IMPACT OF DISTRIBUTED GENERATION ON DISTRIBUTION NETWORK IN IMO STATE;

[1]S.O.E. Ogbogu and [2]Eke, Frank
[1]Department of Electrical/Electronic Engineering, Federal University of Technology, Owerri, Imo State, Nigeria
[2]Department of Electrical/Electronic Engineering, Chukwuemeka Odumegwu Ojukwu University, Uli, Anambra State, Nigeria

ABSTRACT

Despite the government huge investments into the power sector, to adequately ensure regular power supply to electricity consumers, there are still gross inadequacies on the regularity of electricity in the country. This paper analyses the use and impact of Distributed Generation (DG) on regularity and quality of power supply in Nigeria and Imo State in particular. Gas turbine was the DG considered due to its availability and significant impact it could make on network. A 12-bus network in Imo State namely: bus 1 (Alaoji), bus 2 (Onitsha Road), bus 3 (Ahaoda), bus 4 (Egbu 1), bus 5 (Owerri 1), bus 6 (Okigwe Road), bus 7 (Owerri 2), bus 8 (Oguta), bus 9 (Orlu), bus 10 (Mbaise Road), bus 11 (Port Harcourt Road), bus 12 (Onitsha Road) was considered and 25MW DG was individually connected on these buses alternatively and their network conditions assessed for voltage violations, losses, maximum loading factor, etc. This was repeated for simultaneous placement of 2 DGs and 3DGs on the 12-bus network and the buses conditions observed as was done for single DG placement. The results indicated that single DG placement or installations recorded losses in all the 12 buses however, the least was on bus no. 5 (Owerri 1). The best result on loadability was recorded at bus 7 (Owerri 2), with minimum loss recorded at bus 5 (Owerri 1). Simultaneous addition of 2DGs on the network and subsequent dynamic stability test revealed that bus 2 (Onitsha Road 1) and bus 3 (Ahaoda), bus 2 (Onitsha Road) and bus 4 (Egbu 1), bus 2 (Onitsha Road 1) and bus 7 (Owerri 2), bus 3 (Ahaoda) and bus 10 (Mbaise Road); bus 4 (Egbu 1) and bus 11 (Port Harcourt Road), bus 5 (Owerri 1) and bus 10 (Mbaise Road), bus 7 (Owerri 2) and bus 11 (Port Harcourt Road), gave violations of 5 and buses 3 (Ahaoda) and 5 (Owerri 1), 3 (Ahaoda) and 11 (Port Harcourt Road) gave violation of 7. However, when 3DGs were simultaneously added to the network at three buses and the network conditions assessed: the best were observed as buses 5 (Owerri 1), 7 (Owerri 2), and 11 (Port Harcourt Road). At these buses, the network recorded no voltage violation, high loading factor of 1.160 pu, little loss of 0.02355 for normal load flow while at collapse point, it was 0.07019 pu. In conclusion, placement or location of 3 DGs at buses 5 (Owerri 1), 7 (Owerri 2) and 11 (Port Harcourt Road) gave the network, the best condition and performance.

KEYWORDS: Distribution Network, Distributed Generation (DG), Distributed Buses, Voltage Stability, DG Placement.

1.0 INTRODUCTION

The whole essence of power transmission and distribution system is to transport the bulk of electricity energy produced from generating stations at one end and deliver them to the eventual users at the extreme end. It constitutes the interface between the generating status and the electricity consumers.

In this country Nigeria, the electricity power sector has been plagued by myriad of problems which include: low power generation, poor distribution of electricity, poor voltage regulation resulting to very low voltages delivered at consumers' premises. There is widespread line faults and vandalization along our transmission and distribution lines.

Given these trend of events in the power sector, there is need to bring about significant improvements in the power distribution profile on the electricity network hence, there is need for optimal power distribution planning of the grid. The distribution network end of the Nigerian grid is also characterized by the presence of sags and swells at the points of common coupling (PCC) with current harmonics and reactive currents due to wide use of power electronics equipments. The average power generation capacity in Nigeria is both inadequate and unstable. According to official figures, collected from Federal Ministry of Power website, that while it took almost three years (between December 2012, and July 2015) to achieve a new highest peak power generation, a more regular achievement were recorded in gaps of just days and months between July and November 2015. The major challenge facing the system is its lack of capacity to sustain any milestone reached over a period of time. For example, on 29th November 2015, the peak generation dropped to 4,040.00 MW after hitting a highest peak of 4,833.90 MW just a few days earlier on 23rd November, 2015 (Obi and Iloh, 2016).

There are four injection substations with several transformers that supply and distribute power in the heartland of Imo State, notably 2x15MVA at Onitsha Road, 1x15MVA at Nworieubi, 2x15MWA at Egbu Road 1 and 2x15MVA at Egbu Road 2. These injection substations have transformers with 33/11KV voltage ratio. Majority of the distribution consumer transformers in the urban centres are on 11KV primary distribution lines while those in the rural areas are on 33KV primary distribution lines. The load demand in Imo State and Nigeria, however, continues to increase while power generation continue to fluctuate given rise to voltage violations and losses in the distribution subsystem. These pose a great challenge on the power distribution planners on how to avert a situation of possible total system breakdown. This thereby paper focuses in the use of DGs on the distribution network to supplement the power generation capacity of the electricity supply system in Nigeria. On the installation of the DGs, the question of the optimal number of DGs, the best position to realize maximum voltage and minimal losses have to be determined, to penetrate and integrate a given area of a sub-network.

2.0 THE USE OF DG IN DISTRIBUTION SYSTEM

Distributed Generation (DG) is a small-scale generation connected to a local system as an alternative to the centralized large generating system. The voltage profile in the conventional system is known to decrease towards the end of the feeder from the generating or sending end. Hence, the voltage in the conventional distribution system is regulated mainly based on how to counteract the drop in voltage. The integration of DG unit in a power system is to regulate the voltage profile in the power system and it has raised many considerations and challenges on the operation and control of power distribution systems. The investigation of voltage control and stability in the power system in the presence of the generating machine has been discovered to have positive or negative impact on the steady state voltage and reactive control of the stability of the distribution system.

2.1 TYPES OF DISTRIBUTED GENERATION

According to (Gonzalez-longatt (2008)), DG's are classified into two major groups, inverter based DG and rotating machine DG. Depending on the output power characteristics, DG's are also classified as DISPATCHABLE or NON-DISPATCHABLE. When it is dispatchable, the DG operator can determine the power output of the DG units by controlling the primary sources that are supplied to the DG units, for example; Gas turbines, microturbines, etc. When the DG is non-dispatchable, the operator cannot dispatch the DG units because the behavior of the primary sources cannot be controlled, for example; the ones driven by renewal energy sources, where the power output will depend on the availability of the energy sources. DG can be connected to the grid directly using synchronous or induction generators or via like power electronic interface. DG is a small scale generation connected to local distribution systems. Therefore, when the size of the generation technology explained below becomes large and the generation can no longer be connected to the distribution system, the generation is no longer considered as DG. Some DGs include:

2.1.1 GAS TURBINES

These consist of a compressor, combustor and turbine-generator assembly that converts the rotational (mechanical) energy into electric power output. Gas turbines of all sizes are now widely used in the power industry. The maintenance cost is a little less than reciprocating engines but it can also be noisy. Emissions are somewhat lower and cost effective NO_x emission – control technology is commercially available.

2.1.2 SOLAR PHOTOVOLTAIC

Photovoltaic (PV) systems involve the direct conversion of sunlight into electricity without any heat engine. PV systems have been used as the power source for very small applications, like calculators and watches, for water pumping, remote buildings, communications, satellites and space vehicles, as well as megawatt scale power plants. PV implementation is encouraged by the almost unlimited availability of sunlight, long life cycle, high modularity and mobility, easy maintainability, very low operation cost, environmentally friendly, ability for off-grid application and short time for design, installation and start up.

2.1.3 WIND POWER

Wind energy plays a key role in generating electricity from renewable energy resources. Today large winds are competing with fossil-fuelled power plants in supplying economical clean power in many parts of the world. In this sense, wind power is more like central generation than DG. The main challenges of the wind power technology are intermittency and grid reliability since wind power is based on natural forces, it cannot dispatch power on demand.

3.0 METHODOLOGY

Recently, there is increasing need for use of Distributed Generation on our grid to stabilize the power supply in the country. The penetration of DGs on power supply grid among other benefits improves the voltage regulation and decrease losses in the system. The impact of DG on these is dependent on the DG location.

Optimization techniques are tools which can be used to locate and size the DG units in the system, so as to utilize these units optimally within limits and constraints. The impacts of DG units are on these parameters: voltage stability, and voltage profile. The goal of this section is to propose a method of locating and sizing DG units in Imo State grid so as to improve on the stability and voltage profile. The process is to select candidate buses where the DG units are to be installed, prioritizing the buses that are sensitive to voltage variations, then model the load and the DG generation, considering the probabilistic nature of both renewable DG units and the load. This is followed by conducting placement and sizing formulation using mixed integer non-linear programming (MINLP). The objective function is to improve the voltage margin and MINLP solved by an outer approximation method using MATLAB software. The result is subjected to several system constraints so as to be sure that the normal operating practices of the distribution system were not violated. The considered constraints are; system voltage limits, feeder's capacity and DG penetration level. For proper co-ordination of the installed DG units and the regulation devices in the system, most DG units are connected to operate at unity power factor.

3.1 IMPACT OF THE DG SIZE ON VOLTAGE STABILITY

From the figure below, the x-axis represents λ, which is the scaling factor of the load at a certain operating point. λ varies from zero to the maximum loading (λ_{max}). Due to real power injection of a DG unit, the normal operating point of the voltage increases from V_1, to V_2 and at the same time the maximum loadability increases from λ_{max}^1 to λ_{max}^2.

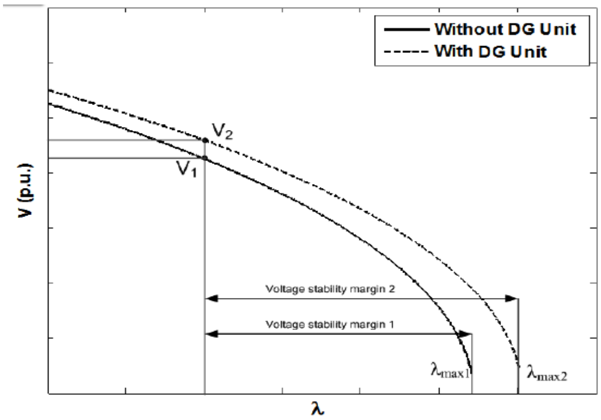

Figure 1: Impact of a DG unit on maximum Loadability and Voltage Stability Margin.

3.2 SELECTION OF THE CANDIDATE BUSES

The selection of buses for the DG installation can be done randomly or choosing sensitive buses to the voltage profile. In this work, the later is preferred since our objective is to improve the voltage stability of our system. Power systems are characterized and demonstrated with non-linear differential algebraic equations with reactive load power (Q) constant. Thus, the incremental change in bus reactive power, Q equals to zero. Then using the partial inversion

$$\Delta \rho = \left(J_{pv} - J_{p\theta} J_{Q\theta}{}^{-1} J_{Qv}\right)\Delta V \qquad (1)$$

or

$$\Delta V = \left(J_{(RPV\,)^{-1}}\Delta P \qquad (2)$$

Where J_{RPV} is a reduced Jacobian matrix, which gives the voltage magnitude variations due to DG active power injection variations. This equation determines buses that are most sensitive to the voltage profile, i.e. to change in the voltage magnitude of the system.

3.3 DG PLACEMENT PROBLEM

Following the selection of the candidate buses, the DG units are not just allocated or placed but the types of load in the system and the criticality of each bus will have to be ascertained. Care must be taken not to violate these chosen sensitive buses as voltage limits or capacity of the feeder, size of DG units and load demand of the distribution system must be taken care of. Therefore, the DG units must be added to the system with the objective of improving voltage stability. In this research work, 3 cases were observed.

Case 1: The reference case, in which no DG unit are connected to the system (base case).
Case 2: PV DG units only connected to single bus for all buses.

Case 3: 2 or more DGs connected to different buses and the best is selected based on voltage profile, losses and loading parameter.

However, the assumptions are that the DG units operate at unity power factor and more than one type of DG can be installed at the same candidate bus, with Buses subjected at same gas turbine output of 25MW.

3.4 DG UNITS MODELLING

The gas turbine is composed of a permanent magnet (PGM), a compressor, and a turbine linked mechanically to a common shaft and thermodynamically to the fuel cell process. The shaft is modelled by Newton's second law for rotation: $J\frac{d\omega}{dt} = T_T - T_C - T_G$ (3)

Where J is the moment of inertia of the linked mechanical system; W is the angular speed of rotation; and T_T, T_C, and T_G are the torques of turbine, compressor, and generator, respectively. The PMG and rectifier approximates as DC generator, the torque and the output voltage of the equivalent DC generator can be approximated as

$$T_G = K_M I_G \quad (4)$$

$$V_G = K_e \omega \quad (5)$$

Where K_M and K_e are the armature and motor constants; I_G and V_G are the DC current and voltage of the equivalent DC generator, I_G can be controlled by the DC-DC converter. Thus, the generator voltage can be regulated according equation above and consequently, the relational speed ω can be controlled.

3.5 OPTIMIZATION

Objective function: The objective function of enhancing the voltage regulation and voltage stability margin of the distribution system was realized by correct DG placement and sizing. To improve the voltage profile of the distribution system, equation below was used which enhanced the voltage stability margin of the distribution system. The equation was modified to include the probabilistic nature of the DG generation.

$$V_n = \frac{V_p \text{ with DG}}{V_p \text{ without DG}} \quad (6)$$

$$V_p = \sum_{2=1}^{m} V_i L_i K_i \quad (7)$$

V_p with DG = The voltage profile in the system with DG units

V_p without DG = The voltage profiles of the system without DG units.

V_i = The voltage magnitude at bus i

L_i = The load demand at bus i

K_i = The weighting factor for load bus i

N = The total number of load buses in the distribution system

Now, maximum $V_{index} = \frac{\sum_{n=1}^{N} V_{nprn}}{96}(n = 1, 2, \dots N)$ (8)

The highest result gave the best location for the installation of the DG units in terms of improving the voltage profile and determining proper voltage regulation of the distribution system. Given below is the flow chart illustrating the optimization method.

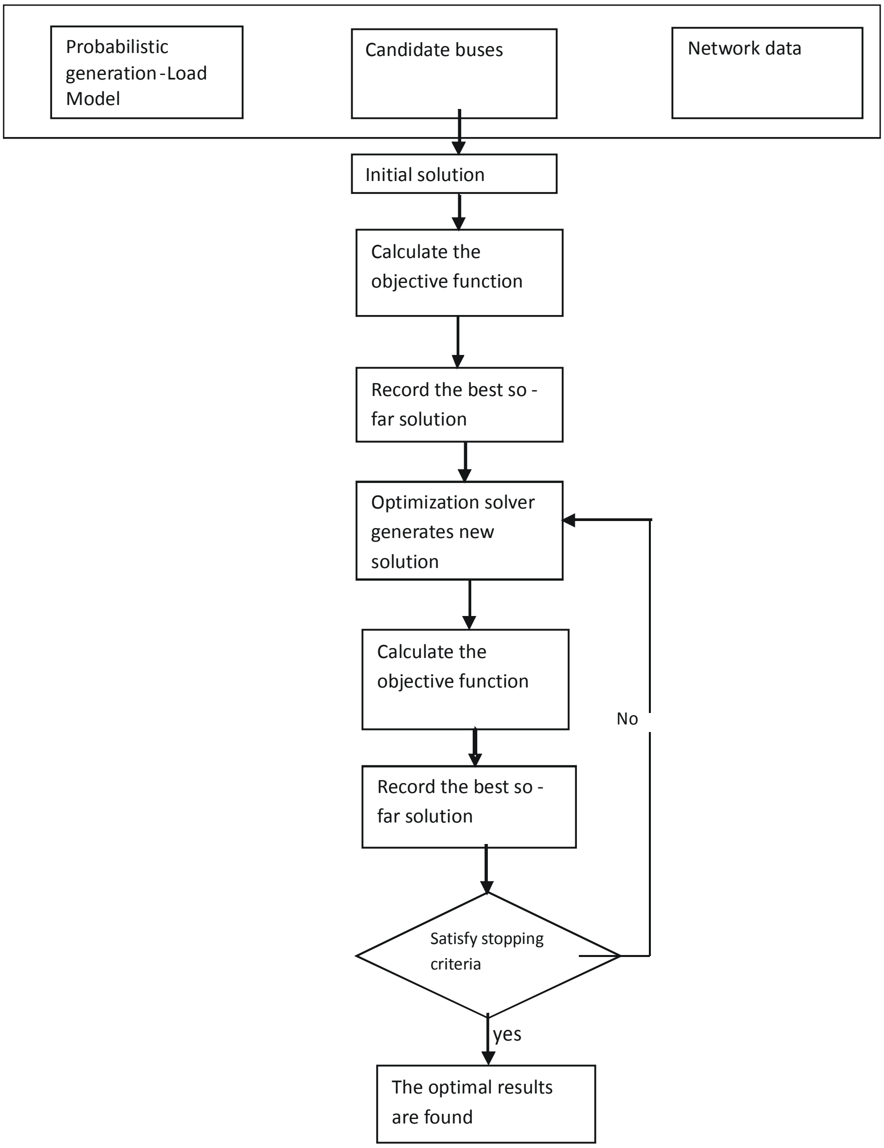

Figure 2: A Flow Chart illustrates the Proposed Optimization Method.

3.6 MATLAB SIMULATION

In order to properly harness the properties of this distribution network, simulation was performed with power system stability toolbox in MATLAB 7.9. The Imo State power system was represented in the MATLAB toolbox and results were realized. During the simulation, single 25MW gas turbine distributed generation was used in a form of PV block. The singe DG was alternatively placed at different buses to know the most sensitive bus. Voltage violations and loading factors sensitivity were some of the considerations. More than one DG were used to consider situations of minimum violation and less losses (see figure 3).

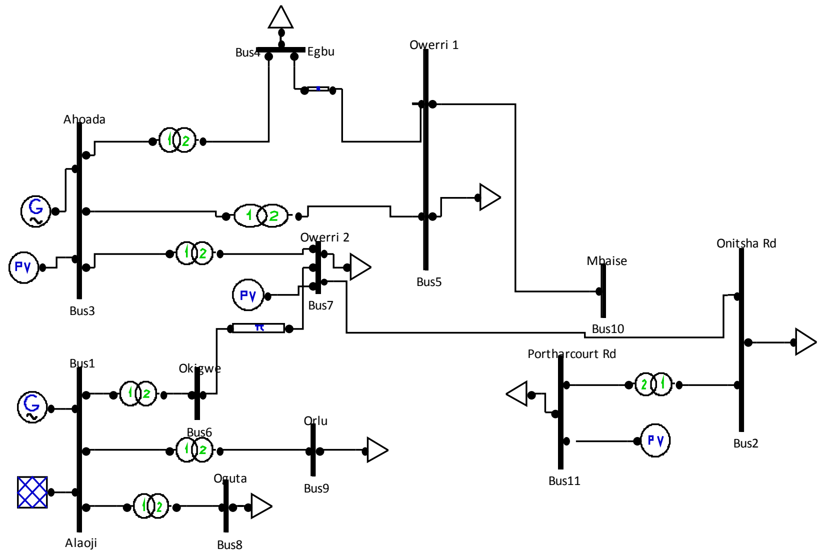

Figure 3: MATLAB/SIMULINK Block for the Best Position of DGs (PVs) Simulation.

4.0 RESULTS AND DISCUSSION

Table 1: Single 25MW DG Placement at Different Buses.

DG placement	Voltage violations	Power losses	Max. loading factor	Max. power loading	Collapse violation	Power losses collapse
No DG	8	0.43334	-	-	-	-
2	4	0.05643	-	-	-	-
3	3	0.04451	1.0788	3.1067	7	0.7447
4	3	0.04682	1.0663	3.071	9	0.7714
5	2	0.04449	1.0648	3.0667	7	0.7438
6	7	0.08979	-	-	-	-
7	3	0.0467	1.0924	3.1145	7	0.9664
8	8	0.43308	-	-	-	-
9	8	0.43308	-	-	-	-
10	4	0.05547	-	-	-	-
11	4	0.05738	-	-	-	-

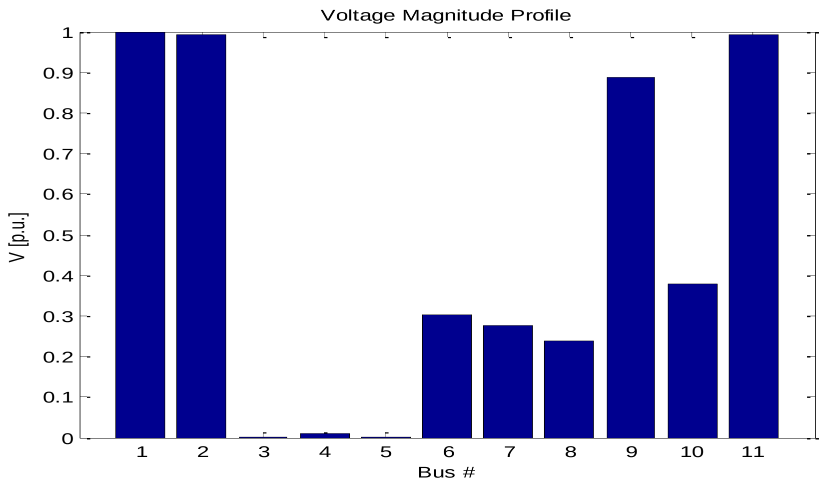

Figure 3: Voltage Profile of Imo Electricity Network without DG.

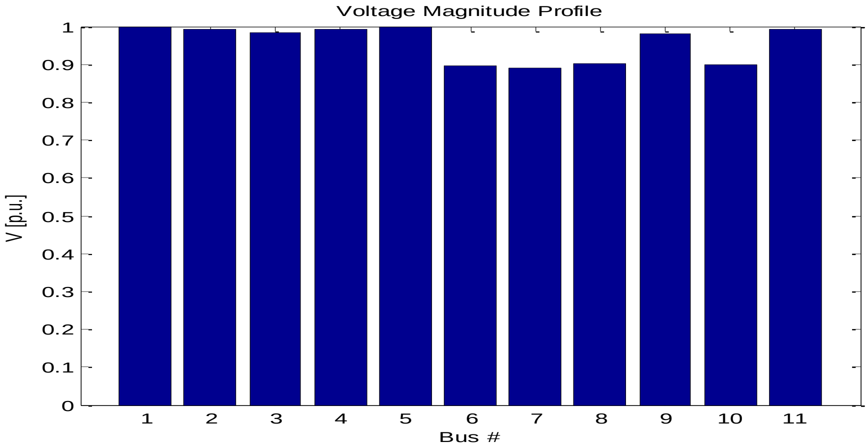

Figure 4: Voltage Profile of Imo Network Placing 25MW DG at Bus 5 (Owerri1).

The results above show the voltage profiler for both normal load flow study and what happened at points of collapse as shown in the Table 1 and figures 3 to figure 4. Bus 5 (Owerri 1) gave the least violation of 2 when compared with all other single DG installations in all buses. It also had the least power loss of 0.0449; buses 3 (Ahaoda), 4 (Egbu 1) and 7 (Owerri 2) had voltage violation while 3 (Ahoada) had the least loss (0.4451 pu) out of the three. Buses 2 (Onitsha Road 1), 10 (Mbaise Road) and 11 (Port Harcourt Road) had voltage violation of 4 and losses of 0.05643 pu, 0.05547 pu and 0.05738 pu respectively.

When subjected to dynamic stability test and comparing their voltage profile at collapse, the maximum loadability 8_{max} and losses as shown the figure above shared that more load cannot be added when DG was palace at bus 2 (Onitsha Road 1), 6 (Okigwe Road), 8 (Oguta), 9 (Orlu) 10 ((Mbaise Road) and 11 (Port Harcourt Road). Placing DGs at buses 3 (Ahaoda), 5 (Owerri 1) and 7 (Owerri 2) gave the same violation of 7 (but the best maximum loading parameter is found in bus 7 (Owerri 2) with 1.0924 pu and the minimum loss is found in adding DG to bus 5 (Owerri 1).

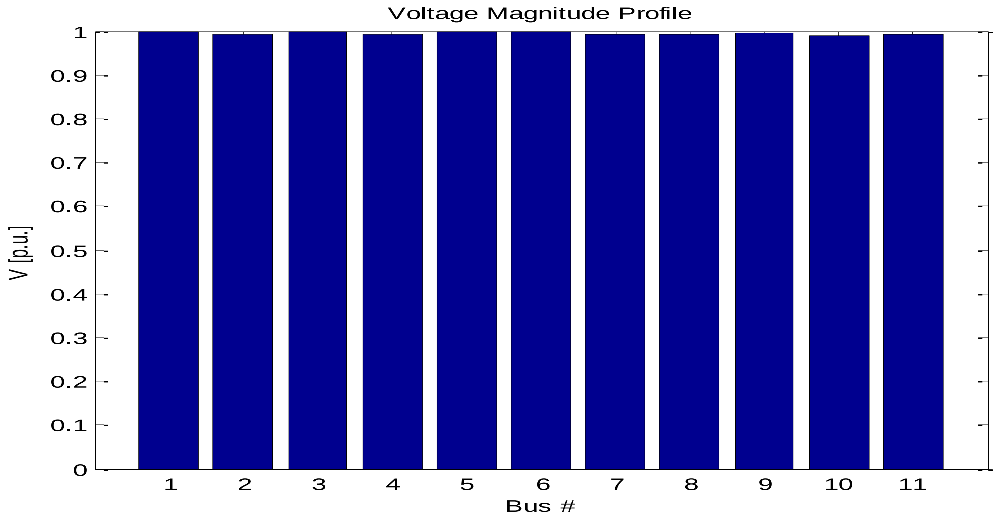

Figure 5: Voltage profile of Imo network placing 25MW DG at buses 2 (Onitsha Road) and 3 (Ahoada).

Table 2: Results for 25MW DG placement at two different buses same time.

DG placement	Voltage violation	Losses	Max. loading factor	Max. power loading	Collapse violation	Real power losses collapse
2 and 3	0	0.03131	1.1019	3.1735	4	0.07089
2 and 4	0	0.0319	1.10877	3.1097	4	0.07481
2 and 5	0	0.03186	1.0872	3.1047	5	0.7487
2 and 8	0	0.03202	1.1281	3.249	4	0.06789
2 and 10	4	0.04329	-	-	-	-
3 and 5	2	0.03497	1.1081	3.1731	7	0.07485
3 and 8	3	0.03626	1.1272	3.2465	7	0.07281
3 and 10	0	0.03164	1.1019	3.1735	4	0.07124
4 and 11	0	0.03223	1.0877	3.1092	4	0.07746
5 and 10	0	0.03219	1.1087	3.1048	4	0.0752
5 and 11	0	0.03155	1.0873	3.1046	5	0.07455
7 and 10	0	0.03236	1.1281	3.2488	4	0.06828
7 and 11	0	0.0317	1.1282	3.2492	4	0.06752

Result of placing DG in two buses showed that all the cases considered (different two buses selected as candidate bus), there were no voltage violation apart from buses 2 (Onitsha Road) and 10 (Mbaise Road); 3 (Ahaoda) and 5 (Owerri 1), 3 (Ahaoda) and 7 (Owerri 2) which had violation of 4, 2 and 3 respectively. Adding DG to bus 2 (Onitsha Road) and 3 (Ahaoda), gave the least loss of 0.0313 pu on a normal voltage profile. When subjected to dynamic stability test, placing DG to buses 2 (Onitsha Road) and 3 (Ahaoda), 2 (Onitsha Road) and 4 (Egbu 1), 2 (Onitsha Road) and 7 (Owerri 2), 3 (Ahaoda) and 10 (Mbaise Road), 2 (Onitsha Road) and 7 (Owerri 2), 3 (Ahaoda), and 10 (Mbaise Road), 7 (Owerri 2), and 11 (Port Harcourt Road), gave a violation of 4, while 2 (Onitsha Road 1) and 5 (Owerri 1), and 5 (Owerri 1) and 11 (Port Harcourt Road) gave a violation of 5, while 3 (Ahaoda) and 5 (Owerri 1); and 3 (Ahaoda) and 11 (Port Harcourt Road) gave a violation of 7. The maximum loading of 1.1282 pu and minimal loss of 0.06752 pu was seen when DG is placed in bus 7 (Owerri 2) and 11 (Port Harcourt Road). These results are indicated in Table 2 and figure 5.

Table 3: Three 25MW DG place at different buses same time

DG placement	Voltage violation	Losses	Max. loading factor	Max. power loading	Collapse violation	Real power losses collapse
1, 2 and 3	0	0.03131	1.1019	3.1735	4	0.07089
2, 3 and 5	0	0.02373	1.1418	3.2264	4	0.07554
2, 5 and 7	0	0.02386	1.1606	3.3426	4	0.7057
5, 7 and 11	0	0.02355	1.1607	3.3428	4	0.07019

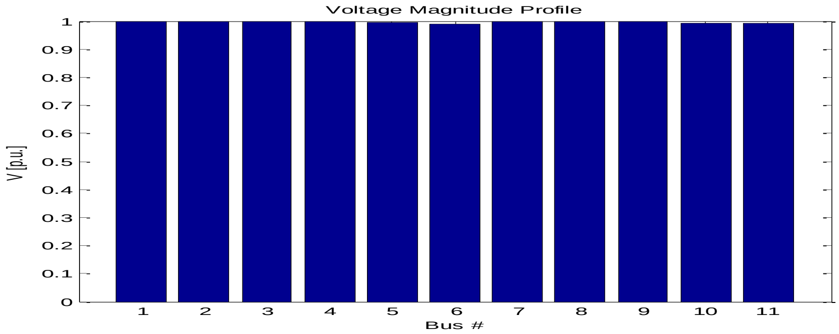

Figure 6: Voltage profile of Imo network placing 25MW DG at buses 5 (Owerri 1), 7 (Owerri 2) and 11 (Port Harcourt Road)

The results of placing 3DGs at three different buses as shown in table 3 and figure 6 revealed that the best result was positioning the DGs at buses 5 (Owerri 1), 7 (Owerri 2) and 11 (Port Harcourt Road), simultaneously. At these buses, there was no violation, the violation at collapse point is 4, the loading factor is 1.1607 pu and the bus is 0.02355 for normal load flow and 0.07019 pu at collapse point.

CONCLUSION

Distributed Generation (DG) is a small-scale generation, connected to a distribution system, is undoubtedly an alternative to large centralized generating status. The voltage profile in a conventional distribution system usually decrease towards the ends of the feeders, but with the use of a DG unit, this is often reversed. The steady state voltage is often achieved with the interaction of the control equipments like; on-load tap changers (OLTC), substation shunt capacitors (SC) and feeder shunt (FC) with the Distributed Generators. Keeping the steady state voltage within the allowed range of time constant, while minimizing energy losses in a considerably long period is the objective. The size and position of the DG in the distributions system is a determinant on its ability to maintain stability and minimize losses in the system. With the presence of small-scale generation introduced at different strategic locations in every distribution network in this country, to feedback power on the line, there will be continuous and reliable power.

REFERENCES

Alexandre, A. F. (2009), "Adaptive Network Protection in Microgrids". ABB Switzerland Ltd., Corporate Research, Segelhof.

Falcão, C. L. (2003), "Impact of Distributed Generation Allocation and Sizing on Reliability, Losses and Voltage Profile", IEEE Conf. on Power, Bologna, Italy.

Fortoul, F. G. L. (2005), "Review of Distributed Generation Concept: Attemp of Unification", Proceeding of International Conference on Renewable Energies and Power Quality, IEEE Conf. on Power, España.

Häger, F. S. (2006), "The Impact of Distributed Energy Resources on Distribution-System Protection", Ludvika, Sweden.

Jaime de la Ree, Y. L. (2005), "Catastrophic Failures in Power Systems: Causes, Analyses, and Countermeasures", Proceedings of the IEEE on Power Systems, Vol. 93, No. 5, pp. 35-41.

Khan, U. N. (2008), "Impact of Distributed Generation on Distributed Network". Wroclav, University of Technology, Poland.

Martin-Arnedo, J. A. (2009), "Impacts of Distributed Generation on Protection and Power Quality",

Obi, P. I. and Iloh, J. P. (2016), "Analysis of Nigeria's Power Generation Statistics from June to December 2015", International Journal of Innovative Engineering, Technology and Science (I JIETS), Vol. 1, No. 1, pp. 95-101.

Philip, R. W. (2000), "Determining the Impact of Distributed Generation on Power Systems: Part 1 - Radial Distribution Systems", IEEE Trans. on Power, Vol. 23, No. 3, pp. 16-24.