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Load Flow Analysis of the Nigerian 330KV Grid Network: A Case Study of Eleven Bus Power Network

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Abstract The Nigerian 330kV grid system has post numerous challenges notable among them is voltage collapse. The load flow analysis determines the steady state solution of the network. This project aims at carrying out the load flow analysis of eleven bus 330kV network. Newton Raphson load flow solution was carried out using Neplan 5.2 power software. The results revealed that out of the eleven buses, 4 buses did not satisfy the statutory voltage levels of 95% to 105%. The buses that were outside tolerance level include Jebba TS (94.89%), Jebba G.S (94.89%), Kaniji G.S (94.64%) and B/Kebbi TS (92.19%). The voltage stability analysis also indicates the critical bus of the network. Eigen values, V-Q sensitivity and participation factor shows B/ Kebbi as the weakest bus of the network. Thus, the specific objective of the work has been achieved. Therefore, it is recommended that a source of reactive power be installed on the network in order to attain stability in voltage level across the buses.

Keywords Load Flow, Voltage Stability, Participation Factor, V-Q Sensitivity, Eigenvalues, Newton-Raphson

Introduction

Load flow analysis is one of the most important analysis in power system, hence the analysis opens room for other forms of analysis. It can also be stated as the fundamental analysis in determining the state of the network. Thus, the analysis determines the steady state stability of the system. According to [1], the main objective of load flow analysis is to determine the complex bus voltages, real and reactive power injected into the transmission system as well as real and reactive power at the slack bus with other parameters being specified. Load flow analysis usually finds its application during power network design and planning. It is also useful for obtaining the system behaviour during operation in order to predict the loading conditions of transmission lines and equipment within the system. A system is usually assumed to be operating under a balance condition such that the analysis can be carried out using a balanced single-phase representation. Reactive power is of the essence in any power network and posed as a challenge or solution to power network control. It is important that a balance reactive power be obtained in the operation of power system. This is relevant if voltage control is to be achieved. [2] performed a Voltage Stability Analysis of Nigerian 330kV Power Grid using Static P-V Plots. From the results obtained, at a load of 100 MW, Makurdi bus recorded a voltage of 0.9301pu which is already below the regulatory standards of 5% of the nominal line voltage. It entered the region of instability at a load of 245 MW as it created a situation of system instability and a possible partial system collapse. This further shows the need for reactive power compensation. In Nigeria, power demand increases steadily while the expansion of transmission and distribution network has been severely limited due to inadequate resources, power infrastructure and other environmental factors that hinder growth in the sector despite increase in generation. This gives reason for concern as it contributes to constant power failure in the Nigerian grid system. Power equipment are stressed due to continuous demand by consumers [3]. The Nigerian power system has a lot of challenges due to increase in economic activities resulting from increase in population and social advancement which has led to increase in electrical energy demands. This has increased the burdens on the existing electrical transmission lines and in some cases, has cause the loading of the transmission lines beyond their design limits with consequent reduction in power quality and power outages in extreme cases. These problems are the reasons for inadequate transmission and distribution of electrical energy. Deterioration and inadequate power infrastructures are among the numerous challenges. For instance, most load and generator buses have no or obsolete reactive power compensators. The laying and commissioning of transmission line is very difficult due to socio-economic problems, like environmental clearances, right of way etc. There is no doubt that the existing Nigerian national power grid is highly over stretched. It is against this backdrop that there is need to perform load flow analysis in order to determine the steady state solution of the network.

Materials and Methods

The detailed modelling and analysis of the power network and load flow solution is presented in this section. The NEPLAN power software is used for simulation of the system.

The eleven-bus power of the Nigerian 330kv network was modelled in the NEPLAN version 5.2 software environment using Newton Raphson load flow method as shown in the Figure 1. The network is made up of 7 load buses, 1 slack bus and 3 generator buses. The data used for the simulation were retrieved at National Control Center (NCC) Oshogbo, Osun State, Nigeria as presented in Table 1 and 2.

Table 1: Line Data of the Network

S/n	Bus Interconnectivity		Length (km)		Resistance	Reactance	Shunt Conductance
	FROM	TO		No of line(s)	(P.U)	(P.U)	(y/2) P.U
1	B. KEBBI T.S	KAINJI T.S	310	1	0.011102	0.094224	1.17723
2	KAINJI G.S	JEBBA T.S	81	2	0.002901	0.02462	0.3076
3	JEBBA G.S	JEBBA T.S	8	2	0.000289	0.00223	0.03312
4	JEBBA T.S	OSOGBO T.S	157	2	0.005623	0.04772	0.59621
5	OSOGBO T.S	AYEDE T.S	119	1	0.004118	0.034954	0.43672
6	AYEDE T.S	OLORUNSOGO	60	1	0.002149	0.018237	0.22785
7	OLORUNSOGO	IKEJA WEST T.S	77	1	0.002757	0.023403	0.29239
8	AKANGBA	IKEJA WEST	18	2	0.000615	0.00437	0.07037
9	IKEJA WEST	EGBIN G.S	15.2	1	0.000645	0.005471	0.06836
10	AJA T.S	EGBIN G.S	14	2	0.000501	0.004255	0.05317
11	IKEJA WEST	OSOGBO	250	1	0.008953	0.075987	0.94938

Table 2: Generator and Load Data for the Network

S/N	Bus No.	Bus Name	Bus Voltage Kv	Generation		Load	
				MW	MVar	MW	Mvar
1	1	Egbin G.S (slack)	330	-	-	-	-
2	2	Olurunsogo G.S	330	750			
3	3	Kainji G.S	330	624.7			
4	4	Jebba G.S	330	495			
5	5	Jebba TS	330			11	8.2
6	6	B/Kebbi TS	330			114.5	85.9
7	7	Osogbo TS	330			201.2	150.9
8	8	Ayede TS	330			275.8	206.8
9	9	Akangba	330			244.7	258.5
10	10	Ikeja West TS	330			633.2	474.9
11	11	Aja TS	330			274.4	205.8

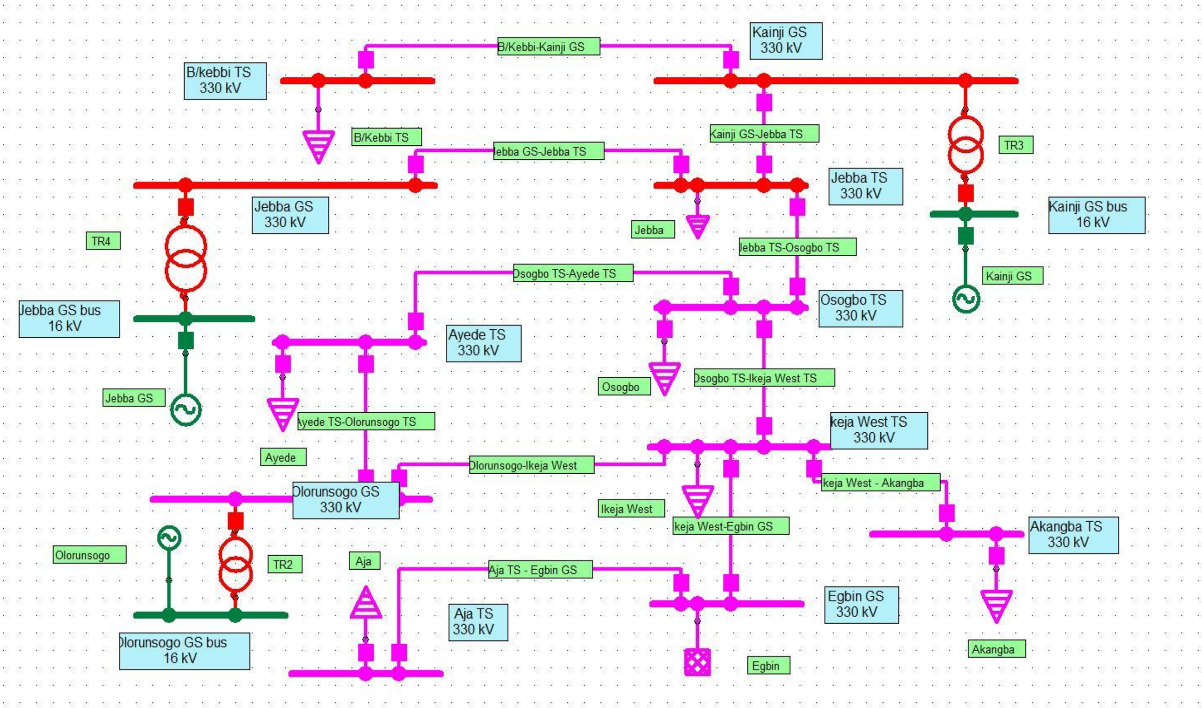

Figure 1: Single Line Diagram of the Network

The modelling of load flow is relevant in all power system analysis. The formulation shows the characteristics of the four qualities of a bus. The load flow problem is formulated as thus:

Given n bus system, there exists four variables; two are known while the other two are unknown. According to [4], The load flow equation is of the form:

$$f(x, y) = 0 \quad (1)$$

where,

$x = 2n$ unknown quantities

$y = 2n$ known quantities, input data controlled or fixed quantities

Figure 2 shows a typical bus of a power system.

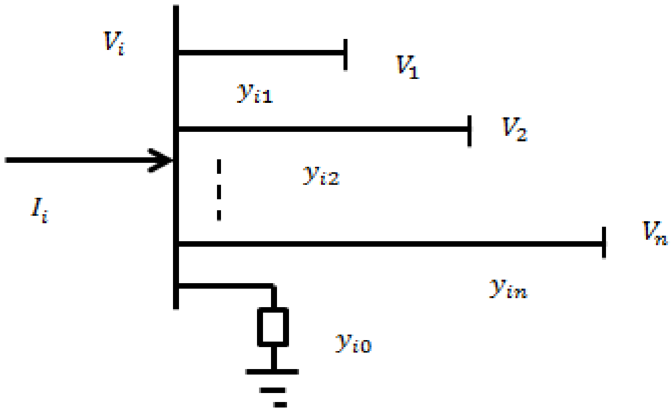

Figure 2: The Bus Loading of a Power System [4]

Transmission lines are represented by their equivalent πmodels, where impedances have been converted to per unit admittances on a common MVA base.

The general nodal current equation describing the performance of the power system network of Figure 2 according to [4] is given as:

$$I_{bus} = Y_{bus} V_{bus} \quad (2)$$

From Figure 2, the whole nodal current entering the i_{th} bus of n bus system is given by:

$$I_i = y_{i0}V_i + y_{i1}(V_i - V_1) + y_{i2}(V_i - V_2) + \cdots + y_{in}(V_i - V_n) \quad (3)$$

$$I_i = (y_{i0} + y_{i1} + y_{i2} + \cdots + y_{in})V_i - y_{i1}V_1 - y_{i2}V_2 - \cdots - y_{in}V_n \quad (4)$$

$$I_i = Y_{ii}V_i + Y_{i1}V_i + Y_{i2}V_2 + \cdots + Y_{in}V_n = \sum_{i-1}^{n} Y_{ik}V_k \quad (5)$$

The complex power injected in *i* bus is

$$S_i = P_i + jQ_i = V_i I_i^* \quad (6a)$$

Taking the complex conjugate of equation (6a) gives

$$S_i^* = P_i - JQ_i = V_i^* I_i \quad (6b)$$

Substituting the value of I_i from equation (5) into equation (6b) gives

$$S_i^* = P_i - JQ_i = V_i^* \sum_{k-1}^{n} Y_{ik}V_k \quad (7)$$

$$P_i = R_e \sum_{k=1}^{n} [|V_i||Y_{ik}||V_k| cos(\theta_{ik} + \delta_i - \delta_k)] \quad (8)$$

While

$$Q_i = I_i \sum_{k=1}^{n} \left[|V_i||Y_{ik}||V_k| e^{-j(\theta_{ik} + \delta_i - \delta_k)}\right] \quad (9)$$

According to Uppal and Rao [5], the load flow equation using Newton-Raphson's (NR) load flow method is much sophisticated and converges much faster than all other methods. It involves approximations, iterations and Taylor's series. A function $f_{(x)}$ can be expanded as:

$$\begin{bmatrix} f_1\left(x_1^{(0)}, x_2^{(0)}\right), \cdots x_n^{(0)} \\ f_2\left(x_1^{(0)}, x_2^{(0)}, \cdots x_n^{(0)}\right) \\ \vdots \\ \vdots \\ f_n\left(x_1^{(0)}, x_2^{(0)}\right), \cdots x_n^{(0)} \end{bmatrix} + \begin{bmatrix} \left[\frac{\partial f_1}{\partial x_1}\right]^{(0)} & \left[\frac{\partial f_1}{\partial x_2}\right]^{(0)} & \cdots & \left[\frac{\partial f_1}{\partial x_n}\right]^{(0)} \\ \vdots & & & \\ \vdots & & & \\ \vdots & & & \\ \left[\frac{\partial f_1}{\partial x_1}\right]^{(0)} & \left[\frac{\partial f_1}{\partial x_2}\right]^{(0)} & \cdots & \left[\frac{\partial f_1}{\partial x_n}\right]^{(0)} \end{bmatrix} \begin{bmatrix} \Delta x_1^{(0)} \\ \Delta x_2^{(0)} \\ \vdots \\ \vdots \\ \Delta x_n^{(0)} \end{bmatrix} \quad (10)$$

Or in vector form.

$$f^{(0)} + J^{(0)}\Delta x^{(0)} = 0 \quad (11)$$

where J is called Jacobian matrix.

Again, from Equation (11)

$$\Delta x^{(0)} = -\left[J^{(0)}\right]^{-1} f^{(0)} \quad (12)$$

Equation (12) gives the exact value of difference variables which results into a better estimate for $x_1^{(1)} and\ x_2^{(1)}$. Now using new values of $x_1^{(1)} and\ x_2^{(1)}$ follow the same procedure to obtain an estimate of $x_1^{(2)} and\ x_2^{(2)}$

Results

The modelled network has been simulated on NEPLAN 5.2 software using NR load flow method to determine the steady state solution of the network. After the simulation, some buses violated the voltage profile of 0.95pu – 1.05pu. Thus, voltage stability analysis is carried to identify the weakest bus of the network.

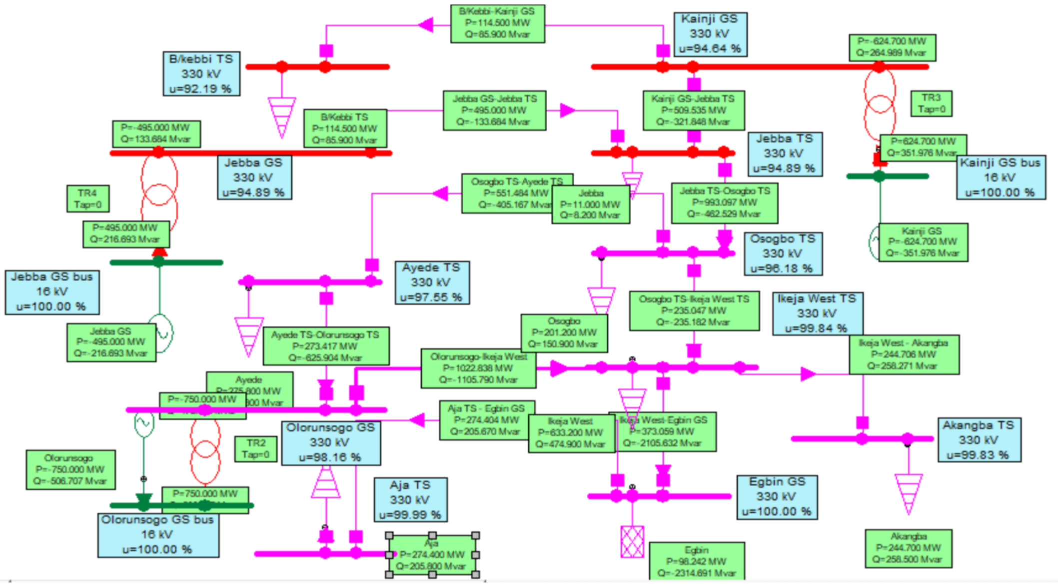

Figure 3: Network Simulation Model

The results obtained from the simulation model are presented under this section, as well as tabulation and graphical presentations.

Table 3: Steady State Load Flow Solution

S/N	Bus Name	Voltage (kV)	voltage (%)	Angle (0°)	P Load (MW)	Q Load (MVar)	P Gen (MW)	Q Gen (MVar)
1	Aja TS	329.979	99.99	0	274.4	205.8	0	0
2	Akangba TS	329.445	99.83	0	244.7	258.5	0	0
3	Ayede TS	321.925	97.55	1.4	275.5	206.8	0	0
4	B|Kebbi TS	304.213	92.19	3.5	114.5	85.9	0	0
5	Egbin GS	330	100	0	98.242	0	0	2314.691
6	Ikeja West TS	329.48	99.84	0	633.2	474.9		0
7	Jebba GS	313.133	94.89	5	0	0		0
8	Jebba GS Bus	16	100	43.8	0	0	495	216.693
9	Jebba TS	313.135	94.89	5	11	8.2	0	0
10	Kaniji GS	312.302	94.64	5.3	0	0	0	0
11	Kaniji GS Bus	16	100	57.7	0	0	0624.7	351.976
12	Olorunsogo GS	423.943	98.16	1.1	0	0	0	0
13	Olorunsogo GS Bus	16	100	67.6	0	0	750	506.707
14	Oshobgo TS	317.406	96.18	2.7	201.2	150.9	0	0

Table 4: Losses on the Network

P Loss line (MW)	Q Loss Line (MVar)
16.658	48.624

Table 5: V-Q Sensitivity Indices for Load

S/N	Bus Name	Sensitivity % MVar
1	B/Kebbi TS	0.0409
2	Jebba TS	0.0087
3	Oshogbo TS	0.0051
4	Ayede TS	0.0026
5	Akangba TS	0.0001
6	Ikeja West TS	0.0001
7	Aja TS	0.000027

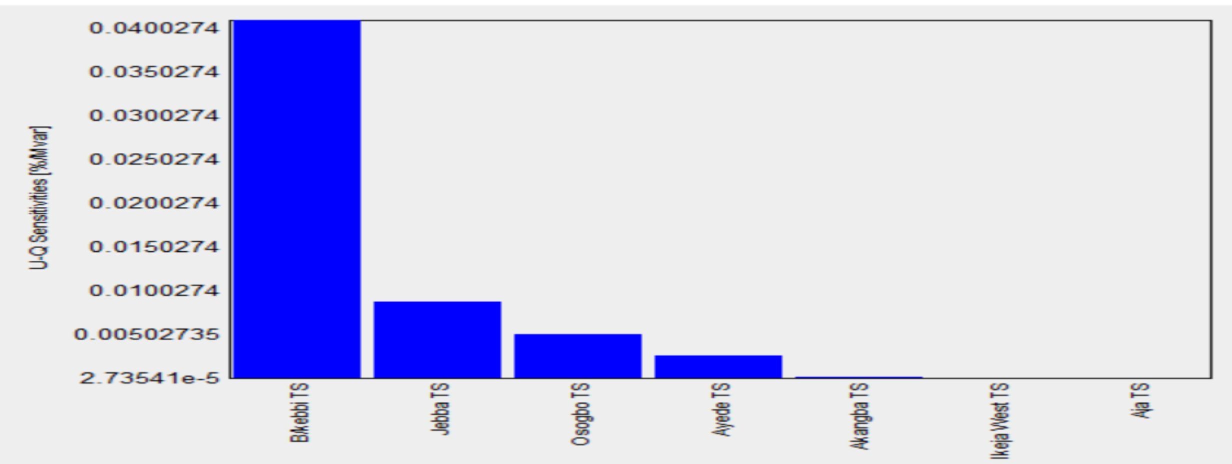

Figure 4: Load V-Q sensitivity

Table 6: Eigenvalues for Load

Serial Number	Bus Name	Eigenvalues (MVar/%)
1	Birnin kebbi TS	22.4045
2	Jebba TS	105.628
3	Ayede TS	486.067
4	Osogbo TS	918.852
5	Akangba TS	5946.15
6	Aja TS	36557.6
7	Ikeja west TS	62850.6

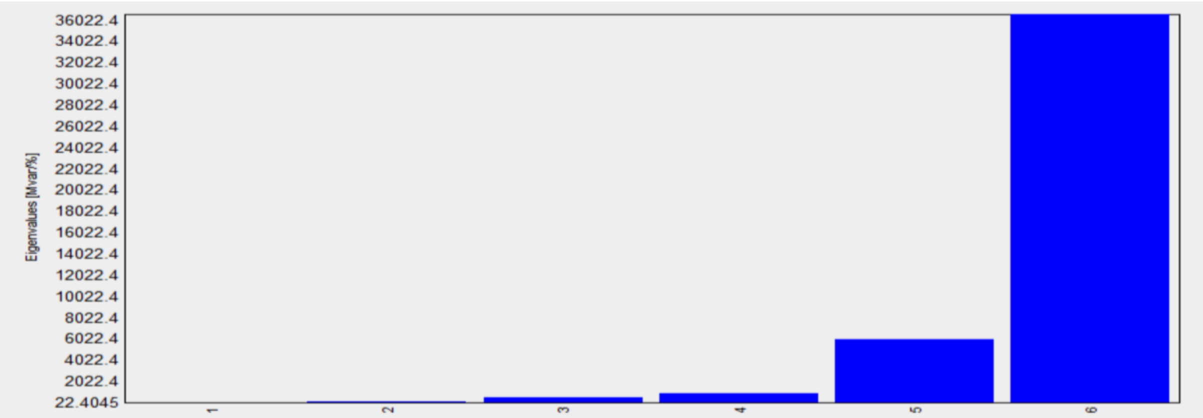

Figure 5: Eigenvalues of the network

Table 7: Bus Participation Factor for the Network Load

Serial Number	Bus Name	Bus Participation Factor
1	Birnin kebbi TS	0.893596
2	Jebba TS	0.496119
3	Ayede TS	0.557888
4	Osogbo TS	0.534352
5	Akangba TS	0.617718
6	Ikeja West TS	0.380413
7	Aja TS	0

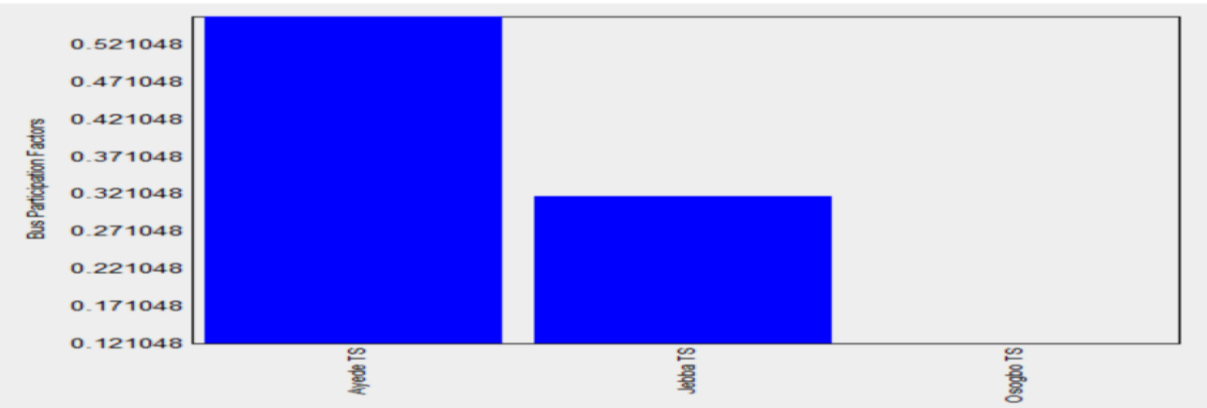

*Figure 6**:** Bus Participation Factor at some bus Eigenvalues*

Discussion

The data needed for the simulation of the eleven bus 330 kV Nigerian grid system was obtained from NCC at Osogbo, Osun state. Load flow analysis of the network was performed on NEPLAN software using NR load flow method. Table 3 shows the steady state load flow solution of the network. From the table, it's observed that 4 buses were out of the statutory limits of 0.95 to 1.05pu or 95% - 105%. The weak buses include Birnin Kebbi TS value at 0.9219pu, Jebba TS at 0.9489pu, likewise Jebba G. S. and Kainji G. S. value at 0.9464pu. The losses in the network is presented in Table 4. The network line losses in MW and MVar in general is 16.658 and 48.624 respectively. The NEPLAN power software has a voltage stability module which has been used for voltage stability analysis of the network. The voltage stability analysis is used to carry out assessment of the unstable and weak areas that are prone to network or voltage collapse in the system network. The V-Q sensitivity for the load was calculated to determine the most critical bus as shown in Table 5. Birinin Kebbi TS is the most critical with the highest sensitivity of 0.0409. Figure 4 shows V-Q sensitivity graph representation. The total number of eigenvalues of the reduced Jacobian matrix was 7 as shown in Table 6. It can be seen that B/K TS has 22.4045 which is the minimum eigenvalue among the load, making it the most critical bus. Figure 5 shows the graphical presentation of the load eigenvalues of the network. The bus participation factors were calculated, the result of table 7 shows that Birnin Kebbi TS has the highest bus participation factor at the least eigenvalue of 0.8936 as shown in Figure 6 and showed the highest contribution of Birnin Kebbi TS to voltage collapse. The analysis helps in identifying weak and critical buses of the network. The eigenvalues, VQ sensitivity and participation factor at the various least eigenvalues were calculated using the power software which confirmed Birnin Kebbi TS as the most vulnerable to initial voltage collapse.

Conclusion

This work presents the load flow study of the modeled 11-bus Nigerian 330-kV grid network using Newton-Raphson iteration techniques in NEPLAN 5.2 power software. The obtained results show that the Nigerian 330kV grid network is associated with various problems such as voltage instability among others. The results further revealed that some of the buses have weak voltage profile, such as Jebba TS (94.89%), Jebba G.S (94.89%), Kaniji G.S (94.64%) and B/Kebbi TS (92.19%). It has line losses in MW and MVar as 16.658 and 48.624 respectively. The reactive power loss of the 11-bus in the Nigerian 330kV grid network is very high, hence, the need for reactive power compensation to ensure network enhancement. Although the objectives of this work were achieved, it is recommended that FACTS devices be introduced into the network to enhance the Nigerian 330kV system for a more reliable, controllable, flexible and efficient network system.

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