Available online at www.elixirpublishers.com (Elixir International Journal)

Electrical Engineering

Elixir Elec. Engg. 133 (2019) 53498-53501

ISSN: 2229-712X

Impact of Distributed Generation in the Grid Network of the Nigerian South-South Region

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ARTICLE INFO

Article history:

Received: 12 July 2019;

Received in revised form:

7 August 2019;

Accepted: 14 August 2019;

Keywords

DG – Distributed Generation,
IPP – Independent Power Producers,
ENS – Energy not supplied,
NEPLAN–Simulation Software

ABSTRACT

The impact of distributed generation in the grid network of the Nigerian South-South Region is studied in this paper. DG capacity installation in the network was modelled using NEPLAN software. Reduction of network and transmission line losses as well as minimization of transmission line congestion and voltage profile improvement for the nodes of the network were observed in the results.

Introduction

Distributed generation (DG) is the generation of electricity at little capacities close to the customer and connected to the distribution network. It can be done by either the final customers, independent power producers (IPPs) or by distribution utilities. It provides consumers with an alternative supply for peak consumption or serves as a backup option. It also provides IPPs with a business opportunity in the face of the competitive electricity market. Utilities see it as a viable option to minimise losses, resolve voltage problems in the network and avoid or delay network expansion needs.

Accelerated technological progress and the unbundling of the Nigerian power market created opportunities to invest in micro generation capabilities with reduced generation facilities size and running costs. Renewable energy technologies and cleaner fossil fuel technologies that are energy friendly are also pushing the demand for distributed energy generation. This will provide investors the ability to deliver energy on their own and to supply power to the grid at low voltages. Energy reliability and security will be improved and losses recorded both in transmission and distribution networks will be minimised [1].

Benefits of this include the reduction of energy losses and energy not supplied (ENS) as well as improvement of voltages profiles. These have been mentioned in literature. However, the impact on the transmission network of a massive roll out of DG, should be considered for proper network expansion and operation planning process.

Definitions

The growth of electricity markets and accelerated technological progress has led to smaller generation facilities sizes and running costs. This brought about new investments in generation with private investors. Environmentally friendly renewable energy technologies and cleaner fossil fuel technologies are driving the demand for distributed energy generation [2]. Distributed generation (also called embedded generation, on-site generation or decentralized generation) can be defined as the generation of small pockets of power located close to the customer and connected to the grid through the distribution system. Different authors have proposed different definitions based on the facility sizes, generation capabilities and storage abilities. These can be summarized as:

- Electricity generation through small applications in relation to big central generation stations and connected to the power system through the distribution network. [4][5]
- DG is generation or storage of electricity in a micro scale and installed near to the load [12], with the option to exchange (sell or buy) with the power network. In some cases, maximum energy efficiency is achieved. [3]
- Electric power generation that corresponds to small units connected at distribution voltage and placed at the consumption point. [2][6][10][11].

These definitions are not exhaustive however. The range of capacity that can be used to consider an installation as DG varies widely and can go from tens of kW to hundreds of MW depending on the total installed capacity of the network.

Mathematical Concepts [1]

The impact of the installation of DG in a network is made using power flow over transmission lines and transformers.

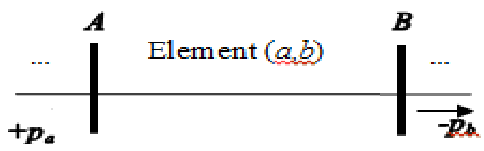

Figure 1. Power flow over a transmission network element.

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Power flow into the network over the element (*a*, *b*) from node *A* is denoted as $+p_a$ while power delivered from the network through node *B* is denoted as $-p_b$. The algebraic difference in the sum of power received in the network and power delivered from the network is the losses in the element [1].

$$E_{ab} = E_{ba} = p_a + p_b \quad (1)$$

Taking *U* as the set of elements of a specific zone, the power losses of the zone are given by:

$$E_U = \sum_{a\neq b\in U} \alpha_{ab} \quad (2)$$

The power entering the element (*a*, *b*) through node *a*, p_a^+ and the power leaving the element (*a*, *b*) through node *b*, p_b^- are given by:

$$p_a^+ = \max(0, p_a)\,;\, p_b^- = \min(0, p_b) \quad (3)$$

For the set *U*, the power entering the set P_a^+ and the power leaving the set P_b^- are given by:

$$P_U^+ = \sum_{a\neq b\in U} p_a^+\,;\; P_U^- = \sum_{b\neq a\in U} p_b^- \quad (4)$$

The power transport, *T*, is defined as the product of the sum of power received or delivered by the element (*a*, *b*) multiplied by its length l_{ab}, for the elements in set *U*, and is given by:

$$T_U^+ = \sum_{a\neq b\in U} p_a^+\, l_{ab};\; T_U^- = -\sum_{b\neq a\in U} p_a^-\, l_{ba} \quad (5)$$

Reduction in the Use of Transmission Lines and Line Losses

Transmission lines losses reduction of the set *U* is evaluated with and without DG as given below:

$$\Delta E_U = E_U^0 - E_U^{DG} \quad (6)$$

For a zone *Z*, which comprises of the set *U* and other sets, the reduction in the use of transmission lines is estimated through the micro-economic analysis of electricity transport activity [7] where the economic product of transport activity is given as a Cobb-Douglas function which is:

$$P_Z * L = V * \phi * \sqrt{\left(\frac{M}{\rho}\right)} * \sqrt{E_Z} \quad (7)$$

Where

P_Z = Transmitted power for zone (*Z*)
L = Transmission distance
V = Transmission voltage
Φ = Voltage phase angle
$(M/\rho)^{0.5}$ = Electrical conducting material
$(E_Z)^{0.5}$ = Losses for the zone (*Z*)

From equation (5), electricity transport in set *U*, T_U, is the sum of the power delivered per element multiplied by the corresponding transmitted distance. From this, the percentage of avoided transport can be evaluated as:

$$\%T_U = \frac{(T_U^0 - T_U^{DG})}{T_U^0} * 100 \quad (8)$$

Economic Evaluation

Economic evaluation is done using the spot market price of electricity. The economic assessment of losses is given by:

$$EAL = \frac{\sum_{i=1}^{Z} \Delta E_i * mp}{IC^{DG}} \quad (9)$$

Where

EAL = Economic Assessment of Losses
ΔE_i = Avoided losses for *Z* zone
mp = Spot market price of electricity
IC^{DG} = Installed DG capacity

The savings in transmitted power can be measured through the difference between the power transmitted with the use of DG and without the use of DG. This can be used to determine the reduction in the use of transmission lines.

For the set of elements in the set *U* (from equation 4), the savings in transmitted power can be determined from the relation:

$$\Delta P_U = P_U^0 - P_U^{DG} \quad (10)$$

Transmission Network and DG Modelling

The power system of the Nigerian South-South Region has an installed capacity of about 4GW of natural gas and steam plants [8].

Given its technical characteristics, DG is installed in medium distribution voltage networks which correspond to 33kV networks in Nigeria. The modelled capacities were added as a reduction in active power in the nodes. Since the entrance of new capacity will bring about a new generation despatch, the method of uniform allocation was used. This is the subtraction of the new DG capacity from the existing conventional generation capacity. The network elements were connected to the network at Delta node.

The choice of the node for the installation of the DG in the region was made by the node with the highest loss or poorest voltage profile in the region. With this, the DG was installed at Onnie.

NEPLAN software was used to model the network elements and perform simulations. The load flow subroutine was used to obtain the results [9].

Result Analysis

The results of the simulation of the network without DG and with DG respectively are shown in tables 1 and 2 while the graphical representation of line losses for both the active and reactive power are depicted in figures 2 and 3 below.

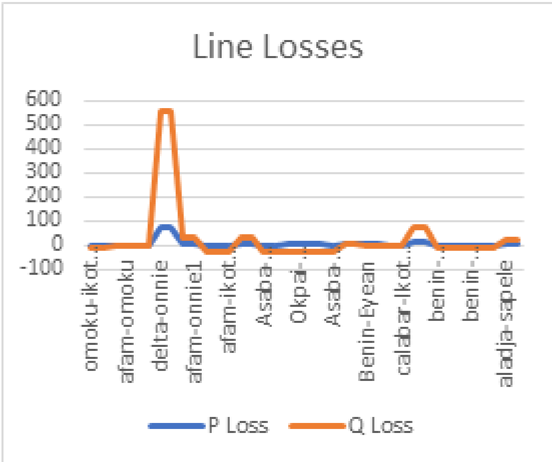

Figure 2. Line losses for the region

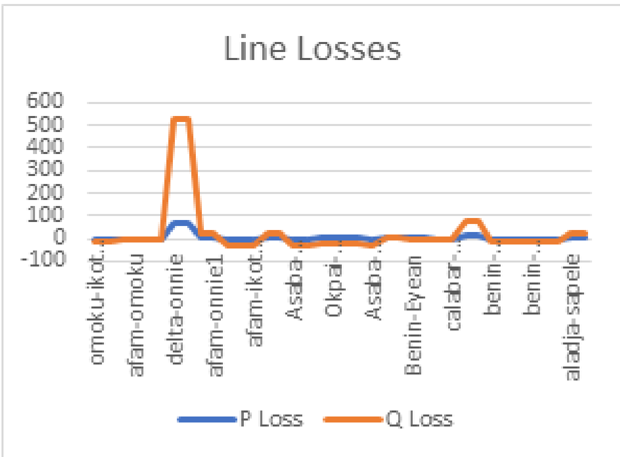

Figure 3. Line losses with DG installation.

Table 1. Network losses and node profiles for the region.

	P Loss (MW)	**Q Loss (MVar)**	**P Imp (MW)**	**Q Imp (MVar)**	**P Gen (MW)**	**Q Gen (MVar)**	**P Load (MW)**	**Q Load (MVar)**
Network	107.931	503.859	-3138.95	379.626	4729	661.233	4621.069	157.374
Node Name	U (kV)	u (%)	Angle U (°)	P Load (MW)	Q Load (MVar)	P Gen (MW)	Q Gen (MVar)	
GS Omoku	327.853	99.35	38.3	255.3	79	323	100	
LC Ikot E.	328.771	99.63	39.2	193.2	67	0	0	
LC Onnie	320.44	97.1	34	165.6	80	0	0	
GS Okpai	330	100	10.6	179.4	118.767	536	0	
GS Eyean	338.382	102.54	7.3	0	0	360	100	
LC Benin	334.928	101.49	5.9	216.66	80	0	0	
LC Asaba	332.299	100.7	7.8	110.4	50	0	0	
GS Calabar	329.8	99.94	39.9	248.4	56	625	100	
GS Delta	330	100	0	3138.949	0	950	479.626	
GS Sapele	337.005	102.12	7.2	0	0	960	100	
LC Aladja	330.928	100.28	2	113.16	45	0	0	
GS Afam	327.796	99.33	38.3	0	0	975	200	

Table 2: Bus nodes with DG installation

	P Loss (MW)	**Q Loss (MVar)**	**P Imp (MW)**	**Q Imp (MVar)**	**P Gen (MW)**	**Q Gen (MVar)**	**P Load (MW)**	**Q Load (MVar)**
Network	102.719	450.874	-3144.16	301.641	4729	686.233	4626.281	235.359
Node Name	U (kV)	U (%)	Angle U (°)	P Load (MW)	Q Load (MVar)	P Gen (MW)	Q Gen (MVar)	
GS Omoku	338.769	102.66	36.4	255.3	79	323	100	
LC Ikot E.	339.744	102.95	37.3	193.2	67	0	0	
LC Onnie	331.47	100.45	32.6	165.6	80	50	25	
GS Okpai	330	100	10.6	179.4	118.767	536	0	
GS Eyean	338.382	102.54	7.3	0	0	360	100	
LC Benin	334.928	101.49	5.9	216.66	80	0	0	
LC Asaba	332.299	100.7	7.8	110.4	50	0	0	
GS Calabar	340.747	103.26	37.9	248.4	56	625	100	
GS Delta	330	100	0	3144.161	0	950	401.641	
GS Sapele	337.005	102.12	7.2	0	0	960	100	
LC Aladja	330.928	100.28	2	113.16	45	0	0	
GS Afam	338.711	102.64	36.4	0	0	925	200	

From figure 2, it is observed that Delta-Onnie lines has the highest active power losses while Afam-Omoku lines have the lowest active power losses. This can be attributed to the line loadings or line flows across the lines. The aggregate active power losses for the region is 107.931MW which is 2.336% of the total load demand of the network.

Onnie has the lowest bus voltage while the bus voltages of Eyean, Sapele and Benin are slightly above the nominal values.

With the installation of a DG of 50MW and connected to the network at Onnie, there was a redistribution of line flows. The installed DG capacity corresponds to 1.081% of the total active power demand of the network. The line losses of Delta-Onnie lines dropped by 5.267% while the total aggregate network losses dropped by 5.074% to 102.719MW. Note that the losses reduced further with an increase in the output of the DG but the output was limited in standing with the definition of a DG as a small unit of power generation.

The node voltages profiles improved by as much as 3.44% in some nodes and the node voltages of all busses in the network corrected to the nominal voltage values and slightly higher.

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