Analysing the Impact Of Distributed Generation in the Nigerian South East Region

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Abstract- The impact of distributed generation in the Nigerian South East Region grid network is analysed in this paper. DG capacity installation in the network was modelled using NEPLAN software. Network loss reduction, transmission line power losses and congestion reduction as well as voltage profile improvement for the nodes of the network were observed in the results.

Indexed Terms- DG – Distributed generation, IPP – Independent Power Producers, ENS – Energy not supplied, NEPLAN – Simulation software, MW – Megawatt.

I. INTRODUCTION

With the unbundling of the Nigerian power market and accelerated progress in technological development, opportunities have been created for individuals to invest in micro generation capabilities with reduced generation facilities size and unitary costs. Environmentally friendly renewable energy technologies and cleaner fossil fuel technologies are also driving the need 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) is the production of small pockets of power close to the customer and connected to the distribution system. It can be implemented either by the customers, independent power producers (IPPs) or by distribution utilities. This will provide customers an alternative supply for peak consumption or a backup option and also create a business opportunity for IPPs in the competitive electricity market. It also gives the utility an interesting option to reduce losses, deal with voltage problems within the network or avoid network expansion.

The reduction of energy losses and energy not supplied (ENS) and improvement of voltages profiles have been mentioned in literature as benefits of DG. Nevertheless, the impact on the transmission network, of a massive installation of DG, should be considered for proper network expansion and operation planning process.

II. DEFINITION

The growth of electricity markets and accelerated progress in technological has brought about reductions in generation facilities sizes and operating costs. This has led to new investments in generation with private participation [2]. Distributed generation (also called embedded generation, on-site generation or decentralized generation) is the generation of small pockets of power located close to the customer and connected to the grid through the distribution system. Different authors, however, 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]

However, these definitions are 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.

III. MATHEMATICAL CONCEPTS [1]

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

Figure 1: Power flow over a transmission network element

Figure 1 depicts a transmission network with nodes denoted as *J* and *K* respectively. Power flow into the network (*j*, *k*) from node *J* is denoted as $+p_j$ while power delivered from the network through node *K* is denoted as $-p_k$. The difference in the sum of power received and power delivered is the power losses in the corresponding element [1].

$$E_{jk} = E_{kj} = p_j + p_k \quad (1)$$

Taking η as the set of elements of a particular zone, the power losses of the zone are given by:

$$E_\eta = \sum_{j \neq \in \eta} \mu_{jk} \quad (2)$$

The power entering the element (*j*, *k*) through node *j*, p_j^+ and the power leaving the element (*j*, *k*) through node *k*, p_k^- are given by:

$$p_j^+ = \max(0, p_j)\,; p_k^- = \min(0, p_k) \quad (3)$$

For the set η, the power entering the set P_j^+ and the power leaving the set P_k^- are given by:

$$P_\eta^+ = \sum_{j \neq k \in \eta} p_j^+\,;\ P_\eta^- = \sum_{j \neq k \in \eta} p_k^- \quad (4)$$

The power transport, τ, which is defined as the product of the sum of power received or delivered by the element (*j*, *k*) multiplied by its length l_{jk}, for the elements in set η, is given by:

$$\tau_\eta^+ = \sum_{j \neq k \in \eta} p_j^+\, l_{jk};\ \tau_\eta^- = -\sum_{j \neq k \in \eta} p_j^-\, l_{jk} \quad (5)$$

IV. REDUCTION IN LINE LOSSES AND IN THE USE OF TRANSMISSION LINES

The reduction of transmission lines losses of the set η is evaluated with and without DG as given below:

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

For a zone $\mathcal{Z}$, which comprises of the set η 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:

$$P_{\mathcal{Z}} * L = V * \phi * \sqrt{\left(\frac{M}{\rho}\right)} * \sqrt{E_{\mathcal{Z}}} \quad (7)$$

Where

$P_{\mathcal{Z}}$ = Transmitted power for zone ($\mathcal{Z}$)

L = Transmission distance

V = Transmission voltage

Φ = Voltage phase angle

$(M/\rho)^{0.5}$ = Electrical conducting material

$(E_{\mathcal{Z}})^{0.5}$ = Losses for the zone ($\mathcal{Z}$)

Therefore, from equation (5), electricity transport in set η, $\tau_{\mathcal{Z}}$, 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:

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

V. ECONOMIC EVALUATION

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

$$EAL = \frac{\sum_{\mathcal{Z}=1}^{3} \Delta E_{\mathcal{Z}} * mp}{IC^{DG}} \quad (9)$$

Where

EAL = Economic Assessment of Losses

$\Delta E_{\mathcal{Z}}$ = Avoided losses for $\mathcal{Z}$ 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 η (from equation 4), the savings in transmitted power can be determined from the relation:

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

VI. TRANSMISSION NETWORK AND DG MODELLING

The power system of the Nigerian South East Region has an installed capacity of about 872MW of natural gas and steam plants [8]. Given its technical characteristics, DG is installed in medium distribution voltage networks which correspond to 33kV voltage networks in Nigeria. The modelled capacities were installed as a reduction in active power in the nodes. Since 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 Egbema node.

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

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

VII. 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.

Figure 2: Line losses for the region

From figure 2, it is observed that Owerri-Egbema lines has the highest active power losses while New-Haven/Ugwuaji 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 0.558MW which is 0.06% of the total load demand of the network.

Owerri has the lowest bus voltage but the bus voltages of all the nodes in the network are about the nominal values.

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	0.558	-97.633	-134.462	-87.633	923	240	922.442	337.633
Node Name	U (kV)	u (%)	Angle U (°)	P Load (MW)	Q Load (MVar)	P Gen (MW)	Q Gen (MVar)	
LC Owerri	328.683	99.6	-1.2	248.4	75	0	0	
GS Egbema	330	100	0	134.462	87.633	338	80	
LC New H,	329.103	99.73	-1	77.28	20	0	0	
LC Ugwuaji	328.921	99.67	-1	82.8	45	0	0	

LC Onitsha	329.181	99.75	-1	158.7	42	0	0	
GS Alaoji	329.249	99.77	-0.9	220.8	68	585	160	

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	0.537	-97.921	-134.483	-95.921	923	248	922.463	345.921
Node Name	U (kV)	u (%)	Angle U (°)	P Load (MW)	Q Load (MVar)	P Gen (MW)	Q Gen (MVar)	
LC Owerri	328.959	99.68	-1.2	248.4	75	25.5	8	
GS Egbema	330	100	0	134.483	95.921	338	80	
LC New H,	329.292	99.79	-1.1	77.28	20	0	0	
LC Ugwuaji	329.111	99.73	-1.2	82.8	45	0	0	
LC Onitsha	329.37	99.81	-1.1	158.7	42	0	0	
GS Alaoji	329.439	99.83	-1.1	220.8	68	559.5	160	

Figure 3: Line losses with DG installation

With the installation of a DG of 25.5MW, connected to the network at Owerri, there was a redistribution of line flows. The DG capacity corresponds to 2.76% of the total load demand of the network. The line losses of Owerri-Egbema lines dropped by 0.571% while the total aggregate network losses dropped by 3.911% to 0.537MW. 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 0.084% in some nodes but the node voltages of all the busses were maintained around the nominal values.

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