Journal of Advances in Science and Engineering 8 (2023) 27 – 48

Journal of Advances in Science and Engineering
(JASE)

Journal homepage: www.sciengtexopen.org/index.php/jase

Evaluating the impact of injecting the 3050MW Mambilla power plant into the Nigerian grid network

A. E. Airoboman *, A. Shaibu, D. E. Aku

Department of Electrical/Electronic Engineering, Nigerian Defence Academy, Kaduna, Nigeria

ARTICLE INFO

Article history:
Received 13 September 2022
Received in revised form
7 November 2022
Accepted 24 January 2023
Available online
31 January 2023

Keywords:
Impact assessment
Load flow analysis
Mambilla power plant
MATLAB
Nigerian national grid

ABSTRACT

The study aims to evaluate the impact of the injection of the 3050 MW Mambilla power plant into the Nigerian National Grid (NNG). To achieve this aim, line and bus data were collated from National Control Centre, Osogbo. The Mambilla power plant was injected at the Makurdi and Jalingo buses respectively in view of determining the optimal injection point. Load flow analysis employing the Newton Raphson technique was first performed without the Mambilla power plant injected into the NNG. The simulation was repeated for the respective power plant injection scenarios. For each case, the voltage profile and line losses were obtained accordingly. Total Voltage Deviations (TVDs) for the various scenarios were computed and used to determine the optimal point of injecting the Mambilla 3050MW power plant to NNG. All simulations were implemented using MATLAB software (version 2020b). A loss of 872.8 MW and 874.1 MW was observed in the network when the Mambilla power plant was injected at Makurdi and Jalingo bus respectively with respect to a base case loss of 876.1 MW. This corresponds to a reduction in a power loss of 0.36% and 0.12% respectively. A TVD of 0.0052 and 0.0169 was observed when the Mambilla power plant was injected at Makurdi and Jalingo buses respectively. This implies that the voltage condition of the network is better when Mambilla was injected at the Makurdi bus. Hence, the Makurdi bus was identified as the optimal point for injecting the Mambilla 3050 MW power plant since it resulted in a better reduction of the system losses and overall voltage profile improvement of the network.

1. Introduction

Any nation's economic growth and industrialisation rate are hinged on its ability to produce adequate and quality electricity for homes and industries. Therefore, for Nigeria to become one of the 20 most developed economies in the world, the electric power issues that have stalled for a long must be tackled. The nation can resolve its electric power issues because it is endowed with massive energy resources both renewable and non-renewable [1].

Despite the numerous sources of energy for power generation, Nigeria remains one of the nations with the lowest electricity consumption per capita in Africa [2,3]. This circumstance has led to the majority of Nigerians powering their homes and businesses using standby generating sets during power outages from the national grid. Nigeria is the world's leading user of standby power generators. A survey carried out by NOI (Ngozi Okonjo-Iweala) Polls Ltd in 2013 shows that about 130 million Nigerians out of a population of 160 million depend solely on the use of standby generators to meet up with their electricity demand [4]. However, constant usage of generators by individuals has led to serious environmental degradation and higher business costs. This situation has forced many industries to relocate to more friendly environmental countries while others became moribund.

Mambilla hydropower project is a 3050 MW facility located in Dongo River close to Baruf, Kakara village, Taraba state, Nigeria. The project is jointly undertaken by Nigeria's Federal Ministry of Power, Works and Housing and Chinese investments. The project, expected to begin operation in 2030, will be Nigeria's biggest power plant, producing

* Corresponding author
E-mail address: airobomanabel@nda.edu.ng
https://doi.org/10.37121/jase.v8i1.200

approximately 4.7 billion kWh of electricity annually [5]. The cost of actualizing the project stands at $ 5.8 bn which is expected to provide up to 50,000 local jobs during the construction stage [5]. The hydro plant will be made up of four dams and two underground power houses having a total of twelve turbine generator units. The four dams include Nya (formerly known as Gembu), Sumsum, Nghu and Api Weir dams. Nya and Sumsum will be 100 m and 35 m tall roller compacted concrete (RCC) dams with crest length of 515 m and 460 m, respectively. Nghu will be a 95 m high rockfill dam with a crest length of 650 m [5] while Api Weir will be a small regulatory dam to raise the water level of the river. Nya and Sumsum dams will be connected through a 16 km long, 6 m diameter tunnel, whereas Sumsum and Nghu dams will be connected by a 1.5 km long and 10 m wide canal. The headrace canal for the plant will be 3.1 km long and 15 m wide. Each of the underground power house will have a dimension of 175 m x 27 m x 38 m and contain six 250 MW Pellton turbine units operating at a total dynamic head of 1,007 m. The diameter of the power shafts connecting each turbine will be in the range of 5.25 m and 8.40 m. Two 6 km long tailrace tunnels for the plant will be of 8 m diameter each, while the tailrace canal will be 3 km long and 25 m wide.

Power generated by the Mambilla hydroelectric power plant will be evacuated to the Nigerian National grid (NNG) using four 500 kV DC transmission lines connecting Makurdi, and one 330 kV DC transmission line connecting Jalingo having a total route length of 700 km.

The epileptic power supply to homes and industries in Nigeria is the major hindrance to her economic growth. The backbone of the power system is the power generation component because it is the quantity of power generated that can be transmitted and distributed to homes and industries. This component of the power system had suffered abjectly from poor funding, poor or lack of maintenance and poor management of infrastructure among other factors. The nation had carried out various reforms to ameliorate the electric power crisis but all to no avail. The electric power crisis has made so many industries to relocate to more environmentally friendly nations thereby impacting negatively on the economy of the nation. Furthermore, the terrible state of the nation's basic infrastructure such as water supply, health care system and petroleum product distribution are all symptoms of an economy that is crumbling because of the nations' incapability to meet electric power demand.

Owing to these aforementioned issues, the subject of injecting a power plant to the National grid is interesting, vital and worthy of assessment. Hence, in this research work therefore, the impact assessment on the injection of Mambilla 3050 MW power plant into NNG is analysed.

2. Review of Related Literature

Airoboman et al. [6] modelled the Benin-Onitsha-Alaoji 330 kV transmission section of the NNG using MATLAB/SIMULINK. The line data of the grid system which include impedance, voltage rating, power and loads at the various buses, were fed into the developed model and simulation performed. The network is made up of two generating plants rated at 1902 MVA and 1430 MVA, 12 kV respectively. Plant 1 represents Delta and Sapele generating stations while Plant 2 represents Afam II-V and Afam VI generating stations supplying power to the Benin-Onitsha-Alaoji 330 kV transmission lines with thermal rating of 760 MVA. The model was simulated for different fault conditions and the performance assessed. The simulation results revealed higher flow of reactive power and current. Furthermore, non-sinusoidal waveforms produced from the simulated results revealed that a high degree of compensation was needed at the examined bus.

Moses et al. [7] suggest a technique for determining the optimal point of injection node of the recently commissioned 216-MW Kribi natural gas thermal plant in Cameroon, based on the minimization of the whole network power losses into an existing grid The southern interconnected grid (SIG) of Cameroon was utilized as a case study to validate the advantages of using the recommended methodology. The SIG of Cameroon comprises of 34 busbars of which one (01) is the slack busbar, eleven (11) are voltage-controlled busbars and twenty-two (22) are load busbars. With two hydropower stations in Songloulou (384 MW) and Edea (264 MW), and three main thermal plants in Limbe (84 MW), Dibamba (86 MW) and the lastly commissioned 216-MW Kribi gas power plant. The new power plant was connected to all the buses on the grid and the respective associated losses were acquired through load flow. Simulation results indicate that node 20 which is Logbaba shows the minimum overall relative loss of 16.14 % with improved voltage profile in the network and thereby making 149.13 MW accessible to the consumers. Therefore, node 20 was chosen as the optimal point of connecting the new incoming power station.

Akwukwuegbu et al. [8] performed a comparative power flow analysis of 28 and 52 buses for 330 kV power grid network in Nigeria using Newton-Raphson method. Data for the respective bus systems were obtained from the Power Holding Company of Nigeria (PHCN). The real and the reactive total load for the 28-bus network was 2096.753 MW and 1979.95 Mvar respectively while that of the 52-bus network was 3000 MW and 2250 MVAr respectively. The respective networks were modelled and simulated using MATLAB/SIMULINK and PSAT. The results obtained revealed that, all the buses of the 28-bus network experienced voltage violations (i.e., voltage profiles outside the acceptable range of 0.95 pu to 1.05 pu) while the critical buses of the 52-bus network falls within the acceptable range. Weak buses identified in the 28-bus network were bus 3 (Kainji GS), bus 5 (Sapele PS) and bus 21 (Onitsha TS) with voltage magnitudes of 0.43687 pu, 0.4811 pu and 0.60515 pu respectively. The 52-bus network presented an improved voltage profile and better power quality. Recommendations were made for the Nigerian 330 kV power network to be upgraded to 52-bus network.

Okakwu et al. [9] carried out an analysis on the load flow evaluation of the Nigeria 330 kV power grid. The network is made up of 32 buses, 11 generating plant and 36 transmission lines. The study of the network was based on Newton-Raphson iteration method. MATLAB/SIMULINK software was used for the simulation. The results acquired revealed voltage violations of some of the buses which were operating outside the acceptable of 0.95-1.05 pu (i.e., 313.5-346.5 kV). The buses affected include buses 16 (Kano, 0.8721 pu), 17 (Kaduna, 0.9046 pu), 18 (Jos, 0.8580 pu), 19 (Gombe, 0.8735 pu) and 21 (Katampe, 0.9167 pu). The total loss recorded is active power l 268.622 MW and that of reactive power amounted to 2247.42 Mvar. It was therefore, concluded that the present Nigerian 330 kV grid network is plagued with high losses on the transmission line that requires adequate reparation using reactive power support of Flexible Alternating Current Transmission Systems (FACTS) strategies for efficient operation of the line.

Idoniboyeobu and Ibeni [10] worked on the analysis for electrical load flow studies in Port Harcourt, Nigeria, using Newton-Raphson Fast Decoupled techniques. The research was carried on Port Harcourt town zone 4, Rivers state power distribution network. The analysis was aimed at solving the problem of frequent power outages caused by heavy I^2R losses in the line on the Port Harcourt Town 33 kV Distribution network. MATLAB codes were written to solve the static load flow equations formulated using Fast decoupled and Newton-Raphson algorithm based on the benefits of time and digital computer memory space. Electrical Transient Analyser Program (ETAP) software was also used to model and simulate the network for comparative purpose. The bus voltages, phase angles, network losses, branch real and reactive power flow were obtained. It was observed that, results obtained using MATLAB and ETAP were similar. The net power received were 130.412 MW and 84.28 MVAr after injecting capacitor banks to buses that experienced low voltage implemented in MATLAB environment while the net real and reactive power received using ETAP software were 126.7 MW and 93.8 MVAr respectively. The total line losses on the network reduced from 4.7512 MW and 10.0517 MVAr to 3.5821 MW and 7.5785 MVAr respectively. A 24.6% reduction of the total real power losses was realized after injection of reactive power into the under-voltage buses, the bus voltage profiles were normalized.

The paper by Airoboman and Tyo [11] worked on the power flow analysis of Maryland transmission station located in Lagos state, Nigeria. The analysis was carried out employing the Newton Raphson Algorithm implemented via ETAP software (version 12.6). The location was chosen because of the sensitivity of Lagos state in terms of its economic activities in Nigeria. Results obtained from the load flow revealed that the network is associated with voltage violations at load1 bus, load3 bus and load5 bus with magnitudes of 94.51 %, 94.91 % and 94.79 % respectively. Consequently, transformers denoted as T2A and T3A experienced the highest and lowest branch losses of 150.0 kW and 18.2 kW respectively. Losses compensation along the lines was done using optimal capacitor placement (OCP) subjected to constraints on the ETAP environment. The results from the OCP revealed that four capacitor banks were optimally sized and placed on four of the candidate buses, which include load1 bus, load2 bus, load3 bus and load5 bus. An improvement of 2.26 %, 1.12 %, 1.93 %, 1.12 % and 2.01 % were recorded for load1 bus, load2 bus, load3 bus, load4 bus and load5 bus respectively.

Ajibola et al. [12] proposed a new and simplified technique aimed at improving the efficiency and output of hydroelectric power plant especially during dry and drought season using Shiroro dam as a case study which is aimed at ensuring an optimum electricity generation throughout the year. In this regard, a pumped storage system was introduced into the hydroelectric power system in order to ensure continuous and adequate water supply from the available water reservoir. Simple mathematical models which include linear programming and statistical analysis were employed to analyse the important parameters using the obtained data from Shiroro power plant. The result obtained from the study revealed that the viability of the pumped storage system for hydroelectric power generation. Integration of the pumped storage system to hydroelectric power system would proffer solution to the epileptic power supply in Nigeria.

Fakehinde et al. [13] surveyed the feasibility of hydroelectric as a viable form of energy and the immense contribution it can offer to the energy industry in Nigeria. Besides other source of energy that will speed up better usage of renewable energy was discussed. It was discovered at the end of the study that both hydroelectric energy and solar energy will play vital roles in the actualization of stable and viable energy need of Nigeria in the likely future.

Imo et al. [14] carried out a study on the impact of small hydropower developments on rural transformation in Nigeria. It has been observed that the rural settlement which constitutes about seventy percent of the Nigerian's population has not been given serious attention in terms of development. The challenge has been identified to be as a result of the non-sustainability policy action of the government towards the rural inhabitants. Driving rural economy through hydropower was recommended as this would greatly reduce the rural-urban migration.

The following research gaps were observed in the works reviewed.

- No extensive work had been done on the impact assessment on the injection of Mambilla power plant to the NNG.
- Focus has been given to the operation of small hydro power schemes despite the huge potential of the large ones.
- Also, most of the analyses were done on the old national grid system which does not really reflect the present network status.

3. Methodology

In order to carry out the analysis, the required data was obtained from the National Control Centre, Osogbo. Data collated include the Single Line Diagram (SLD), Line and Bus data of the 330 kV 64 bus system of the Nigerian National Grid (NNG). Newton Raphson load flow analysis technique was employed in performing the analysis. MATLAB software (version 2020b) was utilized for the implementation. Three scenarios were considered during the analysis. These include the following:

(a) Base case scenario (i.e., load flow analysis without Mambilla power plant injected)
(b) Mambilla power plant injected at Makurdi bus
(c) Mambilla power plant injected at Jalingo bus

The SLD of the network without the Mambilla power plant injected is depicted in Fig. 1 while the SLD showing the injection of the Mambilla power plant at Makurdi and Jalingo buses are represented by Fig. 2 and Fig. 3 respectively. The line data, bus data and bus names are contained in Table 1, Table 2 and Table 3 respectively.

3.1. Overview of the Nigerian National Grid

The Nigerian 330 kV power networks for this study consist of 64 buses/nodes, 23 (PV) generators, 41 load (PQ) buses and 91 transmission lines as depicted in Fig. 1. In this study, the Egbin power station was considered as the swing bus because of its higher installed and generating capacity. The network has a total real and reactive load demand of 4763.7 MW and 2903.91 MVAr respectively.

3.2. Newton-Raphson Method of Load flow Analysis

Newton-Raphson (N-R) load flow technique has faster convergence ability when compared with other conventional methods of power flow analysis. It needs less computer memory for a large power system and increases linearly with respect to the size of the network. The N-R method is an iterative method in which a Jacobian matrix has to be formed at every step to solve for the corrections. On the application of Taylor's series to equations (1) and (2), expanding and neglecting the higher-order values, the following equations are obtained:

$$P_i = \sum_{\substack{j=1 \\ j\neq i}}^{n} |Y_{ij}||V_i||V_j| \cos(\theta_{ij} + \delta_j - \delta_i) \tag{1}$$

$$Q_i = -\sum_{\substack{j=1 \\ j\neq i}}^{n} |Y_{ij}||V_i||V_j| \sin(\theta_{ij} + \delta_j - \delta_i) \tag{2}$$

Where; Y is the admittance, V is the voltage profile and δ is the phase angle.

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 J_2 \\ J_3 J_4 \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta|V| \end{bmatrix} \tag{3}$$

The expressions $J_1,\ J_2,\ J_3\ and\ J_4$ are elements of the Jacobian matrix (J) and are represented as:

$$\mathrm{J}_1 = \left[\frac{\partial P}{\partial \delta}\right];\ J_2 = \left[\frac{\partial Q}{\partial \delta}\right];\ J_3 = \left[\frac{\partial P}{\partial |V|}\right];\ J_4 = \left[\frac{\partial Q}{\partial |V|}\right]$$

$$\therefore J = \begin{bmatrix} \frac{\partial P}{\partial \delta} & \frac{\partial P}{\partial |V|} \\ \frac{\partial Q}{\partial \delta} & \frac{\partial Q}{\partial |V|} \end{bmatrix} \tag{4}$$

The Jacobian element is then computed using partial derivative of equations (1) and (2) and are given as:

$$J_1 = \left[\frac{\partial P}{\partial \delta}\right] = \begin{bmatrix} \frac{\partial P_i}{\partial \delta_i} & \cdots & \frac{\partial P_i}{\partial \delta_n} \\ \vdots & \ddots & \vdots \\ \frac{\partial P_n}{\partial \delta_i} & \cdots & \frac{\partial P_n}{\partial \delta_n} \end{bmatrix} \tag{5}$$

$$J_2 = \left[\frac{\partial Q}{\partial \delta}\right] = \begin{bmatrix} \frac{\partial Q_i}{\partial \delta_i} & \cdots & \frac{\partial Q_i}{\partial \delta_n} \\ \vdots & \ddots & \vdots \\ \frac{\partial Q_n}{\partial \delta_i} & \cdots & \frac{\partial Q_n}{\partial \delta_n} \end{bmatrix} \tag{6}$$

$$J_3 = \left[\frac{\partial P}{\partial |V|}\right] = \begin{bmatrix} \frac{\partial P_i}{\partial |V_i|} & \cdots & \frac{\partial P_i}{\partial |V_n|} \\ \vdots & \ddots & \vdots \\ \frac{\partial P_n}{\partial |V_i|} & \cdots & \frac{\partial P_n}{\partial |V_n|} \end{bmatrix} \tag{7}$$

$$J_4 = \left[\frac{\partial Q}{\partial |V|}\right] = \begin{bmatrix} \frac{\partial Q_i}{\partial |V_i|} & \cdots & \frac{\partial Q_i}{\partial |V_n|} \\ \vdots & \ddots & \vdots \\ \frac{\partial Q_n}{\partial |V_i|} & \cdots & \frac{\partial Q_n}{\partial |V_n|} \end{bmatrix} \tag{8}$$

Table 1 Line data.

From	To	R(pu)	X(pu)	B/2(pu)	Tap
8	7	0.0029	0.0205	0.308	1
7	17	0.0155	0.0172	0.257	1
7	12	0.009	0.007	0.104	1
7	11	0.0155	0.0172	0.104	1
9	7	0.006	0.007	0.104	1
9	10	0.0291	0.0349	0.437	1
17	2	0.0126	0.0139	0.208	1
17	3	0.0341	0.0416	0.521	1
17	5	0.0291	0.0349	0.437	1
5	6	0.0155	0.0172	0.257	1
5	43	0.006	0.007	0.257	1
3	2	0.0126	0.0139	0.208	1
43	44	0.0155	0.0172	0.257	1
44	45	0.0155	0.0172	0.257	1
12	14	0.0155	0.0172	0.065	1
12	13	0.016	0.019	0.239	1
12	11	0.006	0.007	0.308	1
12	23	0.016	0.019	0.239	1
53	40	0.035	0.0419	0.524	1
13	40	0.0155	0.0172	0.257	1
23	1	0.006	0.0007	0.308	1
23	22	0.0205	0.0246	0.308	1
30	29	0.0786	0.0942	1.178	1
23	26	0.0705	0.0779	1.162	1
23	56	0.0126	0.0139	0.208	1
27	55	0.016	0.019	0.239	1
45	46	0.0636	0.0763	0.954	1
45	47	0.0347	0.0416	0.521	1
47	50	0.049	0.056	0.208	1
51	50	0.016	0.019	0.239	1
50	52	0.016	0.019	0.365	1
33	27	0.0126	0.0139	0.208	1
26	23	0.0126	0.0139	0.208	1
26	62	0.0786	0.0942	1.178	1
61	23	0.0786	0.0942	1.178	1
24	23	0.0126	0.0139	0.208	1
24	62	0.0126	0.0139	0.208	1
24	25	0.0155	0.0172	0.257	1
32	23	0.016	0.019	0.239	1
32	31	0.016	0.019	0.239	1
22	14	0.016	0.019	0.239	1
39	54	0.067	0.081	1.01	1
54	42	0.0245	0.0292	1.01	1
30	29	0.0156	0.0172	0.257	1
29	35	0.0155	0.0172	0.257	1
37	36	0.0341	0.0416	0.521	1
36	54	0.024	0.0292	0.365	1
36	35	0.0398	0.0477	0.597	1
29	39	0.0398	0.0477	0.521	1
56	29	0.0155	0.0172	0.257	1
27	4	0.0398	0.0477	0.597	1
4	3	0.0126	0.0139	0.208	1
28	27	0.0155	0.0172	0.257	1
35	29	0.0341	0.0416	0.521	1
38	63	0.002	0.0022	0.033	1
33	35	0.0205	0.0246	0.308	1
60	34	0.062	0.0702	0.927	1
58	34	0.049	0.0599	0.927	1

Table 1 Line data (Cont'd).

From	To	R(pu)	X(pu)	B/2(pu)	Tap
57	34	0.002	0.0022	0.308	1
44	48	0.058	0.0699	0.874	1
48	49	0.0249	0.0292	0.364	1
48	47	0.0205	0.0246	0.308	1
43	42	0.024	0.0292	0.365	1
42	41	0.0205	0.0246	0.308	1
41	39	0.006	0.007	0.104	1
14	64	0.006	0.007	0.104	1
14	22	0.0205	0.0246	0.257	1
14	12	0.016	0.019	0.239	1
1	21	0.0341	0.0416	0.239	1
14	16	0.067	0.081	1.01	1
14	15	0.0205	0.0246	0.308	1
18	19	0.0126	0.0139	0.208	1
1	18	0.0155	0.0172	0.257	1
1	64	0.0155	0.0172	0.257	1
1	14	0.0155	0.0172	0.065	1
1	23	0.016	0.019	0.239	1
59	13	0.006	0.007	0.308	1
59	14	0.016	0.019	0.239	1
39	36	0.035	0.0419	0.524	1
36	37	0.0155	0.0172	0.257	1
36	38	0.006	0.0007	0.308	1
36	33	0.0205	0.0246	0.308	1
33	34	0.0786	0.0942	1.178	1
52	50	0.0705	0.0779	1.162	1
52	35	0.0126	0.0139	0.208	1
52	29	0.016	0.019	0.239	1
29	39	0.0636	0.0763	0.954	1
23	14	0.0347	0.0416	0.521	1
14	20	0.049	0.056	0.208	1
14	21	0.016	0.019	0.239	1
20	13	0.016	0.019	0.365	1

Thus, by raising all the partial derivatives in the matrix of equations (5), (6), (7) and (8) to the power of 'k', equation (9) is obtained:

$$\begin{bmatrix} \Delta P_i^k \\ \vdots \\ \Delta P_n^k \\ \Delta Q_i^k \\ \vdots \\ \Delta Q_n^k \end{bmatrix} = \begin{bmatrix} \begin{bmatrix} \frac{\partial P_i}{\partial \delta_i} & \cdots & \frac{\partial P_i}{\partial \delta_n} \\ \vdots & \ddots & \vdots \\ \frac{\partial P_n}{\partial \delta_i} & \cdots & \frac{\partial P_n}{\partial \delta_n} \end{bmatrix}^{(k)} & \begin{bmatrix} \frac{\partial P_i}{\partial |V_i|} & \cdots & \frac{\partial P_i}{\partial |V_n|} \\ \vdots & \ddots & \vdots \\ \frac{\partial P_n}{\partial |V_i|} & \cdots & \frac{\partial P_n}{\partial |V_n|} \end{bmatrix}^{(k)} \\ \begin{bmatrix} \frac{\partial Q_i}{\partial \delta_i} & \cdots & \frac{\partial Q_i}{\partial \delta_n} \\ \vdots & \ddots & \vdots \\ \frac{\partial Q_n}{\partial \delta_i} & \cdots & \frac{\partial Q_n}{\partial \delta_n} \end{bmatrix}^{(k)} & \begin{bmatrix} \frac{\partial Q_i}{\partial |V_i|} & \cdots & \frac{\partial Q_i}{\partial |V_n|} \\ \vdots & \ddots & \vdots \\ \frac{\partial Q_n}{\partial |V_i|} & \cdots & \frac{\partial Q_n}{\partial |V_n|} \end{bmatrix}^{(k)} \end{bmatrix} \begin{bmatrix} \Delta \delta_i^k \\ \vdots \\ \Delta \delta_n^k \\ \Delta |V_i|^k \\ \vdots \\ \Delta |V_n|^k \end{bmatrix} \tag{9}$$

The linear relationship between changes in the phase angle $\Delta\delta_i^k$ and change in magnitude of bus voltage $\Delta|V_i|^k$ with little changes in active and reactive power $\Delta P_i^k \, and \, \Delta Q_i^k$ has been given by the Jacobian matrix (J).

The diagonal and off diagonal elements of J_1 are

$$\frac{\partial P_i}{\partial \delta_i} = \sum_{j \neq 1}^{n} |Y_{ij}||V_i||V_j| \sin(\theta_{ij} + \delta_j - \delta_i) \tag{10}$$

$$\frac{\partial P_i}{\partial \delta_j} = -\sum_{\substack{j=1 \\ j \neq i}}^{n} |Y_{ij}||V_i||V_j| \sin(\theta_{ij} + \delta_j - \delta_i) \tag{11}$$

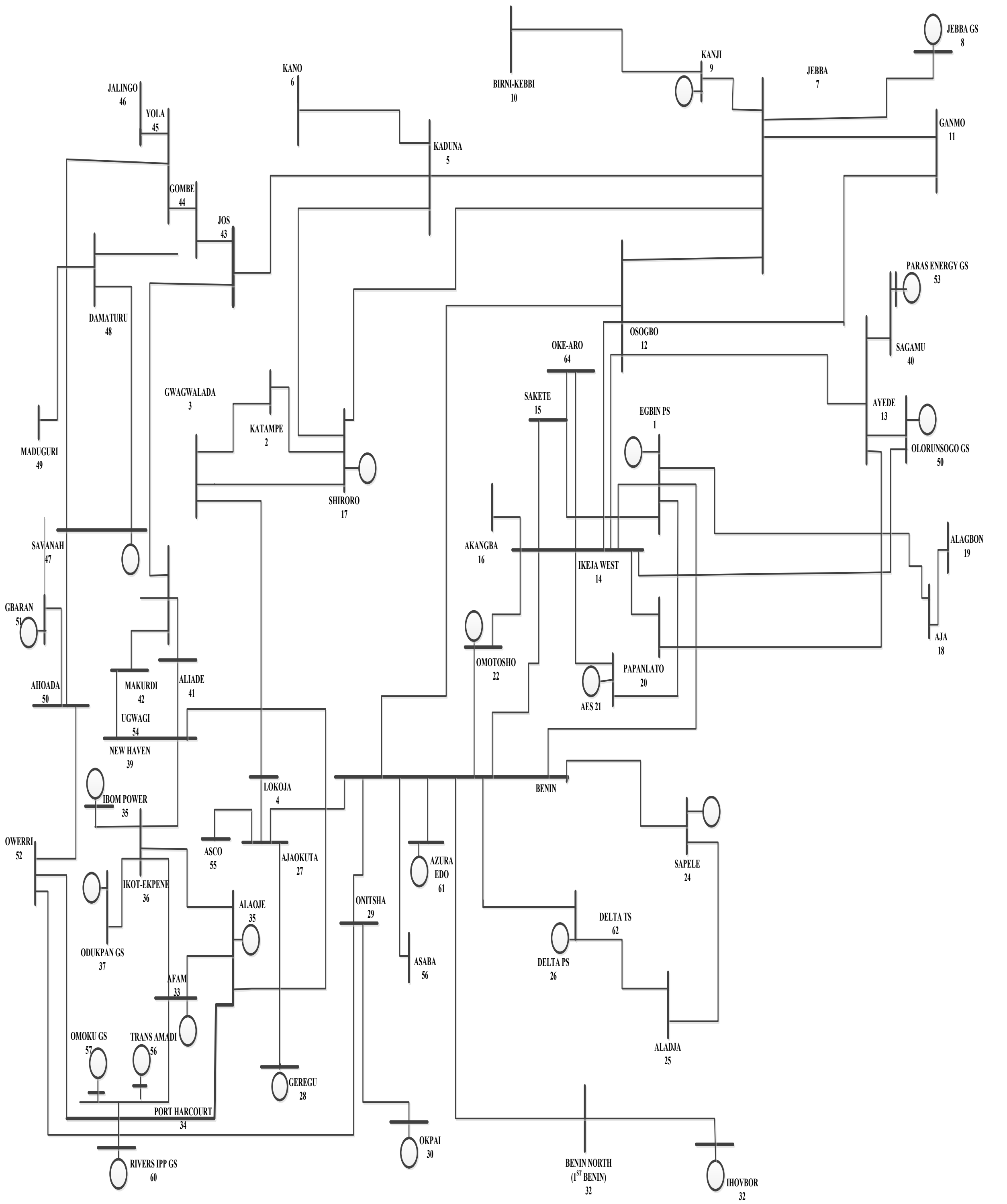

Fig. 1 Single line diagram of the Nigerian national grid.

The diagonal and off-diagonal elements of J_2 are

$$\frac{\partial P_i}{\partial |V_i|} = 2|V_i||Y_{ii}|cos\theta_{ii} + \sum_{j\neq i}^{n}|Y_{ij}||V_i||V_j|\cos(\theta_{ij} + \delta_j - \delta_i) \quad (12)$$

$$\frac{\partial P_i}{\partial |V_j|} = |Y_{ij}||V_i|\,cos(\theta_{ij} + \delta_j - \delta_i)\,, j \neq i \quad (13)$$

The diagonal and off diagonal elements of J_3 are

$$\frac{\partial Q_i}{\partial \delta_i} = \sum_{\substack{j=1 \\ j\neq i}}^{n}|Y_{ij}||V_i||V_j|\,cos(\theta_{ij} + \delta_j - \delta_i) \quad (14)$$

$$\frac{\partial Q_i}{\partial \delta_j} = -|Y_{ij}||V_i||V_j|\,cos(\theta_{ij} + \delta_j - \delta_i)\,, j \neq i \quad (15)$$

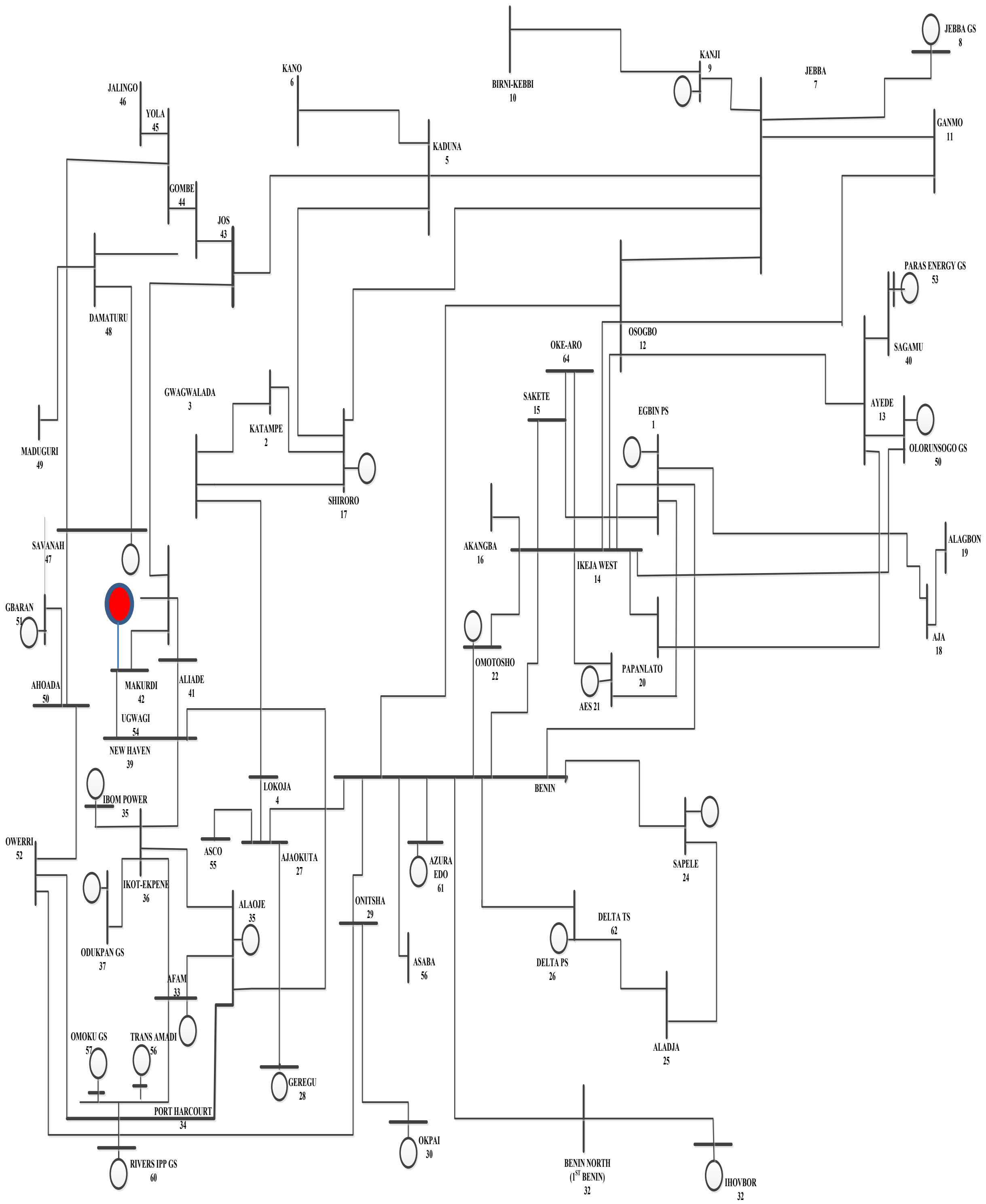

Fig. 2 Single line diagram of the Nigerian national grid with Mambilla power plant injected at Makurdi bus.

The diagonal and off diagonal element of J_4 are

$$\frac{\partial Q_i}{\partial |V_i|} = -2|V_i||Y_{ii}|sin\theta_{ii} - \sum_{j\neq i}^{n}|Y_{ij}||V_i||V_j|\,sin(\theta_{ij} + \delta_j - \delta_i) \qquad (16)$$

$$\frac{\partial Q_i}{\partial |V_j|} = -|Y_{ij}||V_i|\,sin(\theta_{ij} + \delta_j - \delta_i)\,, j \neq i \qquad (17)$$

The expressions ΔP_i^k and ΔQ_i^k are the difference between the schedule and calculated power residuals referred to as the mismatch.

$$\Delta P_i^k = P_i^{sc} - P_i^k \qquad (18)$$

$$\Delta Q_i^k = Q_i^{sc} - Q_i^k \qquad (19)$$

Where P_i^{sc} is the schedule real power at bus i. Q_i^{sc} is the scheduled reactive power at bus i, while P_i^k and Q_i^k are the calculated real and reactive power of the bus. Thus, the voltage magnitude $|V_i|^k$ and phase angle δ_i^k are obtained from Jacobian matrix and the power residuals.

The voltage magnitude and the angle computed are:

$$\left|V_i^{(k+1)}\right| = \left|V_i^{(k)}\right| + \Delta \left|V_i^{(k)}\right| \tag{20}$$

$$\delta_i^{(k+1)} = \delta_i^{(k)} + \Delta\delta_i^{(k)} \tag{21}$$

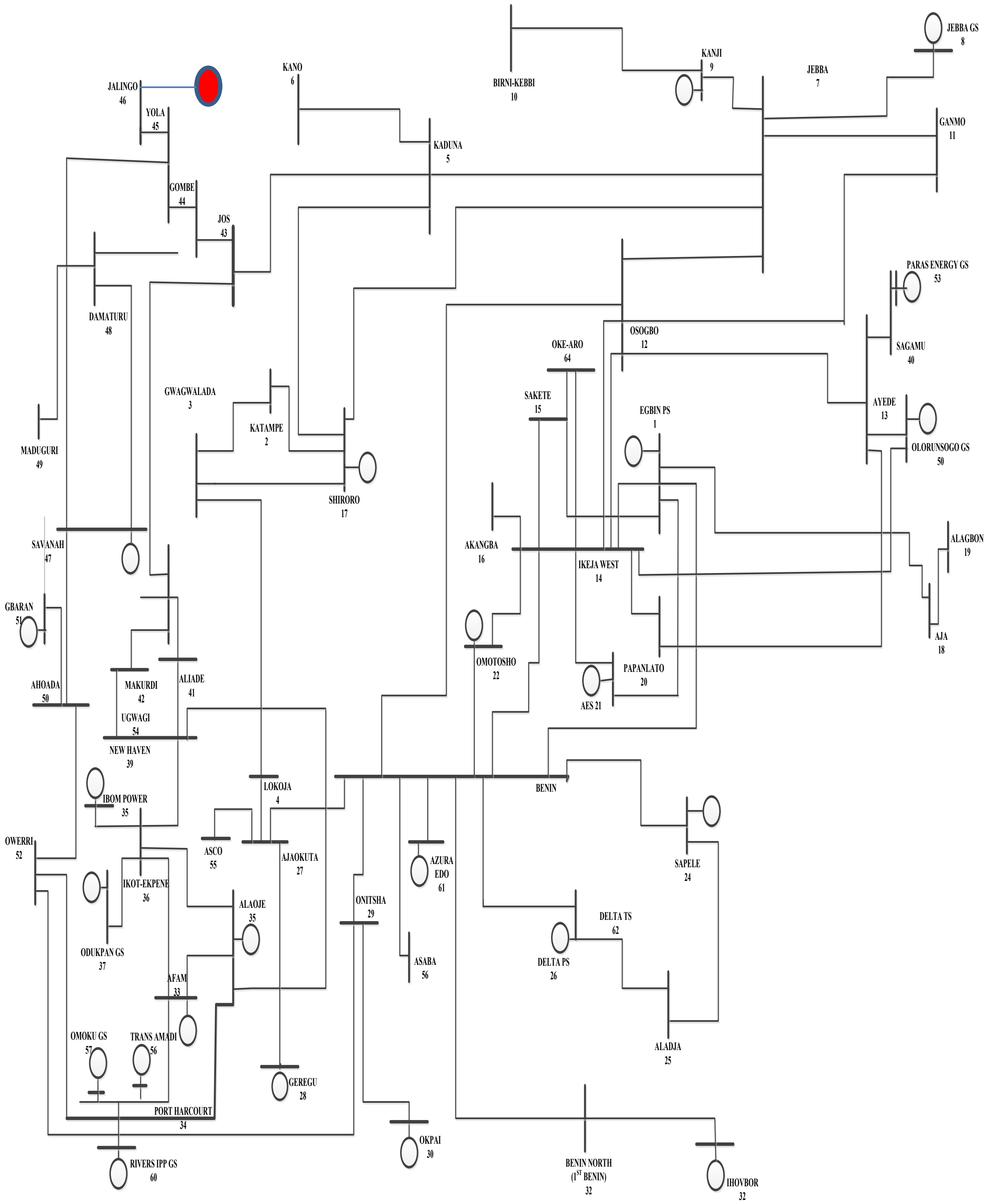

Fig. 3 Single line diagram of the Nigerian national grid with Mambilla power plant injected at Jalingo bus.

Table 2 Bus data.

Bus	Type	Vsp	Theta	PGi	PQi	PLi	QLi	Q_{min}	Q_{max}
1	1	1	0	0	0	0	0	-200	200
2	3	1	0	0	0	20	100	0	0
3	3	1	0	0	0	180	90	0	0
4	3	1	0	0	0	20	10	0	0
5	3	1	0	0	0	60	30	0	0
6	3	1	0	0	0	20.6	10.3	0	0
7	3	1	0	0	0	20	10	0	0
8	2	1	0	422	210	0	0	-90	300
9	2	1	0	278	334	7	3.5	-250	460
10	3	1	0	0	0	114.5	85.9	0	0
11	3	1	0	0	0	120	60	0	0
12	3	1	0	0	0	250	25	0	0
13	3	1	0	0	0	75.8	35	0	0
14	3	1	0	0	0	33.2	316	0	0
15	3	1	0	0	0	240	120	0	0
16	3	1	0	0	0	184.7	10.5	0	0
17	2	1	0	368	323	68.9	51.7	-279	400
18	3	1	0	0	0	274.4	37	0	0
19	3	1	0	0	0	136	84	0	0
20	3	1	0	0	0	80	40	0	0
21	2	1	0	0	0	0	0	0	0
22	2	1	0	0	0	179	89.5	0	0
23	3	1	0	0	0	383.3	92	0	0
24	2	1	0	172.9	389	20.6	15.4	-100	420
25	3	1	0	0	0	96.5	48.5	0	0
26	2	1	0	467	234	0	0	-150	360
27	3	1	0	0	0	25	2.5	0	0
28	2	1	0	396	198	20	10	-200	220
29	3	1	0	0	0	84.6	92	0	0
30	2	1	0	176	385	50	25	-78	500
31	3	1	0	0	0	80	49.6	0	0
32	2	1	0	395.7	48	20	10	-45	50
33	2	1	0	3417	208.5	52.5	9.4	-210	300
34	3	1	0	0	0	16	58	0	0
35	2	1	0	0	0	65	33	0	0
36	3	1	0	0	0	50	76	0	0
37	2	1	0	306.9	183	70.5	5.11	-160	260
38	2	1	0	376.7	338	250	25	-50	400
39	3	1	0	0	0	80	90	0	0
40	3	1	0	0	0	72	45	0	0
41	3	1	0	0	0	38	84	0	0
42	3	1	0	0	0	90	45	0	0
43	3	1	0	0	0	20	10	0	0
44	3	1	0	0	0	30.6	65	0	0
45	3	1	0	0	0	100	50	0	0
46	3	1	0	0	0	70	50	0	0
47	3	1	0	0	0	80	40	0	0
48	3	1	0	0	0	70	35	0	0
49	3	1	0	0	0	45	80	0	0
50	3	1	0	0	0	90	45	0	0
51	2	1	0	0	0	100	50	0	0
52	3	1	0	0	0	240	120	0	0
53	2	1	0	262	371	0	0	-32	400
54	3	1	0	0	0	20	60	0	0
55	2	1	0	0	0	0	0	0	0
56	3	1	0	0	0	60	30	0	0
57	2	1	0	66	373	0	0	-34	400
58	2	1	0	346.1	323	0	0	-24	400
59	2	1	0	363.9	81.9	40	20	-82	200
60	2	1	0	385	372.5	0	0	-72.5	400
61	2	1	0	371	135	0	0	-135	200
62	3	1	0	0	0	80	90	0	0
63	3	1	0	0	0	20	60	0	0
64	3	1	0	0	0	50	75	0	0

Table 3 Bus names.

Bus	Bus Name
1	Egbin PS
2	Katampe
3	Gwagwalada
4	Lokoja
5	Kaduna
6	Kano
7	Jebba
8	Jebba GS
9	Kainji GS
10	Birnin Kebbi
11	Ganmo
12	Oshogbo
13	Ayede
14	Ikeja West
15	Sakete
16	Akangba
17	Shiroro
18	Aja
19	Alagbon
20	Papalanto
21	AES GS
22	Omotosho GS
23	Benin
24	Sapele GS
25	Aladja
26	Delta PS
27	Ajaokuta
28	Geregu GS
29	Onitsha
30	Okpai GS
31	Benin North
32	Ihovbor GS
33	Afam GS
34	Port Harcourt
35	Alaoji GS
36	Ikot-Ekpene
37	Odukpani GS
38	Calabar GS (Ibom Power)
39	New Haven
40	Sagamu
41	Alaide
42	Makurdi
43	Jos
44	Gombe
45	Yola
46	Jalingo
47	Savannah
48	Damaturu
49	Maiduguri
50	Ahoada
51	Gberain GS
52	Owerri
53	Paras Energy GS
54	Ugwuaji
55	ASCO GS
56	Asaba
57	Omoku GS
58	Trans Amadi GS
59	Olorunsogo GS
60	River IPP GS
61	Azura Edo GS
62	Delta TS
63	Calabar TS
64	Oke – Aro

Given these, the new values of active and reactive power are obtained using equations (1) and (2) respectively, concurrently, the new values of the Jacobian matrix are obtained using equations (10) to (17) and also the new values of the bus voltages and phase angles are obtained and the process is continued until the residuals $\Delta P_i^k and\ \Delta Q_i^k$ are less than the specified accuracy, i.e.,

$$\left|\Delta P_i^k\right| \leq \varepsilon \tag{22}$$

$$\left|\Delta Q_i^k\right| \leq \varepsilon \tag{23}$$

The system line losses are computed using equations (24), (25) and (26):

$$S_{ik} = V_i(V_i^* - V_k^*)Y_{ik}^* \tag{24}$$

$$S_{ki} = V_k(V_k^* - V_i^*)Y_{ki}^* \tag{25}$$

$$S_{Loss} = S_{ik} - S_{ki} \tag{26}$$

Where; V_i is voltage at bus i, V_k is voltage at bus k, S_{ik} is line flow from bus i to k, S_{ki} is line flow from bus k to i, and S_{Loss} is the system losses.

The flow chart for the Newton Raphson load flow algorithm is as shown in Fig. 4.

3.3. *Injecting Mambilla Power Plant to the Nigerian National Grid*

The incoming power plant was connected to all the buses of the existing grid closer to it (which in this case is the Makurdi and Jalingo bus as proposed from the Mambilla design) except the slack bus. The slack bus remains the reference bus throughout the process. This is done with the following consideration and modifications:

(a) If the point of injection is at a PV bus, then it will remain a PV bus. The generated active and reactive powers by the new plant will be added to the values of the existing grid network. The voltage profile of the bus on the other hand remains same before connection was made.

(b) If the point of injection is at a PQ bus, it will automatically be converted into a PV bus. The generated active and reactive powers of the PV bus subsequently obtained will be those of the incoming plant; the active and reactive powers consumed at the bus remain the same as the values prior to the connection of the new plant. However, the number of PV buses increases by one leading to a reduction of PQ buses by one.

(c) For each scenario, the network losses are obtained through load flow analysis. The node with the least losses is however, determined and considered as the optimum point of connection.

The flow chart of the process is shown in Fig. 5.

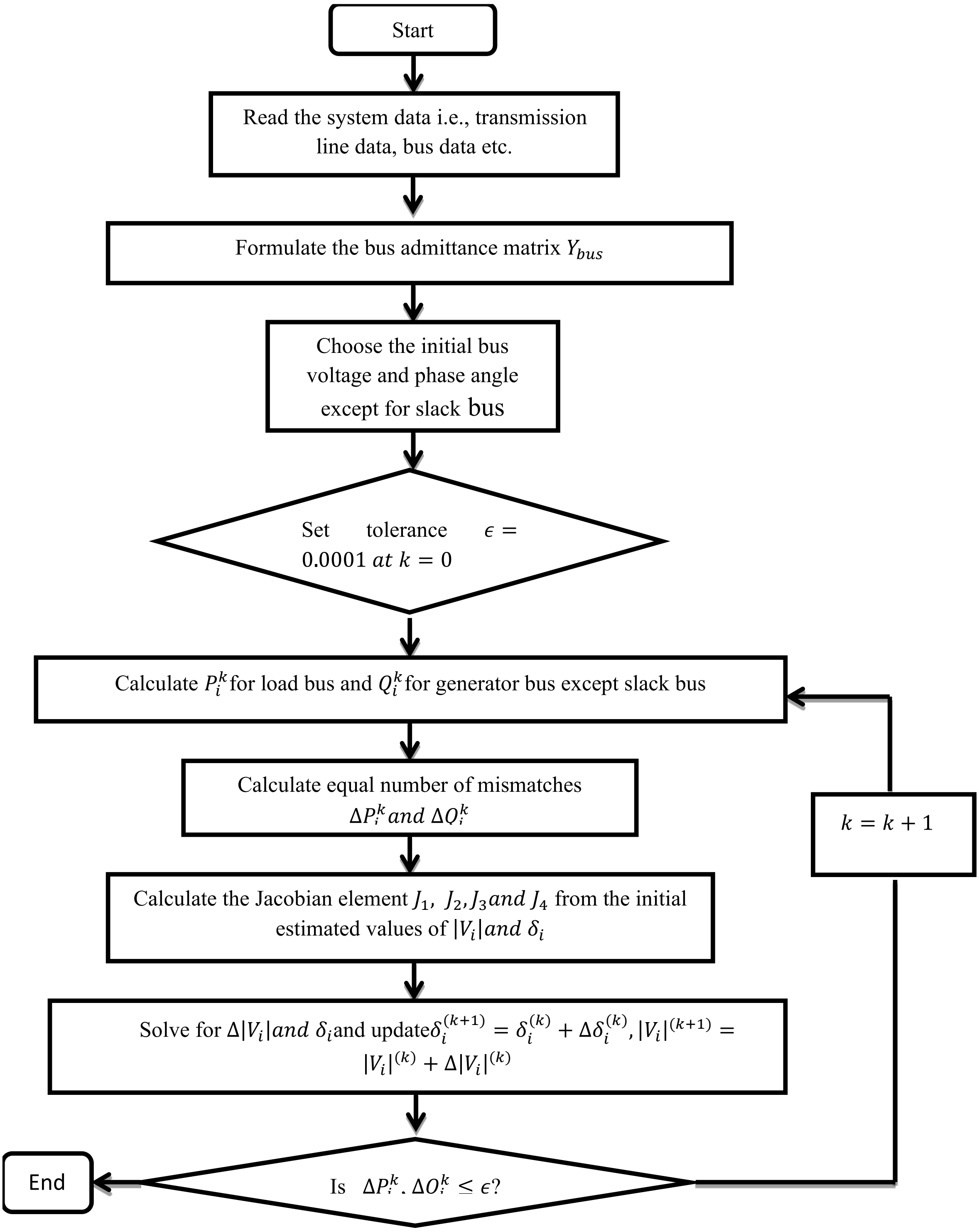

Fig. 4 Flow chart for Newton Raphson load flow solution.

3.4. *Total Voltage Deviation (TVD)*

Voltage deviation is the difference obtained between the nominal voltage and the actual voltage. When the deviation is smaller, the better the voltage condition of the network. A TVD index is obtained as the sum of the squared value of the absolute voltage difference between the nominal voltage and the actual voltage for all buses in the network.

$$TVD = \sum_{i=1}^{N} |V_n - V_i|^2 \quad (27)$$

Where N is the total number of buses, V_n is the nominal voltage and V_i is actual voltage at bus i.

4. Results and Discussion

Simulation was performed for three scenarios (i.e., Base case, Mambilla injected at Makurdi and Jalingo buses). Simulation carried out without the Mambilla power plant represents the base case scenario. Results obtained after different simulations are presented (Tables 4 – 5, and Fig. 6).

4.1. Load Flow for Base Case Scenario

Table 4 contained the power flow result of the base case scenario. This result represents the voltage magnitude and phase angles of the buses. It can be observed from the results that, most of the buses are operating outside the acceptable limit of 0.95pu to 1.05pu. The buses operating outside the acceptable limits are bus 2, bus 3, bus 4, bus 5, bus 6, bus 10, bus 15, bus 16, bus 18, bus 19, bus 42, bus 43, bus 44, bus 45, bus 46, bus 47, bus 48, bus 49, bus 50 and bus 52 with voltage magnitude of 0.9343pu, 0.8898pu, 0.8621pu, 0.9497pu, 0.9487pu, 0.9335pu, 0.8760pu, 0.8463pu, 0.8801pu, 0.8485pu, 0.9460pu, 0.9406pu, 0.9178pu, 0.9022pu, 0.8665pu, 0.8888pu, 0.8819pu, 0.8503pu, 0.9312pu and 0.9344pu respectively. Negative reactive power generated implies that reactive power is flowing from the utility grid to the generator. This occurs when the generator is under-excited or if an induction generator is being used. Table 5 contained the line flow and losses associated with the base case. The real and reactive power loss of 3504.040 MW and 4076.769 MVAr was experienced by the network. Fig. 6 depicts the graphical representation of the voltage profile for base case. This represents a pictorial representation of the voltage magnitude of the respective buses.

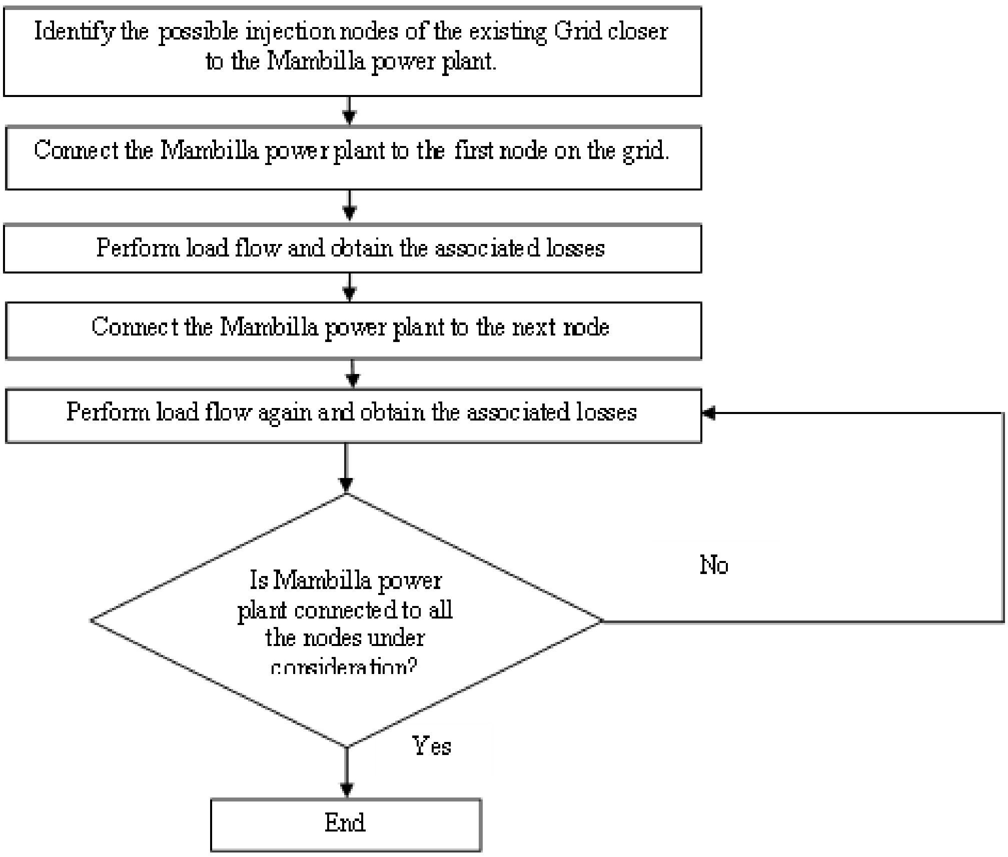

Fig. 5 Flow chart of injecting Mambilla power plant to the grid.

Table 4 Power flow result for base case scenario.

Bus No.	V(pu) (pu)	Angle (Deg)	Injection		Generation		Load	
			MW	MVAr	MW	MVAr	MW	MVAr
1	1.0000	0	-506.89	1348.97	-506.89	1348.97	0	0
2	0.9343	4.7751	-20	-100	0	0	20	100
3	0.8898	9.6378	-180	-90	0	0	180	90
4	0.8621	20.6762	-20	-10	0	0	20	10
5	0.9497	3.9771	-60	-30	0	0	60	30
6	0.9487	3.6253	-20.6	-10.3	0	0	20.6	10.3
7	0.9915	6.9602	-20	-10	0	0	20	10
8	1.0500	15.5846	422	-243.43	422	-243.43	0	0
9	1.0000	7.589	271	78.127	278	81.627	7	3.5
10	0.9335	6.6025	-114.5	-85.9	0	0	114.5	85.9
11	0.9770	6.8467	-120	-60	0	0	120	60
12	0.9786	7.2937	-250	-25	0	0	250	25
13	0.9996	8.5904	-75.8	-35	0	0	75.8	35
14	0.9603	7.9168	-33.2	-316	0	0	33.2	316
15	0.8760	5.24	-240	-120	0	0	240	120
16	0.8463	-5.6789	-184.7	-10.5	0	0	184.7	10.5
17	0.9700	9.8543	299.1	-136.85	368	-85.149	68.9	51.7
18	0.8801	5.8414	-274.4	-37	0	0	274.4	37
19	0.8485	5.0582	-136	-84	0	0	136	84
20	0.9821	7.6411	-80	-40	0	0	80	40
21	0.9700	8.2059	0	2.81	0	2.81	0	0
22	0.9500	8.1748	-179	-173.23	0	-83.729	179	89.5
23	0.9918	10.166	-383.3	-92	0	0	383.3	92
24	1.0100	9.5939	152.3	18.805	172.9	34.205	20.6	15.4
25	0.9908	8.8501	-96.5	-48.5	0	0	96.5	48.5
26	1.0500	11.964	467	-134.8	467	-134.8	0	0
27	0.9844	57.9539	-25	-2.5	0	0	25	2.5
28	1.0100	63.1584	376	-190.82	396	-180.82	20	10
29	0.9825	23.1459	-84.6	-92	0	0	84.6	92
30	1.0400	21.9836	126	36.546	176	61.546	50	25
31	1.0229	12.467	-80	-49.6	0	0	80	49.6
32	1.0400	13.0738	375.7	-2.987	395.7	7.013	20	10
33	1.0500	63.5707	3364.5	-555.25	3417	-545.85	52.5	9.4
34	0.9990	110.12	-16	-58	0	0	16	58
35	0.9500	32.2847	-65	-12.819	0	20.181	65	33
36	0.9932	41.067	-50	-76	0	0	50	76
37	1.0200	42.5749	236.4	-60.969	306.9	-55.859	70.5	5.11
38	1.0000	40.9269	126.7	75.61	376.7	100.61	250	25
39	0.9688	25.0823	-80	-90	0	0	80	90
40	1.0091	10.9845	-72	-45	0	0	72	45
41	0.9578	23.6271	-38	-84	0	0	38	84
42	0.9460	18.4063	-90	-45	0	0	90	45
43	0.9406	5.4684	-20	-10	0	0	20	10
44	0.9178	2.1764	-30.6	-65	0	0	30.6	65
45	0.9022	0.0289	-100	-50	0	0	100	50
46	0.8665	-4.9	-70	-50	0	0	70	50
47	0.8888	2.6048	-80	-40	0	0	80	40
48	0.8819	0.6256	-70	-35	0	0	70	35
49	0.8503	0.6429	-45	-80	0	0	45	80
50	0.9312	15.0034	-90	-45	0	0	90	45
51	0.9500	11.8514	-100	163.693	0	213.693	100	50
52	0.9344	22.7856	-240	-120	0	0	240	120
53	1.0500	18.7118	262	-151.16	262	-151.16	0	0
54	0.9727	28.082	-20	-60	0	0	20	60
55	0.9900	57.6783	0	5.88	0	5.88	0	0
56	0.9784	15.6076	-60	-30	0	0	60	30
57	1.0000	110.2189	66	-44.462	66	-44.462	0	0
58	1.0500	125.1896	346.1	-235.67	346.1	-235.67	0	0
59	1.0100	9.015	323.9	85.104	363.9	105.104	40	20
60	1.0500	130.96	385	-268.17	385	-268.17	0	0
61	1.0500	36.0503	371	-263.63	371	-263.63	0	0
62	1.0130	9.0523	-80	-90	0	0	80	90
63	0.9983	40.9667	-20	-60	0	0	20	60
64	0.9583	8.4333	-50	-75	0	0	50	75

Table 5 Line flows and losses for base case scenario.

From	To	P	Q	From	To	P	Q	Line Losses	
Bus	Bus	MW	MVAr	Bus	Bus	MW	MVAr	MW	MVAr
8	7	422	-240.03	7	8	-360	283.86	61.998	43.826
7	1	382.323	-350.92	1	7	-339.86	398.039	42.461	47.118
7	12	58.275	108.077	12	7	-56.895	-107	1.38	1.073
7	11	47.925	40.807	11	7	-47.301	-40.114	0.625	0.693
9	7	149.871	-6.506	7	9	-148.52	8.081	1.35	1.575
9	10	121.129	90.042	10	9	-114.5	-82.092	6.629	7.95
1	2	-60.236	550.799	2	1	98.919	-508.13	38.683	42.674
1	3	-69.534	352.042	3	1	113.444	-298.47	43.91	53.568
1	5	-37.262	181.672	5	1	47.271	-169.67	10.008	12.003
5	6	20.701	-12.717	6	5	-20.6	12.829	0.101	0.113
5	43	-127.97	238.164	43	5	132.835	-232.49	4.863	5.673
3	2	147.416	-396.66	2	3	-118.92	428.096	28.496	31.436
43	44	225.047	-70.098	44	43	-215.31	80.9	9.734	10.802
44	45	142.781	-41.739	45	44	-138.71	46.257	4.072	4.518
12	14	34.529	169.31	14	12	-32.073	-166.49	2.456	2.816
12	13	-120.77	-5.055	13	12	123.211	7.953	2.441	2.899
12	11	73.13	-38.978	11	12	-72.699	39.48	0.43	0.502
12	23	-179.99	90.23	23	12	186.766	-82.187	6.773	8.043
53	40	262	-93.39	40	53	-237.44	122.793	24.561	29.403
13	40	-160.09	94.205	40	13	165.439	-88.265	5.352	5.939
23	17	437.197	4.902	17	23	-427.62	-2.469	9.579	2.433
23	22	162.505	35.315	22	23	-156.74	-28.398	5.764	6.916
30	29	126	299.916	29	30	-113.26	-285.68	12.742	14.236
23	26	-393.53	-128.58	26	23	412.159	149.131	18.627	20.554
23	56	-300.18	399.161	56	23	332.127	-363.91	31.952	35.249
27	55	0.14	-29.138	55	27	0	29.304	0.14	0.166
45	46	74.547	-16.173	46	45	-70	21.628	4.547	5.455
45	47	-35.837	60.884	47	45	37.965	-58.333	2.128	2.551
47	50	-196.01	138.646	50	47	231.766	-97.781	35.756	40.865
51	50	-100	185.263	50	51	107.858	-175.93	7.858	9.331
50	52	-429.62	399.885	52	50	481.453	-339.18	51.829	60.702
33	27	663.904	-70.476	27	33	-612.96	126.673	50.941	56.197
26	23	412.159	149.131	23	26	-393.53	-128.58	18.627	20.554
26	62	54.841	-3.011	62	26	-52.691	5.588	2.151	2.577
61	23	371	-133.76	23	61	-260.12	266.645	110.882	132.89
24	23	26.576	108.69	23	24	-25.03	-106.98	1.546	1.706
24	62	27.668	-46.231	62	24	-27.309	46.626	0.359	0.396
24	25	98.056	24.998	25	24	-96.5	-23.272	1.556	1.727
32	23	294.629	22.846	23	32	-281.71	-7.506	12.918	15.341
32	31	81.071	25.867	31	32	-80	-24.595	1.071	1.272
22	14	-22.259	-72.269	14	22	22.828	72.949	0.569	0.679
39	54	-37.649	28.083	54	39	39.224	-26.179	1.575	1.904
54	42	376.569	-182.44	42	54	-331.23	236.484	45.342	54.04
30	29	126	299.916	29	30	-113.26	-285.68	12.742	14.236
29	35	-510.72	806.547	35	29	611.448	-691.56	100.724	114.987
37	36	236.4	19.974	36	37	-230.63	-13.385	5.771	6.588
36	54	519.504	-272.41	54	36	-435.79	374.262	83.711	101.849
36	35	233.753	-81.821	35	36	-209.01	111.477	24.745	29.657
29	39	-41.165	82.014	39	29	43.301	-79.453	2.136	2.561
56	29	-392.13	378.423	29	56	440.214	-325.06	48.087	53.361
27	4	938.225	-166.98	4	27	-565.23	614.015	372.999	447.036
4	3	545.226	-564.19	3	4	-440.86	679.323	104.367	115.135
28	27	376	-164.61	27	28	-350.4	193.013	25.599	28.406
35	29	611.448	-691.56	29	35	-510.72	806.547	100.724	114.987
38	63	20.073	56.791	63	38	-20	-56.711	0.073	0.08
33	35	1742.63	-435.73	35	33	-1142.7	1155.68	599.96	719.952
60	34	385	-165.97	34	60	-286.16	277.883	98.845	111.918
58	34	346.1	-133.47	34	58	-284.95	208.229	61.155	74.759
57	34	66	-13.662	34	57	-65.909	13.762	0.091	0.1
44	48	41.932	12.765	48	44	-40.609	-11.17	1.323	1.594
48	49	46.69	55.663	49	48	-45	-53.681	1.69	1.982
48	47	-76.081	40.754	47	48	78.044	-38.398	1.963	2.356
43	42	-377.88	370.352	42	43	453.829	-277.95	75.947	92.403
42	41	-212.6	147.092	41	42	227.912	-128.72	15.309	18.371
41	39	-265.91	82.52	39	41	270.982	-76.606	5.07	5.915

Table 5 Line flows and losses for base case scenario (Cont'd).

From Bus	To Bus	P MW	Q MVAr	From Bus	To Bus	P MW	Q MVAr	Line Losses MW	Line Losses MVAr
14	64	-54.913	74.19	64	14	55.467	-73.543	0.554	0.647
14	22	22.828	72.949	22	14	-22.259	-72.269	0.569	0.679
14	12	-32.073	-166.49	12	14	34.529	169.31	2.456	2.816
17	21	39.373	-31.339	21	17	-38.455	32.458	0.918	1.12
14	16	220.187	-18.942	16	14	-184.7	61.844	35.487	42.903
14	15	257.868	117.807	15	14	-240	-96.365	17.868	21.442
18	19	140.071	73.517	19	18	-136	-69.026	4.071	4.491
17	18	449.961	113.884	18	17	-414.47	-74.502	35.49	39.382
17	64	107.514	-29.426	64	17	-105.47	31.697	2.047	2.271
17	14	129.869	-59.067	14	17	-126.52	62.788	3.353	3.721
17	23	-427.62	-2.469	23	17	437.197	4.902	9.579	2.433
59	13	135.945	33.893	13	59	-134.79	-32.546	1.155	1.347
59	14	187.955	107.011	14	59	-180.62	-98.298	7.337	8.713
39	36	-356.63	330.137	36	39	444.71	-224.7	88.077	105.441
36	37	-230.63	-13.385	37	36	236.4	19.974	5.771	6.588
36	38	-105.78	-52.82	38	36	106.627	52.92	0.85	0.099
36	33	-911.56	853.252	33	36	1235.52	-464.5	323.96	388.752
33	34	-277.55	636.174	34	33	621.009	-224.55	343.454	411.621
52	50	481.453	-339.18	50	52	-429.62	399.885	51.829	60.702
52	35	-587.21	514.852	35	52	675.229	-417.75	88.019	97.1
52	29	-134.24	-123.33	29	52	140.333	130.559	6.09	7.232
29	39	-41.165	82.014	39	29	43.301	-79.453	2.136	2.561
23	14	90.797	1.138	14	23	-87.888	2.349	2.909	3.487
14	20	-13.931	-25.18	20	14	14.371	25.683	0.44	0.503
14	21	-38.146	-14.98	21	14	38.455	15.327	0.31	0.346
20	13	-94.371	-10.419	13	20	95.866	12.195	1.495	1.776

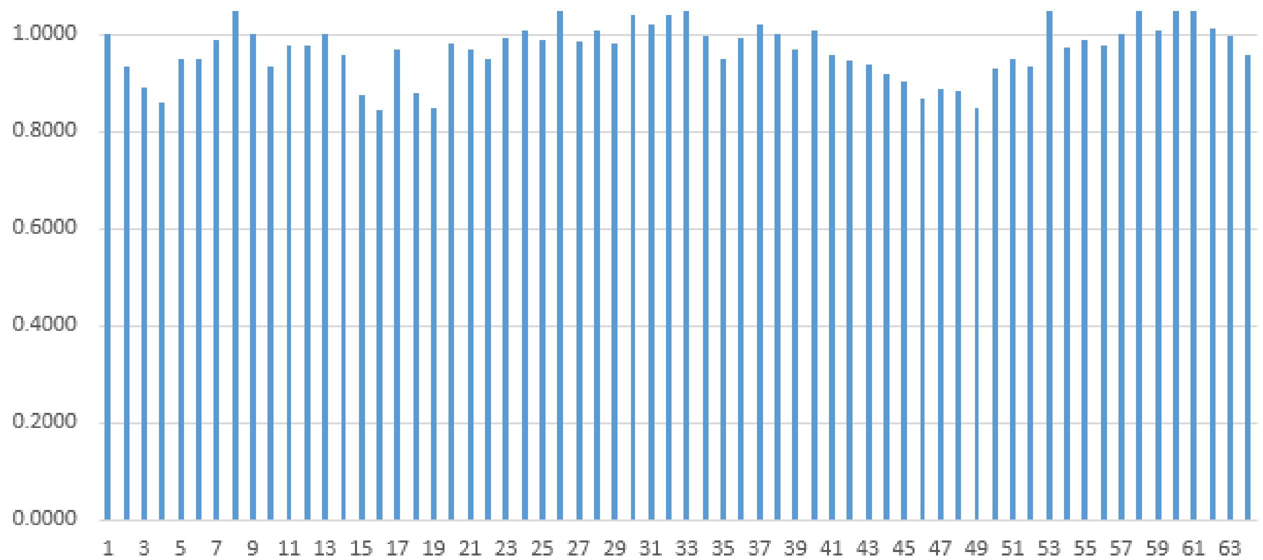

Fig. 6 Voltage profile for the base case.

4.2. Load Flow of Mambilla Power Plant Injected at Makurdi Bus

Table 6 contained the power flow result of Mambilla power plant injection at Makurdi bus. This result represents the voltage magnitude and phase angles of the buses. It can be observed from the results that, most of the buses are operating outside the acceptable limit of 0.95pu to 1.05pu. The buses operating outside the acceptable limits are bus 2, bus 3, bus 4, bus 10, bus 15, bus 16, bus 18, bus 19, bus 44, bus 45, bus 46, bus 47, bus 48, bus 49, bus 50 and bus 52 with voltage magnitude of 0.9350pu, 0.8913pu, 0.8642pu, 0.9335pu, 0.8854pu, 0.8585pu, 0.8916pu, 0.8605pu, 0.9366pu, 0.9213pu, 0.8898pu, 0.9039pu, 0.8995pu, 0.8690pu, 0.9340pu and 0.9361pu respectively. Negative reactive power generated implies that reactive power is flowing from the utility grid to the generator. This occurs when the generator is under-excited or if an induction generator is being used. Table 7 contained the line flow and losses associated with the base case. The real and reactive power loss of 3491.273MW and 4061.221MVAr was experienced by the network. Fig. 7 depicts the graphical representation of the voltage profile for base case. This represents a pictorial representation of the voltage magnitude of the respective buses.

Table 6 Power flow with Mambilla power plant injected at Makurdi Bus.

Bus No.	V(pu) (pu)	Angle (Deg)	Injection MW	Injection MVAr	Generation MW	Generation MVAr	Load MW	Load MVAr
1	1.0000	0	-516.22	1289.48	-516.22	1289.48	0	0
2	0.9350	4.7456	-20	-100	0	0	20	100
3	0.8913	9.5679	-180	-90	0	0	180	90
4	0.8642	20.5086	-20	-10	0	0	20	10
5	0.9650	3.348	-60	-30	0	0	60	30
6	0.9641	3.0001	-20.6	-10.3	0	0	20.6	10.3
7	0.9934	6.8561	-20	-10	0	0	20	10
8	1.0500	15.5946	422	-251.55	422	-251.55	0	0
9	1.0000	7.5769	271	51.186	278	54.686	7	3.5
10	0.9335	6.5904	-114.5	-85.9	0	0	114.5	85.9
11	0.9807	6.6223	-120	-60	0	0	120	60
12	0.9831	7.0195	-250	-25	0	0	250	25
13	1.0011	8.4337	-75.8	-35	0	0	75.8	35
14	0.9686	7.4173	-33.2	-316	0	0	33.2	316
15	0.8854	4.7849	-240	-120	0	0	240	120
16	0.8585	-5.9632	-184.7	-10.5	0	0	184.7	10.5
17	0.9800	9.1103	299.1	32.149	368	83.849	68.9	51.7
18	0.8916	5.1757	-274.4	-37	0	0	274.4	37
19	0.8605	4.4094	-136	-84	0	0	136	84
20	0.9854	7.4038	-80	-40	0	0	80	40
21	0.9700	8.0864	0	-63.356	0	-63.356	0	0
22	0.9700	7.1464	-179	-25.28	0	64.22	179	89.5
23	0.9992	9.7602	-383.3	-92	0	0	383.3	92
24	1.0100	9.5798	152.3	-35.821	172.9	-20.421	20.6	15.4
25	0.9908	8.8359	-96.5	-48.5	0	0	96.5	48.5
26	1.0500	11.9248	467	-199.37	467	-199.37	0	0
27	0.9849	57.4771	-25	-2.5	0	0	25	2.5
28	1.0100	62.7047	376	-193.72	396	-183.72	20	10
29	0.9850	22.5958	-84.6	-92	0	0	84.6	92
30	1.0400	21.5714	126	18.029	176	43.029	50	25
31	1.0229	12.3858	-80	-49.6	0	0	80	49.6
32	1.0400	12.9925	375.7	-42.185	395.7	-32.185	20	10
33	1.0500	63.0192	3364.5	-557.14	3417	-547.74	52.5	9.4
34	0.9990	109.569	-16	-58	0	0	16	58
35	0.9500	31.7987	-65	-46.404	0	-13.404	65	33
36	0.9935	40.3074	-50	-76	0	0	50	76
37	1.0200	41.8277	236.4	-63.096	306.9	-57.986	70.5	5.11
38	1.0000	40.2971	126.7	38.09	376.7	63.09	250	25
39	0.9784	24.0076	-80	-90	0	0	80	90
40	1.0102	10.8417	-72	-45	0	0	72	45
41	0.9705	22.4144	-38	-84	0	0	38	84
42	0.9700	16.8086	-90	54.395	0	99.395	90	45
43	0.9584	4.6796	-20	-10	0	0	20	10
44	0.9366	1.4185	-30.6	-65	0	0	30.6	65
45	0.9213	-0.6905	-100	-50	0	0	100	50
46	0.8898	-5.5644	-70	-50	0	0	70	50
47	0.9039	1.9109	-80	-40	0	0	80	40
48	0.8995	-0.0807	-70	-35	0	0	70	35
49	0.8690	-0.0854	-45	-80	0	0	45	80
50	0.9340	14.5333	-90	-45	0	0	90	45
51	0.9500	11.5445	-100	148.837	0	198.837	100	50
52	0.9361	22.277	-240	-120	0	0	240	120
53	1.0500	18.6074	262	-153.61	262	-153.61	0	0
54	0.9834	26.804	-20	-60	0	0	20	60
55	0.9900	57.2277	0	3.102	0	3.102	0	0
56	0.9838	15.1239	-60	-30	0	0	60	30
57	1.0000	109.667	66	-44.462	66	-44.462	0	0
58	1.0500	124.638	346.1	-235.67	346.1	-235.67	0	0
59	1.0100	8.9282	323.9	19.343	363.9	39.343	40	20
60	1.0500	130.409	385	-268.17	385	-268.17	0	0
61	1.0500	35.7511	371	-270.22	371	-270.22	0	0
62	1.0130	9.0347	-80	-90	0	0	80	90
63	0.9983	40.337	-20	-60	0	0	20	60
64	0.9673	7.8638	-50	-75	0	0	50	75

Table 7 Line flows and losses with Mambilla power plant injected at Makurdi Bus.

From	To	P	Q	From	To	P	Q	Line Losses	
Bus	Bus	MW	MVAr	Bus	Bus	MW	MVAr	MW	MW
8	7	422	-248.15	7	8	-358.96	292.712	63.04	44.563
7	1	382.151	-341.04	1	7	-340.95	386.762	41.204	45.723
7	12	56.031	74.532	12	7	-55.238	-73.916	0.793	0.617
7	11	49.234	28.987	11	7	-48.722	-28.418	0.513	0.569
9	7	149.871	-33.446	7	9	-148.46	35.096	1.415	1.651
9	10	121.129	90.042	10	9	-114.5	-82.092	6.629	7.95
1	2	-61.498	546.105	2	1	99.552	-504.13	38.054	41.98
1	3	-70.227	348.761	3	1	113.386	-296.11	43.159	52.651
1	5	-43.549	141.429	5	1	49.922	-133.79	6.372	7.643
5	6	20.702	-13.473	6	5	-20.6	13.586	0.102	0.113
5	43	-130.62	205.811	43	5	134.452	-201.34	3.829	4.467
3	2	147.536	-393.26	2	3	-119.55	424.13	27.984	30.871
43	44	228.585	-75.777	44	43	-218.8	86.637	9.786	10.859
44	45	144.921	-44.045	45	44	-140.87	48.544	4.054	4.499
12	14	36.509	125.77	14	12	-35.11	-124.17	1.398	1.603
12	13	-120.02	9.299	13	12	122.415	-6.45	2.399	2.849
12	11	71.645	-27.817	11	12	-71.278	28.244	0.367	0.428
12	23	-182.9	76.392	23	12	189.403	-68.669	6.504	7.724
53	40	262	-95.839	40	53	-237.29	125.418	24.708	29.579
13	40	-159.89	96.713	40	13	165.292	-90.72	5.4	5.992
23	17	421.564	-118.26	17	23	-412.1	120.666	9.463	2.404
23	22	166.491	-15.832	22	23	-160.75	22.723	5.742	6.891
30	29	126	281.398	29	30	-114.55	-268.61	11.446	12.788
23	26	-395.24	-65.404	26	23	412.42	84.363	17.182	18.959
23	56	-292.27	406.897	56	23	323.939	-371.96	31.672	34.939
27	55	0.115	-26.39	55	27	0	26.526	0.115	0.136
45	46	74.46	-20.186	46	45	-70	25.536	4.46	5.35
45	47	-33.593	68.649	47	45	35.981	-65.786	2.388	2.863
47	50	-192.65	156.332	50	47	229.571	-114.14	36.918	42.192
51	50	-100	170.406	50	51	106.921	-162.19	6.921	8.219
50	52	-426.49	403.543	52	50	478.046	-343.16	51.554	60.379
33	27	656.367	-68.579	27	33	-606.59	123.488	49.774	54.909
26	23	412.42	84.363	23	26	-395.24	-65.404	17.182	18.959
26	62	54.58	-2.815	62	26	-52.451	5.367	2.129	2.552
61	23	371	-140.35	23	61	-258.83	274.778	112.17	134.433
24	23	26.332	54.282	23	24	-25.883	-53.786	0.45	0.496
24	62	27.912	-46.448	62	24	-27.549	46.848	0.363	0.4
24	25	98.056	24.998	25	24	-96.5	-23.272	1.556	1.727
32	23	294.629	-16.352	23	32	-281.75	31.648	12.881	15.296
32	31	81.071	25.867	31	32	-80	-24.595	1.071	1.272
22	14	-18.252	27.645	14	22	18.356	-27.52	0.105	0.125
39	54	-36.696	25.699	54	39	38.101	-24.001	1.405	1.698
54	42	379.449	-223.56	42	54	-330.31	282.124	49.136	58.562
30	29	126	281.398	29	30	-114.55	-268.61	11.446	12.788
29	35	-505.96	825.267	35	29	608.991	-707.65	103.03	117.62
37	36	236.4	17.847	36	37	-230.64	-11.268	5.763	6.579
36	54	528.465	-307.61	54	36	-437.55	418.224	90.915	110.613
36	35	227.875	-77.766	35	36	-204.5	105.783	23.377	28.017
29	39	-36.316	53.455	39	29	37.369	-52.191	1.054	1.263
56	29	-383.94	386.964	29	56	431.525	-334.16	47.587	52.806
27	4	931.733	-169.46	4	27	-563.77	610.458	367.959	440.996
4	3	543.774	-560.33	3	4	-440.92	673.798	102.852	113.464
28	27	376	-167.5	27	28	-350.26	196.069	25.745	28.568
35	29	608.991	-707.65	29	35	-505.96	825.267	103.03	117.62
38	63	20.073	56.791	63	38	-20	-56.711	0.073	0.08
33	35	1739.11	-435.2	35	33	-1141.5	1152.32	597.598	717.118
60	34	385	-165.97	34	60	-286.16	277.883	98.845	111.918
58	34	346.1	-133.47	34	58	-284.95	208.229	61.155	74.759
57	34	66	-13.662	34	57	-65.909	13.762	0.091	0.1
44	48	43.278	14.157	48	44	-41.907	-12.504	1.371	1.652
48	49	46.577	54.364	49	48	-45	-52.515	1.577	1.85
48	47	-74.67	48.227	47	48	76.672	-45.825	2.002	2.402
43	42	-383.04	347.862	42	43	452.989	-262.76	69.952	85.108
42	41	-212.68	193.379	41	42	230.678	-171.78	18.002	21.603
41	39	-268.68	126.585	39	41	274.297	-120.03	5.619	6.555
14	64	-50.651	62.604	64	14	51.066	-62.121	0.415	0.484

Table 7 Line flows and losses with Mambilla power plant injected at Makurdi Bus (Cont'd).

From Bus	To Bus	P MW	Q MVAr	From Bus	To Bus	P MW	Q MVAr	Line Losses MW	Line Losses MW
14	22	18.356	-27.52	22	14	-18.252	27.645	0.105	0.125
14	12	-35.11	-124.17	12	14	36.509	125.77	1.398	1.603
17	21	36.152	-5.712	21	17	-35.677	6.292	0.476	0.58
14	16	219.426	-21.966	16	14	-184.7	63.947	34.726	41.982
14	15	257.464	116.81	15	14	-240	-95.853	17.464	20.957
18	19	139.948	72.954	19	18	-136	-68.598	3.948	4.355
17	18	448.864	111.292	18	17	-414.35	-72.991	34.516	38.301
17	64	102.83	-18.94	64	17	-101.07	20.897	1.764	1.958
17	14	123.354	-44.064	14	17	-120.59	47.136	2.769	3.073
17	23	-412.1	120.666	23	17	421.564	-118.26	9.463	2.404
59	13	135.27	12.371	13	59	-134.18	-11.105	1.085	1.266
59	14	188.63	62.771	14	59	-182.43	-55.41	6.199	7.361
39	36	-354.97	354.521	36	39	446.992	-244.36	92.023	110.164
36	37	-230.64	-11.268	37	36	236.4	17.847	5.763	6.579
36	38	-105.93	-15.318	38	36	106.627	15.399	0.696	0.081
36	33	-916.77	864.585	33	36	1246.57	-468.81	329.81	395.772
33	34	-277.55	636.174	34	33	621.009	-224.55	343.454	411.621
52	50	478.046	-343.16	50	52	-426.49	403.543	51.554	60.379
52	35	-583.61	523.725	35	52	672.022	-426.19	88.41	97.532
52	29	-134.43	-127.57	29	52	140.705	135.021	6.271	7.447
29	39	-36.316	53.455	39	29	37.369	-52.191	1.054	1.263
23	14	93.208	-2.293	14	23	-90.187	5.914	3.021	3.622
14	20	-14.145	-16.623	20	14	14.393	16.907	0.249	0.284
14	21	-35.337	25.054	21	14	35.677	-24.674	0.34	0.38
20	13	-94.393	-1.266	13	20	95.862	3.01	1.468	1.744

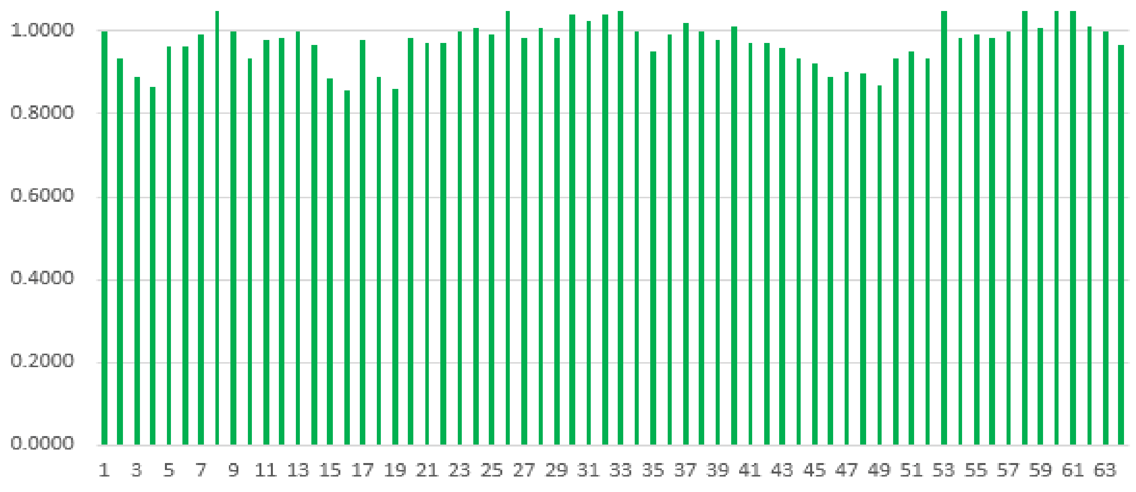

Fig. 7 Voltage profile with Mambilla power plant injected at Makurdi Bus

4.3. Load Flow of Mambilla Power Plant Injected at Jalingo Bus

Table 8 contained the power flow result of Mambilla power plant injection at Jalingo bus. This result represents the voltage magnitude and phase angles of the buses. It can be observed from the results that, most of the buses are operating outside the acceptable limit of 0.95pu to 1.05pu. The buses operating outside the acceptable limits are bus 2, bus 3, bus 4, bus 10, bus 15, bus 16, bus 18, bus 19, bus 44, bus 45, bus 47, bus 48, bus 49, bus 50 and bus 52 with voltage magnitude of 0.9352pu, 0.8916pu, 0.8647pu, 0.9335pu, 0.8854pu, 0.8585pu, 0.8916pu, 0.8605pu, 0.9439pu, 0.9387pu, 0.9135pu, 0.9093pu, 0.8794pu, 0.9346pu and 0.9358pu respectively. Negative reactive power generated implies that reactive power is flowing from the utility grid to the generator. This occurs when the generator is under-excited or if an induction generator is being used. Table 9 contained the line flow and losses associated with the base case. The real and reactive power loss of 3501.750MW and 4084.325 MVAr was experienced by the network. Fig. 8 depicts the graphical representation of the voltage profile for base case. This represents a pictorial representation of the voltage magnitude of the respective buses.

The TVD analysis with Mambilla power plant injection at Makurdi and Jalingo is shown in Table 10.

Table 8 Power flow with Mambilla power plant injected at Jalingo Bus

Bus No.	V(pu) (pu)	Angle (Deg)	Injection		Generation		Load	
			MW	MVAr	MW	MVAr	MW	MVAr
1	1.0000	0	-500.14	1277.54	-500.14	1277.54	0	0
2	0.9352	4.7388	-20	-100	0	0	20	100
3	0.8916	9.5519	-180	-90	0	0	180	90
4	0.8647	20.4704	-20	-10	0	0	20	10
5	0.9630	2.9454	-60	-30	0	0	60	30
6	0.9620	2.5969	-20.6	-10.3	0	0	20.6	10.3
7	0.9935	6.8011	-20	-10	0	0	20	10
8	1.0500	15.5414	422	-251.67	422	-251.67	0	0
9	1.0000	7.5233	271	50.779	278	54.279	7	3.5
10	0.9335	6.5368	-114.5	-85.9	0	0	114.5	85.9
11	0.9807	6.5518	-120	-60	0	0	120	60
12	0.9831	6.9428	-250	-25	0	0	250	25
13	1.0011	8.3496	-75.8	-35	0	0	75.8	35
14	0.9686	7.3262	-33.2	-316	0	0	33.2	316
15	0.8854	4.6939	-240	-120	0	0	240	120
16	0.8585	-6.0543	-184.7	-10.5	0	0	184.7	10.5
17	0.9800	9.0093	299.1	32.132	368	83.832	68.9	51.7
18	0.8916	5.0747	-274.4	-37	0	0	274.4	37
19	0.8605	4.3084	-136	-84	0	0	136	84
20	0.9854	7.318	-80	-40	0	0	80	40
21	0.9700	7.992	0	-63.329	0	-63.329	0	0
22	0.9700	7.0505	-179	-25.093	0	64.407	179	89.5
23	0.9992	9.6557	-383.3	-92	0	0	383.3	92
24	1.0100	9.473	152.3	-35.512	172.9	-20.112	20.6	15.4
25	0.9908	8.7292	-96.5	-48.5	0	0	96.5	48.5
26	1.0500	11.8182	467	-199	467	-199	0	0
27	0.9850	57.3688	-25	-2.5	0	0	25	2.5
28	1.0100	62.6015	376	-194.37	396	-184.37	20	10
29	0.9841	22.4117	-84.6	-92	0	0	84.6	92
30	1.0400	21.3395	126	24.458	176	49.458	50	25
31	1.0229	12.2795	-80	-49.6	0	0	80	49.6
32	1.0400	12.8862	375.7	-41.963	395.7	-31.963	20	10
33	1.0500	62.8938	3364.5	-555.6	3417	-546.2	52.5	9.4
34	0.9990	109.443	-16	-58	0	0	16	58
35	0.9500	31.5627	-65	-31.874	0	1.126	65	33
36	0.9933	40.2633	-50	-76	0	0	50	76
37	1.0200	41.7741	236.4	-61.464	306.9	-56.354	70.5	5.11
38	1.0000	40.1536	126.7	66.821	376.7	91.821	250	25
39	0.9718	24.1634	-80	-90	0	0	80	90
40	1.0102	10.7577	-72	-45	0	0	72	45
41	0.9617	22.6577	-38	-84	0	0	38	84
42	0.9529	17.285	-90	-45	0	0	90	45
43	0.9559	4.1951	-20	-10	0	0	20	10
44	0.9439	0.2657	-30.6	-65	0	0	30.6	65
45	0.9387	-2.438	-100	-50	0	0	100	50
46	0.9700	-10.188	-70	19.325	0	69.325	70	50
47	0.9135	0.6448	-80	-40	0	0	80	40
48	0.9093	-1.3135	-70	-35	0	0	70	35
49	0.8794	-1.3299	-45	-80	0	0	45	80
50	0.9346	14.0095	-90	-45	0	0	90	45
51	0.9500	11.0516	-100	146.021	0	196.021	100	50
52	0.9358	21.9569	-240	-120	0	0	240	120
53	1.0500	18.5233	262	-153.61	262	-153.61	0	0
54	0.9757	27.0945	-20	-60	0	0	20	60
55	0.9900	57.1253	0	2.473	0	2.473	0	0
56	0.9835	14.9813	-60	-30	0	0	60	30
57	1.0000	109.542	66	-44.462	66	-44.462	0	0
58	1.0500	124.513	346.1	-235.67	346.1	-235.67	0	0
59	1.0100	8.8421	323.9	19.421	363.9	39.421	40	20
60	1.0500	130.283	385	-268.17	385	-268.17	0	0
61	1.0500	35.646	371	-270.18	371	-270.18	0	0
62	1.0130	8.928	-80	-90	0	0	80	90
63	0.9983	40.1935	-20	-60	0	0	20	60
64	0.9673	7.7699	-50	-75	0	0	50	75

Table 9 Line flows and losses with Mambilla power plant injected at Jalingo Bus

From Bus	To Bus	P MW	Q MVAr	From Bus	To Bus	P MW	Q MVAr	Line Losses MW	Line Losses MW
8	7	422	-248.27	7	8	-358.94	292.846	63.056	44.574
7	1	378.883	-338.59	1	7	-338.33	383.582	40.549	44.996
7	12	58.332	72.194	12	7	-57.547	-71.583	0.786	0.611
7	11	50.183	28.334	11	7	-49.661	-27.755	0.522	0.579
9	7	149.871	-33.853	7	9	-148.46	35.506	1.416	1.653
9	10	121.129	90.042	10	9	-114.5	-82.092	6.629	7.95
1	2	-61.779	545.037	2	1	99.69	-503.22	37.911	41.823
1	3	-70.381	348.015	3	1	113.37	-295.57	42.989	52.444
1	5	-29.641	134.487	5	1	35.16	-127.87	5.519	6.619
5	6	20.702	-13.373	6	5	-20.6	13.486	0.102	0.113
5	43	-115.86	199.427	43	5	119.303	-195.41	3.442	4.016
3	2	147.558	-392.48	2	3	-119.69	423.227	27.868	30.743
43	44	237.712	-135.12	44	43	-225.03	149.196	12.682	14.073
44	45	151.224	-101.82	45	44	-145.44	108.238	5.782	6.416
12	14	37.934	124.387	14	12	-36.555	-122.81	1.379	1.58
12	13	-119.67	8.924	13	12	122.05	-6.093	2.384	2.831
12	11	70.695	-27.166	11	12	-70.339	27.581	0.356	0.415
12	23	-181.42	75.163	23	12	187.799	-67.582	6.384	7.581
53	40	262	-95.835	40	53	-237.29	125.413	24.707	29.578
13	40	-159.89	96.708	40	13	165.293	-90.716	5.4	5.992
23	17	420.435	-117.32	17	23	-411.03	119.711	9.406	2.389
23	22	166.039	-15.659	22	23	-160.33	22.512	5.711	6.853
30	29	126	287.828	29	30	-114.11	-274.55	11.887	13.28
23	26	-395.23	-65.764	26	23	412.418	84.73	17.187	18.965
23	56	-288.7	405.386	56	23	319.959	-370.9	31.258	34.483
27	55	0.109	-25.767	55	27	0	25.897	0.109	0.13
45	46	81.356	-95.463	46	45	-70	109.087	11.356	13.623
45	47	-35.914	89.83	47	45	39.6	-85.411	3.686	4.419
47	50	-196.18	178.499	50	47	237.497	-131.28	41.313	47.215
51	50	-100	167.591	50	51	106.752	-159.57	6.752	8.018
50	52	-434.25	418.269	52	50	488.549	-354.67	54.3	63.595
33	27	654.651	-68.141	27	33	-605.14	122.759	49.51	54.618
26	23	412.418	84.73	23	26	-395.23	-65.764	17.187	18.965
26	62	54.582	-2.816	62	26	-52.452	5.368	2.13	2.552
61	23	371	-140.31	23	61	-258.84	274.732	112.163	134.424
24	23	26.334	54.589	23	24	-25.88	-54.089	0.454	0.501
24	62	27.91	-46.447	62	24	-27.548	46.847	0.363	0.4
24	25	98.056	24.998	25	24	-96.5	-23.272	1.556	1.727
32	23	294.629	-16.13	23	32	-281.75	31.424	12.88	15.295
32	31	81.071	25.867	31	32	-80	-24.595	1.071	1.272
22	14	-18.672	28.043	14	22	18.781	-27.914	0.108	0.129
39	54	-37.072	27.546	54	39	38.585	-25.716	1.513	1.83
54	42	378.758	-195.09	42	54	-332.04	250.774	46.718	55.68
30	29	126	287.828	29	30	-114.11	-274.55	11.887	13.28
29	35	-505.72	816.458	35	29	607.317	-700.48	101.596	115.982
37	36	236.4	19.479	36	37	-230.63	-12.893	5.769	6.586
36	54	523.491	-283.03	54	36	-437.34	387.846	86.148	104.813
36	35	231.975	-80.633	35	36	-207.65	109.792	24.33	29.159
29	39	-37.654	74.275	39	29	39.407	-72.173	1.753	2.102
56	29	-379.96	385.878	29	56	426.957	-333.73	46.998	52.153
27	4	930.253	-170.02	4	27	-563.44	609.644	366.816	439.627
4	3	543.437	-559.45	3	4	-440.93	672.539	102.509	113.086
28	27	376	-168.16	27	28	-350.22	196.761	25.778	28.605
35	29	607.317	-700.48	29	35	-505.72	816.458	101.596	115.982
38	63	20.073	56.791	63	38	-20	-56.711	0.073	0.08
33	35	1745.06	-436.09	35	33	-1143.5	1158	601.593	721.911
60	34	385	-165.97	34	60	-286.16	277.883	98.845	111.918
58	34	346.1	-133.47	34	58	-284.95	208.229	61.155	74.759
57	34	66	-13.662	34	57	-65.909	13.762	0.091	0.1
44	48	43.206	11.288	48	44	-41.908	-9.724	1.298	1.565
48	49	46.518	53.632	49	48	-45	-51.852	1.518	1.78
48	47	-74.61	48.929	47	48	76.583	-46.561	1.974	2.368
43	42	-377.02	400.855	42	43	456.552	-304.09	79.537	96.77
42	41	-214.51	161.124	41	42	230.763	-141.62	16.251	19.501
41	39	-268.76	95.724	39	41	274.044	-89.563	5.281	6.161
14	64	-50.29	62.245	64	14	50.699	-61.768	0.409	0.478

Table 9 Line flows and losses with Mambilla power plant injected at Jalingo Bus (Cont'd).

From	To	P	Q	From	To	P	Q	Line Losses	
Bus	Bus	MW	MVAr	Bus	Bus	MW	MVAr	MW	MW
14	22	18.781	-27.914	22	14	-18.672	28.043	0.108	0.129
14	12	-36.555	-122.81	12	14	37.934	124.387	1.379	1.58
17	21	35.994	-5.587	21	17	-35.523	6.161	0.471	0.575
14	16	219.426	-21.964	16	14	-184.7	63.946	34.726	41.982
14	15	257.464	116.811	15	14	-240	-95.854	17.464	20.957
18	19	139.948	72.954	19	18	-136	-68.598	3.948	4.355
17	18	448.864	111.292	18	17	-414.35	-72.991	34.516	38.301
17	64	102.449	-18.603	64	17	-100.7	20.544	1.75	1.942
17	14	122.822	-43.587	14	17	-120.08	46.629	2.741	3.042
17	23	-411.03	119.711	23	17	420.435	-117.32	9.406	2.389
59	13	134.993	12.647	13	59	-133.91	-11.385	1.081	1.261
59	14	188.907	62.574	14	59	-182.7	-55.198	6.211	7.376
39	36	-356.38	338.177	36	39	445.833	-231.09	89.454	107.09
36	37	-230.63	-12.893	37	36	236.4	19.479	5.769	6.586
36	38	-105.83	-44.037	38	36	106.627	44.131	0.799	0.093
36	33	-914.84	859.835	33	36	1242.35	-466.83	327.508	393.009
33	34	-277.55	636.174	34	33	621.009	-224.55	343.454	411.621
52	50	488.549	-354.67	50	52	-434.25	418.269	54.3	63.595
52	35	-588.83	527.776	35	52	678.791	-428.53	89.965	99.247
52	29	-139.72	-120.24	29	52	145.931	127.61	6.208	7.372
29	39	-37.654	74.275	39	29	39.407	-72.173	1.753	2.102
23	14	92.825	-2.09	14	23	-89.829	5.682	2.996	3.592
14	20	-14.234	-16.546	20	14	14.483	16.83	0.249	0.284
14	21	-35.186	24.892	21	14	35.523	-24.516	0.337	0.376
20	13	-94.483	-1.19	13	20	95.954	2.937	1.471	1.747

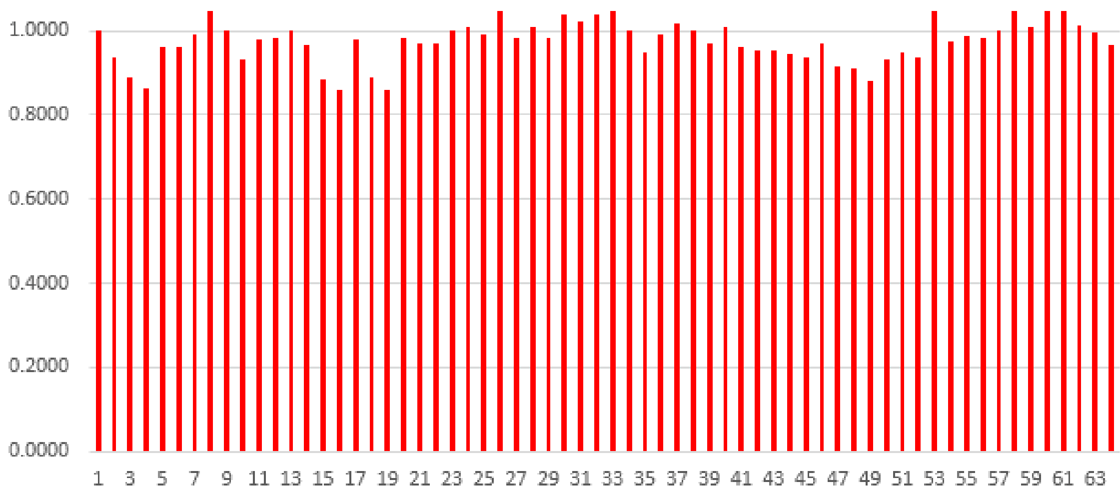

Fig. 8 Voltage profile with Mambilla power plant injected at Jalingo Bus.

Table 10 TVD with Mambilla power plant injection.

Bus	TVD
Makurdi	0.0052
Jalingo	0.0169

5. Conclusion

The impact assessment on the injection of Mambilla 3050 MW power plant to the Nigerian National Grid was carried out by considering three scenarios as contained in the work. Load flow analysis was first performed without the Mabilla power injected to the grid. The Mambilla 3050 MW power plant was subsequently injected at the Makurdi and Jalingo buses respectively in order to determine the optimal point of injection and assess the impact. Voltage profiles and system losses for the various conditions were obtained accordingly. Newton Raphson power flow technique was employed for the simulations implemented through MATLAB codes. The analysed results through TVD approach shows that, Makurdi bus was the optimal point of injecting the Mambilla 3050 MW power plant as it has the minimum TVD value.

Conflict of Interests

The authors declare that there is no conflict of interest regarding the publication of this paper.

Acknowledgement

The authors express their gratitude to the Tertiary Education Trust Fund (TETF/DR&D/CE/NDA/KADUNA/IBR/2022/VOL.1) for funding this research.

ORCID

A. E. Airoboman https://orcid.org/0000-0001-2840-2506

References

[1] A. Iwayemi, “Investment in electricity generation and transmission in Nigeria: issues and option”, *Int. Association for Energy Economics*, pp. 37-42, 2008. Retrieved from https://www.iaee.org/en/publications/newsletterdl.aspx?id=38

[2] T. Olaoye, T. Ajilore, K. Akinluwade, F. Omole, A. Adetunji, “Energy crisis in Nigeria: Need for renewable energy mix”, *American Journal of Electrical Electronics Engineering*, vol. 4, no. 1, pp. 1-8, 2016.

[3] I. Emovon, and O. D. Samuel, “An integrated statistical variance and VIKOR methods for prioritising power generation problems in Nigeria”, *Journal of Engineering and Technology,* vol. 8, no. 1, pp. 92-104, 2017.

[4] O.J IseOlorunkanmi, “Issues and challenges in the privatized power sector in Nigeria”, *Journal of Sustainable Development Studies*, vol. 6, no. 1, pp. 161-174, 2014.

[5] www.nsenergybusiness.com (accessed: Mar 13, 2022).

[6] A.E. Airoboman, I.K., Okakwu, A.S., Alayande, O.E. Seun, “On the assessment of power system stability using MATLAB/Simulink model”, *Int. Journal of Energy and Power Engineering,* vol. 4, no. 2, pp. 51-64, 2015.

[7] M. Tabe, R. Tchuidjan, J. Ngundam and H. Manfouo, “Choosing the power injection network node based on overall minimum losses: The case of the 216-MW Kribi natural gas power plant in the southern interconnected grid of Cameroon”, *Global Journal of Researches in Engineering Electrical and Electronics Engineering,* vol. 15, no. 1 ver 1.0, pp. 1-11, 2015.

[8] I.O. Akwukwuegbu, O.C. Nosiri, C.K. Agubor and M. Olubiwe, “Comparative power flow analysis of 28 and 58 Buses for 330kV power grid network in Nigeria using Newton-Raphson method”, *Int. Journal of Recent Engineering Research and Development,* vol. 2, no. 5, pp. 1-23, 2017

[9] I.K. Okakwu, E.A. Ogujor, and P.A. Oriaifo, “Load flow assessment of the Nigerian 330 kV power system”, *American Journal of Electrical and Electronic Engineering,* vol. 5, no. 4, pp.159-165, 2017.

[10] D.C. Idoniboyeobu and C. Ibeni, “Analysis for electrical load flow studies in Port Harcourt, Nigeria, using Newton Raphson fast decoupled techniques” *American Journal of Engineering Research,* Vol. 6, Issue 12, pp. 230-240, 2017.

[11] A.E. Airoboman, T.M. Tyo, “Power loss determination, assessment and enhancement of the Nigerian power system network”, *Journal of Advances in Science and Engineering,* vol. 1, no. 2, pp. 17-24, 2018.

[12] O.O.E. Ajibola, O.S. Ajala, J.O. Akanmu and O.J. Balogun, “Improvement of hydroelectric power generation using pumped storage system”, *Nigerian Journal of Technology,* vol. 37, Ino. 1, pp. 191 – 199, 2018.

[13] O.B. Fakehinde, O.S. Fayomi, U.K. Efemwenkieki, K.O. Babaremu, D.O. Kolawole, S.O. Oyedepo, “Viability of hydroelectricity in Nigeria and the future prospect”, *Technologies and Materials for Renewable Energy, Environment and Sustainability*, vol. 18, pp. 872-878, 2019.

[14] E.E. Imo, A. Olayanju, F.A. Ibikunle and S.O. Dahunsi, “Impact of small hydropower developments on rural transformation in Nigeria”, *IOP Conference Series: Earth and Environmental Science*, pp. 1-5. 2020.