THE CHOICE OF A SWING BUS IN A POWER SYSTEM NETWORK. A CASE STUDY OF THE NIGERIAN NATIONAL GRID.

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ABSTRACT

This work provides a simple and alternative method of selecting a swing bus bar in a power system network; the Nigerian National Grid was used as a case study. An algorithm for this study was developed based on Newton-Raphson iterative method. The model was implemented in matlab 7.5 environment. The network was simulated taking one generating station at a time as a slack bus. The system bus voltage magnitudes, angles, real and reactive powers were computed. The values obtained showed that Egbin generating station bus with voltage and angle limits of ($0.9998 \le /V_i/ \le 1.002$ PU) and ($-0.1 \le \delta_i \le 0.09$) provided the optimum system network stability when used as a swing bus amongst others.

Keywords: Slack bus, Transmission, Network, Reactive, Power, Voltage,

1.0 INTRODUCTION

Electric energy is an essential ingredient for the industrial and all-round development of any country. It is a coveted form of energy, because it can be generated centrally in bulk and transmitted economically over long distances [1]. Further, it can be adapted easily and efficiently to domestic and industrial applications, particularly for lighting purposes and mechanical work (drives). The per capita consumption of electrical energy is a reliable indicator of a country‘s state of development. The generation of electric power involves the conversion of energy from a non-electrical form (such as a thermal, hydraulic, or solar energy) to electric energy.

Successful operation of electrical power system requires that; generation must supply the demand (load) plus losses, bus voltage magnitude must remain close to rated values, generators must operate within specified real and reactive power limits, transmission lines and transformers should not be overloaded for long periods [2]. In order to achieve equilibrium state between the generation and consumption of electrical energy, the performance and operational features of the power system has to be studied. The most important aspect of the study is load flow study. Load flow studies is essential in planning, the most economic operation mode, addition of new generating stations and transmission lines to ultimately guaranty reliability and efficiency of the national grid [3,4]. The swing, slack or reference bus is one of the buses in the electrical network; it is a special type of generator bus that is needed by the load (power) flow solution process. There is normally one swing bus in a power system network. A swing or reference bus-bar has the ability to maintain system stability after faults. In other words, it is a bus-bar that can accommodate system disturbances and still maintain the network in its normal operating state. It is a special generator bus that serves as a reference bus and is large enough to supply the required power, keeping the system balanced in terms of power flows. At the swing or reference bus-bar, the Voltage magnitude and voltage angle are specified (normally set to 1 per unit and Zero per unit). It is required to provide a 'reference' voltage and angle to which all other voltages and angles are referred. It is generally chosen from amongst the generator bus-bar.

1.1 Overview of A Section of The National Grid Used As Test System

The Nigerian National Grid is a large power system network spanning across the nation, consisting of several power generating stations and transmission station interconnected. In this study a section of the network involving six generating stations, namely; Egbin, Delta, Okpai, Afam, shiroro and Jebba power station was considered. The system under investigation is a 12-bus system and comprises of double and single circuit transmission lines. These stations were considered because; they are among the six highest generating stations. The generating stations spreads across the northern and southern parts of the country and their position are very strategic. The figure 1.0 is a single line diagram of the section of the national grid under consideration.

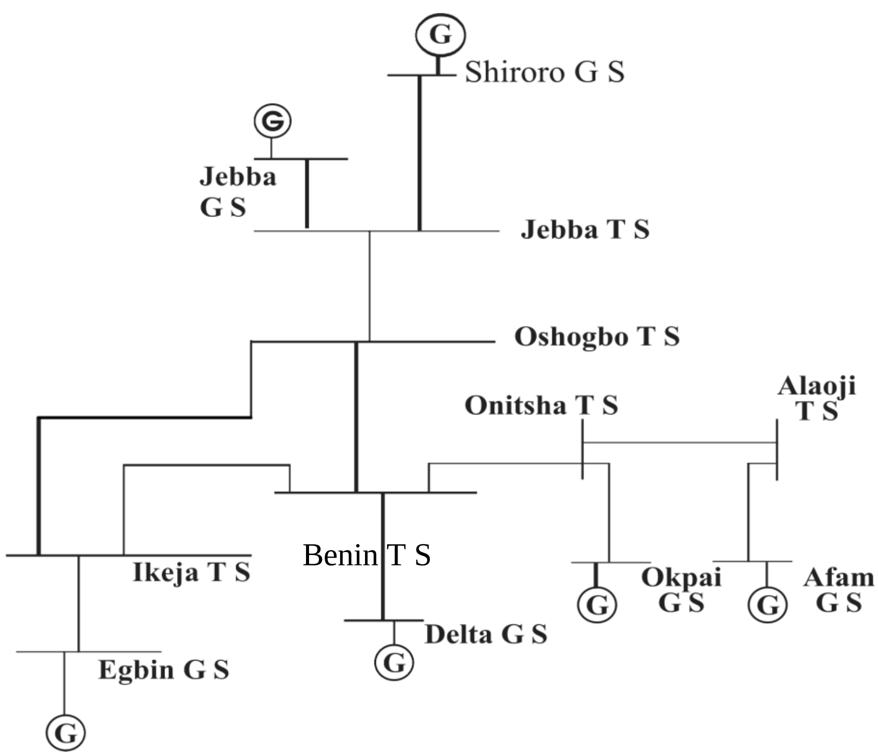

Fig 1.0 A Section of the National Grid Under Consideration

1.2 POWER FLOW STUDY USING NEWTON-RAPHSON'S TECHNIQUE

The Newton-Raphson's method is a powerful method of solving non-linear algebraic equations. It works faster, and is sure to converge in most cases as compared to the Guass-Siedel method. It is indeed the practical method of load flow solution of large power networks. Its only drawback is the large requirement of computer memory, which can be overcome through a compact storage scheme. Convergence can be considerably speeded up by performing the first iteration through the Guass-Siedel method, and using the values so obtained for solving the Newton-Raphson iterations [1,2,5]. Consider a set of nonlinear algebraic equations given as follows.

$$f_i(x_1, x_2, ..., x_n) = 0 \qquad (1)$$

where i = 1,2,3, . . . n

The theory requires that we assume initial values of unknowns as $x_1^0, x_2^0, ...x_n^0$.

Let $\Delta x_1^0, \Delta x_2^0, ...\Delta x_n^0$, be the correction to be found out, which on being added to initial values give the actual solution therefore,

$$f_i(x_1^0 + \Delta x_1^0, ..., x_n^0 + \Delta x_n^0) = 0 \quad i = 1,2,...,n. \qquad (2)$$

Expanding these equations around the initial values by Taylor series, yields

$$f_i^0(x_1^0, .., x_n^0) + \left[\left(\frac{\partial f_i}{\partial x_1}\right)^0 \Delta x_1^0 + ... + \left(\frac{\partial f_i}{\partial x_n}\right)^0 \Delta x_n^0\right] + \text{higher order terms} = 0 \qquad (3)$$

where $\left(\frac{\partial f_i}{\partial x_1}\right)^0, ...\left(\frac{\partial f_i}{\partial x_n}\right)^0$ are the derivatives of f_i with respect to $x_1, x_2, ..., x_n$ evaluated at $x_1^0, x_2^0, ...x_n^0$.

Neglecting the higher order terms, equation (3) can be written in matrix form as

$$\begin{bmatrix} f_i^0 \\ . \\ . \\ f_n^0 \end{bmatrix} + \begin{bmatrix} \left(\frac{\partial f_1}{\partial x_1}\right)^0 ... \left(\frac{\partial f_1}{\partial x_n}\right)^0 \\ . \\ . \\ \left(\frac{\partial f_n}{\partial x_1}\right)^0 ... \left(\frac{\partial f_n}{\partial x_n}\right)^0 \end{bmatrix} \begin{bmatrix} \Delta x_1^0 \\ . \\ . \\ \Delta x_n^0 \end{bmatrix} = \begin{bmatrix} 0 \\ . \\ . \\ 0 \end{bmatrix} \qquad (4)$$

or, in vector matrix form

$$f^0 + J^0 \Delta x^0 = 0 \qquad (5)$$

Where J^0 is the Jacobian matrix evaluated at x^0. Then in compact notation,

$$J^0 = \left(\frac{\partial f(x)}{\partial x}\right)^0 \qquad (6)$$

In equation (6), Δx^0 is the vector of approximate correction, which can be written in the form

$$\Delta x^0 = \left(-J^0\right)^{-1} f^0 \tag{7}$$

and $J(x)$ is the jacobian matrix of the form

$$J(x) = \begin{bmatrix} -J_{11}(x) - J_{12}(x) \\ -J_{21}(x) - J_{22}(x) \end{bmatrix} \tag{8}$$

The elements of $-J_{11}, -J_{12}, -J_{21}, -J_{22}$ are $\frac{\partial P_i(x)}{\partial \delta_k}, \frac{\partial P_i(x)}{\partial |V_k|}, \frac{\partial Q_i(x)}{\partial \delta_k}, \frac{\partial Q_i(x)}{\partial |V_k|}$ respectively where $i = 2,...n; k = 2,...n$

The real and reactive parts of a complex power injected by the source into the ith bus of a power system is

$$P_i \text{ (Real Power)} = |V_i| \sum_{k=1}^{n} |V_k||Y_{ik}| \cos(\theta_{ik} + \delta_k - \delta_i) \tag{9}$$

$$Q_i \text{ (Reactive Power)} = -|V_i| \sum_{k=1}^{n} |V_k||Y_{ik}| \sin(\theta_{ik} + \delta_k - \delta_i) \tag{10}$$

$$i = 1,2,....n$$

V_i = Voltage at i^{th} bus,

Y_{ik} = Admittance between bus i^{th} and k

θ_{ik} = Phase angle between bus i^{th} and k

Equations (9) and (10)are called power flow equations from which results

$$\frac{\partial P_i(x)}{\partial \delta_k} = -\sum_{\substack{k=1 \\ k \neq i}}^{n} \left(|V_i||V_k||Y_{ik}| \sin(\theta_{ik} + \delta_k - \delta_i)\right) \tag{11}$$

$$\frac{\partial P_i(x)}{\partial |V_k|} = 2|V_i||Y_{ii}| \cos\theta_{ii} + \sum_{\substack{k=1 \\ k \neq i}}^{n} \left(|V_k||Y_{ik}| \cos(\theta_{ik} + \delta_k - \delta_i)\right) \tag{12}$$

$$\frac{\partial Q_i(x)}{\partial \delta_k} = -\sum_{\substack{k=1 \\ k \neq i}}^{n} \left(|V_i||V_k||Y_{ik}| \cos(\theta_{ik} + \delta_k - \delta_i)\right) \tag{13}$$

$$\frac{\partial Q_i(x)}{\partial |V_k|} = 2|V_i||Y_{ii}| \sin\theta_{ii} + \sum_{\substack{k=1 \\ k \neq i}}^{n} \left(|V_k||Y_{ik}| \sin(\theta_{ik} + \delta_k - \delta_i)\right) \tag{14}$$

With the voltage and angle at the slack bus fixed at $V_1\angle\delta_1, \left(1\angle 0^0\right)$, assume $|V|\angle\delta$ at all PQ buses and δ at all PV buses. In the absence of any other constraint mentioned in the information provided, flat voltage is recommended for a start of the iteration.

In the rth iteration, yields

$$P^r{}_i = \sum_{k=1}^{n} |V_i|^r |V_k|^r |Y_{ik}| \cos(\theta_{ik} + \delta^r{}_k - \delta^r{}_i) \quad (15)$$

$$Q^r{}_i = -\sum_{k=1}^{n} |V_i|^r |V_k|^r |Y_{ik}| \sin(\theta_{ik} + \delta^r{}_k - \delta^r{}_i) \quad (16)$$

1.3 Data Collection

The collected data include the following:

Single line diagram of the Nigeria National Grid, lines impedance, lines length, monthly power generation at the various stations, between January – December, 2010. Daily peak and off peak generation within the period under consideration, impedance values for various distances for single and double circuits.

Table 1.0 Average power Generation Capabilities for the Year 2010

[Source: PHCN National Control Centre, Oshogbo]

S/N	POWER STATION	LOCATION (STATE)	CAPACITY (MW)
1	Jebba Hydro	Niger	431.83
2	Kainji Hydro	Niger	412. 55
3	Shiroro Hydro	Niger	390.21
4	Egbin steam	Lagos	819.55
5	A E S Gas	Lagos	208 .20
6	Sapele Steam	Delta	125 .17
7	Okpai Gas	Delta	441.57
8	Afam Gas	Rivers	457.264
9	Delta Gas	Delta	342.95
10	Geregu Gas	Kogi	208 . 69
11	Omoku Gas	Rivers	80. 18
12	Omotosho Gas	Ondo	118.93
13	Trans – Amadi Gas	Rivers	32.63
14	Ibom Gas	Akwa Ibom	82.89
15	Olorunsogo Gas	Ondo	60.13
	TOTAL		4,191.12

Table 2.0 Identification of Buses in 330kV Transmission Network

BUS NUMBER	BUS NAME		BUS NUMBER	BUS NAME
1	Oshogbo		15	Aladja
2	Benin		16	Kano
3	Ikeja West		17	Sapele-GS
4	Aiyede		18	Aja
5	Jos		19	Ajaokuta
6	Onitsha		20	New Haven
7	Akangba		21	Alaoji
8	Gombe		22	Afam GS
9	Abuja		23	Jebba
10	Egbin-GS		24	Jebba-GS
11	Delta-GS		25	Kainji-GS
12	AES-GS		26	Bini Kebbi
13	Okpai-GS		27	Shiroro-GS
14	Calabar		28	Kaduna

Table 3.0 Impedance Value for Various Distances for Double and Single Circuits

Length of Line (km)	Single Circuit			Double Circuit		
	R=0.0000358 (ohms)	X=000304 (ohms)	B=0.0038/km	R=0.0000357 (ohms)	X=0.000278 (ohms)	B=0.00415
10	0.0000358	0.00304	0.038	0.0000357	0.00278	0.0415
20	0.000716	0.00608	0.076	0.000714	0.00556	0.083
40	0.001432	0.01216	0.152	0.001428	0.01112	0.166
60	0.002148	0.01824	0.228	0.002142	0.01668	0.249
80	0.002864	0.02432	0.304	0.002856	0.02224	0.332
100	0.00358	0.0304	0.38	0.00357	0.0278	0.415
120	0.004296	0.03648	0.456	0.004284	0.03336	0.498
140	0.005012	0.04256	0.532	0.004998	0.03892	0.581
160	0.005728	0.04864	0.608	0.005712	0.04448	0.664
180	0.006444	0.05472	0.684	0.006426	0.05004	0.747
200	0.00716	0.0608	0.76	0.00714	0.0556	0.83
220	0.007876	0.06688	0.836	0.007854	0.06116	0.913
240	0.008592	0.07296	0.912	0.008568	0.06672	0.996
260	0.009308	0.07904	0.988	0.009282	0.07228	1.079
280	0.010024	0.08512	1.064	0.009996	0.07784	1.162
300	0.01074	0.0912	1.14	0.01071	0.0834	1.245
320	0.011456	0.09728	1.216	0.011424	0.08896	1.328
340	0.012172	0.10336	1.292	0.012138	0.09452	1.411
360	0.012888	0.10944	1.368	0.012852	0.10008	1.494
380	0.013604	0.11552	1.444	0.013566	0.10564	1.577
400	0.01432	0.1216	1.52	0.01428	0.1112	1.66

Table 4.0 Line Impendance and Admittance Value of 330kv Transmisssion lines

CIRCUITS		LENGTH	IMPEDANCES (Per Unit)		
FROM	TO	(KM)	Z1	B1	Admittance
AKANGBA	IKEJA WEST I	17	0.0006 +j 0.0051	0.065	32.75-j1932
IKEJA WEST	EGBIN I	62	0.0022 +j 0.0172	0.257	7308-j57.14
"	BENIN I	280	0.0101 +j 0.0779	1.162	1.637-j12.626
IKEJA WEST	AIYEDE	137	0.0049 +j 0.0416	0.521	2.8-j33.771
AIYEDE	OSHOGBO	115	0.0041 +j 0.0349	0.437	3.333-j38.37
OSHOGBO	BENIN	251	0.0089 +j 0.0763	0.954	1.508-j12.932
"	JEBBA I	249	0.0056 +j 0.477	0.597	0.0246-j3.092
JEBBA T. S.	JEBBA GS I	8	0.003 +j 0.0022	0.033	3174-j1594
"	SHIRORO I	244	0.0087 +j 0.0742	0.927	1.559-j13.297
"	KAINJI I	81	0.0022 +j 0.0246	0.308	3.607-j40.328
KAINJI	BIRNIN-KEBBI	310	0.0111+.j0.0942	1.178	1.235-j10.478
SHIRORO	KADUNA I	96	0.0034 +j 0.0292	0.364	3.935-j3379
KADUNA	KANO	230	0.0082 +j 0.0699	0.874	1.657-j14.12
JOS	GOMBE	265	0.0095 + j 0.081	1.01	1.923-j16.456
BENIN	AJAOKUTA I	195	0.007 +j 0.056	0.745	1.429-j12.180
"	SAPELE I	50	0.0018 +j 0.0139	0.208	3.194-j17.555
"	ONITSHA	137	0.0049 +j 0.0416	0.521	2.8-j33.771
ONITSHA	NEW-HAVEN	96	0.0034 +j 0.0292	0.365	3.935-j3379
"	ALAOJI I	138	0.0049 +j 0.0419	0.524	2.754-j33.553
ALAOJI	AFAM I	25	0.009 +j 0.007	0.104	59.230-j53.846
SAPELE	ALADJA	63	0.0023 +j 0.019	0.239	5.284-j51.913
"	DELTA	57	0.002 +j 0.017	1.178	5.826-j58.021
DELTA	ALADJA	30	0.0011+.j0.0088		13.995-j1119

1.4 Implementation Of Test System Model

A section of the system network comprising of six generating stations and six transmission stations were considered during the modeling and simulation, this is because most of the large generating stations and long transmission station are contained in this section under consideration and this is clearly shown in Fig. 2.0. A load flow file incorporated in MATLAB 7.5 environment was used for the load flow simulation. The computer model was developed using Newton- Raphson method to evaluate the bus voltage magnitude and angles. The test system was modeled using one generator bus at a time as the swing bus. The study is modeled with the following blocks; PQ node, overhead line (OHL) branch, initialization block, slack node, display and constant blocks and solved for steady states voltage magnitude and angles at the various buses. Each generating station bus was taken as a slack bus and the network performance simulation was done for each one. Base values of 100MVA, 50Hz and 330KV were used. The corresponding results obtained for each of the generating station bus simulated were recorded. Figure 2.0 shows the computer model of Egbin bus as Slack bus for simulation. The bus voltage magnitude and angle at all buses, power flow through the transmission lines and the slack bus power were obtained with this model.

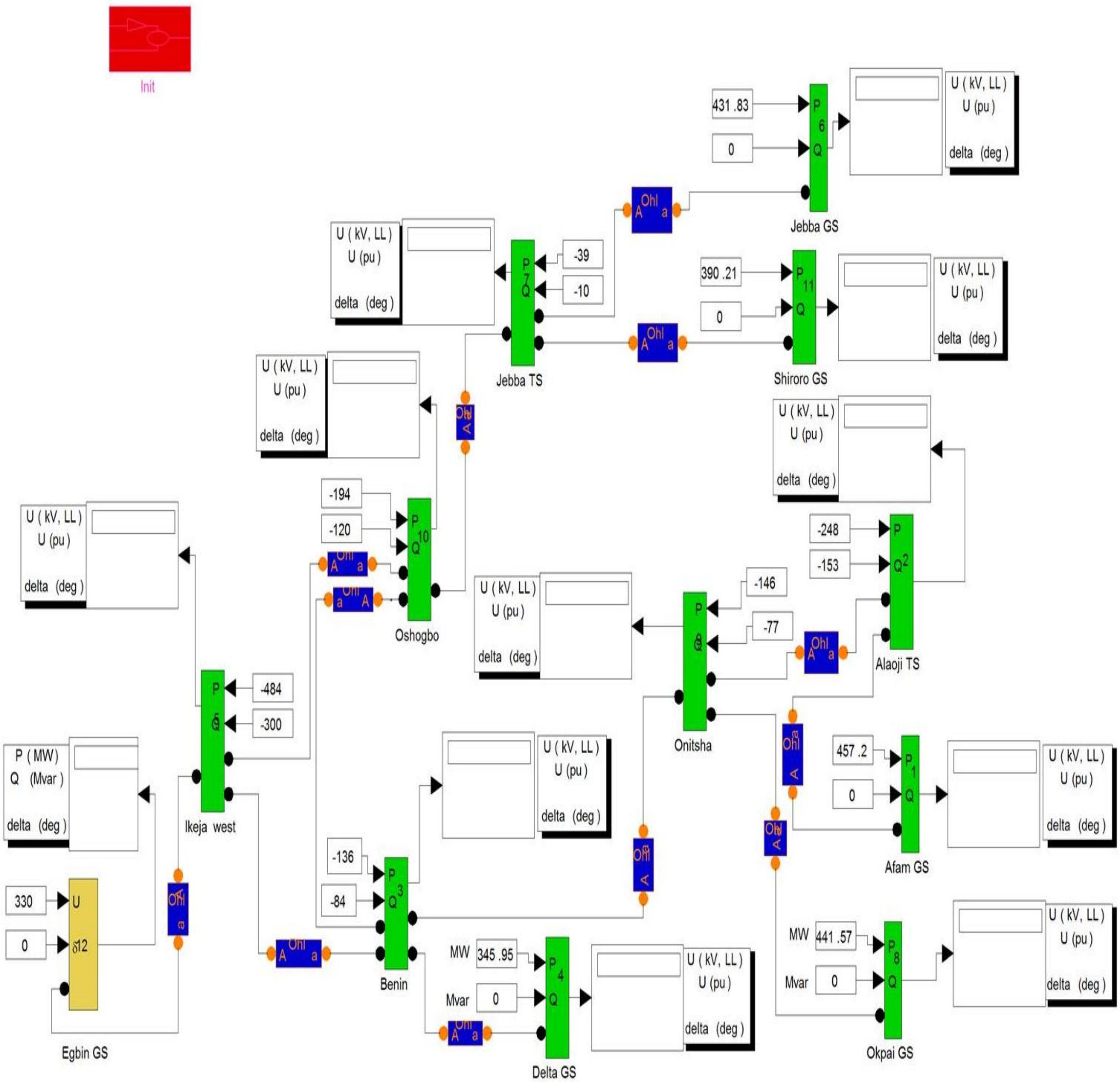

Fig. 2.0 Computer Simulation Model of the Network

Table 5 Result of Egbin Generating Station as Slack Bus

Bus Number	Bus Name	Magnitude Voltage (kV)	Voltage Angle	Per Unit of Voltage
1	Oshogbo T S	329.94	0.0400	0.9998
2	Benin T S	329.93	0.0371	0.9998
3	Ikeja West T S	329.97	0.0083	0.9998
4	Egbin G S	330	0.0000	1.0000
5	Delta G S	329.93	0.0400	0.9998
6	Okpai G S	329.91	0.0528	0.9997
7	Afam G S	329.89	0.0555	0.9997
8	Alaoji T S	329.96	0.0664	0.9999
9	Onitsha T S	329.91	0.0500	0.9997
10	Jebba T S	329.96	0.0700	0.9999
11	Jebba G S	329.96	0.0700	0.9999
12	Shiroro G S	329.97	0.0800	0.9999

P(MW) = -819.5612, Q(MVar) = 745.64

Table 6.0 Result Jebba Generating Station as Slack Bus

Bus Number	Bus Name	Magnitude Voltage (kV)	Voltage Angle	Per Unit of Voltage
1	Oshogbo T S	329.85	0.0400	0.9995
2	Benin T S	329.79	0.0644	0.9994
3	Ikeja West T S	329.79	0.0593	0.9994
4	Egbin G S	329.80	0.0700	0.9994
5	Delta G S	329.80	0.0700	0.9994
6	Okpai G S	329.78	0.0800	0.9993
7	Afam G S	329.76	0.0872	0.9993
8	Alaoji T S	329.76	0.0800	0.9993
9	Onitsha T S	329.77	0.0760	0.9993
10	Jebba T S	330.00	0.0000	1.0000
11	Jebba G S	330.00	0.0000	1.0000
12	Shiroro G S	330.01	0.02	1.0000

Table 7.0 Result of Shiroro Generating Station as Slack Bus

Bus Number	Bus Name	Magnitude Voltage (kV)	Voltage Angle	Per Unit of Voltage
1	Oshogbo T S	329.72	0.0900	0.9992
2	Benin T S	329.66	0.1200	0.9990
3	Ikeja West T S	329.66	0.1100	0.9990
4	Egbin G S	329.67	0.1200	0.9990
5	Delta G S	329.67	0.1200	0.9990
6	Okpai G S	329.64	0.1307	0.9989
7	Afam G S	329.63	0.0898	0.9989
8	Alaoji T S	329.63	0.1300	0.9989
9	Onitsha T S	329.64	0.1300	0.9989
10	Jebba T S	329.87	0.0500	0.9996
11	Jebba G S	329.87	0.0500	0.9996
12	Shiroro G S	330.00	0.0000	1.0000

P(MW) = -1248.7213, Q(MVar) = 747.2

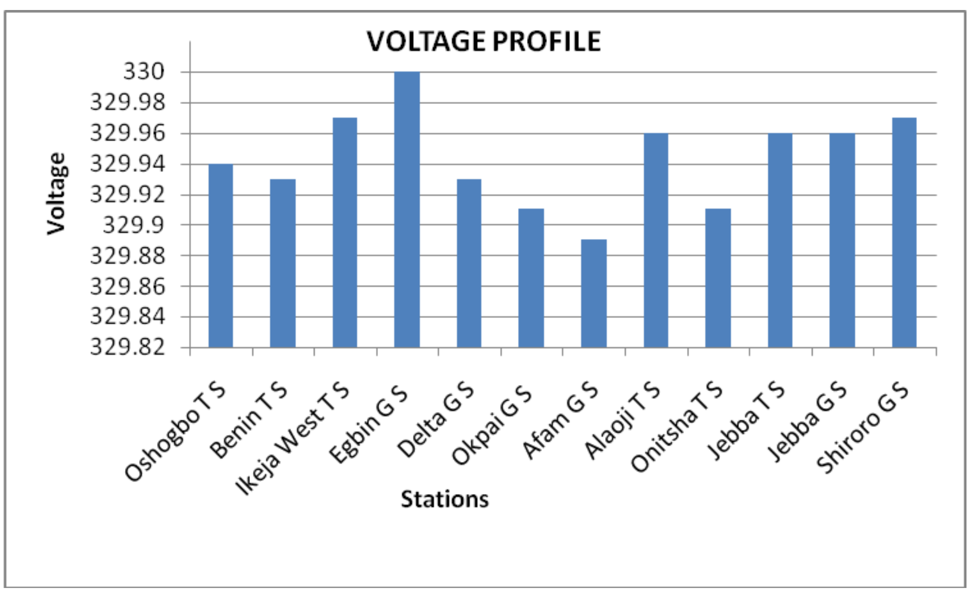

Fig.3.0 Network Voltage Profile with Egbin Power Station as a Slack Bus

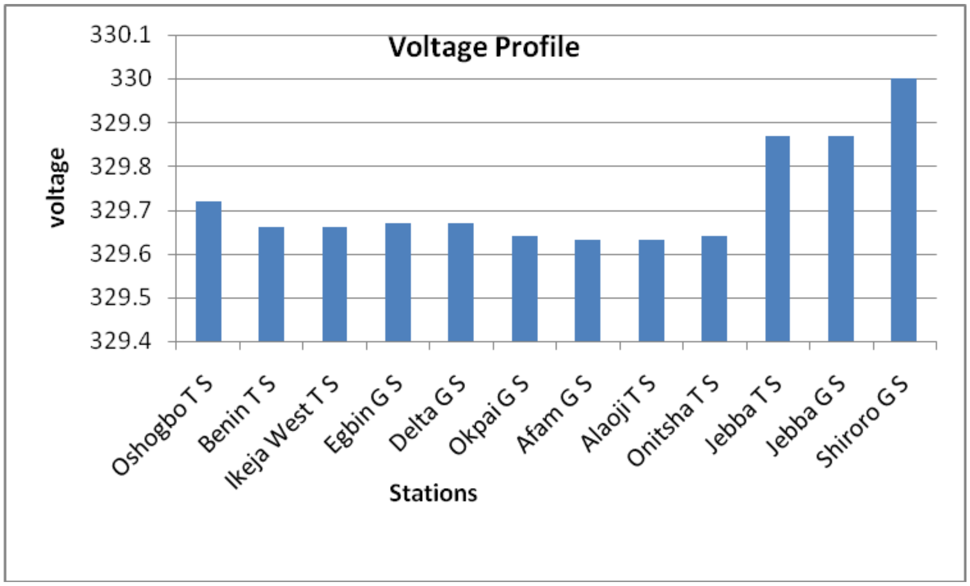

Fig.4.0 Network Voltage Profile with Shiroro Power Station as a Slack Bus

1.5 CONCLUSION

The choice of a swing or reference bus in a power system network is essential for an effective operation of the network to meet up with stability and reliability demand of its customers and the society in general. From this study, the generator bus with the highest generation capacity in a power system network showed a higher reliability as a slack bus in terms of stable and evenly distributed voltage profile. The location of a generator bus also plays important role in selecting a slack bus. The work shows that Egbin station bus bar performed better than the other six generating stations in the network for slack or reference bus. The result showed that the system bus voltages values were all within acceptable limits, which also indicate a high percentage of system stability. Shiroro bus gave the second best result which shows that the location of a bus bar in the network also influences the selection of a slack bus. The swing bus is needed to supply the excess real and reactive power in load flow solution. It has the ability to keep the system balanced in terms of power flow; However, the Nigeria National Grid generating capacity is non-linear as such operates in a constantly changing generating capacity, and hence no one generator bus bar can be permanently selected as the Grid slack bus. The highest generator may not always be the best slack, in situations where the difference in generation capabilities of stations is very small, the location of the generator buses should be considered in selecting a swing or slack bus.

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