Benefits of Distributed Generation in the Nigerian South West Zone Power System

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Abstract- The benefits of distributed generation in the Nigerian South West zone power system is studied in this paper. DG capacity installation in the power system was modelled using NEPLAN software. Network loss reduction, reduction in transmission line losses and congestion as well as voltage profile improvement for the nodes of the network were some of the observed advantages in the results.

Indexed Terms- DG – Distributed generation, IPP – Independent Power Producers, ENS – Energy not supplied, NEPLAN – Simulation software, kW – Kilowatts

I. INTRODUCTION

The unbundling of the Nigerian power market and accelerated technical progress has created opportunities for investors to invest in small generation capabilities with attendant reduction in the generation facilities size and unitary costs. Environmentally friendly renewable energy technologies and cleaner fossil fuel technologies are driving the demand for distributed energy generation. Users will be able to deliver energy on their own and to supply energy 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].

Distributed generation (DG) corresponds to small power production located close to the customer and connected to the distribution system. It can be implemented either by final customers, independent power producers (IPPs) or by distribution utilities. Final customers get an alternative supply for peak consumption or a backup option. IPPs have a business opportunity in the competitive electricity market and the utility see it as an interesting option to reduce losses, deal with voltage problems within the system, or to avoid or delay network expansion.

Benefits, such as the reduction of energy losses and energy not supplied (ENS) as well as improvement of voltages profiles have been mentioned in literature. Impact on the transmission network, due to a massive installation of DG, should be considered for proper network expansion and operation planning process.

II. DEFINITIONS

Growth of power markets and accelerated technical progress has led to reductions in the generation facilities size and unitary costs. This trend has led to new investments in generation with private participation. 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. However, different authors have proposed different definitions based on the facility sizes, storage abilities and generation capabilities. 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 however, not exhaustive. The range of capacity used to consider an installation as DG varies widely, going from tens of kW to hundreds of MW depending on the total installed capacity of the power system.

- Mathematical Concepts [1]

Evaluation of DG effects is made using the power flow over transmission lines and transformers.

Figure 1: Power flow over a transmission network element

A transmission network element is denoted in Figure 1 above with its initial and end nodes denoted by *X* and *Y* respectively. Power flow over the element (*x*, *y*) from node *X* is denoted as $+p_x$ as power flows into the network through the node while power delivered from the network through node *Y* is denoted as $-p_y$. The difference in the sum of power received and power delivered is the power losses in the corresponding element [1].

$$E_{xy} = E_{yx} = p_x + p_y \quad (1)$$

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

$$E_Z = \sum_{x \neq y \in z} \alpha_{xy} \quad (2)$$

The power entering the element (*x*, *y*) through node x, p_x^+ and the power leaving the element (*x*, *y*) through node y, p_y^- are given by:

$$p_x^+ = \max(0, p_x)\,;\, p_y^- = \min(0, p_y) \quad (3)$$

For the set *Z*, the power entering the set P_x^+ and the power leaving the set P_y^- are given by:

$$P_Z^+ = \sum_{x \neq y \in Z} p_x^+\,;\; P_Z^- = \sum_{y \neq x \in Z} p_y^- \quad (4)$$

The power transport, *T*, which is defined as the product of the sum of power received or delivered by the element (*x*, *y*) multiplied by its length l_{xy}, for the elements in set *Z*, is given by:

$$T_Z^+ = \sum_{x \neq y \in Z} p_x^+\, l_{xy}\,;\; T_Z^- = -\sum_{y \neq x \in Z} p_x^-\, l_{yx} \quad (5)$$

- Reduction in Line Losses and in The Use of Transmission Lines

Power transmission lines losses reduction of the set *Z* is evaluated with and without DG as given below:

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

For a zone *g*, which comprises of the set *Z* 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:

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

Where

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

Therefore, from equation (5), electricity transport in set *Z*, T_Z, 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:

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

- Economic Evaluation

Economic evaluation is done using the spot market price of electricity. Thus, the economic assessment of losses is obtained using the relation:

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

Where

EAL = Economic Assessment of Losses
ΔE_i = Avoided losses for *g* 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 Z (from equation 4), the savings in transmitted power can be determined from the relation:

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

- Transmission Network and DG Modelling

The Nigerian South West zone power system has an installed capacity of about 3.4GW of natural gas and steam [8]. In fact, the biggest thermal station in Nigeria is within the zone.

Given its technical characteristics, DG is installed in medium voltage networks which correspond to 33kV voltage networks in Nigeria. The modelled capacities were installed as a reduction in active power in the nodes. Knowing that the entrance of new capacity will necessitate a new generation despatch, this is avoided by subtracting the DG capacity to be installed from the existing conventional generation capacity. This adjustment is known as uniform allocation. The network elements were connected to the grid network at Egbin node.

The choice of the node for the installation in the region was influenced by the node with the highest loss or poorest voltage regulation in the region. To this end, the DG was installed at Osogbo.

The 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

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

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	25.397	-98.914	2817.717	967.086	3425.717	1207.086	3400.32	1306
Node Name	U (kV)	u (%)	Angle U (°)	P Load (MW)	Q Load (MVar)	P Gen (MW)	Q Gen (MVar)	
LC Oshogbo	308.76	93.56	-9.3	277.38	137	0	0	
LC Okearo	325.96	98.78	-1.4	138	80	0	0	
GS Olurunsogo	325.317	98.58	-3.1	0	0	304	120	
LC Akangba	320.481	97.12	-3.7	648.6	186	0	0	
LC Ikeja.W	322.749	97.8	-2.7	592.02	248	0	0	
LC Alagbon	327.426	99.22	-1	69	30	0	0	
LC Lekki	327.437	99.22	-1	110.4	70	0	0	
LC Ayade	316.975	96.05	-6.5	191.82	61	0	0	
GS Egbin	330	100	0	0	0	2817.717	967.086	
LC Sakete	309.527	93.8	-6.9	331.2	140	0	0	
LC Aja	327.708	99.31	-0.9	627.9	166	0	0	
GS Omotosho	317.114	96.1	-4.2	414	188	304	120	

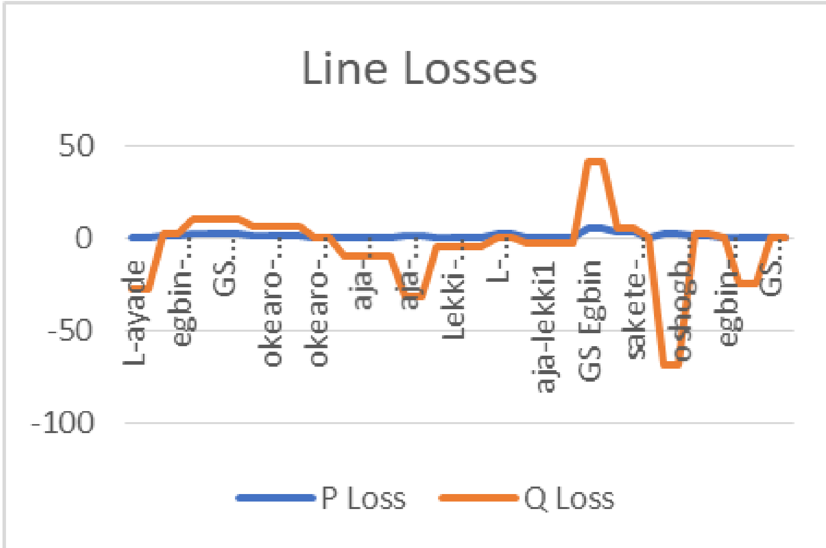

Figure 2: Line losses for the region

From figure 2, it is observed that Egbin-Ikeja West lines has the highest active power losses while Sakete-Ikeja West and Egbin-Aja 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 25.397MW which is 0.75% of the total load demand of the network.

Osogbo has the lowest bus voltage and only at Egbin is the bus voltage at the nominal value. All other buses have their voltages below nominal values.

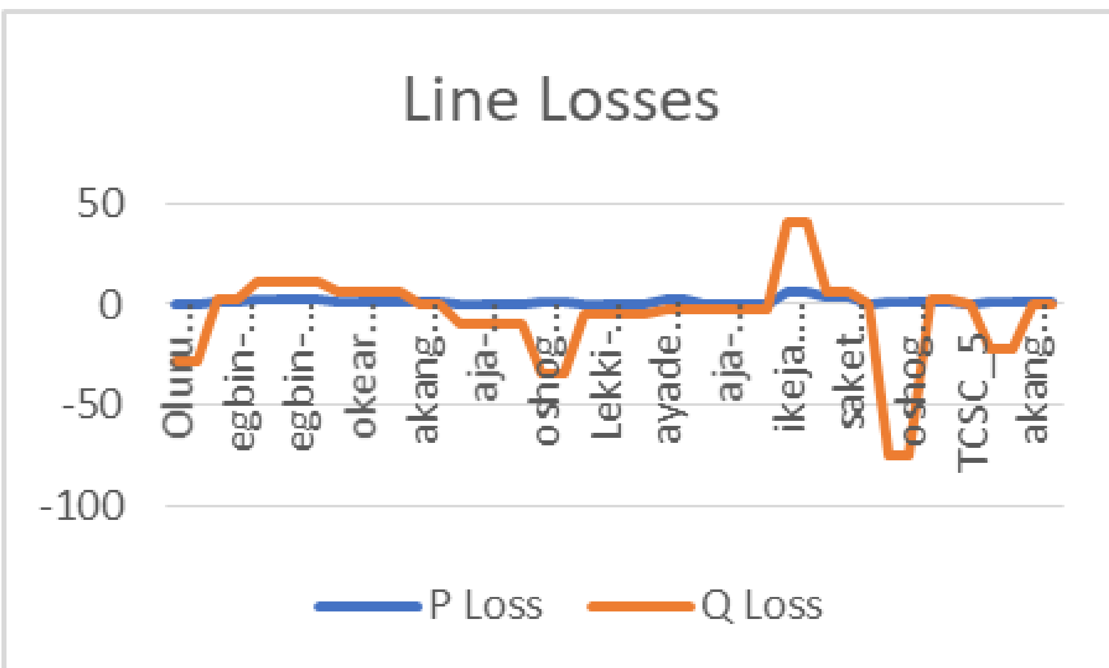

Figure 3: Line losses with DG installation

With the installation of a DG of 42.5MW and connected to the network at Osogbo, there was a redistribution of line flows.

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	24.302	-110.664	2816.622	940.336	3424.622	1195.336	3400.32	1306
Node Name	U (kV)	u (%)	Angle U (°)	P Load (MW)	Q Load (MVar)	P Gen (MW)	Q Gen (MVar)	
LC Oshogbo	312.692	94.76	-8.3	277.38	137	42.5	15	
LC Okearo	326.07	98.81	-1.4	138	80	0	0	
GS Olurunsogo	326.831	99.04	-2.8	0	0	304	120	
LC Akangba	320.702	97.18	-3.7	648.6	186	0	0	
LC Ikeja.W	322.969	97.87	-2.7	592.02	248	0	0	
LC Alagbon	327.426	99.22	-1	69	30	0	0	
LC Lekki	327.437	99.22	-1	110.4	70	0	0	
LC Ayade	319.449	96.8	-6	191.82	61	0	0	
GS Egbin	330	100	0	0	0	2816.622	940.336	
LC Sakete	309.76	93.87	-6.8	331.2	140	0	0	
LC Aja	327.708	99.31	-0.9	627.9	166	0	0	
GS Omotosho	316.801	96	-4.8	414	188	261.5	120	

The DG capacity corresponds to 1.25% of the total active power demand of the network.

The line losses of Shiroro-Jebba lines dropped by 0.97% while the total aggregate network losses dropped by 4.506% to 24.302MW. 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 1.273% in some nodes but the node voltages of still tended towards the lower limit requiring reactive power compensation to bring them to nominal values.

REFERENCES

[1] Camilo Tautiva, Hernando Duran and Angela Cadena "Technical and Economic Impacts of Distributed Generation on the Transmission Networks" IEEE 2011

[2] Lorrin Philipson and H. Lee Willis "Understanding Electric Utilities and De-Regulation" Taylor & Francis group. 2006

[3] SN Singh, Jacob Ostergaard and Naveen Jain "Distributed Generation in Power Systems: An Overview and Key Issues" www.orbit.dtu.dk/fedora/objects/orbit:59722/datastreams/file_5202512/content

[4] American Council for an Energy Efficient Economy "Distributed Generation" https://aceee.org/topics/distributed-generation. 2002-2016

[5] Cypress Creek "What Is Distributed Generation and How Might It Shape the Utility Industry's Future?" https://ccrenew.com/news/what-is-distributed-generation-and-how-might-it-shape-the-utitlity-industrys-future. March 2016

[6] Thomas Ackerman, Goran Andersson, and Lennart Soder "Distributed Generation: A Definition". Science Direct Journal, 2001.

[7] A. Cadena, A. Marcucci, J. F. Pérez, H. Duran, H. Mutis, C. Tautiva, F. Palacios, "Efficiency analysis in electricity transmission utilities". Journal of Industrial & Management Optimization, 2009, 5 (2): 253-274. doi: 10.3934/jimo.2009.5.253

[8] Engr. Kingsley Osuoha "Daily Operational Report" www.nigeriasystemoperator.org May 2019.

[9] BCP Busarello + Cott + Partner Inc.; NEPLAN Users Guide V553, July 2011. http://www.neplan.ch/support_area/index.php

[10] Roger C. Dugan, Mark F. McGranaghan, Surya Santoso, H. Wayne Beaty "Electrical Power Systems Quality". McGraw-Hill Companies. 2004.

[11] Eltaib Said Elmubarak, Ali Mohamed Ali "Distributed Generation: Definitions, Benefits, Technologies and Challenges". International Journal of Science and Research (IJSR), Volume 5 Issue 7. 2016.

[12] U.S. Department of Energy "The Potential Benefits of Distributed Generation and Rate Related Issues That May Impede Their Expansion: A Study Pursuant to Section 1817 of The Energy Policy Act of 2005". www.ferc.gov/legal/fed-sta/exp-study. 2007