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DETERMINATION OF BUS VOLTAGES, POWER LOSSES AND LOAD FLOW IN THE NORHTERN NIGERIA 330kV TRANSMISSION SUB-GRID

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ABSTRACT

In this paper an attempt has been made to investigate power flow in the northern Nigeria 330kV transmission sub – grid using PowerWorld software. The 13 – bus sub – grid was developed on base values of 100MVA and 330kV (transmission line) using data obtained from the National Control Center, Osogbo, Nigeria. The data is valid through 31st December, 2010. The power flow was run using Gauss – Siedel power flow algorithm and low voltage violations were found at buses 1, 7, 8, 9, 10, and 13. To minimize these voltage violations, shunt capacitor compensators were placed at affected buses, resulting in a network with a minimum bus voltage of 0.95 p.u.. The voltage control also resulted in reduced reactive MVar demand on two of the three generators, with the slack bus experiencing a decrease of 60.27 MVar. The results also indicated that incorporation of compensators yielded a reduction in 8.76 MW and 96.51 MVar line power losses, justifying the study.

1 NIGERIAN ELECTRIC POWER TRANSMISSION SYSTEM

The Nigerian electric power transmission network, operated by the Transmission Company of Nigeria (TCN), operates at a high pressure of 330kV while its lower transmission pressure is 132kV. The grid is an integrated network consisting of sixteen generating stations and twenty – four 330kV transmission sub-stations; two of the generating stations (Trans Amadi G.S. and Omoku G.S.) are run on island operation. Only three generating stations (Jebba, Kainji and Shiroro Hydro power stations) and eleven transmitting stations were sited in the northern part of the country as at data collection time. Three of these transmitting stations (Damaturu T.S., Maiduguri T.S., and Yola T.S.) had no record of operation as at data collection time [3].

Voltage instability in the Nigerian 330 kV transmission grid is very high due to low generation, radial and fragile nature of the transmission lines and poor system protection [4], [6].

2 LOAD FLOW ANALYSIS

The planning, design and operation of power systems require load flow computations to analyze the steady – state performance of the power system under various operating conditions and to study the effects of changes in equipment configuration. These load flow studies can be performed using computer programs designed specifically for this purpose [5].

Essentially, there are four bus types in a power transmission network. These are generator buses, load buses, swing buses, and disconnected buses.

1. **Generator Bus/Voltage Controlled Bus (P,V bus)** – This is a bus that has a generator connected to it. The generated real power P and voltage V are usually specified while the reactive power demand and voltage angle are to be computed. The voltage is kept constant by adjusting the field current of the synchronous generator exciter connected to it. The voltage controlled bus can be grouped with the generator bus, but it has voltage control capabilities and uses a tap – adjustable transformer and/or a static VAr compensator instead of generator.
2. **Load Bus (P, Q bus)** – A load bus is any bus that does not have a generator connected to it. It is not compulsory for a load bus to have a load; it may simply be an interconnection for two or more lines. In a load bus the real and reactive powers are specified from which the voltage and voltage angle are to be computed.
3. **Slack Bus (or Swing Bus or Reference bus)** – The slack bus is a special type of generator bus that is needed by the solution process. The swing generator adjusts its scheduled power to supply the system MW and MVAr demand and losses. There is normally only one swing bus. Its real and reactive powers are not specified, but its voltage magnitude (normally set to 1.0 p.u.) and voltage angle (normally set to 0^o) are specified. The swing bus serves as a reference bus and is large enough to supply the required power, keeping

the system balanced in terms of power flows [1].

4. **Disconnected Bus** – A disconnected bus is a bus that is temporarily de – energized. It is usually not included in the load flow solution and must not have in – service lines connected to it. Its data is retained so that it could be re – energized later in the studies if necessary [4].

A system comprises of several buses interconnected through transmission lines. Power is injected into a bus from generators, while the loads are tapped from it. Of course, there may be buses with only generators, and there may be others with only loads. Some buses may have both generators and loads while some others may have static capacitors (or synchronous condensers) for reactive power compensation or voltage control. The surplus power at some of the buses is transported through transmission lines to the buses deficient in power [2].

Fig. 1 shows a one line diagram of a simple 4-bus system with generators and loads at each bus. To arrive at the network model of a power system, a short line may be represented by a series impedance, long line by a nominal π model while very long line by equivalent π. It is convenient to consider loads as negative generators and lump together the generator and load powers at the buses.

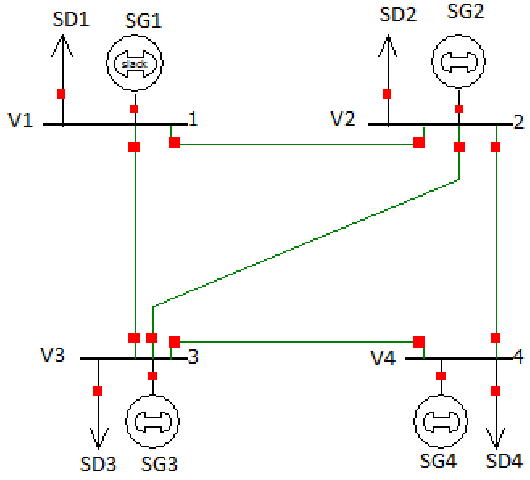

Fig. 1. One line diagram of a 4-bus system

The net complex power S_{Gi} denotes the 3-phase complex generator power flowing into the ith bus and S_{Di} denotes the 3-phase complex power demand at the ith bus. Then S_{Gi} and S_{Di} may be represented as in (1) and (2).

$$S_{Gi} = P_{Gi} + jQ_{Gi} \qquad (1)$$

$$S_{Di} = P_{Di} + jQ_{Di} \qquad (2)$$

Where P and Q are real and reactive power values respectively.

The net complex power S_i injected into the ith bus is given by (3).

$$\begin{aligned} S_i &= P_i + jQ_i \\ &= (P_{Gi} - P_{Di}) + j(Q_{Gi} - Q_{Di}) \qquad (3) \end{aligned}$$

For a system of n buses, (3) can be written as in(4).

$$\begin{aligned} S_i &= P_i + jQ_i \\ &= V_i I_i^* \end{aligned} \qquad (4)$$

$$i = 1,2,3,\ldots n$$

Where V_i is the $n-bus$ voltage matrix, and I_i^* is the complex conjugate of source current I_i injected into the ith bus.

The general equation for $n-bus$ network based on Kirchhoff's current law in admittance form is given in (5).

$$I = Y_{bus}V \qquad (5)$$

Where Y_{bus} is the bus admittance matrix.

Because it is more convenient to handle load flow problems by using I_i rather than I_i^*, the complex conjugate of (4) was taken to obtain (6).

$$\begin{aligned} S^* &= P_i - jQ_i \\ &= V_i^* I_i \end{aligned} \qquad (6)$$

From (6), the current which flows through the ith bus is given in (7).

$$I_i = \frac{P_i - jQ_i}{V_i^*} \qquad (7)$$

Using the Gauss – Siedel method of load flow, it can be shown that for an ith bus its voltage V_i, real power P_i and reactive power Q_i are related by (8).

$$V_i = \frac{1}{Y_{ii}}\left[\frac{P_i - jQ_i}{V_i^*} - \sum_{\substack{k=1 \\ k\neq i}}^{n} Y_{ik}V_k\right] \qquad (8)$$

Where Y_{ii} is the driving point admittance matrix of the ith bus [2].

The solutions of this load flow equation for the n buses were achieved using Gauss – Siedel numerical iterative method. After computing bus voltages (magnitudes and phase angles) for all the buses, injected powers S_i using (6) and line flows were computed using the nodal voltages obtained from (8).

3 METHODOLOGY, ANALYSIS AND RESULTS

The data employed in this analysis was obtained from the National Control Center (NCC) Osogbo, Osun State, Nigeria. The per unit values of the line impedances were computed on the following base values:

$$S_{base} = 100MVA, V_{base} = 330kV$$

Using PowerWorld program, the northern Nigeria 330kV network was developed and the load flow was run. The network showing connected devices is depicted in fig. 2. It depicts a solution with Newton – Raphson power flow algorithm. Tables 1 and 2 show generator records and bus records after load flow, respectively. The results in table 2 show voltage violation in the p.u. values of buses 1, 7, 8, 9, 10, and 13. The normal range of bus voltages is assumed to be 0.95 - 1.05 p.u. [7].

Table 1a: Generator records after load flow (before compensation)

Bus No.	Bus Name	Status	Gen. MW	Gen. MVar	AGC	AVR	Min. MW	Max. MW	Min. MVar	Max. MVar
2 (slack bus)	Kainji	Closed	374.42	136	YES	YES	0	760	-9999	9900
5	Shiroro	Closed	600	1726.92	YES	YES	0	600	-9900	9900
11	Jebba	Closed	578.4	144.48	YES	YES	0	578.4	-9900	9900

Table 1b: Generator records after load flow (after compensation)

Bus No.	Bus Name	Status	Gen. MW	Gen. MVar	AGC	AVR	Min. MW	Max. MW	Min. MVar	Max. MVar
2 (slack bus)	Kainji	Closed	474.7	75.73	YES	YES	0	760	-9999	9900
5	Shiroro	Closed	600	1369.11	YES	YES	0	600	-9900	9900
11	Jebba	Closed	578.4	157.45	YES	YES	0	578.4	-9900	9900

Table 2a: Bus records after load flow (before compensation)

Bus No.	Name	Nom kV	P.U. Volt	Volt (kV)	Angle (Deg)	Load MW	Load MVar	Gen MW	Gen MVar
1	Birnin-Kebbi T.S.	330	0.86508	285.476	-8.89	153	94.82		
2	Kainji G.S.	16	1	16	0			374.42	136
3	Kainji S.Y.	330	0.99999	329.995	0				
4	Jebba T.S.	330	0.99716	329.061	-1.53	51	31.61		
5	Shiroro G.S.	16	1	16	-17.17			600	1726.92
6	Shiroro S.Y	330	0.96554	318.627	-17.88	280.5	173.84		
7	Katampe T.S.	330	0.91911	303.306	-21.22	255	158.04		
8	Kaduna T.S.	330	0.77669	256.309	-25.02	306	189.64		
9	Jos T.S.	330	0.47355	156.272	-39.84	97.32	60.31		
10	Kano T.S.	330	0.515	169.951	-45.25	213.52	132.32		
11	Jebba G.S.	16	1	16	-1.08			578.4	144.48
12	Jebba S.Y.	330	0.99971	329.906	-1.14				
13	Gombe T.S.	330	0.25006	82.521	-66.93	72.21	44.75		

Table 2b: Bus records after load flow (after compensation)

Bus No.	Name	Nom kV	P.U. Volt	Volt (kV)	Angle (Deg)	Load MW	Load MVar	Gen MW	Gen MVar	Switched Shunts MVar
1	Birnin-Kebbi T.S.	330	0.95	313.5	-8.69	153	94.82			45.12
2	Kainji G.S.	16	1	16	0			474.7	75.73	
3	Kainji S.Y.	330	0.99999	329.997	0					
4	Jebba T.S.	330	0.99697	329.001	-2.26	51	31.61			
5	Shiroro G.S.	16	1	16	-20.1			600	1369.11	
6	Shiroro S.Y	330	0.97269	320.989	-20.8	280.5	173.84			
7	Katampe T.S.	330	0.95	313.5	-24.16	255	158.04			90.25
8	Kaduna T.S.	330	0.95	313.5	-28.78	306	189.64			90.25
9	Jos T.S.	330	0.95	313.5	-45.97	127.5	79.02			135.37
10	Kano T.S.	330	0.95	313.5	-45.99	255	158.03			180.5

11	Jebba G.S.	16	1	16	-1.8			578.4	157.45	
12	Jebba S.Y.	330	0.99969	329.897	-1.87					
13	Gombe T.S.	330	0.95	313.5	-75.59	255	158.04			225.62

Table 3: Line losses without and with voltage control

		Without Compensation		With Compensation	
From Name	**To Name**	**MW Loss**	**MVar Loss**	**MW Loss**	**MVar Loss**
Kainji S.Y.	Birnin-Kebbi T.S.	4.81	40.79	3.47	29.46
Kainji G.S.	Kainji S.Y.	0	0.02	0	0.02
Kainji S.Y.	Jebba T.S.	0.34	2.89	0.73	6.24
Kainji S.Y.	Jebba T.S.	0.34	2.89	0.73	6.24
Shiroro S.Y	Jebba T.S.	12.35	104.84	15.87	134.68
Shiroro S.Y	Jebba T.S.	12.36	104.84	15.87	134.68
Jebba T.S.	Jebba S.Y.	0.25	2.16	0.26	2.18
Jebba S.Y.	Jebba T.S.	0.26	2.16	0.26	2.18
Shiroro G.S.	Shiroro S.Y	0	66.84	0	44.69
Shiroro S.Y	Katampe T.S.	1.37	11.66	1	8.48
Shiroro S.Y	Katampe T.S.	1.37	11.66	1	8.48
Shiroro S.Y	Kaduna T.S.	18.83	159.83	14.27	121.1
Shiroro S.Y	Kaduna T.S.	18.84	159.83	14.28	121.1
Kaduna T.S.	Jos T.S.	22.58	191.69	22.46	190.64
Kaduna T.S.	Kano T.S.	19.6	166.3	11.31	96.01
Jos T.S.	Gombe T.S.	10.95	92.97	13.98	118.67
Jebba G.S.	Jebba S.Y.	0	0.7	0	0.71
	Savings			**8.76 MW**	**96.51MVar**

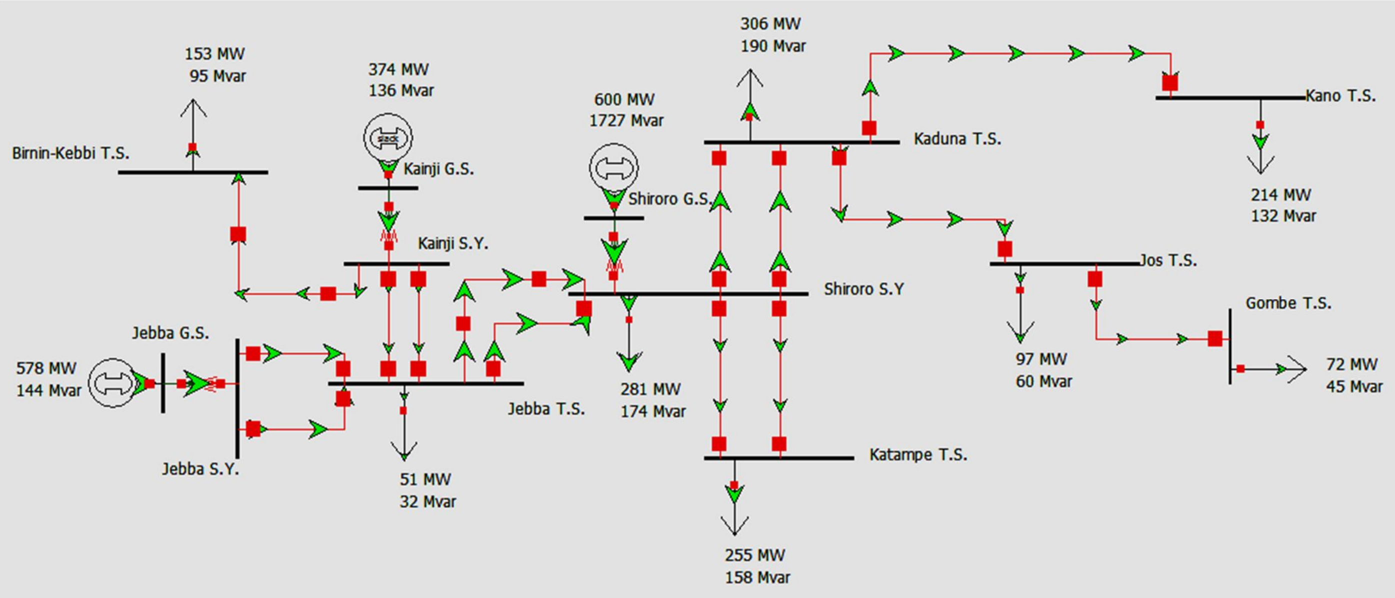

Fig. 2. Northern Nigeria 330kV sub – grid showing load flow

To compensate for the voltage violations, capacitor banks were placed as shown in fig. 3.

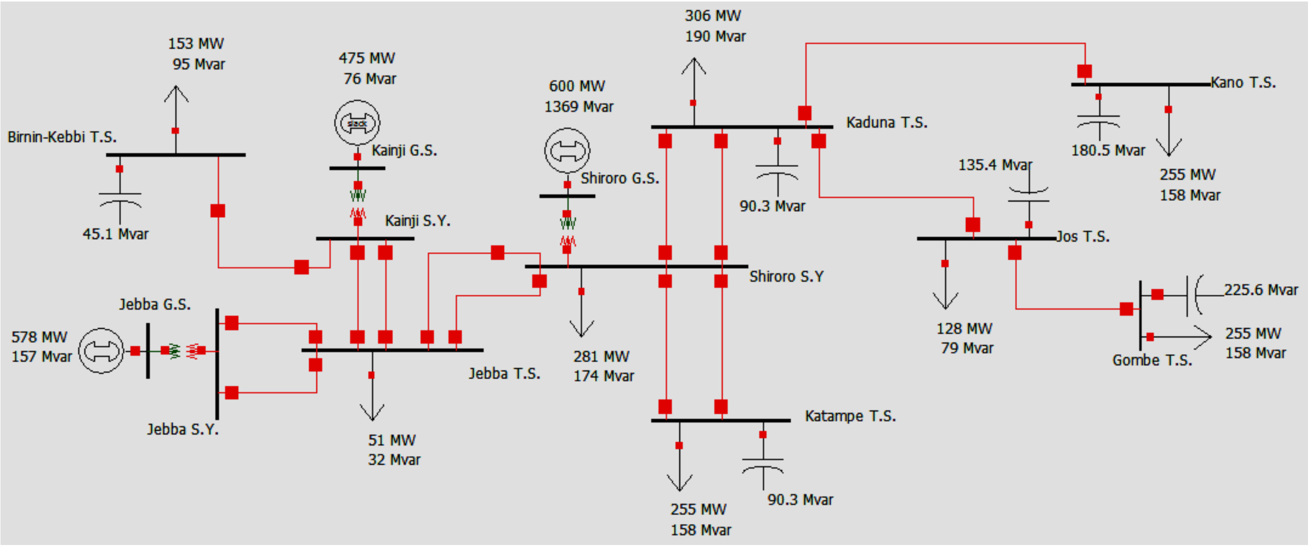

Fig. 3. Northern Nigeria 330kV sub – grid showing switched shunts (compensators)

4 CONCLUSION AND RECOMMENDATION

Although this study does not represent the entire Nigeria integrated 330kV grid, it surely provides mimicry of the entire network. The very low bus voltages and poor power magnitude obtained from this study without voltage compensation at Gombe T.S., Kano T.S., Jos T.S. Kaduna T.S., and Katampe T.S. revealed the reality of the perpetual poor power supply at the North – Western part of Nigeria. In order to augment this disturbing situation, it is recommended that relevant stakeholders ensure construction of power generating station(s) at this region of the country and ensure construction of 330kV transmission lines connecting Maiduguri, Damaturu, and Yola.

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