Indonesian Journal of Electrical Engineering and Computer Science
Vol. 21, No. 3, March 2021, pp. 1263~1270
ISSN: 2502-4752, DOI: 10.11591/ijeecs.v21.i3.pp1263-1270

Impact of distributed generation on the Nigerian power network

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Article Info

Article history:

Received Jul 5, 2020
Revised Sep 7, 2020
Accepted Oct 17, 2020

Keywords:

Distributed generation
Energy storage system
Network losses
Power system simulation
Renewable generation
Voltage profile

ABSTRACT

Distributed generations (DG) are being installed at increasing rates, both in developed and developing countries. The increasing number of DG connected to the distribution system could have a significant impact on the power system operation. This paper presents a case study investigating the impact of grid-connected DG on the Nigerian power network in terms of bus voltages and network losses. The results showed that without DG, some of the bus voltage magnitudes of the test system were outside the permissible voltage limit of 0.95pu≤Vi≤1.05p.u. However, with DG connected, the voltage magnitudes were improved to allowable values. The network active power loss was reduced by 12.03% from 85.60MW to 75.30MW. In this way, the power system becomes more efficient and secured.

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1. INTRODUCTION

The electric power supply in Nigeria is problematic and unreliable. These problems include under voltages, high network losses, and frequent partial and total network collapse. Nigeria's power system has total network losses of 19% of generated power [1]. The available generation capacity in Nigeria is less than the power demand, thus resulting in power network being overloaded. Electricity demand in Nigeria is growing rapidly due to industrialization and rising population [2]. In fact, less than forty percent of Nigeria's population have access to quality electricity supply [3, 4]. There are cases of occasional system collapse in the network [5]. The federal government planned to address these challenges by introducing a renewable distributed generation to the power system [6]. Distributed generation is preferred to centralized synchronous generation because it is cheaper and does not require network upgrade. Distributed generations are small-scale generation which are connected to the electricity distribution system [7]. Distributed generation can be renewable generation or small-scaled conventional generation. They are widely used in distributed generation systems such as wind turbines, solar PV, fuel cells, and storage batteries [8].

The federal ministry of power has targeted 30% electricity generation from renewable energy by 2030 [9]. In 2005, the Ministry of Power in Nigeria launched the electric power reform act 2005, which introduces feed-in-tariff (FiT) scheme to promote renewable energy generation [10]. The installation of grid-connected DG will help to overcome the current challenges facing the power system [11]. Therefore, the aim of this paper is to determine the impact of DG on the Nigerian power system.

The design of the power system in Nigeria considered unidirectional power flow, that is, from the generating station down to the end users. This situation might lead to reverse power flow in the system when DG is connected to the power network. Therefore, it is necessary to carry out the impact study of DG on the power grid. This will help in the planning and operation of the future power system to minimize the negative impact of the DG integration. DG connected to the electricity distribution system may result in overvoltage [12], as well as overloading of power transformers and cables.

Previous studies have been carried out to determine the impact of DG on the electricity grid. For example, the impact of distributed generation with respect to voltage profile [13], line losses [14, 15], short-circuit current [8], and harmonic [16]. Majority of the studies consider power network in the UK power systems, where the DGs are mostly wind turbines and combined heat and power (CHP) type. In Nigeria, DGs are mostly solar PV and Diesel generators. Therefore, it is necessary to carried out impact studies on the Nigerian distribution network with available DG in order to understand the potential impacts on the network. Therefore, this paper examines the impacts of DG on the Nigerian electricity distribution network with respect to network voltage and power losses using the Newton-Raphson method in the Neplan software environment.

2. RESEARCH METHOD

The Nigerian 330 kV power grid shown in Figure 1 was developed using Neplan software. Power flow analysis is carried out using the Newton-Raphson solution. The input data for the power flow analysis include the generator output power, MW and MVAR peak loads, voltage, and power ratings of the line and transformer data. The modeled network is simulated with and without DG.

The network data was obtained from the power holding company of Nigeria (PHCN), interaction with PHCN staff, and transmission station at Osogbo. The limits for the distribution voltage (330kV) in Nigeria are ±5% of nominal [17]. The single line diagram of the Nigerian 330kV power network is shown in Figure 1 and the transmission line data is presented in Table 1. It consists of twenty-eight load stations and nine generating stations [18]. The population in Nigeria has increased due to industrial and economic growth.

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Table 1. Line parameter for 330kV lines

From Bus	To Bus	L (km)	R (p.u)	X (p.u)	B (p.u)
Osogbo	Ikeja	252	0.0099	0.0745	0.4949
Osogbo	Benin	251	0.0098	0.0742	0.4930
Egbin	Aja	27.5	0.0006	0.0044	0.0295
Ikeja	Akangba	17	0.0007	0.0050	0.0333
Osogbo	Ayede	115	0.0045	0.0340	0.2257
Ikeja	Egbin	62	0.0023	0.0176	0.1176
Ikeja	Benin	280	0.0110	0.0828	0.5500
Ikeja	Ayede	137	0.0054	0.0405	0.2669
Benin	Delta	107	0.0043	0.0317	0.2101
Benin	Sapele	50	0.0020	0.0148	0.0982
Kainji	Jebba	81	0.0032	0.0239	0.1589
Shiroro	Kaduna	96	0.0038	0.0284	0.1886
Afam(iv)	Alaoji	25	0.0010	0.0074	0.0491
Ajaokuta	Benin	195	0.0077	0.0576	0.3830
Jebba	Osogbo	249	0.0061	0.0461	0.3064
Kaduna	Kano	265	0.0090	0.0680	0.4516
Kaduna	Jos	197	0.0081	0.0609	0.4046
Jos	Gombe	265	0.0118	0.0887	0.5892
Sapele	Aladja	63	0.0025	0.0186	0.1237
Benin	Onitsha	137	0.0054	0.0405	0.2691
Onitsha	Newhaven	96	0.0036	0.0272	0.1807
Delta(iv)	Aladja	30	0.0012	0.0089	0.0589
Onitsha	Alaoji	80	0.0060	0.0455	0.3025
Jebba G	Jebba	8	0.0002	0.00020	0.0098
JebbaTS	Shiroro	244	0.0096	0.0721	0.4793
Kainji	Birnin	310	0.0122	0.0916	0.6089
Jos	Markudi	275	0.0029	0.0246	0.1450
Ikeja	Papalanto	45	0.0012	0.0089	0.0589

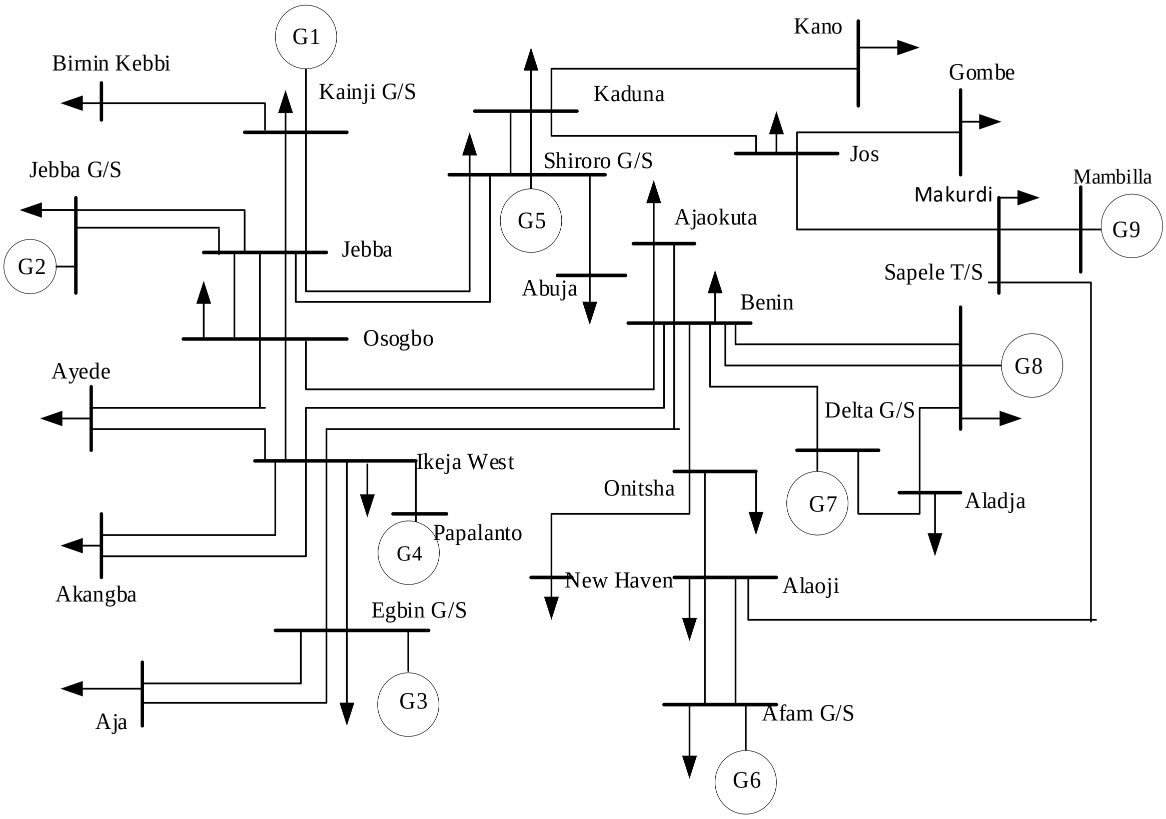

Figure 1. Nigeria power network [19], [20]

2.1. Formulation of Power flow Equations

In a typical bus of a power system network as shown in Figure 2. Transmission lines are represented by their equivalent π models [21]. The current I_i in Figure 2 is given as:

$$I_i = y_{i0}V_i + y_{i1}(V_i - V_1) + y_{12}(V_i - V_2) + \cdots + y_{in}(V_i - V_n)$$
$$= (y_{i0} + y_{i1} + y_{i2} + \cdots y_{in})V_i - y_{i1}V_1 - y_{i2}V_2 - \cdots - y_{in}V_n$$

$$I_i = V_i \sum_{j=0}^{n} y_{ij} - \sum_{j=1}^{n} y_{ij}V_j \quad j \neq i \tag{1}$$

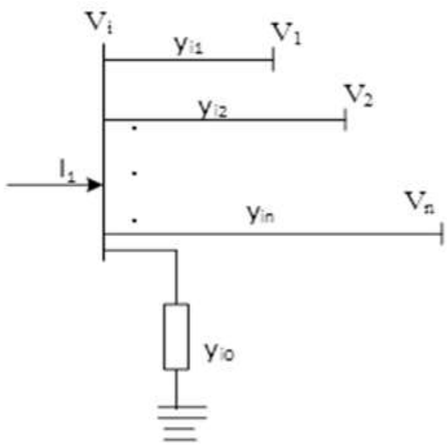

Figure 2. A typical bus of the power system [21]

The real and reactive power at bus is:

$$P_i + jQ_i = V_i I_i^*$$
$$I_i = \frac{P_i - jQ_i}{V_i^*} \quad (2)$$

Substitute for I_i in (1):

$$\frac{P_i - jQ_i}{V_i^*} = V_i \sum_{j=0}^{n} y_{ij} - \sum_{j=1}^{n} y_{ij} V_j \ \ j = \neq \quad (3)$$

As shown above, the power flow problem can be solved by iterative techniques [21, 22].

2.2. Newton Raphson Method

In Figure 2, this equation can be rewritten as:

$$I_i = \sum_{j=1}^{n} Y_{ij} V_j \quad (4)$$

Expressing this equation in polar form, we have:

$$I_i = \sum_{j=1}^{n} \left|Y_{ij}\right| \left|V_j\right| < \theta_{ij} + \delta_j \quad (5)$$

Therefore:

$$P_i - jQ_i = V_i^* I_i \quad (6)$$

Substituting (4) for Ii in (5):

$$P_i - jQ_i = |V_i| < -\delta_i \sum_{j=1}^{n} \left|Y_{ij}\right| \left|V_j\right| < \theta_{ij} + \delta_j \quad (7)$$

Separating the real and imaginary parts:

$$P_i = \sum_{j=1}^{n} |V_i| \left|V_j\right| \left|Y_{ij}\right| \cos\left(\theta_{ij} - \delta_i + \delta_j\right) \quad (8)$$

$$Q_i = \sum_{j=1}^{n} |V_i| \left|V_j\right| \left|Y_{ij}\right| \sin\left(\theta_{ij} - \delta_i + \delta_j\right) \quad (9)$$

Expanding (7) and (8) in Taylor's series, we have:

$$\begin{bmatrix} \Delta P_2^{(k)} \\ \vdots \\ \Delta p_n^{(k)} \\ \hline \Delta Q_2^{(k)} \\ \vdots \\ \Delta Q_n^{(k)} \end{bmatrix} = \left[\begin{array}{c|c} \begin{bmatrix} \frac{\partial P_2^{(k)}}{\partial \delta_2} & \cdots & \frac{\partial P_2^{(k)}}{\partial \delta_n} \\ \vdots & \ddots & \vdots \\ \frac{\partial P_n^{(k)}}{\partial \delta_2} & \cdots & \frac{\partial P_n^{(k)}}{\partial \delta_n} \end{bmatrix} & \begin{bmatrix} \frac{\partial P_2^{(k)}}{\partial |V_2|} & \cdots & \frac{\partial P_2^{(k)}}{\partial |V_n|} \\ \vdots & \ddots & \vdots \\ \frac{\partial P_n^{(k)}}{\partial |V_2|} & \cdots & \frac{\partial P_n^{(k)}}{\partial |V_n|} \end{bmatrix} \\ \hline \begin{bmatrix} \frac{\partial Q_2^{(k)}}{\partial \delta_2} & \cdots & \frac{\partial Q_2^{(k)}}{\partial \delta_n} \\ \vdots & \ddots & \vdots \\ \frac{\partial Q_n^{(k)}}{\partial \delta_2} & \cdots & \frac{\partial Q_n^{(k)}}{\partial \delta_n} \end{bmatrix} & \begin{bmatrix} \frac{\partial Q_2^{(k)}}{\partial |V_2|} & \cdots & \frac{\partial Q_2^{(k)}}{\partial |V_n|} \\ \vdots & \ddots & \vdots \\ \frac{\partial Q_n^{(k)}}{\partial |V_2|} & \cdots & \frac{\partial Q_n^{(k)}}{\partial |V_n|} \end{bmatrix} \end{array}\right] \begin{bmatrix} \Delta \delta_2^{(k)} \\ \vdots \\ \Delta \delta_n^{(k)} \\ \hline \Delta |V_2^{(k)}| \\ \vdots \\ \Delta |V_n^{(k)}| \end{bmatrix}$$

The element of the Jacobian matrix is evaluated at $\Delta\delta_i^{(k)}$ and $\Delta|V_i^{(k)}|$:

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \begin{bmatrix} \Delta\delta \\ \Delta|V| \end{bmatrix} \quad (10)$$

ΔP and ΔQ represents the difference between specified value and calculated value.
ΔV and $\Delta\delta$ represents magnitude voltage and voltage angle.

2.3. Newton Raphson method

The flowchart for the power flow solution by Newton-Raphson method is shown in Figure 3.

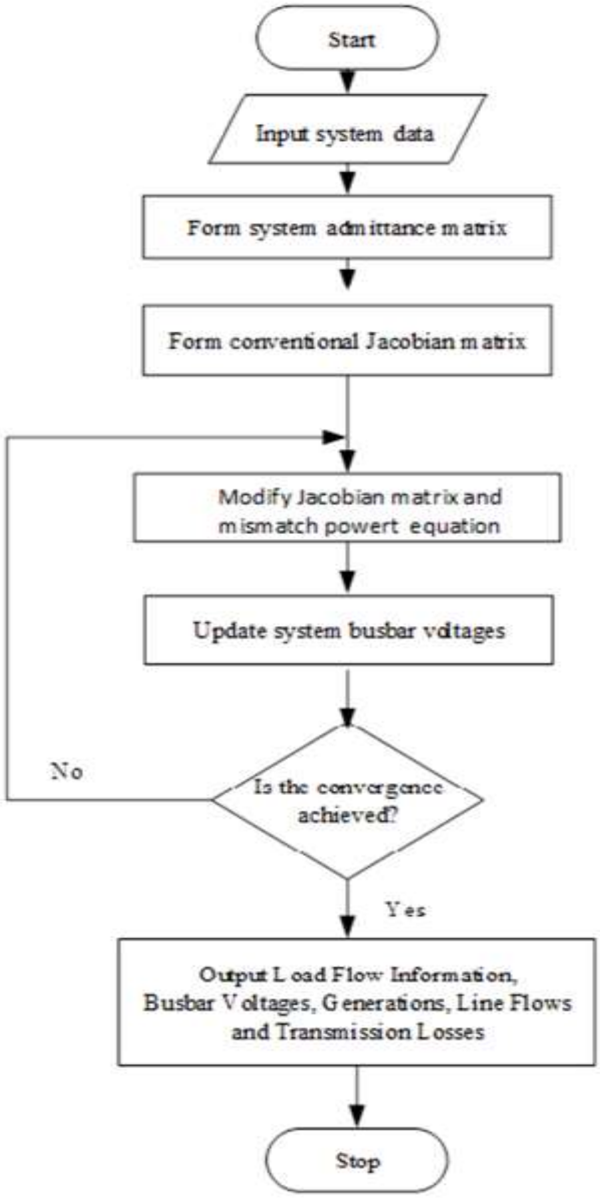

Figure 3. Power flow solution using newton raphson method

3. RESULTS AND DISCUSSION

In this study, all the simulations are carried out in the Neplan software environment. The first simulation is carried out with existing system data without DG. The result showed that voltage at the following buses, namely Gombe (0.897pu), Onitsha (0.937pu), New Haven (0.946pu), Ayede (0.932pu), Kano (0.885pu) and Jos (0.925pu) were outside the voltage statutory limit of 0.95pu $\leq V_i \leq$ 1.05pu as shown in Table 2. The total network active power loss without DG is 85.6MW. The results of the base case load flow providing active power losses with and without DG are shown in Figure 4. This result agree with previous studies on the network as reported in [23-25]. Therefore, incorporation of DG in the distribution network will help to alleviate the problems of voltage limit violations, and high-power loss in the system. In the second simulation, six DGs, 10MW each was connected in the network and are optimally located at the following buses, NewHaven, Ayede, Jos, Onitsha, Gombe, and Kano in Figure 1 [17].

The second power flow results showed that immediately the DGs were installed in the network there is redistribution of power flows and the system total active power loss reduced to 75.3MW (12.07% reduction) as depicted in Figure 4. The high-power losses in the system represent a huge financial deficit to the wheeling utility. Therefore, the installation of DG will reduce the financial burden on wheeling utility. The simulation results show that Jos to Gombe transmission lines had the highest losses in the network as a result of excessive reactive power build up along the transmission lines. Reactive power flows along the line were due to a low power factor in the nodes.

Table 2. Voltage profile with and without DG

Bus No	Bus Name	Bus Voltage without DG (pu)	Bus Voltage with DG (pu)
1	Kainji	1.050	1.050
2	Oshogbo	1.014	1.021
3	Benin	1.028	1.031
4	Ikeja West	1.019	1.021
5	Ayede	0.932	0.980
6	Jos	0.925	0.968
7	Onitsha	0.937	0.976
8	Akangba	1.012	1.013
9	Gombe	0.897	0.972
10	Abuja	0.98	1.000
11	Egbin	1.050	1.050
12	Delta	1.050	1.050
13	Papalanto	1.050	1.050
14	Mambilla	1.050	1.050
15	Makurdi	1.015	1.027
16	Aladja	1.045	1.045
17	Kano	0.885	0.965
18	Sapele	1.050	1.050
19	Aja	1.045	1.045
20	Ajaokuta	1.036	1.040
21	New haven	0.946	0.984
22	Alaoji	1.030	1.033
23	Afam GS	1.050	1.050
24	Jebba	1.049	1.049
25	Jebba GS	1.050	1.050
26	Birnin Kebbi	1.033	1.033
27	Shiroro	1.050	1.050
28	Kaduna	1.012	1.022

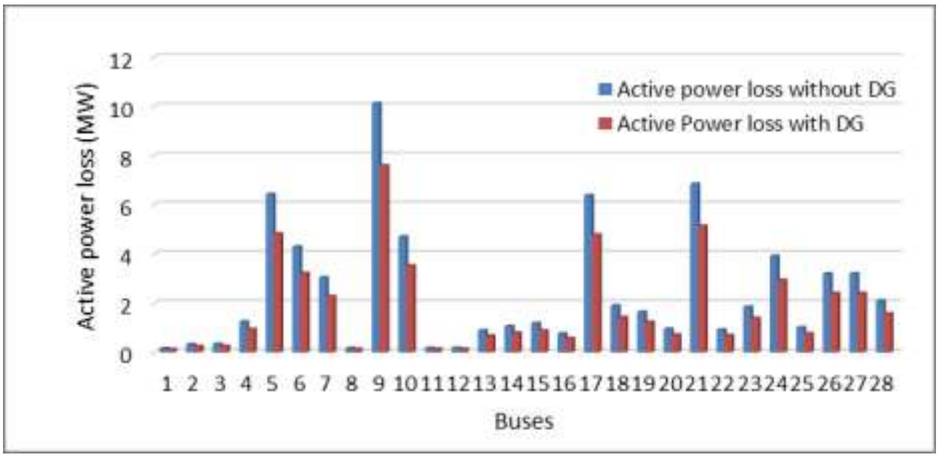

Figure 4. Active power loss in the system

4. CONCLUSION

In this work, load flow analysis of the Nigerian 330 kV power network was performed using Neplan software and the buses with low voltages were identified. The ability of DG to enhance reduction in power loss and voltage improvement was demonstrated. The DGs gave a satisfactory result, raising the magnitude of the voltage at the buses where they were connected. Also, it raised the magnitude of voltage at other load buses sufficiently to safe operating limit of 0.95pu≤V≤1.05pu, thus, enhancing network security and efficiency. The power flow analysis of the Nigerian power grid conducted showed that the power network is weak with high power loss and voltage limit violations. Moreso, when the DG is connected to the network it helps in reducing power losses in the system depending on the size and location of the DG installed. The network losses reduced by 12.07% leading to savings in the overall network cost. It is observed that at higher penetration of DG, the voltage rise problem could arise. This voltage rise problem could damage network equipment and affect network operation. The impact of DG is location-dependent, as such, in this study, the DG was optimally connected to the distribution network to avoid unnecessary voltage rise. It is expected that the results obtained will help future research in this area and assist the PHCN in network planning and maintenance.

ACKNOWLEDGEMENTS

This research work was supported in part by the Ekiti State University, Ado-Ekiti, Nigeria and the Institute of Energy, School of Engineering, Cardiff University, United Kingdom. The authors are grateful to all the staff and students of these institutions for their assistance.

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