) 0.8738pu, and bus 30(Makurdi) 0.8247pu under normal uncompensated condition. Capacitive shunt compensation because of its advantages was implemented on these buses, and the results recorded appreciable values. Results obtained after compensation reveal acceptable voltage levels at the problem buses. For instance bus 14(Jos) come up to 0.9823p.u, bus 17(Gombe) 1.0242p.u, bus 18(Abuja) 0.9667p.u, bus 19(Maiduguri) 1.0455p.u, bus 22(Kano) which is heavily loaded was linked to Jos and a 60 percent compensation on Kano bus yielded an increase of 0.7609pu to 0.947p.u.*

Keywords: *Power System, Compensation, Reactive Power, Power Flow*

I. Introduction

The rate at whichpower supply fails in Nigeria has reached an unprecedented level that the public is almost demanding for a state of emergency in respect of electricity supply. The various efforts made to rescue the power short fall has not yielded the expected outcome.

Reactive power is both the challenge and the solution to power system network voltage control. It is important that a balance of reactive power be obtained in the operation of a power system because control of voltage can be lost if this is not achieved. The electrical machines and apparatus have a certain maximum and minimum operating voltage range in which the normaloperation is maintained. Beyond the voltagelimits, the operating characteristics may be seriously affected in terms of speed, output torque, energy losses, and the continuity of the process may be lost.Adequate reactive power control and compensation of transmission networks solve power quality problems by improving the system stability and control voltage. In Nigeria, power demand increases steadily while the expansion of power generation and transmission has been severely limited due to inadequate resources and environmental factors. This gives cause for concern as it contributes to the constant power failure in the Nigeria power system, since greater demands have been placed on the transmission network by the continuous addition of load due to the increasing number of consumers.Compensation provides a veritable way to reduce the excess voltage/current to avoid damage to the utility centers. Compensation techniques such asStatic VAR Compensators (SVC), Static Synchronous Compensators(STACOM) and Synchronous condensers play a very important role in this case.

Shunt and series reactive compensation using capacitors has been widely recognized as powerful tools to combat the problems of voltage drops, power losses, and voltage flickers in power distribution networks. The importance of compensation schemes has increased in recent years due to the increased awareness of energy conservation and quality of supply on the part of the Power Utility as well as power consumers. Though shunt compensation are expensive but they control voltage directly and also control temporary over voltage rapidly.Compensation in power system becomes very essentialsincepower flow problem is the computation of voltage magnitude and phase angle at each bus in a power system under balanced three-phase steady-state conditions.

The voltage magnitude statutorilyshould lie between $0.95 \le |V_i| \le 1.05pu$ and the angle should be very small for a balanced steady state 50Hz power station to achieve the effective operation. Against these backdrops, this paper will address the following issues: (i) develop a model-based simulation algorithm that will be used to solve the network problems due to reactive and real power imbalance (ii) determine causes of constant power failure that de-stabilizes the Nigeria power system with a view to achieve high performance and efficient stability of the power system (iii) evaluate individual buses to make sure that based on the demand imposed on it that the voltage lies within $\pm 5\%$ of the normal voltage. Also compensation on the problem buses to improve the system efficiency will be presented.

II. Nigeria 330kv Interconnected Electric Power System

The engineer who works in the electrical power industry will encounter some challenges in designing future power systems to deliver increasing amounts of energy in a safe, clean and economical manner [1]. The origin of the Nigeria Electric power System can be traced back to the year 1898 [2] when a small generating plant was installed in Lagos. The first power interconnection was a 132KV link constructed in 1962 between Lagos and Ibadan. By 1968 the first National grid structure emerged with the construction of the kainji hydro station which supplied power via a 330KV, primarily radial type transmission network into the three members' 132KV subsystem then existing in the Western, Northern and Eastern parts of the country. The 330KV and 132KV systems were initially run by two separate bodies- "Nigeria Dams Authority (NDA)", and "Electricity Corporation of Nigeria (ECN)" respectively. Central control for the 330KV Network was coordinated from kainji power supply control room, while the 132KV Network was run by load dispatcher located at Ijora Power Supply Lagos. These two bodies were merged formally into single power utility known as National Electric Power Authority (NEPA) in 1972 thus ushering in centralized regulation and coordination of the entire rapidly growing 330KV and 132KV National network. These networks are characterized by many disturbances which cause various hindrances and outages..

2.1 Network Description

The Nigerian power network like many practical systems in developing countries consists of a few generating stations mostly sited in remote locations near the raw fuel sources which are usually connected to the load centers by long transmission lines.

Generation, transmission, distribution and marketing of electricity in Nigeria are the statutory functions of the National Electric Power Authority (NEPA) now known as Power Holding Company of Nigeria (PHCN). Presently, the national electricity grid consists of nine generating stations comprising three (3) hydro and six (6) thermal with a total installed generating capacity of 6500MW. The thermal stations are mainly in the southern part of the country located at Afam, Okpai, Delta (Ughelli), Egbin and Sapele. The hydroelectric power stations are in the country's middle belt and are located at Kainji, Jebba and Shiroro. The transmission network is made up of 5000km of 330KV lines, 6000km of 132KV lines, 23km of 330/132KV sub-stations and 91 of 132/33KV substations. The distribution sector is comprised of 23,753km of 33KV lines 19,226km of 11kv lines, 679 of 33/11KV sub-stations. There are also 1790 distribution transformers and 680 injection substations [3].Although, the installed capacity of the existing power stations is 6500MW the maximum load ever recorded was 4,000MW. Presently, most of the generating units' have broken down due to limited available resources to carry out the needed maintenance. The transmission lines are radial and are overloaded. The switchgears are obsolete while power transformers have not been maintained for a long time.

The present installed generating capacity is about 6000MW and the maximum generation of 4000MW for a population of about 160 million. This indeed is grossly inadequate to meet the demand of electricity consumers'. The current projected capacity that needs to be injected into the system is estimated at 10,000MW which is hoped to come in through the independent power producers (IPPs) as soon as the deregulation of electricity supply industry is successfully achieved. Also, massive injection of funds is needed to expand the distribution and transmission networks to adequately transport the power generated to consumers[4,5,6]. The existing generating stations in the country are shown in table 1 and those under construction are shown in table 2.

S/No	Power Station Name	Location/State	Status	Capacity (MW)
1	Egbin Thermal Power Station	Lagos	Operating	1320
2	Afam Thermal PS	Rivers	Operating	969.6
3	Sapele Thermal PS	Delta	Operating	1020
4	Ijora Thermal PS	Lagos	Operating	40
5	Delta Thermal PS	Delta	Operating	912
6	Kainji Hydro PS	Niger	Operating	760
7	Jebba Hydro PS	Niger	Operating	578

8	Shiroro Hydro PS	Niger	Operating	600
9	AES Thermal PS	Lagos	Operating	300
TOTAL CAPACITY =				6500

Source: [7]

Table 2 Power Stations/plants Under Construction

S/N	NAME	STATE
Thermal Power Plant Under Construction		
1	Eyeon	Edo
2	Sapele	Delta
3	Omoku	Rivers
4	Egbema	Rivers
5	GbaranUbic	Beyelsa
6	Onne	Rivers
7	Calabar	Cross River
Proposed Hydro Power Plant		
1	Dadinkowa	Gombe
Proposed Biomass Power Plant		
1	Ikeja	Lagos
Total	9	

Source: [7]

2.2 Nigeria 330kV 30 Bus Transmission Network.

The single-line diagram of the existing 330KV Nigeria transmission network used as the case study is as shown in Fig.1. It has 30 buses with nine generating station. The Egbin power station was chosen as the slack bus because of its location in the network.

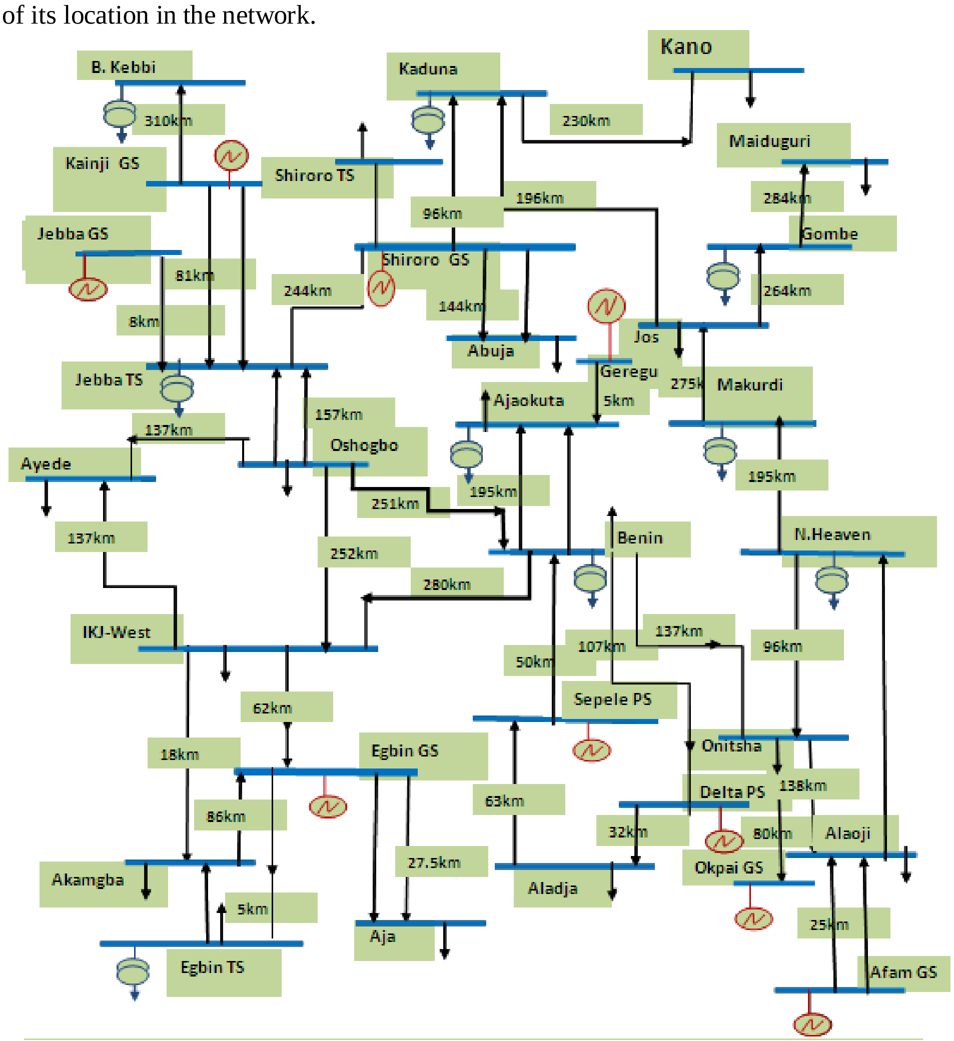

Fig.1. One Line Diagram of the PHCN 330KV 30 Bus Interconnected Network

III. Methodology

The Nigeria330KV transmission Integrated Power Plant (NIPP) network system in its current state has been presented in this work. For the investigation of the existing 330KV 30 bus system of Nigeria transmission network the Egbin power station was chosen as the slack bus. Data collection from PHCN are based on 2008 to 2010 reports. Line data, load data, the generators and other system components were also collected. Equations for the power flow analysis are formulated incorporating these parameters. The algorithm was developed, andNewton-Raphson's solution method was used to carry out the analysis with equations. 1 and2 because of its sparsity, fast convergence and simplicity attributes when compared to other solution methods. Using the relevant data as obtained from Power Holding Company of Nigeria (PHCN). MATLAB m-file program and SIMULINK model were developed and used for the simulation analysis.The mismatch in real and reactive power can be written as follows:

$$\Delta P = J_{11}\Delta\delta \quad (1)$$

$$\Delta Q = J_{22}\Delta|V| \quad (2)$$

IV. Input Data

The input data for the power flow analysis include the bus data that is real and reactive powers of the generator buses, transmission line data (impedance of lines), voltages and transformer/load data obtained from Power Holding Company of Nigeria (PHCN) are as presented in Tables 1 to 11. They were used to carry out the simulation analysis.

Table 3 Transmission Line Data (of Bison, two conductors per phase & 2x350 mm2X-section Conductor) for 330KV Lines.

S/N	Bus Name		Length (km)	$R_{1(P.U)}$	X_1(p.u)	Shunt $\frac{y}{2}(p.u)$
	From	To				
1.	Akamgbe	Ik-West	17	0.0006	0.0051	0.065
2.	Ayede	Oshogbo	115	0.0041	0.0349	0.437
3.	Ik-West	Egbin	62	0.0022	0.0172	0.257
4.	Ik-West	Benin	280	0.0101	0.0799	1.162
5.	Oshogbo	Jebba	249	0.0056	0.477	0.597
6.	Oshogbo	Benin	251	0.0089	0.0763	0.954
7.	JebbaTs	JebbaGs	8	0.003	0.0022	0.033
8.	Jebba TS	Shiroro	244	0.0087	0.0742	0.927
9.	Jebba TS	Kainji	81	0.0022	0.0246	0.308
10.	Kainji	B.Kebbi	310	0.0111	0.942	1.178
11.	Shiroro	Kaduna	96	0.0034	0.0292	0.364
12.	Kaduna	Kano	320	0.0082	0.0899	0.874
13.	Jos	Gombe	265	0.0095	0.081	1.01
14	Benin	Ajaokuta	195	0.007	0.056	0.745
15.	Benin	Sapele	50	0.0018	0.0139	0.208
16.	Benin	Onitsha	137	0.0049	0.0416	0.521
17.	Onitsa	N.Heaven	96	0.0034	0.0292	0.0355
18.	Onitsha	Alaoji	138	0.0049	0.0419	0.524
19.	Alaoji	Afam	25	0.009	0.007	0.104
20.	Sapele	Aladja	63	0.0023	0.019	0.239
21.	Delta	Aladja	30	0.0011	0.0088	0.171
22.	*Kainji GS	Jebba TS	81	0.0022	0.0246	0.308
23.	Ayede	lk West	137	0.0049	0.0416	0.521
24.	Egbin TS	Aja	27.5	0.0022	0.0172	0.257
25	Egbin TS	Aja	27.5	0.0022	0.0172	0.257
26.	Kaduna	Jos	197	0.007	0.0599	0.748
27.	Jos	Makurdi	275	0.0029	0.0246	0
28.	Oshogbo	lk West	252	0.0049	0.0341	0.521
29.	Benin	Delta	107	0.0022	0.019	0.239
30	Onitsha	Okpai	80	0.009	0.007	0.104
31.	Geregu	Ajokuta	5	0.0022	0.0172	0.257
32.	Shiroro	Kaduna,	96,	0.0034	0.0292	0.364

Source: [7]

4.1 Line Data

The load and generation expressed in per unit values is given as $\frac{MW + jMVAr}{base.value}$.

Slack Bus = Egbin GS

Table4 Line Data

S/N	CIRCUIT (BUSES)		LENGHT	IMPEDANCE	ADMITTANCE	SHUNT
	FROM	TO	(KM)	Z.(p.u.)	Y (pu)	$\frac{y}{2}(p.u)$
1.	Akamgbe	Ik-West	17	0.0006+j0.0051	22.75-j19.32	0.065
2.	Ayede	Oshogbo	115	0.0041+jo.o349	3.333-j38.37	0.437
3.	Ik-West	Egbin	62	0.0022+j0.0172	7.308-j57.14	0.257
4.	Ik-West	Benin	280	0.0101+j0.0799	1.637-j12.626	1.162
5.	Oshogbo	Jebba	249	0.0056+j0.477	0.0246-j3.092	0.597
6.	Oshogbo	Benin	251	0.0089+j0.0763	1.508-j12.932	0.954
7.	JebbaTs	JebbaGs	8	0.003+j0.0022	3.174-j1.594	0.033
8.	Jebba TS	Shiroro	244	0.0087+j0.0742	1.559-j13.297	0.927
9.	Jebba TS	Kainji	81	0.0022+j0.0246	3.607-j40.328	0.308
10.	Kainji	B.Kebbi	310	0.0111+j0.942	1.235-j10.478	1.178
11.	Shiroro	Kaduna	96	0.0034+j0.0292	3.935-j3.379	0.364
12.	Kaduna	Kano	320	0.0082+j0.0899	1.657-j14.17	0.874
13.	Jos	Gombe	265	0.0095+j0.081	1.923-j15.456	1.01
14	Benin	Ajaokuta	195	0.007+j0.056	1.429-j12.180	0.745
15.	Benin	Sapele	50	0.0018+j0.0139	3.194-j17.555	0.208
16.	Benin	Onitsha	137	0.0049+j0.0416	2.8-j33.771	0.521
17.	Onitsa	N.Heaven	96	0.0034+j0.0292	3.935-j3.379	0.0355
18.	Onitsha	Alaoji	138	0.0049+j0.0419	2.754-j33.553	0.524
19.	Alaoji	Afam	25	0.009+j0.007	59.230-j53.846	0.104
20.	Sapele	Aladja	63	0.0023+j0.019	5.284-j51.913	0.239
21.	Delta	Aladja	30	0.0011+j0.0088	13.995-j1.119	0.171
22.	*Kainji GS	Jebba TS	81	0.0022+j0.0246	3.607-j40.328	0.308
23.	Ayede	lk West	137	0.0049+j0.0416	2.8-j33.771	0.521
24.	Egbin TS	Aja	27.5	0.0022+j0.0172	7.316-j57.2036	0.257
25	Egbin TS	Aja	27.5	0.0022+j0.0172	7.316 –j57.2036	0.257
26.	Kaduna	Jos	197	0.007+j0.0599	1.924 –j16.469	0.748
27.	Jos	Makurdi	275	0.0029+j0.0246	4.726-j40.093	0
28.	Oshogbo	lk West	252	0.0049+j0.0341	4.128-j28.732	0.521
29.	Benin	Delta	107	0.0022+j0.019	6.013-j51.935	0.239
30	Onitsha	Okpai	80	0.009+j0.007	59.230-j53.846	0.104
31.	Geregu	Ajokuta	5	0.0022+j0.0172	7.316-j57.203	0.257
32.	Shiroro TS	Kaduna	96	0.0034+j0.0292	3.935-j3.379	0.364

Source: [7]

Table 5Bus Data

B No	Bus Name	Generation		Load		V	Angle	Remarks
		P (MW)	Q(MVar)	P (MW)	Q (MVar)	(volts)	(degree)	
1.	Egbin	-	-	0,0000	0.0000	1.02	0.0000	Slack
2.	Delta Ps	55.000	28.160	-	-	1.0000	0,0000	PV Bus
3.	Okpai	220.000	112.700	-	-	1.0000	0.0000	PV Bus
4.	Sapele	75.000	38.420	-	-	1.0000	0.0000	PV Bus
5.	Afam	479.000	245.390	-	-	1.0000	0.0000	PV Bus
6.	Jebba	322,000	164.960	-	-	1.0000	0.0000	PV Bus
7.	Kainji	323.000	165.490	-	-	1.0000	0.0000	PV Bus
8.	Shiroro	280.000	143.440	-	-	1.0000	0.0000	PV Bus
9.	Geregu	200.000	102.440	-	-	1.0000	0.0000	PV Bus
10.	Oshogbo	-	-	120.370	61.650	1.0000	0.0000	Load Bus
11.	Benin	-	-	160.560	82.240	1.0000	0.0000	Load Bus
12.	Ikj-West	-	-	334.000	171.110	1.0000	0.0000	Load Bus
13.	Ayede	-	-	176.650	90.490	1.0000	0.0000	Load Bus
14.	Jos	-	-	82.230	42.129	1.0000	0.0000	Load Bus
15.	Onitsha	-	-	130.510	66.860	1.0000	0.0000	Load Bus
16.	Akamgbe	-	-	233.379	119.560	1.0000	0.0000	Load Bus
17.	Gomgbe	-	-	74.480	38.140	1.0000	0.0000	Load Bus
18.	Abuja(kata mkpe)	-	-	200.000	102.440	1.0000	0.0000	Load Bus
19.	Maiduguri	-	-	10.000	5.110	1.0000	0.0000	Load Bus
20.	Egbin TS	-	-	0.000	0.000	1.0000	0.0000	Load Bus
21.	Aladja	-	-	47.997	24.589	1.0000	0.0000	Load Bus
22.	Kano	-	-	252.450	129.330	1.0000	0.0000	Load Bus
23.	Aja	-	-	119.990	61.477	1.0000	0.0000	Load Bus
24.	Ajaokuta	-	-	63.220	32.380	1.0000	0.0000	Load Bus
25.	N.Heaven	-	-	113.050	57.910	1.0000	0.0000	Load Bus
26.	Alaoji	-	-	163.950	83.980	1.0000	0.0000	Load Bus
27.	Jebba TS	-	-	7.440	3.790	1.0000	0.0000	Load Bus
28.	B.Kebbi	-	-	69.990	35.850	1.0000	0.0000	Load Bus

29.	Kaduna	-	-	149.77	76.720	1.0000	0.0000	Load Bus
30.	ShiroroTS	-	-	73.070	37.430	1.0000	0.0000	Load Bus

Source: [7]

Base value = 100MVA
Base voltage = 330KV,

$$\text{Per Unit Value} = \frac{MVA}{BaseValue}$$

Table 6Bus Data In Per Unit

B/ No	Bus Name	Generation		Load	
		P (p.u)	Q (p.u)	P (p.u)	Q (p.u)
1.	Egbin	-	-	0,0000	0.0000
2.	Delta Ps	0.55	0.2816	-	-
3.	Okpai	2.20	1.127	-	-
4.	Sapele	0.75	0.3842	-	-
5.	Afam	4.79	2.4539	-	-
6.	Jebba	3.22	1.6496	-	-
7.	Kainji	3.23	1.6549	-	-
8.	Shiroro	2.80	1.4300	-	-
9.	Geregu	2.00	1.0244	-	-
10.	Oshogbo	-	-	1.2037	0.6165
11.	Benin	-	-	1.6056	0.8224
12.	Ikj-West	-	-	3.340	1.7111
13.	Ayede	-	-	1.7665	0.9049
14.	Jos	-	-	0.8223	0.42129
15.	Onitsha	-	-	1.3051	0.6686
16.	Akamgbe	-	-	2.33379	1.1956
17.	Gomgbe	-	-	0.7448	0.3814
18.	Abuja(katamkpe)	-	-	2.000	1.0244
19.	Maiduguri	-	-	0.1000	0.0511
20.	Egbin TS	-	-	0.000	0.000
21.	Aladja	-	-	0.47997	0.24589
22.	Kano	-	-	2.5245	1.2933
23.	Aja	-	-	1.1999	0.61477
24.	Ajaokuta	-	-	0.6322	0.3238
25.	N.Heaven	-	-	1.1305	0.5791
26.	Alaoji	-	-	1.6395	0.8398
27.	Jebba TS	-	-	0.0744	0.0379
28.	B.Kebbi	-	-	0.6999	0.3585
29.	Kaduna	-	-	1.4977	0.7672
30.	ShiroroTS	-	-	0.7307	0.3743

Source: [8]

V. Shunt Capacitor Compensation Algorithm

The flow chart in Fig. 2 shows the procedural method applied to achieve compensation of weak bus voltages. First, we obtain the base solution using Newton-Raphson's (NR) solution method. Then we check bus voltages range. After which we identify the problem buses by checking the bus voltages outside $\pm 5\%$ of the normal values (i.e. 0.95 to 1.05) per unit. We them calculate the capacitor values using the equation $C = \frac{Q_C}{\omega V^2}$ and determine compensation values using the equation $Q_C = \frac{P}{Pf_1} \times \sin(\cos^{-1}(pf_1)) - \frac{P}{Pf_2}\sin(\cos^{-1}(pf_2))$. Finally we output the result and stop. The following procedures represented in Fig. 2 are simulated using MATLAB/SIMULINK and the results are as presented in section 8..

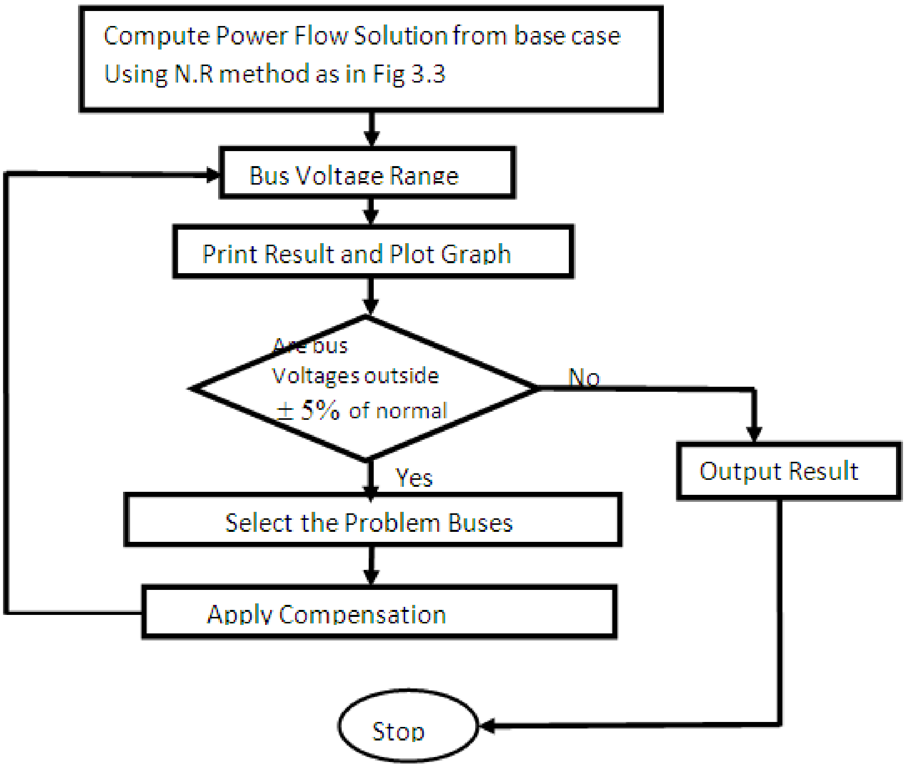

Fig. 2 Flow Chart for the Analysis of Shunt Capacitor Compensation Algorithm

The results from the N.R. iterative solution method give the bus voltages, line flows, and power losses under normal (uncompensated) conditionas shown in Tables 7 and 8 respectively. The voltages at buses 14, 17, 18, 19, 22, 29 and 30 are low and in order to ensure that they are within acceptable limits, shunt capacitive compensation were injected into the buses. Based on Power Holding Company of Nigeria (PHCN) power factor of 0.85 for transmission lines the MVAR capacities of the various capacitors required to carry out compensation of the network at the buses were determined using

$$Q_C = \frac{P}{Pf_1} \times \sin(\cos^{-1}(pf_1)) - \frac{P}{Pf_2}\sin(\cos^{-1}(pf_2))$$

Abuja Bus
Total Load =200MW

$$\frac{200}{0.85}\sin(\cos^{-1} 0.85) - \frac{200}{0.95}\sin(\cos^{-1} 0.95)$$

$$123.948 - 56.736 = 58.212 MVAr$$

Rating of Capacitor Bank =58.212MVAr.

Kano Bus
Total Load =252.45

$$\frac{252.45}{0.85}\sin(coa^{-1} 0.85) - \frac{252.45}{0.95}\sin(\cos^{-1} 0.95)$$

$$156.45 - 82.976 = 73.45 MVAr$$

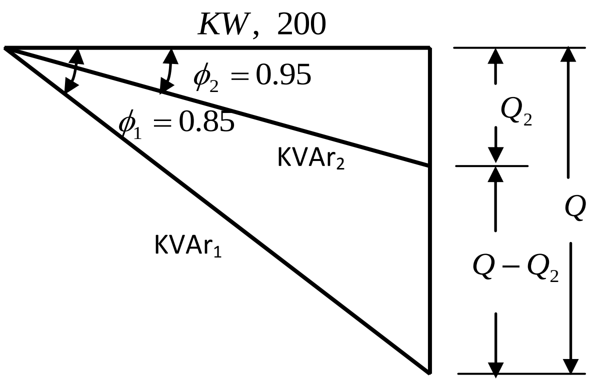

Fig.3. Determination of Capacity of Shunt Capacitors

Rating of Capacitor Bank = 73.45MVAr. etc.
The following capacitor sizes were selected for the various lines. Jos bus (30MVAr), Gombe bus (30MVAr), Abuja bus (60MVAr), Kano bus (40MVAr), Kaduna bus (40MVAr), Makurdi bus (30MVAr). These were injected into the network and the results were as shown in Tables 11 and Fig. 6.

VI. Production And Absorption Of Reactive Power

Synchronous generators can absorb or generate reactive power depending on the excitation pattern. If the system is overexcited, they supply reactive power and as well absorb reactive power when under excited. The capacity to continuously absorb or supply reactive power is limited by the field current and armature current. Synchronous generators are normally equipped with automatic voltage regulators which continually adjust the excitation so as to control the armature voltage [9].

- Loads normally absorb reactive power. Both active power and reactive power of the composite loads vary as a function of voltage magnitudes. Loads at low-lagging power factors cause excessive voltage drops in the transmission network and are uneconomical to supply.
- Transformers always absorb reactive power regardless of their loading; at no load, the shunt magnetizing reactance effects predominate; and at full load, the series leakage inductance effects predominate[10,11].
- Reactive power compensation in transmission systems improves the stability of the ac system by increasing the maximum active power that can betransmitted. It also control steady-state and temporal over voltages. This results in an improved functionality of the power system.

VII. Effect Of Reactive Power Flow On Line Voltage Drop

The voltage variation is due to imbalance in the generation and consumption of reactive power in the system. If the generated reactive power is more than the consumed power, the voltage levels go up and vice versa. However, if the two are equal, then the voltage profile becomes flat and it happens only when the load is equal to the natural load. Unfortunately the reactive power in the system keeps varying because of different types of load and if the reactive power generation is simultaneously controlled, a more or less flat voltage profile could be maintained. Too wide variation of voltage causes excessive heating of distribution transformers thereby reducing the transformer capacity [9, 12].

VIII. Results

The results obtained using the source (m-file codes) are recorded in Tables 7 to 11.The buses with weak values are identified.The plots of the tables are as shown in Figs. 4 to 8.

Table 7: Per Unit Bus Voltages for Compensated and Uncompensated

B/N	Bus Name	With Compensation Volts (p.u)	Without Compensation Volts (p.u)
1	Egbin-GS (Slack)	1.0000	1.0000
2	Delta-PS	1.0000	1.0000
3	Okpai-PS	1.0000	1.0000
4	SAP /PS	1.0000	1.0000
5	AFAM-GS	1.0000	1.0000
6	Jebba-GS	1.0000	1,0000
7	KAINJI-GS	1.0000	1,0000
8	Shiroro-PS	1.0000	1,0000
9	Geregu(PS)	1.0000	1,0000
10	Oshogbo	1.0035	0.9919
11	Benin	0.9998	0.9957
12	Ikeja-West	0.9969	0.993
13	Ayede	0.9967	0.9792
14	**Jos**	**0.9823**	**0.8171**
15	Onitsha	0.9793	0.9748
16	Akangba	0.9931	0.9859
17	**Gombe**	**1.0242**	**0.8144**
18	**Abuja (Katampe)**	**0.9667**	**0.9402**
19	**Maiduguri**	**1.0455**	**0.8268**
20	Egbin TS	0.9469	0.9816
21	Aladja	1.0006	0.9994
22	**Kano**	**0.9338**	**0.7609**
23	Aja	0.9692	0.9838
24	Ajaokuta	0.9999	0.9997
25	N-Heaven	0.9721	0.9582
26	Alaoji	0.9598	0.9564
27	Jebba-TS	0.9993	0.9988
28	B.Kebbi	1.0075	0.9873
29	**Kaduna**	**0.9654**	**0.8738**
30	**Makurdi**	**0.9943**	**0.8247**

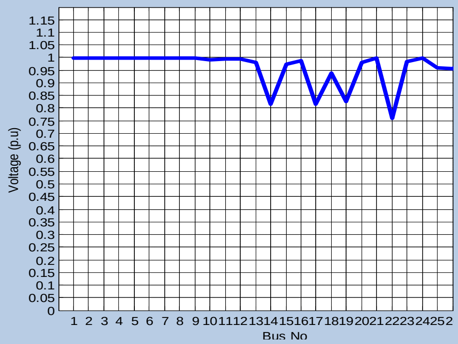

Fig. 4 Plot of Bus Voltages under normal (Uncompensated)

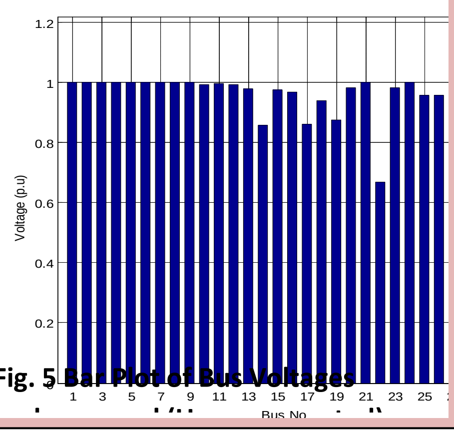

Fig. 5 Bar Plot of Bus Voltages

Table 7 gives the per unit bus voltages of Newton-Raphson (N-R) for compensated and uncompensated

Table8: Bus Angle, Shunt (Y-shunt) and Injection Powers (Sg) (Uncompensated)

B/N	BUS NAME	Angle(rad)	Yshunt	Sg(p.u) Real	Sg(p.u) Imaginary
1	Egbin-GS (Slack)	0	0.5140	0.0000	0.0000
2	Delta-PS	0.02565	0.4780	0.5500	0.2816
3	Okpai-PS	0.1437	0.1040	2.2000	1.1270
4	SAP /PS	0.0263	0.44700	0.7500	0.3842
5	AFAM-GS	0.3043	0.1040	4.7900	2.4539
6	Jebba-GS	-0.1049	0.0200	3.2200	1.6496
7	KAINJI-GS	-0.0484	1.4860	3.2300	1.6547
8	Shiroro-PS	-0.5057	1.8150	2.8000	1.4344
9	Geregu(PS)	0.0992	0.0332	2.0000	1.0244
10	Oshogbo	-0.1103	2.0770	1.2037	-0.6165
11	Benin	0.0198	2.8750	1.6056	-0.8224
12	Ikeja-West	-0.0961	1.7000	3.3400	-1.7111
13	Ayede	-0.1373	0.9580	1.7665	-0.9049
14	Jos	-0.8691	1.3000	-0.8223	-0.4212
15	Onitsha	0.135	1.5140	1.3051	-0.6686
16	Akangba	-0.1076	0.2570	2.3337	-1.1956
17	Gombe	-0.9738	1.0500	-0.74480	-0.3814
18	Abuja (Katampe)	-5964	0.2000	2.0000	-1.0244
19	Maiduguri	-0.9903	0.6000	0.1000	-0.0511
20	Egbin TS	-0.1038	0.5140	-2.3500	-0.0200
21	Aladja	0.0214	0.4780	0.4800	-0.2459
22	Kano	-0.9144	0.4000	2.5245	-1.2933
23	Aja	-0.0615	0.2570	1.1999	-0.6147
24	Ajaokuta	0.0972	0.7650	0.6322	-0.3238
25	N-Heaven	0.101	0.3650	-1.1305	-0.5791
26	Alaoji	0.2707	0.6280	1.6395	-0.8398
27	Jebba-TS	-0.1111	1.8650	-0.0744	-0.0379
28	B.Kebbi	-0.1149	0.7000	0.6999	-0.3685
29	Kaduna	-0.694	0.9000	1.4977	-0.7672
30	Makurdi	-0.8779	0.4000	-0.0744	-0.0379

Table 9: Line Current, Line Flows, and Line Losses (Uncompensated)

B/Sequence		Line Current (p.u)		Line Flows (p.u)		Line Losses (p.u)	
From	To	Real	Imaginary	Real	Imaginary	Real	Imaginary
16	12	0.1842	-1.4405	0.1783	-1.3941	-0.0046	0.036 3
12	1	0.0514	-0.4023	0.05109	-0.3994	0.051 1	-0.399 5
12	11	0.0047	-0.036 4	0.004 7	-0.0361	-0.00001	0.0001
12	13	-0.0386	0.3280	-0.038 4	0.3257	-0.0005	0.0045
13	10	0.0423	-0.3605	0.041 5	-0.3530	-0.0005	0.004 6
10	11	0.0059	-0.0512	0.0059	-0.0507	-0.00002	0.0002
10	27	0.0166	-0.1417	0.0165	-0.140 6	-0.0001	0.0009
12	6	1.5244	-1.1179	1.5137	-1.110 1	-0.011	0.0078
27	8	0.0016	-0.0177	0.001 7	-0.0177	-0.0000	0.00002
27	7	0.0059	-0.050 4	0.0059	-0.0503	-0.0000	0.00006
7	28	-0.0156	0.1328	-0.0156	0.1328	-0.000 2	0.001 7
8	29	-0.5455	4.6854	-0.5456	4.685 4	-0.0756	0.6497
29	22	-0.3214	2.7405	-0.2769	2.360 5	-0.0624	0.532 2
14	17	0.0054	-0.0462	0.0046	-0.039 6	-0.00002	0.000 2
11	24	0.0085	-0.0678	0.0084	-0.067 6	-0.00003	0.000 3
11	4	0.0380	-0.2938	0.0378	-0.2926	-0.000 2	0.0012
11	15	-0.0587	0.498 4	-0.0584	0.496 3	-0.0012	0.010 5
15	25	-0.0579	0.564 1	-0.0565	0.5498	-0.0009	0.009 4
15	26	-0.0508	0.4346	-0.049 6	0.4237	-0.0009	0.0080
26	5	3.0208	-2.3495	2.8890	-2.2470	-0.1318	0.1025
4	21	-0.0039	0.0327	-0.00396	0.0327	-0.0000	0.0000 2
2	21	-0.0039	0.0327	-0.0039	0.0327	-0.000 0	0.00002
1	23	-0.1185	0.9261	-0.1184	0.9261	-0.0019	0.0149
29	14	-0.0094	0.0807	-0.0081	0.0695	-0.0000	0.0004
14	30	0.0137	-0.1170	0.0117	-0.1002	-0.0001	0.0009
10	12	0.0030	-0.0256	0.0029	-0.0254	-0.0000	0.0000
11	2	0.026 1	-0.217 3	0.0259	-0.2145	-0.0001	0.0009
15	3	1.742 7	-1.35 6	1.6988	-1.3213	-0.0439	0.0341
8	18	-0.1486	0.6769	-0.1486	1.3112	-0.00890	0.0784
9	24	-0.056 7	0.2838	-0.0566	0.283 3	-0.0000 2	0.000 1
19	17	-0.0408	0.226 5	-0.0357	0.1432	-0.000 6	0.002 3

20	23	0.0158	-0.1236	0.0155	-0.121 4	-0.0000	0.000 3
27	26	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Fig. 4 and 5 represent the Plot of Bus Voltages under normal uncompensated conditions. As can be seen from the plot the voltages that are outside the renge are clearly seen from the plot.

Table10: Line Current, Line Flows, and Line Losses (Compensated)

B/Sequence		Line Current (p.u)		Line Flows (p.u)		Line Losses (p.u)	
From	To	Real I(p.u)	Imagi I(p.u)	Real P(p.u)	Imag P(p.u)	Real L(p.u)	Imag L(p.u)
16	12	0.0859	-0.7304	0.0853	-0.7254	-0.0003	0.0028
12	1	0.0226	-0.1768	0.0225	-0.1762	0.0225	-0.1762
12	11	0.0047	-0.036	0.0047	-0.0359	0.000	1E-04
12	13	-0.0006	0.0048	-0.0006	0.0048	0.0000	0.0000
13	10	0.0224	-0.1908	0.0223	-0.1901	-0.0002	0.0013
10	11	-0.0056	0.0477	-0.0056	0.0479	0.0000	0.0002
10	27	-0.01	0.085	-0.010	0.0853	0.0000	0.0003
12	6	0.6698	-0.4912	0.6677	-0.4897	-0.0021	0.0015
27	8	0.0009	-0.0093	0.0009	-0.0093	0.0000	0.0000
27	7	0.0031	-0.0263	0.0031	-0.0263	0.0000	0.0000
7	28	0.0093	-0.079	0.0093	-0.079	-1E-04	0.0006
8	29	-0.1362	1.1695	-0.1362	1.1695	-0.0047	0.0405
29	22	-0.0522	0.4453	-0.0504	0.4299	-0.0016	0.014
14	17	0.0599	-0.5103	0.0588	-0.5013	-0.0025	0.0214
11	24	0.0004	-0.0031	0.0004	-0.0031	0.0000	0.0000
11	4	0.0022	-0.0167	0.0022	-0.0167	0.0000	0.0000
11	15	-0.0571	0.4845	-0.0571	0.4844	-0.0012	0.0099
15	25	-0.0252	0.2455	-0.0247	0.2405	-0.0002	0.0018
15	26	-0.0539	0.4605	-0.0527	0.451	-0.0011	0.009
26	5	2.785	-2.1661	2.673	-2.079	-0.112	0.0871
4	21	0.0037	-0.0305	0.0037	-0.0305	0.0000	0.0000
2	21	0.0037	-0.0305	0.0037	-0.0305	0.0000	0.0000
1	23	-0.2254	1.7619	-0.2254	1.7619	-0.0069	0.0543
29	14	0.0326	-0.2792	0.0315	-0.2695	-0.0006	0.0047
14	30	0.0198	-0.1691	0.0195	-0.1661	-0.0002	0.0020
10	12	-0.0183	0.1552	-0.0183	0.1557	-1E-04	0.0010
11	2	0.0015	-0.0123	0.0015	-0.0123	0.0000	0.0000
15	3	1.431	-1.113	1.4014	-1.09	-0.0296	0.023
8	18	-0.0827	0.7296	-0.0827	0.7296	-0.0027	0.0243
9	24	-0.0117	0.0586	-0.0117	0.0586	0.0000	0.0000
19	17	-0.0623	0.2498	-0.0651	0.2612	-0.0013	0.0053
20	23	0.1632	-1.2761	0.1546	-1.2083	-0.0036	0.0285
27	26	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Table 11: Bus Voltages (Compensated in p.u)

B/N	Bus Name	Volts (p.u)	Angle(rad)
1	Egbin-GS (Slack)	1.0000	0.0000
2	Delta-PS	1.0000	0.0284
3	Okpai-PS	1.0000	0.1510
4	SAP /PS	1.0000	0.0291
5	AFAM-GS	1.0000	0.3091
6	Jebba-GS	1.0000	-0.0967
7	KAINJI-GS	1.0000	-0.0401
8	Shiroro-PS	1.0000	-0.4886
9	Geregu(PS)	1.0000	0.1016
10	Oshogbo	1.0035	-0.1067
11	Benin	0.9998	0.0221
12	**Ikeja-West**	**0.9969**	**-0.0936**
13	**Ayede**	**0.9967**	**-0.1345**
14	**Jos**	**0.9823**	**-0.8059**
15	**Onitsha**	**0.9793**	**0.1365**
16	**Akangba**	**0.9931**	**-0.1054**
17	**Gombe**	**1.0242**	**-0.8803**
18	**Abuja (Katampe)**	**0.9667**	**-0.5797**
19	**Maiduguri**	**1.0455**	**-0.8935**
20	**Egbin TS**	**0.9469**	**-0.1026**
21	**Aladja**	**1.0006**	**0.024**
22	**Kano**	**0.9338**	**-0.8361**
23	**Aja**	**0.9692**	**-0.0606**
24	**Ajaokuta**	**0.9999**	**0.0996**
25	**N-Heaven**	**0.9721**	**0.1022**
26	**Alaoji**	**0.9598**	**0.2712**
27	**Jebba-TS**	**0.9993**	**-0.1029**
28	**B.Kebbi**	**1.0075**	**-0.1077**
29	**Kaduna**	**0.9654**	**-0.667**

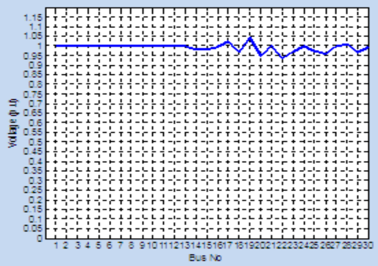

Fig. 6.Graph of Bus Voltages with Compensation

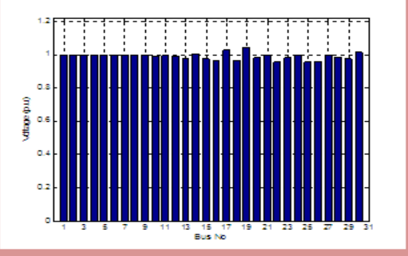

Fig. 7. Bar Plot of Bus Voltages with Compensation

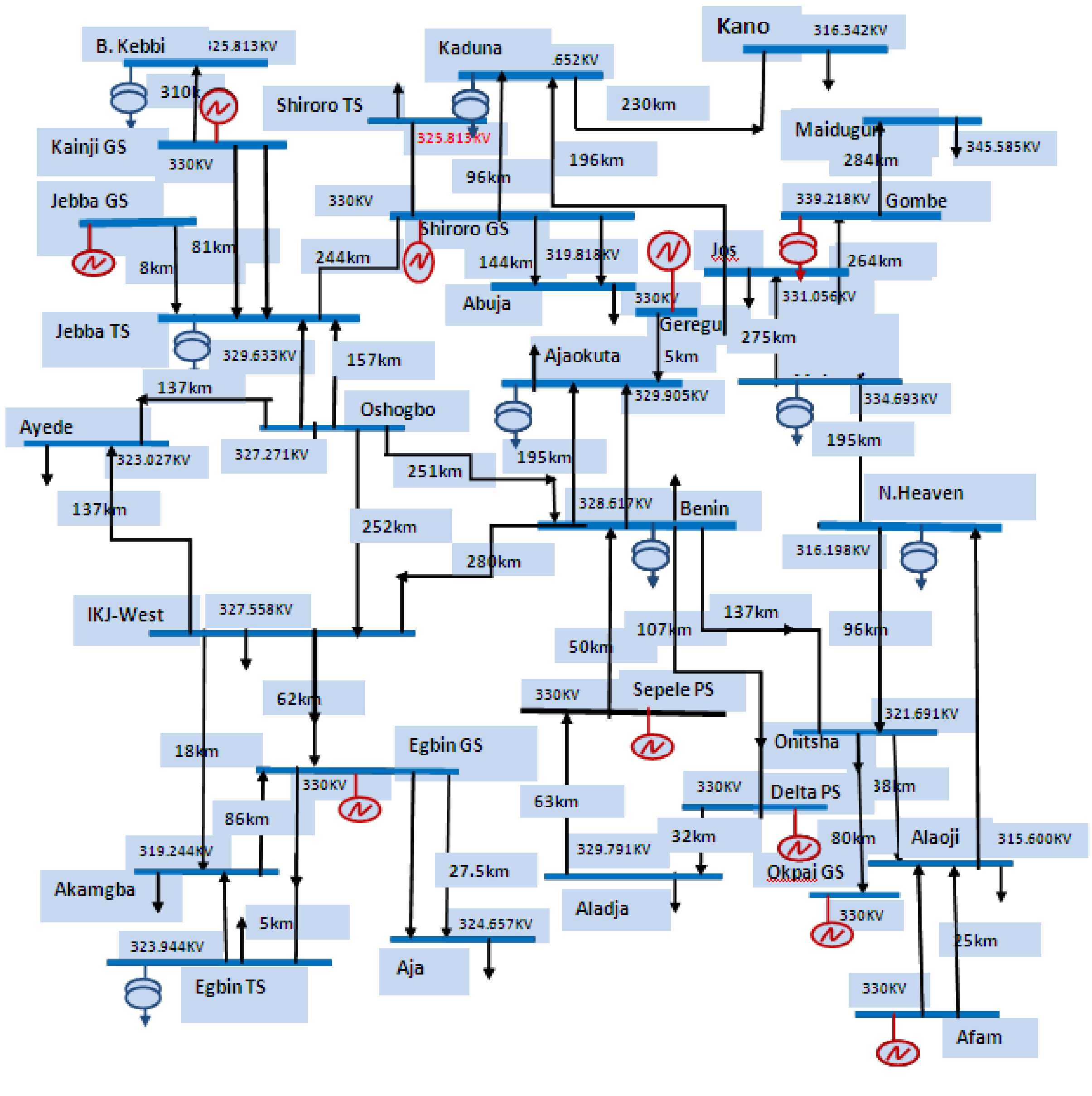

Fig. 8.One Line Diagram of the PHCN 330KV 30 Bus Interconnected Network with Compensated Voltage Values.

IX. Discussion

The Nigerian 330KV, 30 bus system using N-R power flow algorithm with MATLAB/SIMULINK softwarewas analyzedusing the data collected from Power Holding Company of Nigeria (PHCN). The results obtained showed that the weak buses with values outside the statutory limit of 0.95pu or 313.5KV and 1.05pu or 346.5KV were buses 14 (Jos) with value 0.8171pu , 17 (Gombe) 0.8144p.u, 18 (Abuja) 0.9402p.u,, 19 (Maiduguri) 0.8268p.u, 22 (Kano) 0.7609p.u, 29 (Kaduna) 0.8738p.u, and bus 30 (Makurdi) 0.8247p.u under normal uncompensated condition as shown in Table 7with the corresponding angles at buses14(0.869rad), 17(-0.973rad), 18(-0.596rad), 19(-0.990rad), 22(-0.914rad), 29(-0.694rad), and bus 30(-0.877rad). We could see from the graph that bus (22) which is Kano has the highest voltage dip because of its distance from the grid, followed by Jos, Gombe, Kaduna, Makurdi, Maiduguri and Abuja respectively. These buses with low voltage values were examined and shunt capacitive compensation was carried out and the output results were as recorded in Table 7 with the corresponding angles at buses 14(0.805rad), 17(-0.880rad), 18(-o.579rad), 19(-0.893rad), 22(-0.836rad), 29(-0.667rad), and bus 30(-0.812rad) as shown in Table 11. The graphs of the corresponding voltage values versus bus number were plotted as shown in Figs.6 and 7. On gradual application of 5percent compensation intervals, it was observed that at 45 percent compensation most of the problem buses came up to a tolerable range except bus(22), which is Kano and it came up to appreciable value at sixty percent compensation as shown in Tables 11 and Fig 6 respectively. With 45 percent capacitive shunt compensation on these buses, bus 14 (Jos) became 0.9823.u, bus 17 (Gombe) 1.0242p.u, bus 18(Abuja) 0.9667pu, bus 19 (Maiduguri) 1.0455p.u, 29 (Kaduna) 0.9654 and 30 (Makurdi) 0.9943. Kano which is heavily loaded was provided with additional line between Jos and Kano, and this made compensation effect very fast. Bus 22 (Kano) at 60 percent compensation yielded an increase from 0.7609p.u to 0.947 p.u.

The analysis from the compensated results shows that a reasonable and appreciable values better than when uncompensated with improved network performance was recorded as shown in Table 7. The graphs of the corresponding compensated voltage values versus bus number were plotted as shown in Figs.6 and 7. From the values recorded in Table 11, it could be seen that the values of the angles are improved to the acceptable values. System efficiency improved from 65 percent (uncompensated) to 85 percent after compensation. The losses in the system are minimal as can be seen through Table 10.

It is also seen from the computer results that the use or incorporation of system compensation will lead to many benefits like increasing transmission lines loadability which enable electrical company to transmit more power with the existing transmission lines. And also to absorbs more customers without increasing the number of generators.it was also noticed that all these buses are in the Northern part of the country and some are still far from the generating stations.

X. Conclusion

The Nigerian 330KV transmission system associated with various challengeslike instability of the system as a result of voltage profile violation, transmission line inefficiency, problem of long transmission lines, network being stretched beyond thermal limit, and poor power quality that causes constant power failure in Nigeria power system were discussed.Solution methods were examined and Newton-Raphson's solution method because of its sparsity, fast convergence and simplicity attributes compared to other solution methods was chosen. Various compensation techniques were reviewed. Shunt and series reactive compensation using capacitors has been widely recognized as powerful methods to combat the problems of voltage drops (reactive power control), power losses, and voltage flicker in power system networks. Though each compensating technique has its area and limit of application, but shunt capacitor compensation method was used because of its outstanding performance in long transmission lines and its control of reactive power flow. Though they are expensive but they control voltage directly and also control temporary over voltage rapidly.

Finally, more Substations and additional lines should be introduced into the network to assist in the strengthening and reduction of long lines to improve the voltage profile of the network, especially Kano, Kaduna and Maiduguri lines. Also planned and routine maintenance should be carried out on the network to reduce the incident of collapsed spans. Importation and installation of high quality power equipment like transformers, breakers & control panels.

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