



Distribution Network Reliability and Efficiency Enhancement Using Distributed Generation

**Raymond Onyeka Nwajuonye^{1*}, Innocent Ifeanyi Okonkwo^{1*}
and Johnpaul I. Iloh¹**

¹Department of Electrical Electronic Engineering, Chukwuemeka Odumegwu Ojukwu University, Anambra State, Nigeria.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The Nigerian power sector is faced with many challenges such as: generation deficit, inefficiency and power loss over lengthy transmission and distribution lines, contribution to greenhouse gas emission, weak and dilapidated transmission and distribution infrastructure, dependence on fossil fuels, insufficient power. Efforts should be put in place by relevant authorities to improve the power sector. With the distribution network being the closest to the final consumer, efforts should be made to make it more efficient. This study therefore aims at improving the performance of poor distribution network using Distributed Generation (DG), optimally placed and sized in the network. The Asaba, 2 X 15MVA, 33/11kV injection substation in Asaba, Delta state of Nigeria consisting of Anwai road feeder and SPC feeder radiating outwardly from this injection substation was the focus of this study. Relevant data collected from Benin Electricity Distribution Company (BEDC) was used to carry out load flow study. The simulation and analysis of the result and injection of photovoltaic (PV) DG of Asaba injection substation distribution network using Newton-Raphson iteration technique in ETAP 12.6 environment to ascertain the overall performance of the network under base loading condition was modelled from a drawn detailed single line diagram of the network. DGs were optimally placed in specific buses in the network using loss sensitivity analysis. The result revealed that prior to DG placement in the network, only 10.4% of the buses were within

*Corresponding author: Email: nwajuonye@gmail.com, fin95@yahoo.com;

statutory voltage limit (394.25V – 435.75V or 0.95p.u – 1.05p.u) and 89.6% of the load buses in the network violated the statutory voltage limit and high losses (active and reactive) of 1329.08kW and 2031kVar. After the optimal placement of DG, the active and reactive power losses on the network reduced by 57.5% and 70.7%. While the voltage profile improved by 94.8%, thereby increasing the capacity, reliability and efficiency of distribution network.

Keywords: Capacitor banks; newton-raphson; ETAP; loss sensitivity analysis; voltage profile; Distributed Generation (DG); compensation; enhancement.

1. INTRODUCTION

Electrical energy is one of the most widely used forms of energy and is the yardsticks that determine the growth of the developed and developing countries. The depletion of conventional fossil fuels, instability of fuel price and increased awareness on environmental emission minimization in line with the new climate change policies and obligation. There is an increasing interest in renewable energy and recent trends reflect the need for developing countries to focus on renewable energy technologies and to seriously consider distributed generation (DG) as a viable alternative to the conventional means of power generation. The ill-maintained, out dated and infrastructural inadequacy of Nigeria's electricity thereby resulting in perennial epileptic power to the residential, commercial and industrial sectors of the nation's economy and more than half of the country's population has no access to electricity [1]. The trend in energy demand in Nigeria is growing rapidly and the energy demand in Nigeria far exceeds its supply [2]. The current model in Nigeria electricity generation and distribution is dominated by centralized power plants (hydro and thermal) on an interconnected system (National Grid). The actual users of power generated are far away from the generating centre. So, there is need to transmit power across a long distance which has many disadvantages; there exist inefficiencies and power loss over lengthy transmission lines, security related issues and contribute to greenhouse gas emission. However, Nigeria's energy mix consists of mostly non-renewable energy schemes and considering her diverse and unlimited renewable energy resources, as well as global challenges aforementioned, it is imperative that Nigeria consider DG option to ensure that supply meets demand [3].

Because power injections from DG have not been properly designed to cope with distribution network, therefore DG proliferation on the electric networks results in a number of adverse impacts,

including voltage variation, bi-directional power flow, harmonics, degraded protection, altered transient stability and increased fault level. Moreover, the voltage variation has been addressed as the dominant effect and, one of the most severe situations is that voltage magnitude at the proximity of DG exceeds the statutory limits during maximum power output from DG and minimum power demand from the network. Here the network experiences the largest reverse power flow and large voltage change which have an effect on the network safety and stability [4]. By means of DG systems, consumers may establish their own generation facilities and supply their own energy needs. Consumers may even earn more money by selling excess energy to the network. Large or small scale businesses established for this purpose can liberalize the market and prevent excessive increases in electricity prices [5].

This study is aimed at improving the voltage profile and overall performance of a Nigerian 33/11 kV distribution network with the use of DG properly sized and optimally placed in the network using Loss Sensitivity Factor (LSF).

2. USE OF DGs FOR DISTRIBUTION SYSTEM ENHANCEMENT

Distributed Generation (DG) is the process of using a small scale modular technology to produce or generate electricity located or close to the end user. DG also is a method that helps to reduce the amount of power losses which occurs during transmission or distribution by generating the power very close to load centre or may be even in the same vicinity [6].

Some of the technologies that are employed for DG sources include photovoltaic cells, wind generation, combustion engines, fuel cells etc, depending on their sources that are available in the geographical area [7, 8]. Usually, DGs are integrated with the existing distribution system and lot of studies is done to find out the best position to locate them as well as the size of DGs

to produce utmost benefits [6, 9]. The main characteristics that are considered for the identification of an optimal DG location and size are the minimization of transmission or distribution loss, maximization of supply reliability, maximization of profit of the distribution companies (DISCOs), etc [10]. Due to extensive costs, proper placement of DGs with optimal location and sizing should be done for the enhancement of the system performance in order to minimize the system loss as well as to get some improvements in the voltage profile while also maintaining the system stability [11].

In the literature review, there is a vast amount of work reported in the area of DG planning, optimization, allocation, sizing and integration on distribution network. Numerous studies can be found on DG planning and optimization. The scope, approach and methodology adopted for these studies of DG differ from each other. The challenges and prospects of DG in Nigeria power sector was investigated and the findings shows that despite this challenges faced, Nigeria has abundant natural renewable energy sources to reap the full benefit and implement DG technologies to achieve power supply efficiency and reliability [1]. The impact of connecting wind DG to distribution network was examined and the results show that when DG is optimally placed, it improves the voltage profile and reduce losses. [12]. Distributed generation interconnection to three-phase four-wire grid using a Novel Control Technique (NCT) for the connection of DG resources to Three-Phase Four-Wire (3P4W) distribution grids via interfaced converters [13]. In order to achieve and improve the power quality, efficiency and transient response of the system, the differential equation and the switching state function of the grid interface converter system were established. The results showed that the proposed approach, the grid-interfacing converter can transfer active power at main frequency from DG resources to grid, and also compensate all reactive, unbalanced load current components with a fast-transient waveform, neutral and harmonic. The demonstration of the control technique of the simulation studies in Matlab/Simulink environment was effective.

3. METHODOLOGY

The study was carried out using Anwai and SPC feeders of Asaba, 2 x 15MVA, 33/11KV injection substation in Asaba, Delta state of Nigeria. The distribution network has 96 buses and field data was used for this study, which was collected from

Benin Electric Distribution Company (BEDC). Data collected include the network diagram, names and ratings of secondary distribution transformers, the line parameters like impedance, route distances from one transformer to the other, load on each of the transformers, cables types and diameters etc. Simulation and analysis of the result and injection of photovoltaic (PV) DG of Asaba injection substation distribution network using Newton-Raphson algorithm and loss sensitivity factor algorithm to ascertain the optimal location and sizing of DG in ETAP 12.6 environments was modelled from a drawn detailed single line diagram of the network as shown in Fig. 1. The load flow analysis was done using Newton-Raphson iteration technique as shown in Fig. 2 and 3 with the deficient buses appearing in red. Under base loading condition simulation was carried out. The overall performance of the network was noted with parameters like the bus voltages, percentage loading, etc. being taken into consideration. The loss sensitivity analysis was then used to optimally allocate the location and the size of DGs placement in the deficient network. The simulation procedure was then repeated for the enhanced network as shown in Fig. 3 and 5, and the performance of the enhanced network was then compared to that of the original network.

4. LOSS SENSITIVITY ANALYSIS

Loss sensitivity analysis is used to calculate the factor for determining the candidate nodes where enhancement devices will be placed in a network. This helps to reduce the search space [8].

The active power loss in a distribution network can be determined using equation (1);

$$P_{\text{line loss}}(q) = \frac{[P_{\text{eff}}(q)^2 + Q_{\text{eff}}(q)^2]R_k}{V_q^2} \quad (1)$$

Where $P_{\text{eff}}(q)$ and $Q_{\text{eff}}(q)$ are the effective active and reactive power flows supplied beyond the node 'q'

$$\frac{\partial P_{\text{line loss}}(q)}{\partial P_{\text{eff}}(q)} = \frac{2 * P_{\text{eff}}(q) * R_k}{V_q^2} \quad (2)$$

$$\frac{\partial P_{\text{line loss}}(q)}{\partial Q_{\text{eff}}(q)} = \frac{2 * Q_{\text{eff}}(q) * R_k}{V_q^2} \quad (3)$$

Equation (2) and (3) help in determining the sensitivity factors of the buses and they are ranked in value. The candidate buses considered as the highest priority is the one that have the

highest value of LSF. LSF is also considered based on both the closeness and priority of buses to the distribution network (generation and load). LSF based on priority list alone should be considered due to the fact that, it may indicate nearby buses as optimal site for placing DGs which makes the identified sites ineffective to satisfy the objectives [14].

The actual loss formula used in determining the active power loss of the system can be obtained from the active power injected based on loss sensitivity factor

$$P_L = \sum_{i=1}^N \sum_{j=1}^N \alpha_{ij} (P_i P_j + Q_i Q_j) + \beta_{ij} (Q_i P_j - P_i Q_j) \quad (4)$$

Where,

$$\alpha_{ij} = \frac{r_{ij}}{V_i V_j} \cos(\delta_i - \delta_j); \beta_{ij} = \frac{r_{ij}}{V_i V_j} \sin(\delta_i - \delta_j) \quad (5)$$

Based on the active power injected on the i th bus, the loss sensitivity factor of the particular bus can be represented as:

$$\alpha_{ij} = \frac{\partial P_L}{\partial P_i} = 2 \sum_{j=1}^N (\alpha_{ij} P_j - \beta_{ij} Q_j) = \frac{2QR}{V^2} \quad (6)$$

4.1 DG Sizing Location Analyses

The active and reactive power injected at bus i , where the DG located, are given by (7) and (8), respectively [15,16].

$$P_i = P_{DG_i} - P_{D_i} \quad (7)$$

$$Q_i = Q_{DG_i} - Q_{D_i} = P_i = aP_{DG_i} - Q_{D_i} \quad (8)$$

From (4), (7), and (8), the active power loss can be rewritten as

$$P_L = \sum_{i=1}^N \sum_{j=1}^N (\alpha_{ij} [(P_{DG_i} - P_{D_i}) P_j + (aP_{DG_i} - Q_{D_i}) Q_j] + \beta_{ij} [aP_{DG_i} P_j - P_{D_i} Q_j]) \quad (9)$$

If the partial derivative of equation (9) with respect to the active power injection from DG at bus i becomes zero then, the total active power loss of the system is minimum. By simplification and rearrangement, equation (9) becomes;

$$\alpha_{ii} (P_i + aQ_i) + \beta_{ii} (aP_i - Q_i) + \sum_{j \neq i}^N (\alpha_{ij} P_j - \beta_{ij} Q_j) + a \sum_{j \neq i}^N (\alpha_{ij} Q_j + \beta_{ij} P_j) = 0 \quad (10)$$

Let,

$$X_i = \sum_{j \neq i}^N (\alpha_{ij} P_j - \beta_{ij} Q_j), Y_i = \sum_{j \neq i}^N (\alpha_{ij} Q_j + \beta_{ij} P_j) \quad (11)$$

From equations 7,8,10 and 11, equation (12) was developed;

$$\alpha_{ii} (P_{DG_i} - P_{D_i} + a^2 P_{DG_i} - a Q_{D_i}) + \beta_{ii} (Q_{D_i} - a P_{D_i}) + X_i + a Y_i = 0 \quad (12)$$

Hence, the optimal size of DG at each bus i for minimizing loss can be written as;

$$P_{DG_i} = \frac{\alpha_{ii} (P_{D_i} + a Q_{D_i}) + \beta_{ii} (a P_{D_i} - Q_{D_i}) - X_i - a Y_i}{a^2 \alpha_{ii} + \alpha_{ii}} \quad (13)$$

4.2 Optimal Allocation of Distributed Generators

The following steps are followed for the optimal allocation of DG

1. Run the Base case power flow distribution network and find out the voltage magnitude and reactive power drawn of each bus.
2. Identify the prospective candidate buses by their location, reactive power drawn, voltage magnitude and distance from the injection substation.
3. Calculate the Loss sensitivity factors based on equations (1), (2) and (3) for all buses.
4. Determine the number of DGs that needs to be placed for the transforming the distribution network.
5. The buses are ranked in ascending order based on their Loss sensitivity factors.
6. Buses having high priority, proximity to load and other generation units is considered for placing the multiple DG units for the distribution network.

4.3 Optimal Sizing of Distributed Generators

The procedure for finding the optimal size of DGs:

1. Run the power flow distribution network base case.
2. Determine the base case loss using (4).
3. Determine DG optimal size for each bus using (13), and (8).
4. Place a DG with the optimal size obtained in step 3 at each bus found through the LSF based on optimal allocation method where the total loss is minimum.
5. Run the load flow at the optimal location obtained in step 4.
6. Fix the DG size if any one of the conditions mentioned in step 8 violates.
7. The load data should be updated after fixing each DG and continue with step 3 finding the size of next DG.

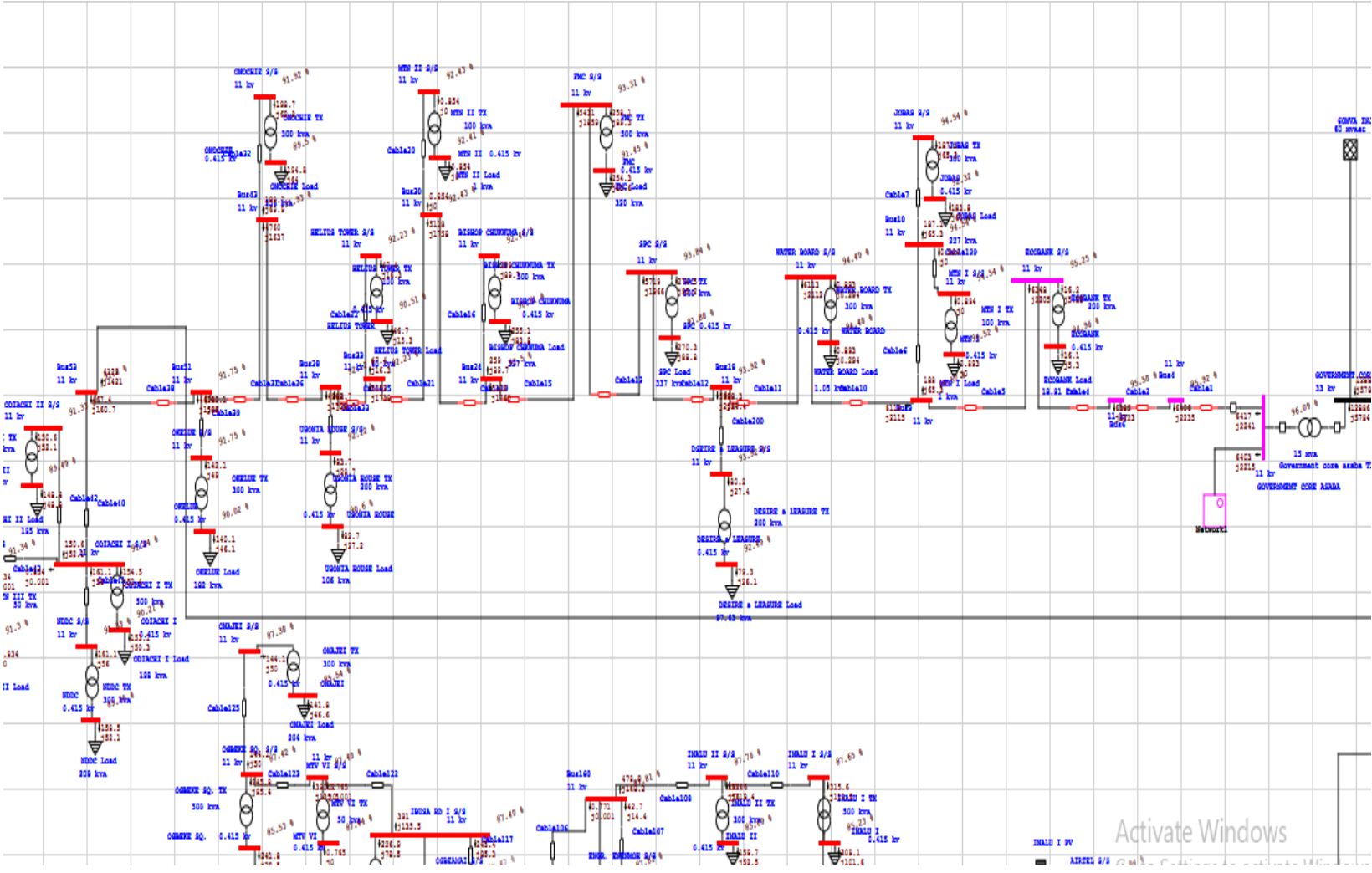


Fig. 2. Section of BEDC Asaba 2x15MVA 33/11KV injection substation before enhancement in ETAP run mode

Table 1. Load Flow Results for Base Bus Loading Condition of the Original Network

S/N	Load Buses	Rated kV	kW	kVAR	Amp.	Bus voltage (V)
1	ABBAY Load	0.415	5.07	1.67	8.245	373.8
2	ABUTA Load	0.415	213.6	70.21	370.2	350.6
3	AIRTEL Load	0.415	45.89	15.08	76.44	364.8
4	AIRTELS Load	0.415	70.55	23.19	114.2	375.3
5	ALUME DRIVE Load	0.415	195.7	64.31	317.3	374.8
6	ANWAI CAMPUS Load	0.415	329.1	108.2	544.7	367.2
7	ANWAI GRA II Load	0.415	196.4	64.54	323.3	369.1
8	ANWAI I Load	0.415	184.8	60.74	291.9	384.8
9	ANWAI II Load	0.415	276.8	90.99	437.1	384.9
10	ANWAI RIVER Load	0.415	220.4	72.44	364.7	367.2
11	ARCH. MARTINS ODIAKA Load	0.415	90.36	29.7	141.8	394.3
12	BAKARE Load	0.415	168.9	55.52	291.8	351.8
13	BENCLINTON Load	0.415	85.88	28.23	145.5	358.6
14	BENITA I Load	0.415	176.4	57.98	299	358.6
15	BENITA II Load	0.415	190.6	62.63	323.8	357.7
16	BISHOP CHKWUMA Load	0.415	317.7	104.4	514.4	375.4
17	BUDGET Load	0.415	286.8	94.26	476.6	365.7
18	CHINEDU OKO Load	0.415	117.2	38.52	184.4	394.3
19	CHYKES Load	0.415	241.5	79.37	386.6	379.6
20	CHYZ PETRO. Load	0.415	42.28	13.9	68.16	376.9
21	DAVNOTCH Load	0.415	209.1	68.72	325.5	394.3
22	DESIRE & LEASURE Load	0.415	99.78	32.8	157.5	385.0
23	DESIRE&LESURE GARDEN Load	0.415	136.6	44.91	216.7	383.1
24	EBUBE Load	0.415	218.2	71.72	353.6	375.0
25	ECOBANK Load	0.415	20.46	6.72	31.3	397.1
26	ELGREEN HOTEL Load	0.415	107.7	35.4	175.3	373.4
27	ENGR. ENENMOH Load	0.415	51.83	17.04	88.21	357.1
28	FAVORITE Load	0.415	86	28.27	132.4	394.9
29	FIRS Load	0.415	5.74	1.89	8.772	398.0
30	FITMAURICE ESTATE Load	0.415	5.34	1.76	8.458	383.8
31	FMC Load	0.415	318.1	104.6	509.2	379.7
32	FUNNAYA Load	0.415	208.3	68.47	348.5	363.2
33	HELIUS TOWER Load	0.415	58.14	19.11	94.26	374.9

34	HILIOUS TOWER Load	0.415	70.28	23.1	113.2	377.4
35	IBORI GOLF I Load	0.415	181.4	59.62	298.6	369.2
36	IBORI GOLF II Load	0.415	290.9	95.61	478.4	369.4
37	IBUSA RD I Load	0.415	271.5	89.22	470.3	350.8
38	ICON Load	0.415	220.9	72.62	382.5	351.0
39	IKECHUKWU HOUSE Load	0.415	153.4	50.43	251.6	370.6
40	INALU I Load	0.415	374.3	123	653.5	348.1
41	INALU II Load	0.415	193.9	63.74	336.3	350.4
42	INFANT JESUS I Load	0.415	175.7	57.74	286.9	372.1
43	INFANT JESUS II Load	0.415	236.2	77.63	387	370.9
44	INFANT JESUS SCH GAT Load	0.415	272	89.41	445.1	371.4
45	INFANT JESUS SCH Load	0.415	45.14	14.84	72.97	375.9
46	JAMES IBORI Load	0.415	253	83.17	414	371.4
47	JASMINE SCHOOL Load	0.415	41.2	13.54	67.29	372.1
48	JOBAS Load	0.415	230.1	75.64	364.7	383.4
49	LEASURE HOME Load	0.415	4.2	1.38	6.71	380.4
50	MARCULEY I Load	0.415	112.9	37.12	181.1	379.1
51	MARCULEY II Load	0.415	265.7	87.32	435.2	370.9
52	MIKE OKECHUKWU Load	0.415	51.27	16.85	82.06	379.7
53	MOCIWS Load	0.415	5.18	1.7	8.328	377.8
54	MTN ANWAI RD Load	0.415	52.9	17.39	83.36	385.7
55	MTN CAMPUS Load	0.415	5.15	1.69	8.304	376.7
56	MTN I Load	0.415	64.66	21.25	102	394.3
57	MTN II Load	0.415	49.58	16.3	79.88	377.2
58	MTN III Load	0.415	5.17	1.7	8.325	377.7
59	MTN IV Load	0.415	4.8	1.58	8.022	363.9
60	MTN Load	0.415	4.7	1.54	7.93	359.8
61	MTV VI Load	0.415	0.938	0	1.506	359.4
62	NDDC Load	0.415	196.2	64.48	323.1	369.0
63	NEW SSG Load	0.415	121.4	39.92	195	378.4
64	NWOBOSHI Load	0.415	192.2	63.17	298.5	394.3
65	ODIACHI I Load	0.415	190.3	62.56	309.8	373.4
66	ODIACHI II Load	0.415	183.7	60.39	302.1	369.6
67	OGBEAMAI Load	0.415	293	96.3	508.8	349.9
68	OGBEKE SQ. Load	0.415	293.3	96.42	509.9	349.6
69	OKECHUKWU OKAFOR Load	0.415	58.04	19.08	96.62	365.1

70	OKELUE Load	0.415	174	57.19	284	372.4
71	ONAJEI Load	0.415	172	56.54	298.9	349.7
72	ONOCHIE Load	0.415	241.2	79.28	396.5	369.6
73	ONWUKA ST. Load	0.415	230.6	75.79	376.2	372.5
74	PARKISON Load	0.415	260.9	85.77	444.3	356.9
75	PHASE II COMMUNITY Load	0.415	208.3	68.48	344	368.1
76	SKY LYN HOTEL Load	0.415	61.13	20.09	96.64	384.4
77	SOBOTE Load	0.415	5.39	1.77	8.496	385.5
78	SPC Load	0.415	338.8	111.4	539.2	381.8
79	SSS I Load	0.415	191.1	62.81	309.6	375.1
80	SSS OFFICE Load	0.415	200.2	65.82	324.1	375.5
81	ST. JOSEPH Load	0.415	192.7	63.33	334.5	350.1
82	STADIUM Load	0.415	330.9	108.8	567.4	354.5
83	STADIUM OFFICE Load	0.415	233	76.57	398	355.7
84	STARCOM Load	0.415	4.06	1.34	6.602	374.2
85	TEMPO CLINIC I Load	0.415	208.1	68.41	325.6	388.5
86	TEMPO CLINIC II Load	0.415	195	64.11	308	384.8
87	TOBI I Load	0.415	212.5	69.85	334.7	385.9
88	TOBI II Load	0.415	197	64.74	311.9	394.3
89	UDUAGHAN I Load	0.415	310.8	102.2	500.1	377.7
90	UDUAGHAN II Load	0.415	183.1	60.17	293.7	378.9
91	UMUAGU I Load	0.415	228.7	75.17	380.8	365.0
92	UMUAGU II Load	0.415	267.8	88.03	448.6	362.9
93	USONIA HOUSE Load	0.415	103	33.84	166.7	375.3
94	VICTOR OCHIE Load	0.415	176.1	57.88	284.9	375.7
95	WATER BOARD Load	0.415	1.13	0.372	1.742	394.8
96	ZANZIBAR Load	0.415	86.87	28.55	136.5	386.8

Table 2. Table of loss sensitivity factor arranged in order of priority selection

S/N	BUS NAME	KVAR	Voltage magnitude (V)	Total Route Resistance	Loss Sensitivity Factor
1	Inalu I	123	348.6	0.32237	0.000653
2	Ogbeke Square	96.42	348.6	0.32237	0.000512
3	Stadium	108.8	352.8	0.23873	0.000417
4	Budget	94.26	365.2	0.23873	0.000337
5	Anwai Campus	108.2	365.2	0.16496	0.000268
6	Ibori Golf II	95.61	369.4	0.16496	0.000231
7	Anwai II	90.99	386.0	0.16496	0.000202
8	Bishop Chukwuma	104.4	373.5	0.11937	0.000179
9	Uduaghan I	102.2	377.7	0.11937	0.000171
10	Parkison	85.77	356.9	0.11937	0.000161
11	SPC	111.4	381.8	0.07696	0.000118

Table 3. Load Flow Results Showing Bus Voltages on the load buses with and without DG placement

S/N	LOAD BUSES	WITH DG PLACEMENT					WITHOUT DG PLACEMENT				
		Rated kV	kW	kvar	Amp	Bus voltage (V)	kW	kvar	Amp	Bus voltage (V)	
1	ANWAI II Load	0.415	370.8	121.9	578.2	389.8	5.07	1.67	8.245	373.8	
2	ANWAI RIVER Load	0.415	248.3	81.62	387.1	389.8	213.6	70.21	370.2	350.6	
3	PHASE II COMM. Load	0.415	234.8	77.16	365.1	390.8	45.89	15.08	76.44	364.8	
4	ANWAI GRA II Load	0.415	221.3	72.72	343.2	391.8	70.55	23.19	114.2	375.3	
5	IBORI GOLF I Load	0.415	204.4	67.18	316.9	391.9	195.7	64.31	317.3	374.8	
6	IBORI GOLF II Load	0.415	327.8	107.7	507.9	394.3	329.1	108.2	544.7	367.2	
7	IKECHUKWU HOUSE Load	0.415	172.9	56.82	267.1	394.3	196.4	64.54	323.3	369.1	
8	INFANT JESUS II Load	0.415	266.1	87.48	410.8	394.3	184.8	60.74	291.9	384.8	
9	INFANT JESUS SCH GAT Load	0.415	306.5	100.7	472.5	394.3	276.8	90.99	437.1	384.9	
10	INFANT JESUS I Load	0.415	197.9	65.06	304.5	395.0	220.4	72.44	364.7	367.2	
11	JASMINE SCHOOL Load	0.415	46.42	15.26	71.43	395.0	90.36	29.7	141.8	387.3	
12	OGBEKE SQ. Load	0.415	376.7	123.8	577.8	396.2	168.9	55.52	291.8	351.8	
13	ONAJEI Load	0.415	220.9	72.6	338.7	396.3	85.88	28.23	145.5	358.6	
14	ELGREEN HOTEL Load	0.415	121.3	39.88	186	396.4	176.4	57.98	299	358.6	
15	ICON Load	0.415	281.8	92.62	432	396.4	190.6	62.63	323.8	357.7	

16	OGBEAMAI Load	0.415	376.3	123.7	576.6	396.6	317.7	104.4	514.4	375.4
17	ABUTA Load	0.415	273.5	89.88	418.9	396.7	286.8	94.26	476.6	365.7
18	ST. JOSEPH Load	0.415	247.4	81.33	379	396.7	117.2	38.52	184.4	386.1
19	UMUAGU II Load	0.415	320.9	105.5	491	397.2	241.5	79.37	386.6	379.6
20	IBUSA RD I Load	0.415	348.6	114.6	533	397.5	42.28	13.9	68.16	376.9
21	STADIUM OFFICE Load	0.415	291	95.65	444.8	397.6	209.1	68.72	325.5	390.3
22	MARCULEY II Load	0.415	305.3	100.3	466.5	397.7	99.78	32.8	157.5	385.0
23	ARCH. MARTINS ODIAKA Load	0.415	95.29	31.32	145.6	397.7	90.36	29.7	141.8	394.3
24	EBUBE Load	0.415	245.9	80.81	375.3	398.1	218.2	71.72	353.6	375.0
25	ECOBANK Load	0.415	290.8	95.57	443.8	398.2	20.46	6.72	31.3	397.1
26	ONOCHIE Load	0.415	280	92.03	427.2	398.3	107.7	35.4	175.3	373.4
27	AIRTELS Load	0.415	79.49	26.13	121.3	398.4	51.83	17.04	88.21	357.1
28	Favourite load	0.415	418.2	137.4	637.8	398.4	86	28.27	132.4	394.9
29	FIRS Load	0.415	216.9	71.29	330.7	398.6	5.74	1.89	8.772	398.0
30	INFANT JESUS SCH Load	0.415	50.86	16.72	77.45	399.1	5.34	1.76	8.458	383.8
31	JOBAS Load	0.415	249.3	81.95	379.7	399.1	318.1	104.6	509.2	379.7
32	ONWUKA ST. Load	0.415	265	87.09	403.3	399.3	208.3	68.47	348.5	363.2
33	CHYKES Load	0.415	267.3	87.85	406.7	399.4	58.14	19.11	94.26	374.9
34	UMUAGU I Load	0.415	274	90.07	416.8	399.5	70.28	23.1	113.2	377.4
35	BENITA II Load	0.415	238	78.23	361.8	399.8	181.4	59.62	298.6	369.2
36	MTN CAMPUS Load	0.415	5.8	1.91	8.814	399.9	290.9	95.61	478.4	369.5
37	INALU II Load	0.415	252.7	83.05	383.9	400.0	271.5	89.22	470.3	350.8
38	CHYZ PETRO. Load	0.415	47.64	15.66	72.36	400.1	220.9	72.62	382.5	351.0
39	SPC Load	0.415	372.6	122.5	565.5	400.4	153.4	50.43	251.6	370.6
40	BENITA I Load	0.415	220.4	72.43	334.2	400.7	374.3	123	653.5	348.1
41	INALU I Load	0.415	496	163	752.3	400.7	193.9	63.74	336.3	350.4
42	DAVNOTCH Load	0.415	220.5	72.48	334.3	400.9	209.1	68.72	325.5	394.3
43	PARKISON Load	0.415	329.2	108.2	499	400.9	236.2	77.63	387	370.9
44	FMC Load	0.415	354.7	116.6	537.7	401.0	272	89.41	445.1	371.4
45	BISHOP CHKWUMA Load	0.415	362.6	119.2	549.5	401.0	45.14	14.84	72.97	375.9
46	NDDC Load	0.415	231.8	76.18	351.2	401.0	253	83.17	414	371.4
47	MOCIWS Load	0.415	5.83	1.92	8.84	401.1	41.2	13.54	67.29	372.1
48	MTN I Load	0.415	70.06	23.03	106.2	401.1	64.66	21.25	102	394.3
49	TOBI I Load	0.415	229.6	75.48	347.9	401.1	4.2	1.38	6.71	380.4
50	TEMPO CLINIC II Load	0.415	212.5	69.85	321.5	401.7	112.9	37.12	181.1	379.1

51	ALUME DRIVE Load	0.415	224.8	73.9	340.1	401.8	265.7	87.32	435.2	370.9
52	ODIACHI II Load	0.415	217	71.34	328.3	401.8	51.27	16.85	82.06	379.7
53	HILIOUS TOWER Load	0.415	79.7	26.19	120.5	401.8	5.18	1.7	8.328	377.8
54	NWOBOSHI Load	0.415	202.7	66.62	306.5	401.9	192.2	63.17	298.5	394.3
55	HELIUS TOWER Load	0.415	66.87	21.98	101.1	402.1	5.15	1.69	8.304	376.7
56	SSS I Load	0.415	219.6	72.18	331.9	402.1	64.66	21.25	102	385.3
57	OKELUE Load	0.415	203.2	66.78	306.9	402.4	49.58	16.3	79.88	377.2
58	FUNNAYA Load	0.415	255.8	84.07	386.2	402.5	5.17	1.7	8.325	377.7
59	SSS OFFICE Load	0.415	230.1	75.63	347.4	402.5	4.8	1.58	8.022	363.9
60	VICTOR OCHIE Load	0.415	202.4	66.51	305.4	402.7	4.7	1.54	7.93	359.8
61	TOBI II Load	0.415	217	71.34	327.5	402.8	197	64.74	311.9	394.3
62	BENCLINTON Load	0.415	108.3	35.61	163.5	402.8	196.2	64.48	323.1	369.0
63	CHINEDU OKO Load	0.415	127.7	41.96	192.5	403.0	117.2	38.52	184.4	394.4
64	DESIRE&LESURE GARDEN Load	0.415	151.2	49.69	228	403.0	192.2	63.17	298.5	391.3
65	MIKE OKECHUKWU Load	0.415	57.77	18.99	87.11	403.0	190.3	62.56	309.8	373.4
66	ANWAI I Load	0.415	202.9	66.69	305.8	403.2	183.7	60.39	302.1	369.6
67	USONIA HOUSE Load	0.415	118.8	39.06	179.1	403.2	293	96.3	508.8	349.9
68	DESIRE & LEASURE Load	0.415	109.5	36	165	403.3	293.3	96.42	509.9	349.6
69	MTN II Load	0.415	56.69	18.63	85.41	403.4	58.04	19.08	96.62	365.1
70	UDUAGHAN II Load	0.415	207.6	68.24	312.7	403.4	174	57.19	284	372.4
71	SKY LYN HOTEL Load	0.415	67.36	22.14	101.5	403.5	172	56.54	298.9	349.7
72	LEASURE HOME Load	0.415	4.73	1.56	7.123	403.8	241.2	79.28	396.5	369.6
73	OKECHUKWU OKAFOR Load	0.415	71.26	23.42	107.1	404.5	230.6	75.79	376.2	372.5
74	UDUAGHAN I Load	0.415	357.1	117.4	536.1	404.9	260.9	85.77	444.3	356.9
75	BUDGET Load	0.415	351.8	115.6	527.8	405.0	208.3	68.48	344	368.1
76	MTN ANWAI RD Load	0.415	58.41	19.2	87.59	405.2	61.13	20.09	96.64	384.4
77	STADIUM Load	0.415	90.7	29.81	135.9	405.5	5.39	1.77	8.496	385.5
78	TEMPO CLINIC I Load	0.415	226.8	74.54	339.9	405.5	338.8	111.4	539.2	381.8
79	AIRTEL Load	0.415	56.71	18.64	84.98	405.6	191.1	62.81	309.6	375.1
80	NEW SSG Load	0.415	139.5	45.87	209.1	405.6	200.2	65.82	324.1	375.5
81	ODIACHI I Load	0.415	224.9	73.91	336.7	405.8	192.7	63.33	334.5	350.1
82	Awai II Load	0.415	308.4	101.4	461.4	406.3	330.9	108.8	567.4	354.5
83	MARCULEY I Load	0.415	129.8	42.66	194.1	406.3	233	76.57	398	355.7
84	ENGR. ENENMOH Load	0.415	67.24	22.1	100.5	406.7	4.06	1.34	6.602	374.2
85	MTV VI Load	0.415	1.2	0	1.707	407.3	208.1	68.41	325.6	388.5

86	ZANZIBAR Load	0.415	96.57	31.74	143.9	407.8	195	64.11	308	384.8
87	MTN IV Load	0.415	6.06	1.99	9.01	408.8	212.5	69.85	334.7	385.9
88	MTN Load	0.415	6.09	2	9.032	409.8	197	64.74	311.9	383.7
89	James Ibori load	0.415	21.82	7.17	32.33	410.1	310.8	102.2	500.1	377.7
90	MTN III Load	0.415	6.11	2.01	9.048	410.5	183.1	60.17	293.7	378.9
91	Bakare Load	0.415	6.13	2.02	9.063	411.2	228.7	75.17	380.8	365.0
92	ABBEY Load	0.415	1.23	0.404	1.815	411.3	267.8	88.03	448.6	362.9
93	FITMAURICE ESTATE Load	0.415	6.14	2.02	9.067	411.3	103	33.84	166.7	375.3
94	SOBOTE Load	0.415	6.19	2.04	9.108	413.2	176.1	57.88	284.9	375.7
95	Water board load	0.415	6.22	2.05	9.132	414.1	1.13	0.372	1.742	394.8
96	STARCOM Load	0.415	4.99	1.64	7.315	414.5	86.87	28.55	136.5	386.8

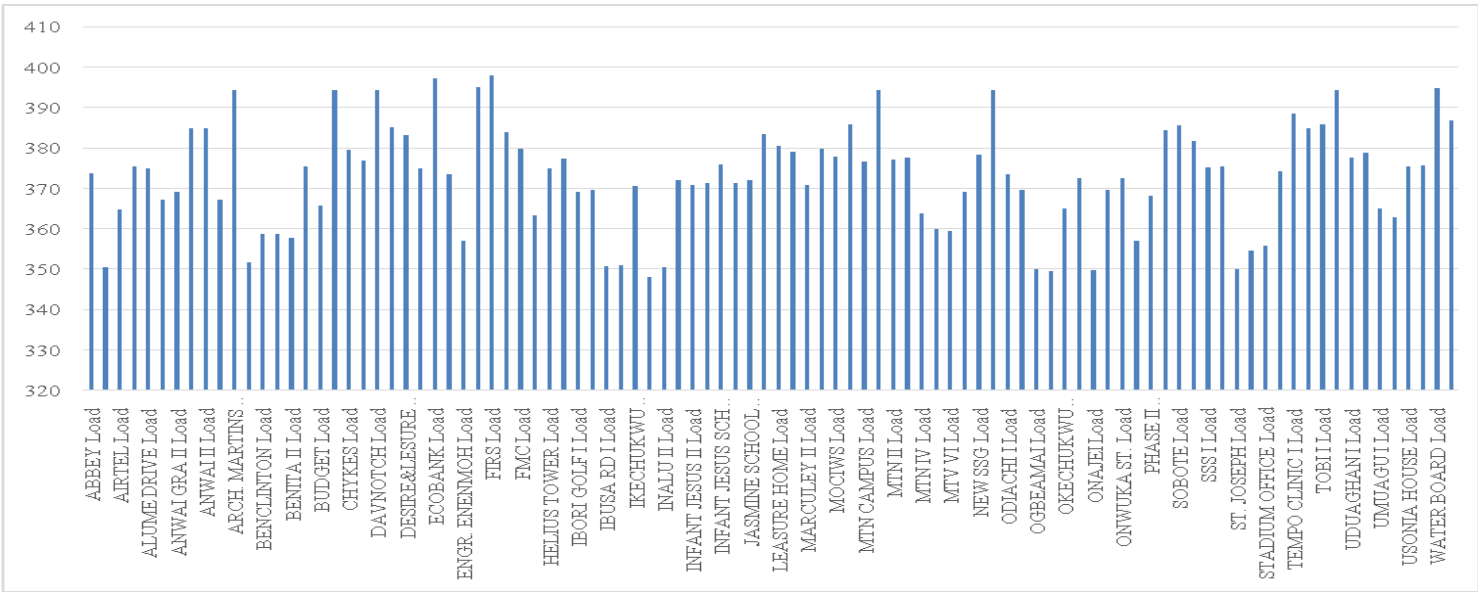


Fig. 4. Voltage profile diagram without DG

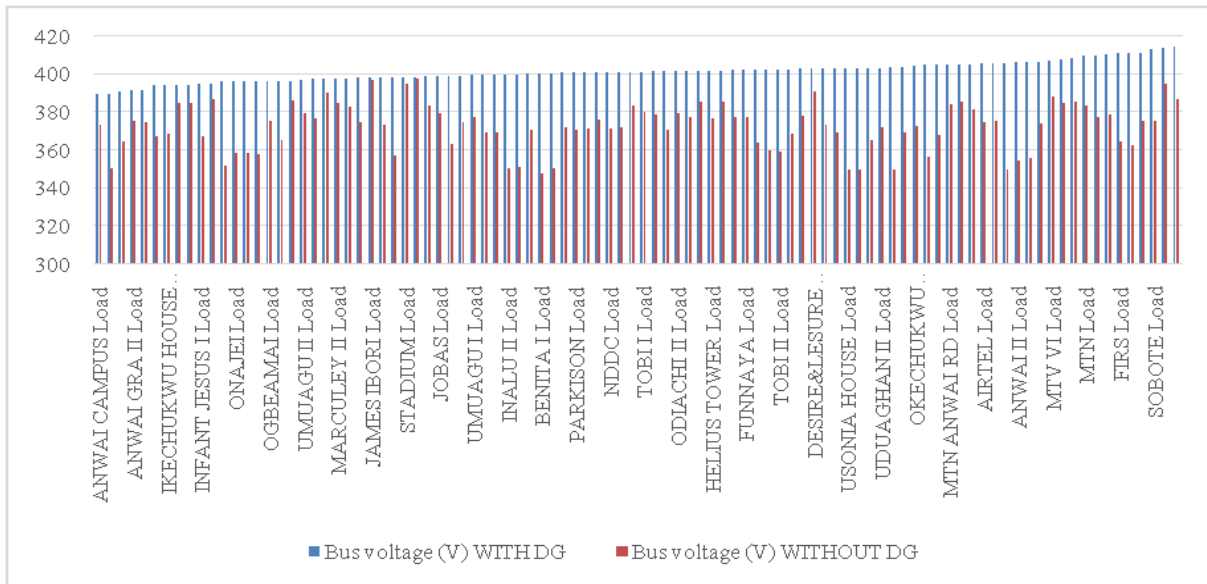


Fig. 5. Voltage profile diagram with and without DG

8. The procedure can be stopped if any of following occurs:
 - (a). When upper limit of the voltage is violated.
 - (b). When total size of DG more than that of total load plus loss.
 - (c). When DG sizing have been done for all Number of DG units.

5. RESULTS AND DISCUSSION

Load flow analysis was carried out using Newton-Raphson iteration technique in ETAP 12.6 environment for both the original and the enhanced networks. Table 1 shows the results obtained from the analysis of the original network. For a statutory voltage limits between 394.25V – 435.75V (0.95p.u – 1.05p.u) which is the considerable voltage limit for the Nigeria distribution network. Only 10.4% out of the ninety six total buses in the network were within the statutory voltage limit and 89.6% of the buses in the network were out of the statutory voltage limit before DG was place on the network as shown in Table 1, Fig. 2 and 4. The buses that are within voltage limit are the closest to the injection substation and they are Davnotch (394.3V), Ecobank (397.1V), Favorite (394.9V). FIRS (398.0V), Nwoboshi (394.3V), Water board (394.8V), MTN I (394.3V), Tobi II (394.3V), Arc. Martins Odiaka (394.3) and ChineduOko (394.3V) as shown in Table 1. It was also ascertained that total average active and reactive power losses of the network is 1,329.081kW and

2,031.157kVar.It therefore infers that the network seriously needs enhancement as it is very weak. Base on this result, eleven (11) buses were identified as prospective candidate buses for DG placement using LSF base on their location, reactive power drawn and losses, voltage magnitude and distance from the injection substation. The buses are Anwai II, Budget, Inalu I, Ogbeke, Stadium, Parkison, SPC, Anwai Campus, Bishop Chukuma, Uduaghan I and Ibori Golf load buses as shown in Table 2.The optimal sizing and location of the DG was done and placement of the DG was carried out in the order of loss sensitivity priority to find the best location of the DG. A DG of 16MW was placed in the entire network and had its best effect when it was incorporated on Inalu I (6MW), Budget (4.MW), Anwai Campus (3.7MW) and Uduaghan I (2.3MW) buses base on the algorithm for finding the optimal location of DG as seen in Section 3 and 4. With this information taken into consideration, the network was enhanced and load flow analysis repeated. The result of the load flow analysis on the enhanced network is shown in Table 3 and Fig. 3 and 5. It can be observed from the table that the overall voltage profile of the network improved considerably by 94.8% (i.e. only ninety-one buses out of ninety six buses in the network were within voltage limit). While only 5.2 % (i.e. five buses out of ninety six of the total buses in the network was out of voltage limit), after DG was placed on the network. The buses that are out of voltage limit are; Anwai II (389.8V), Anwai river (389.8V), Phase II community (390.8V), Anwai G.R.A

(391.8V) and Ibori Golf (391.9V.) It was also observed that the active power losses in the network reduced by 57.5% (from 1,329.08kW to 565.09kW) and the reactive power losses in the network reduced by 70.7% (2,031.16kVar to, 596.16kVar). It is worthy of note that this device did not only affect the weak buses, but the entire power flow results of the network under study.

6. CONCLUSION

It can be inferred from results of this study that the Anwai and SPC feeder of Asaba 2x15MVA 33/11kV injection substation network is quite deficient with only ten (10) buses operating within the statutory voltage limit. With the optimal sizing, location and placement of DG done, the load flow analysis was repeated, the results obtained showed that ninety one (91) buses in the network was within the voltage limit while only five (5) buses in the network was out of voltage limit. It is therefore recommended that the Anwai and SPC feeder of Asaba 2x15MVA 33/11kV injection substation network should be enhanced.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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