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Power Supply Enhancement in Onitsha Distribution Network using Distribution Generations

P. I. Obi[1, *], I. I. Okonkwo[2] and C. O. Ogba[3]

[1] *Department of Electrical/Electronic Engineering, Michael Okpara University of Agriculture, Umudike, Abia State, NIGERIA*
[2, 3] *Department of Electrical/Electronic Engineering, Chukwuemeka Odumegwu Ojukwu University Uli, Anambra State, NIGERIA*

Abstract

The research explored ways in which power supplied in Onitsha distribution line network would be enhanced using distributed generation. The problem of insufficient power supply in densely populated metropolis which is characterised by frequent load shedding was solved using optimal placement and sizing of multiple distributed generation. A gas plant was optimally placed at 33 kV injection substations at Awada and General Cotton Mill (GCM). The generators were optimally placed using voltage sensitivity index factor, while their optimum capacities were sized using step method. Simulations were done by power system analysis toolbox (PSAT) 2.1.11 simulation tool in MATLAB 2018a environment and the result of the findings revealed that 32 buses out of 34 buses were violated. The result of the simulation also showed that the optimal operating power output of the generators at Awada and GCM of 12.5 MW and 2.5 MW respectively could only clear 29 out of the 32 bus voltage violations. Overloading of Fegge injection substation transformer was identified as the cause and its upgrade from 7.5 MVA to 15.0 MVA cleared all the voltage violations. The system active loss and reactive loss were 1.82 MW and 35.03 MVar and the research was able to reduce them by 23.30% and 23.80% respectively. The statutory bus voltage limits of ±5% and the requirement that distributed generators installed must be less than the maximum demanded had been achieved in the research. The power supply in Onitsha distribution network was enhanced using distribution generations and the usage of optimal placement and sizing of multiple distributed generation is therefore recommended for problematic distribution networks not only for loss reduction also for better performance.

Keywords: Distribution network, distributed generation, load shedding, insufficient power supply, optimal placement, optimal sizing.

1.0 INTRODUCTION

Electricity has remained an essential requirement for the progress of any country's economy whether developed, emerging, or developing. The increasing human activities due to technological advancement coupled with population growth, has made the demand for power more than doubling by the decades, thereby broadening the gap between power generated and the demand by the consumer.

Conservatively, the existing power system in Nigeria is one in which power is generated conventionally at remote stations and transmitted at high voltage through the transmission station to the distribution network, and subsequent delivery to the end consumers at a lower voltage level [1]. The cost of power delivery is so expensive due to the distance from the generating stations to the point of utilization and that has caused increase in lack of accessibility to electricity, most especially in the rural areas.

The advent of renewable energy and improved technologies, whereby power can be generated through the use of solar power system, wind power system, biogas power system and solar hybrid systems, have created a means of generating power close to residential areas and industries because of the ability to construct using a limited size of land and its low emission of Carbon-dioxide (CO_2) into the atmosphere. Such generated power is directly distributed to homes and industries without passing through transmission substations.

The federal government to ensure supply of power to residential, corporate organisations, government buildings and industrial customers has burdened generation companies, Transmission Company and distribution companies. All three tiers have their own peculiar constrain which has affected the quantity and quality of power delivered to the consumers and therefore

***Corresponding author (Tel:** +234 (0) 8037202765**)**

Email addresses: *patndyobi@gmail.com* (P. I. Obi), *fin212@gmail.com* (I. I. Okonkwo), *ogbacharles@gmail.com* (C. O. Ogba).

caused a mismatch in power supplied and power demand. Over the years, the three tiers have not been able to provide sufficient power to the growing population of every region in Nigeria, which has greatly affected the industrial companies in growing their businesses.

Specifically, the power distribution situation in Onitsha, a city with a fast growing population of 1,483,000 [2] and its environs according to the load demand record of Enugu Electricity Distribution Company (EEDC) for the year ending December 31st 2019, is approximately 104 MW.93, but 6 MW is what the utility company could supply. The inability of EEDC to provide industries sufficient power supply thereby leading to an epileptic power supply in Onitsha, which is evident in the increasing rate at which the power distribution companies carry out load shedding. The power situation in Onitsha is even more pathetic owing to the fact that Enugu Electricity Distribution Company (EEDC) has not made commensurate investment in its infrastructure to improve the power delivery that will match the very fast growing population and industrial growth.

This paper is set to solve the problem of epileptic power supply in Onitsha with distribution generation (DG). The appealing proposition of DG is that it is distributed round the network close to customers and DGs constitute diverse technologies and primary energy sources. There has been tremendous research work in the areas of DG technologies, sitting and sizing of DG, impact studies of the increased penetration of DG. Various researches related to the DGs technology and integration are presented.

2.0 LITERATURE REVIEW

Classical methods use formulation derived from mathematical equations to search for optimal sizing and placement of distributed generator. Classical methods may be relatively simple but it is not time cost efficient. Examples of classical techniques include analytic method, mixed integer programming, linear programming, Index method, optimal power flow method, sensitivity method etc. The author in [3] presented loss sensitivity factor based method to optimally locate and size DG generator. The analytic expression and the methodology are derived from exact loss formula. Result did not lead to best position for loss reduction. Analytic approach was used in [4] to locate and size DG without the requirement of bus impedance matrix. An analytic expression was used in [5] to find the optimal size, location and four types of distribution generation DG units. The method was simple, required less computation time, and can lead to optimal solution for multiple placements. In [6] authors used voltage stability index to optimally size and position distribution generations (DGs) and power losses were reduced in two different radial distribution systems. Genetic algorithm was used by some authors to locate and size distribution generations (DGs), a simple minimization of active power loss is the basis [7–9]. In some papers multiple objective functions were solved using genetic algorithm in order to locate the optimum position and size of the distribution generation (DG). Authors in [10] use genetic algorithm to optimally place and size the distribution generation (DG) by minimizing the power loss and the cost of the DG. In [11] , the authors genetic algorithm to minimize multiple objective power loss, voltage unbalance, current unbalance and enhance voltage profile of the system in order to locate and find the size of the distribution generation (DG). Authors in [12] used quantum genetic algorithm combine with Newton – Raphson's power flow to optimize the placement and sizing of distribution generations (DGs) in power system. Power loss was minimized while bus voltage profiles were still maintained within the acceptable limits. In [13], the authors used hybrid optimization method, Genetic Algorithm (GA) and Ant colony optimization (ACO) Algorithm techniques to find optimal size and position for distributed generation in electrical networks. The objective function of the work relied upon a linearized model to compute the active power losses as a function of power supplied from the generators. This strategy based on a strong coupling between active power and power flow which also take consideration of the voltage angles. In [14], the authors optimally size and place distribution generators (DGs) in appropriate buses in the system, the objective function minimize the real power losses, operating cost and enhancing the voltage stability using the hybrid of genetic algorithm (GA) and particle swarm optimization (PSO).

The results obtained proved the effectiveness of the proposed hybrid GA-PSO algorithm when comparison with those of GA and PSO methods when applied independently. In [13] the authors presented an optimal allocation and sizing of Distributed Generation (DG) in Radial Distribution Network (RDN). The locations of DGs were identified by using Index Vector Method (IVM) approach and Artificial Bee Colony (ABC) optimization algorithm was employed to determine the optimum size of DG. In [14–21] authors used particle swarm optimization (PSO) to locate and size the distribution generations (DGs) in order to minimize power loss in distribution system. In [22] authors used Ant Colony Optimization (ACO) algorithm for optimum sizing and sitting of distribution generations (DGs) in power distribution system. A significant reduction in total real power losses within the system and improvement in voltage profile were observed.

3.0 CAUSES OF POWER SUPPLY SHORTAGE

Many research works by different authors have been written and published about the poor power situation in Nigeria and in extension Onitsha and they also identified the various causes of poor power supply in the Onitsha. A critical analysis of these problems clearly show that the cause of power shortage falls into two major categories, which are technical and non-technical issues. The non-technical issues are said to be those problems that are not related to the power industry but indirectly affect the supply of power while the technical issues are power related.

3.1 Non-Technical Issues

Top on the list on the non-technical issues is the failure of both political and administrative leadership. Corruption and embezzlement of funds are the major failure of the political and administrative leaders [23].Corruption in the power sector has prevailed because some of the key leaders in politics and administration are directly or indirectly involved in the misappropriation of funds of the sector. Contracts in the sector are awarded to politicians as compensation for political patronage. These politicians lack the necessary skills/expertise to execute such projects and this in turn will cause many of sure power project to be abandoned. Closely related to the above problem is the challenge of political instability and lack of political commitment in Nigerian governance [24, 25]. In view of other needs on its revenues, the government has shown itself unable to continue to meet up past energy financing responsibilities and this has affected budgetary allocations in the power sector. According to Adenikinju in [26] low funding remains a major cause of power shortage in Nigeria.

Another cause is Vandalism: This is the ignorant destruction of public or private property. Vandalism of materials and equipment is the greatest danger posed against the power industry [27, 28] and it is the only single act that if not properly addressed will render the efforts of government and power industry useless. There have been several reported cases of vandalism of power equipment across Nigeria. This is commonly found in the rural areas, especially on the area where the transmission lines pass through the forest areas. The vandals targeted items like aluminum conductors, pin insulators, stay rods, transformers, and energy meters. Though the motives of these vandals might be economic in nature but their actions put their lives at very high risk. Whenever any electrical equipment is vandalized, it always takes a long period before reconstruction.

3.2 Technical Issues

Top on the list of the technical issues will be the insufficient generation in Nigeria. The present power demand in Nigeria has far outreached its available generating capacity. There has been some improvement in recent months. Power generation reached a new peak of 5,074.70 MW on February 2nd 2016, while the least occurred on the 6th of March 2016 with 4697.55 MW [29]. If all the installed generators are working to their maximum capacity, they will still not be able to meet the demand of the population [30]. As there are no means of getting additional supply apart from what is been generated, the situation then calls for some part of the network to be taken out for others to have supply.

Next is the insufficient capacity of power transformers, which leads to overloading of equipment. The distribution networks in various part of Nigeria are undergoing severe overloading due to limitation in transformer capacities. This overloading normally results in failure of distribution transformers or melting of protective devices, like fuses. At times, this overloading results in low voltages that may not be useful for most domestic purposes. The situation is very serious in many places particularly in some parts of Onitsha and some urban centers with high population [31].

4.0 DISTRIBUTED GENERATION

The concept of distributed generation is based on the provision of many small capacity generation units situated much closer to the electricity consumers. To fully exploit the potential advantages of DGs, it is necessary to re-think the basic philosophy governing the electricity distribution system. The distribution network in a DGs system will effectively and efficiently link small and medium scale electric power sources with customer demands [32]. Distributed generation is emerging as an important option for the future development and restructuring of electricity infrastructure. DG is often used as back-up power to enhance reliability or as a means of deferring investment in transmission, distribution networks, avoiding network charges, reducing line losses, deferring construction of large generation facilities, displacing expensive grid-supplied power, providing alternative sources of supply in markets and providing environmental benefits.

The major driving forces behind the increased penetration of DGs can be categorized into environmental, commercial and regulatory factors [32]. There are several small generators that produce very small or no greenhouse gas emissions, which is one of the major environmental driving factors for the use of DGs. Another environmental driver is to reduce the transmission and distribution expansion along with the avoidance of large power plants. In the commercial driver, the uncertainty in electricity markets favours small generation schemes and DGs are now cost effective to improve the power quality and reliability [33]. Diversification of energy sources to enhance the energy security and support for competition policy are the major regulatory drivers.

4.1 Types of Distribution Generation

Base on generated power, DGs can be categorized into different types as [34]:
Type I: DGs that are capable of injecting real power only, like photovoltaic, fuel cells etc. are the good examples of these Type-I DGs,
Type II: DGs that are capable of injecting reactive power and therefore can only help to improve the voltage profile fall in Type-II DGs, e.g. KVar compensator, synchronous compensator, capacitors etc.
Type III: DGs that are capable of injecting both real and reactive power, e.g. synchronous generators,
Type IV: DGs that are capable of injecting real power but consuming reactive power, e.g. induction generators used with turbines.

5.0 MATERIALS AND METHODS

The materials and methods used in the analysis are presented in this Section. The materials used are presented in Section 5.1, and the methodology is described thoroughly in Section 5.2.

5.1 Materials

The research analyses the Onitsha distribution network which has twenty – nine (29) load centers that are fed from two injection substations namely the Awada and GCM substations. Data as in Table 1 is from Enugu Electricity Distribution Company (EEDC). Figure 1 shows the one line diagram of Onitsha distribution network system. While the names of the load centers and their demands are shown in Table 1.

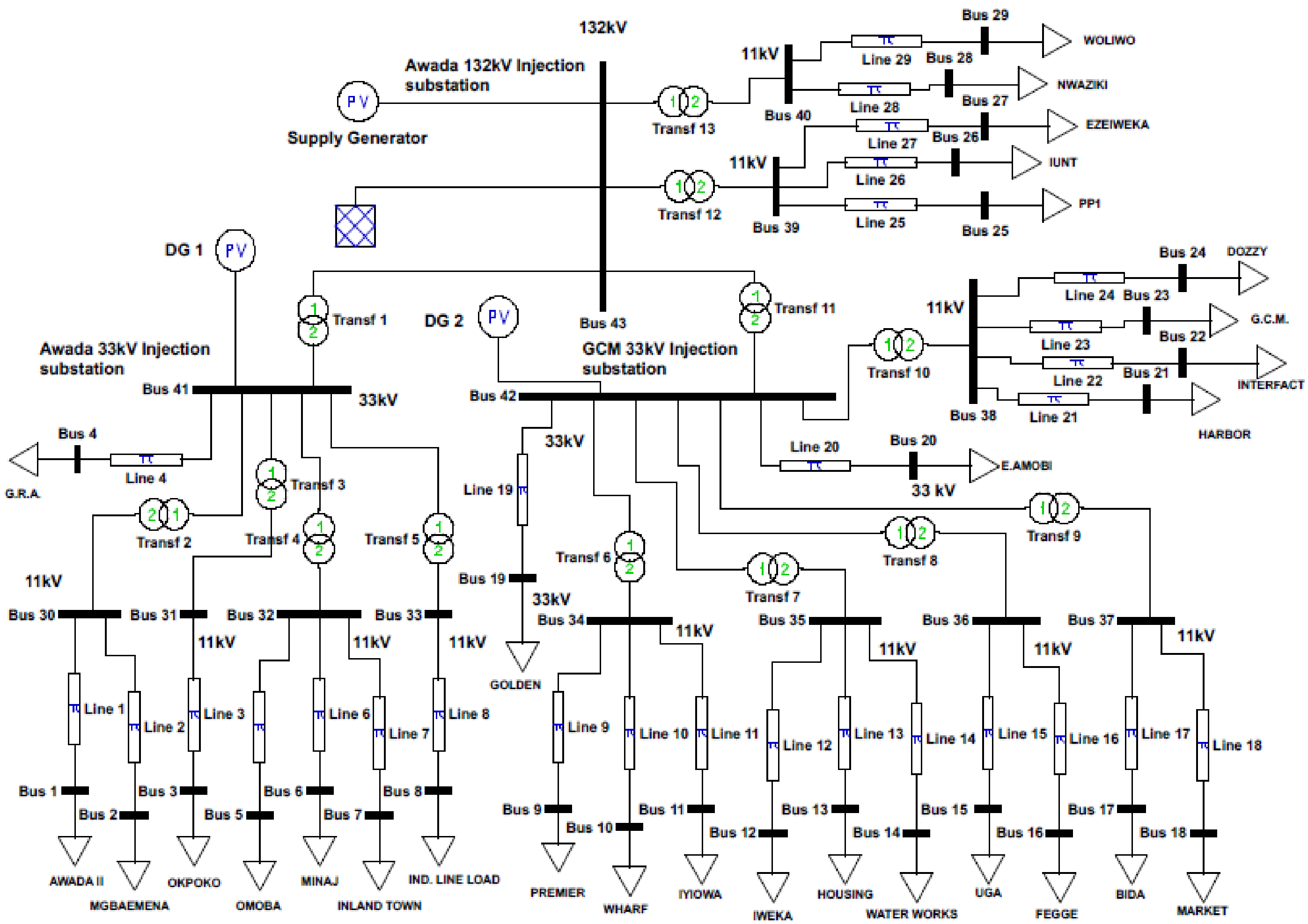

Figure 1: Onitsha distribution network system [35].

Table 1: Onitsha distribution load centers

Bus Number	Bus Name	Active Load (MW)	Power Factor	Apparent Load (KVA)
1	Awada FDR 8 11kv	7	0.935	7.4866
2	Mgbemena 11kv	8	0.952	8.4034
3	Okpoko 11kv	5	0.891	5.6117
4	G.R.A 11kv	5	0973	0.0051
5	Omoba 11kv	5	0.941	5.3135
6	Minaj 11kv	2	0.934	2.1413
7	Inland Town 11kv	5	0.954	5.2411
8	Industrial Line Load	2	0.978	2.045
9	Primer 11kv	1	0.944	1.0593
10	Whaft 11kv	0.1	0.997	0.1003
11	Iyiowa 11kv	4	0.885	4.5198
12	Iweka 11kv	4	0.897	4.4593
13	Housing 11kv	3	0.902	3.3259
14	Water Works 11kv	3.5	0.911	3.8419
15	Uga 11kv	3.5	0.959	3.6496
16	Fegge 11kv	1.5	0.95	1.5789
17	Bida 11kv	4	0.897	4.4593
18	Market 11kv	5.5	0.919	5.9848
19	Harbor 11kv	3.5	0.9	3.8889
20	Golden Oil 33kv	2.6	0.95	2.7368
21	E.Amobi 33kv	1.5	0.945	1.5873
22	Interfact 11kv	3	0.942	3.1847
23	G.C.M 11kv	0.1	0.95	0.1053
24	Dozzy 11kv	2	0.905	2.2099
25	PP1 11kv	1	0.931	1.0741
26	IUNT 11kv	2	0.91	2.1978
27	Ezeiweka 11kv	6	0.92	6.5217
28	Nwaziki 11kv	6	0.952	6.3025
29	Woliwo 11kv	4	0.939	4.2599

Source: [35].

5.2 Methodology

The method used in the research to enhance power supply in Onitsha distribution network using distribution generators is by predicting the location of the distributed generator using voltage sensitivity index. However, the optimum size of the DG is determined by calculating the system loss at each incremental step of the DG output power when placed at the priority locations predicted by the voltage sensitivity index simulations.

5.2.1 Power loss

Estimation of the power loss in an electrical network is of paramount importance as most of the analytical methods of sizing the optimal capacity of distributed generator use exact loss formula. The exact real power loss in a system is given in [36].

$$P_L = \Sigma_{i=1}^{N}\Sigma_{j=1}^{N}\left[\alpha_{ij}\left(P_iP_j + Q_iQ_j\right) + \beta_{ij}\left(Q_iP_j - P_iQ_j\right)\right] \quad (1)$$

Where,

$$\alpha_{ij} = \frac{r_{ij}}{V_iV_j}cos(\delta_i - \delta_j) \quad (2)$$

$$\beta_{ij} = \frac{r_{ij}}{V_iV_j}sin(\delta_i - \delta_j) \quad (3)$$

$$r_{ij} + jx_{ij} = z_{ij} \quad (4)$$

are the ij_{th}element of $[Z_{bus}]$ matrix with $[Z_{bus}] = [Y_{bus}]^{-1}$

5.2.2 DG Placement

The major challenges on the placement of DG in the distribution network are the location and DG sizing selection. Optimal placement of DG is able to improve the system performance specifically on system loss reduction, voltage profile and voltage stability improvement as well as enhancement of system loadability and reliability [37-40].

5.2.3 Optimal Location of DG based on Voltage Sensitivity Index

In order to reduce solution space to few buses, voltage sensitive nodes will first be identified by penetrating DG of 25% of the total feeder loading capacity at each node at a time and then, the voltage sensitivity index (VSI) is calculated using Equation (5). If the DG is connected at bus *i*, VSI for bus *i* will be defined as [41]:

$$VSI_i = \sqrt{\frac{\sum_{k=1}^{n}(1 - V_k)^2}{n}} \qquad (5)$$

Where $V_k$is voltage at *kth* node and *n* is the number of nodes.

The node with least VSI is the best location for the DG placement.

5.2.4 Sizing of Power Plant

It is obvious that for a particular bus, as the size of DG is increased, the losses are reduced to a minimum value and any further increased beyond a size of DG (i.e. the optimal DG size at that location) the losses start to increase and it is likely that it may surpass the losses of the base case. Also notice that the location of DG plays an important role in minimizing the losses. From these reasoning, step-by-step method is implored in this research to determine the optimal size of the distributed generator. In this method the following steps are taken to achieve the objective of size determination.

(i) Perform the base simulation of the study system.
(ii) Identify the bus voltage violations.
(iii) Calculate the system loss of the base simulation using Equation (1).
(iv) Perform voltage sensitivity index simulation using Equation (5) to reduce the candidate bus search for optimal DG placement. Rank the result of the voltage sensitivity simulation and choose few buses with least voltage sensitive indices for onward search of the optimal position and sizing the distribution generator.
(v) Vary the output of the distribution generator when placed at the selected candidate positions, while simulating for system loss from zero output until the system loss changes from decreasing to increasing. Stop if the system loss increased beyond the base system loss.
(vi) For single DG placement use quadratic curve fitting to determine the minimum system loss that could be achieved by the DG at these candidate positions.
a) The position with the least system loss is the position of the DG for optimal placement and
b) The output of the generator that produce this minimum system loss is the optimal capacity of the generator.
(vii) For multiple DG placement, having verified the optimal position for the first DG and its optimal operating capacity, place a DG at this first optimal position and allow it to operate at its optimal output value. Repeat step five (5) for the optimal placement and sizing of the second DG. Use the procedure in step six (6) to decide the optimal position and the size of the second generator.
(viii) After placement of the second DG, check for the bus voltage violation and if not cleared, upgrade the transformer that feeds that area with bus voltage violation.
(ix) If all the bus voltage violation is cleared at this juncture, note the final system loss. Otherwise repeat all the steps from five (5) to seven (7) as done for the second DG placement for the placement of the third DG, otherwise stop.

6.0 RESULTS AND DISCUSSION

The simulation of the forty – three bus system for Onitsha environ electric power distribution system that includes both the primary and secondary part of the distribution was done using PSAT 2.1.11 simulation tool in MATLAB environment and the simulation model is shown in Figure 1. The following procedures were used to augment the deficit in power supply to the study system that had been characterized by load shedding and low voltage supply. All simulations are done on 100 MVA base values.

6.1 Simulation of the Voltage Sensitivity Index

The simulation of the voltage sensitivity index was done in MATLAB environment using Equation (5) to select the candidate buses for the optimal placement of the

DG, see step four (4) for the optimal placement and sizing of the DG. The result of the voltage sensitivity index is presented in Table 2. The result showed that Awada 33 kV injection station is the optimum position placement.

6.2 Simulation of the Optimal Size of the Distribution Generator

The optimum distribution generation (DG) sizing started by placing the first DG at Awada 33 kV injection substation and gradually increasing the sizing of the DG and fulfilling the conditions as presented in step five (5) to step seven (7) of Section (5.2.4).The second distribution generation (DG) is placed at GCM 33kV injection station and simulation is performed according to step eight (8) and step nine (9) of Section (5.2.4).

A contrary of the above sizing was also performed by placing the DG at GCM first and then secondly placing at Awada. The simulation results are presented in Table 3 through Table 5 and Figure 2 through Figure 8.

6.3 Result Analysis

The voltage sensitivity factor (VSF) simulation showed that the optimum position for the placement of distribution generation (DG) in the Onitsha distribution network is at Awada 33kV injection substation (bus 41) Table 2. The bus 30 and bus 32 which are second and third on the VSF priority list respectively are on the same radial line that are fed from Awada 33 kV injection substation, DG optimal performances at those positions are less than its performances at Awada 33 kV injection substation and GCM 33 kV injection substation (bus 42). The result of the simulation confirmed the prediction, that Awada 33 kV injection substation is a better positional placement for DG than the GCM 33 kV injection substation. Despite the fact that the optimum size of DG at GCM 33 kV substation is 11 MW and 12.5 MW at Awada 33 kV substation, the optimum system loss with 12.5 MW DG at Awada 33 kV substation is 1.53 MW and 1.60 MW for 11 MW DG at GCM 33 kV injection substation.

Table 2: Voltage sensitivity factor

Bus Number	Bus name	Voltage sensitivity factor
41	Awada 33kV injection station	0.0516
30	Awada – Mgbemena 11 kV injection station	0.0540
32	Omaba – Inland town 11 kV injection station	0.0545
42	GCM 33kV injection station	0.0580
37	Bida – Market 11 kV injection station	0.0615
35	Iweka – Housing – Water works 11 kV injection station	0.0631
36	Fegge – Uga 11 kV injection station	0.0676
31	Okpoko 11 kV injection station	0.0681
33	Industry Line 11 kV injection station	0.0681
43	Awada 132 kV injection station	0.0740

Table 3: Bus voltages comparison

Bus number	No DG	One DG	Two DGs	Two DGs with Transformer
Bus 1	0.866025	0.959775	0.959775	0.959775
Bus 2	0.867359	0.960912	0.960912	0.960912
Bus 3	0.89702	0.983302	0.983302	0.983302
Bus 4	0.917126	0.999933	0.999933	0.999933
Bus 5	0.882923	0.972533	0.972533	0.972533
Bus 6	0.881643	0.971436	0.971436	0.971436
Bus 7	0.884641	0.974046	0.974046	0.974046
Bus 8	0.891586	0.979182	0.979182	0.979182
Bus 9	0.946785	0.946785	0.992941	0.992941
Bus 10	0.947093	0.947093	0.993234	0.993234
Bus 11	0.945637	0.945637	0.991859	0.991859
Bus 12	0.925242	0.925242	0.973899	0.973899
Bus 13	0.925109	0.925109	0.973777	0.973777
Bus 14	0.922145	0.922145	0.97108	0.97108

Bus number	No DG	One DG	Two DGs	Two DGs with Transformer
Bus 15	0.943601	0.943601	0.990018	0.990018
Bus 16	0.94504	0.94504	0.991358	0.991358
Bus 17	0.879828	0.879828	0.935575	0.977422
Bus 18	0.879687	0.879687	0.935448	0.977304
Bus 19	0.954515	0.954515	0.999982	0.999982
Bus 20	0.954525	0.954525	0.999992	0.999992
Bus 21	0.939555	0.939555	0.986471	0.986471
Bus 22	0.939787	0.939787	0.98669	0.98669
Bus 23	0.940041	0.940041	0.986932	0.986932
Bus 24	0.93977	0.93977	0.986674	0.986674
Bus 25	0.999842	0.999842	0.999842	0.999842
Bus 26	0.999511	0.999511	0.999511	0.999511
Bus 27	0.997805	0.997805	0.997805	0.997805
Bus 28	0.982441	0.982441	0.982441	0.982441
Bus 29	0.981314	0.981314	0.981314	0.981314
Bus 30	0.869204	0.962535	0.962535	0.962535
Bus 31	0.904892	0.990077	0.990077	0.990077
Bus 32	0.885008	0.974377	0.974377	0.974377
Bus 33	0.893646	0.98101	0.98101	0.98101
Bus 34	0.947127	0.947127	0.993266	0.993266
Bus 35	0.929036	0.929036	0.977427	0.977427
Bus 36	0.946428	0.946428	0.992669	0.992669
Bus 37	0.883484	0.883484	0.938926	0.980576
Bus 38	0.940043	0.940043	0.986934	0.986934
Bus 39	1	1	1	1
Bus 40	0.982736	0.982736	0.982736	0.982736
Bus 41	0.9172	1	1	1
Bus 42	0.954534	0.954534	1	1
Bus 43	1	1	1	1

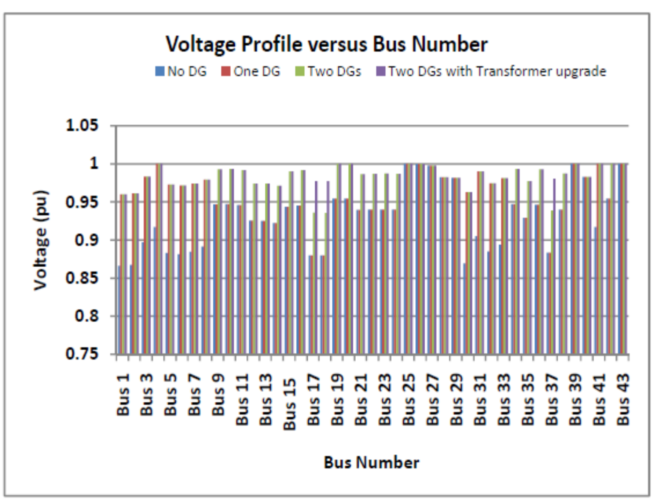

Figure 2: Bus voltage profile bar comparison

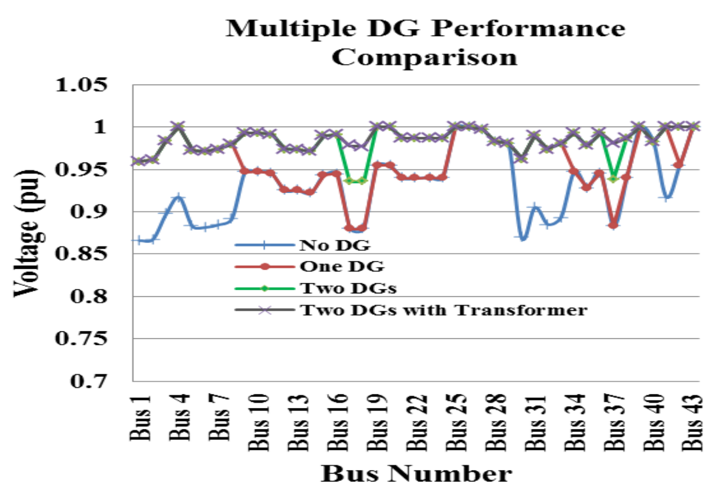

Figure 3: Line graph of bus voltage profiles

For optimum sizing of multiple DGs order of placement is important, the result of the research showed that if two distribution generators were to be placed at two positions, Awada 33 kV injection substation and GCM 33 kV injection substation that placing and sizing DG optimally at Awada 33 kV injection substation before placing the second DG at GCM 33 kV injection substation is better. This order has system active loss of 1.396 MW with total DG capacity of 15 MW as shown in Figure 4 while reverse that is DG placed first at GCM before Awada has system active loss of 1.419 MW from total DG capacity of 17 MW as seen in Figure 5.

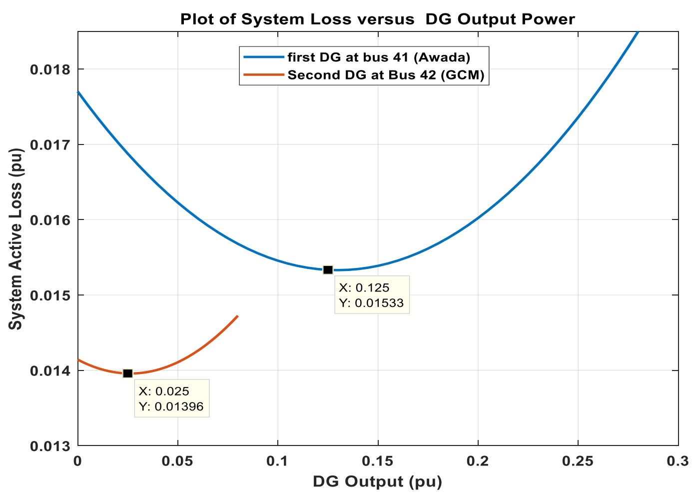

Figure 4: System active loss for step DG output starting with DG placed at Awada and then at GCM with Awada DG operating at its optimum of 12.5 MW

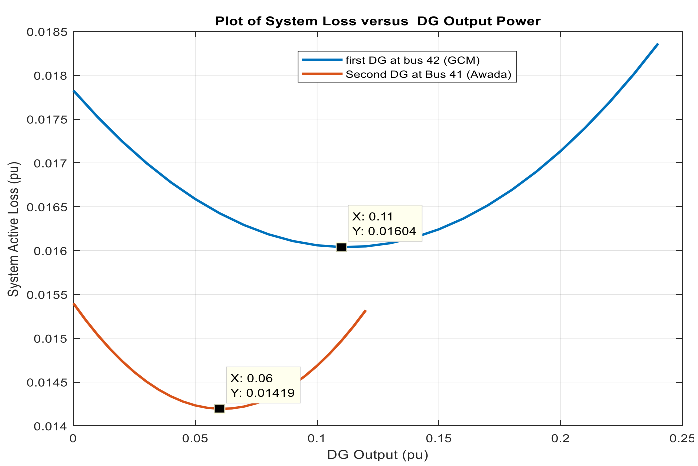

Figure 5: System active loss for Step DG output starting with DG placed at GCM and then at Awada with GCM operating at its optimum of 11 MW

The research simulation also showed that both active loss sensitivity and reactive loss sensitivity index have the same outcome when used to predict the optimal size of generator. These are shown in Figure 6 and Figure 7 respectively that optimal size of second DG when placed at GCM is 2.5 MW and this DG size gave minimal system active loss and reactive loss of 1.396 MW and 26.69 MVar respectively.

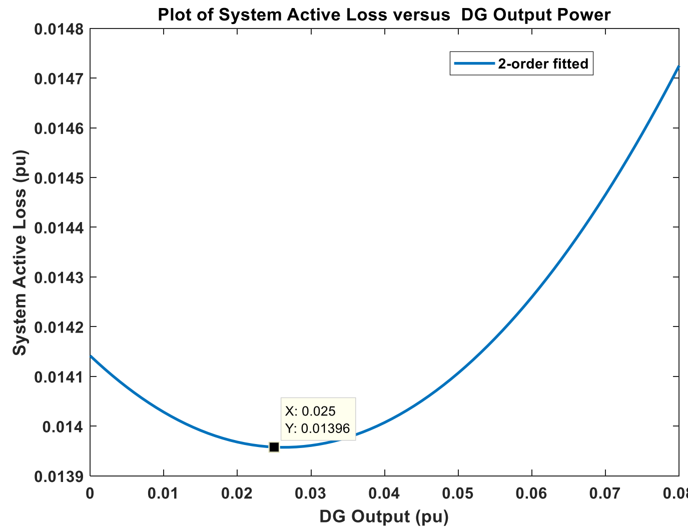

Figure 6: System active loss for optimum multiple DGs placement

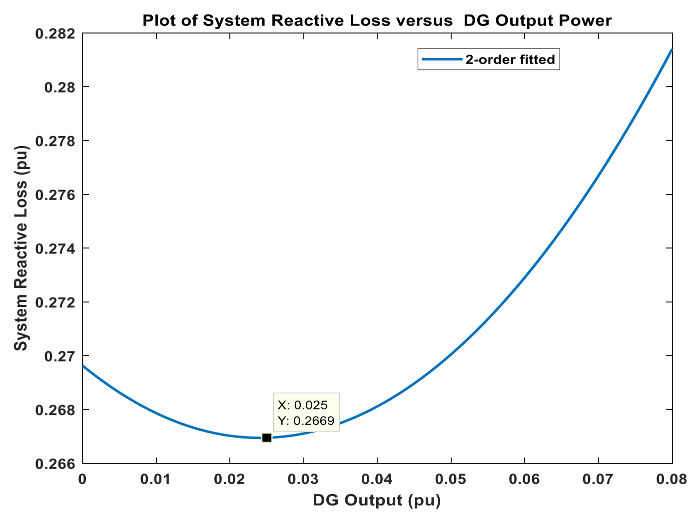

Figure 7: System reactive loss for optimum multiple DGs placement

The result of the simulation also showed that proper sizing and placement of DG with appropriate transformer sizing, bus voltage violation were totally removed (see Table 3) and system loss could be further mitigated as shown in Table 4. With two DGs placed each at Awada 33 kV injection substation and GCM 33 kV substation, 3 buses were still violated and the system active loss stood at 1.45 MW but upgrade of Fegge substation 7.5 MVA transformer to 15 MVA cleared all the violations and the system active loss and reactive loss were reduced to 1.396 MW and 0.2669 KVar respectively as can be seen in Table 4 and Figure 8. These reductions are 23.30% and 23.80% for system active and reactive loss respectively, as shown in Table 5 and Figure 9.

Table 4: Simulation system loss

	System active loss (pu)	System reactive loss (pu)
No Distribution generation (DG)	0.01820	0.3505
Multiple Distribution generation (DGs)	0.0145	0.2812
Multiple Distribution generation (DGs) and transformer upgrade	0.01396	0.2669

Table 5: Simulation system loss percentage

	System active loss % reduction	System reactive loss % reduction
Multiple Distribution generation (DGs)	23.30	23.80

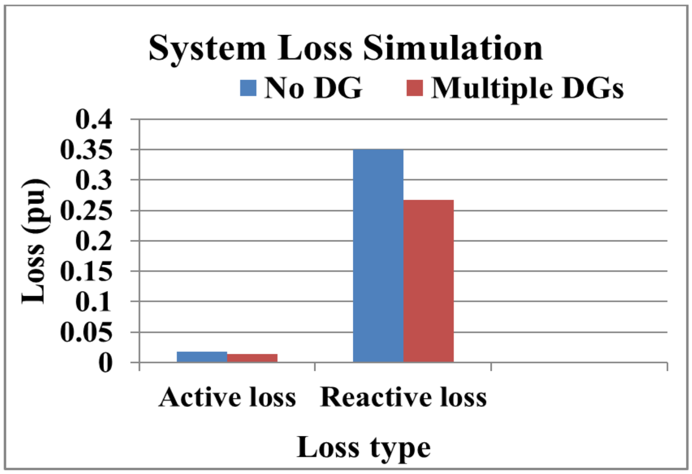

Figure 8: Bar chart for system loss simulation

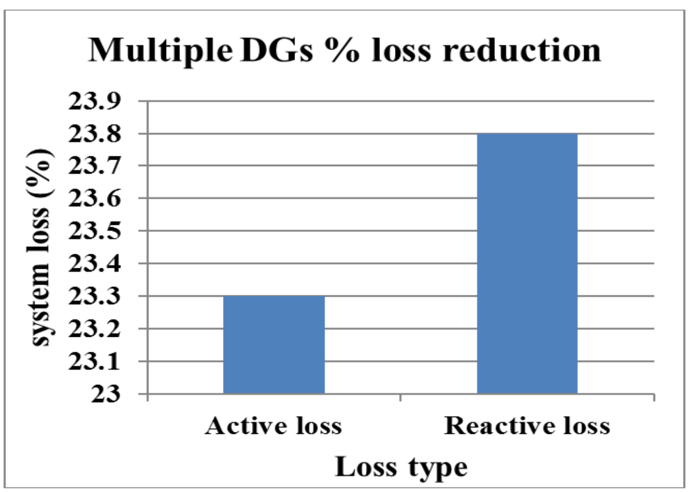

Figure 9: Bar chart of percentage system loss simulation

7.0 CONCLUSION

Simulations of the voltage sensitivity index and the optimal size of the DG were done using power analysis toolbox (PSAT) 2.1.11 simulation tool in MATLAB 2018a environment employing the necessary equations as contained in the study. The results obtained assisted in the eventual optimal placement of a DG at Awada 33 kV and at GCM 33 kV injection substations respectively using voltage sensitivity index factor while their optimum capacities were sized using step method. The result further revealed that proper sizing and placement of multiple DGs and appropriate transformer sizing removes voltage violations totally and reduces to barest minimum the system losses. The identification of overloaded transformer in Fegge substation and the consequent upgrade of the transformer from 7.5 MVA to 15 MVA not only cleared voltage violations totally but also reduced system losses drastically for better performance. The power supply in Onitsha distribution network was enhanced using distribution generations, precisely type 3 distribution generations – synchronous gas power plants. The usage of optimal placement and sizing of multiple distributed generation is therefore recommended for problematic distribution networks for loss reduction and better performance.

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