OPTIMAL PLACEMENT OF DISTRIBUTED GENERATION IN AN 11KV DISTRIBUTION NETWORK FOR IMPROVED PERFORMANCE IN A DEVELOPING ECONOMY

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ABSTRACT:*The secondary and tertiary distribution systems of an electric power network are often occasioned with high power losses and low voltage profile. The high power losses could result from technical and non-technical issues. This work investigates the impact of optimally sizing and placing Distributed Generation (DG) in the Ikwerre Road 11KV distribution network for the purpose of enhancing the overall performance of the network by reducing total power losses and enhancing the voltage profile of the network. Necessary data were gathered from Port Harcourt Electricity Distribution Company (PHEDC) and the Adaptive Newton Raphson load flow technique was used to simulate the network in ETAP 12.6 to ascertain the state of the network. Loss Sensitivity Factor (LSF) technique was used to select the optimal buses for DG integration while Particle Swam Optimization (PSO) technique was adopted to optimally size the DG corresponding to each bus. The choice of a gas powered plant as against installation of a photo-voltaic power system was influenced by the availability of materials locally, the urban nature of the research area and the economic feasibility of the project. From the results obtained, total branch loses without DG is 113.668Kw, 64.41Kvar; with DG at optimal bus, the branch losses are 27.046Kw and 16.277Kvar.Voltage at the least bus improved from 0.943pu which is below NERC acceptable limit to 0.992pu; while the maximum voltage is 1.003pu.*

***Keywords** –Distribution feeder, Distributed Generation, Load Flow Techniques, Optimal sizing and allocation, Power loss reduction, Voltage profile improvement.*

I.   INTRODUCTION

Electrical power systems are fundamentally designed to provide economic and reliable instruments or mechanisms for adequate electric power generation and transfer from point of generation to the end-users. Current situations across nations are a proof that the socio-economic development of a nation is proportional to the degree to which its power needs are met. Nigeria, as well as other developing economies in Africa are yet to meet their electric power needs leading to severe economic and social consequences [1-2].

Traditionally, power is generated at large centralized power plants and transmitted via a complex architecture of interconnected transmission and distribution networks spanning several kilometres. To deal with the problem of inadequate power generation in Nigeria, over the decades, households and businesses have resorted to owning independent power generating plants (mainly diesel and petrol powered plants). The deployment of green energy sources like photo-voltaic, wind and biogas are in their early stages in Nigeria and their impacts are yet to be felt on a significant level [3-4].

Such energy sources that are independent of the central generating energy sources are termed "Distributed Generation (DG)".DGs can either be stand-alone or grid connected. A stand-alone DG is such that

is connected directly to the consumer's terminal without passing through the distribution network. Grid connected DGs on the other hand are connected to an existing distribution network. Distributed generation differs from central distribution in that:

    (i)   The level of power generation is low in DG

    (ii)   DG is connected directly to the distribution system avoiding entirely any form of transmission

    (iii)   DGs are situated closer to the load points

    (iv)   They could be stand – alone or grid connected [5].

Studies carried out in Port Harcourt, Rivers State, Nigeria show that among the factors militating against adequate and reliable supply of electricity to the area are: weak and broken transmission and distribution networks, inadequate power generation, lack of good maintenance of facilities and climatic conditions. Citizens were also found to be wasteful of electricity and electricity infrastructure. The mainly radial configuration of the distribution system was also found to contribute significantly to the losses in the network contributing to low voltage profiles on the networks [6].

Several solutions have been proposed for the energy problem facing developing economies like Nigeria; among which is the deployment of functional off-grid and grid-connected Distributed Generation sources. Integrating DGs into an existing distribution system presents several technical and reliability issues like increase in fault levels, protection systems disturbances and power quality compromise[7-8].Therefore, it is vital to implement a proper power flow analysis of the network and other optimization processes to determine the optimal size(s) and location(s) of DGs required to enhance the performance of the target distribution network. This work sets toimprove the overall performance of the Ikwerre Road 11kv distribution network by optimally sizing and placement of distribution generation focusing primarily on loss reduction and voltage profile improvement.

II. RELATED WORKS

 There have been recent works on the benefits of optimally integrating distributed generation to the distribution network. A few of the works are stated below:

- In [9] the authors carried out a performance assessment on the 33/11kv Rivers State University (RSU) injection substation with the objective of improving the overall performance of the distribution system. Load-flow analysis using Newton Raphson method was implemented. The operational algorithm utilised for the sizing and placement of DG unit(s) constituted four (4) scenarios: examining the ranking of the voltage profile and power loss levels, without DG. Examining and ranking of the voltage profile and losses with DG at each bus, and with sizeable DG units at the optimal locations. Upon implementation of the procedural steps, the restructured network had a significant increment in voltage profile (from 4.676KV to 10.8KV) and a reduction in line losses (from 2824KW to 195KW)

- Adaptive Neuro-Fuzzy logic technique was adopted in [10] to optimize DG location and size. The Adaptive Neuro-Fuzzy logic technique was simulated using ANIF Toolbox MatlabR20136(8.2.0701) software and tested on the Guagwalada injection substation in southern Abuja, Nigeria. In executing the technique, the ANN system was used to obtain the optimal value of power losses using variables obtained from the power flow studies of the network. The power losses and voltage stability indexes calculated for each bus served as an intermittent input for the Adaptive Neuro Fuzzy inference system. The results of this approach was significantly impressive as power losses at the buses cumulatively reduced by 49.21% and the lowest voltage improvement from .9254 to 1.05pu.

- Both active and reactive power play important roles in power system transmission and distribution. For reliability purposes, reactive power flow must be controlled in the electrical system to minimize the amount of real power that can be transferred across power transmitting media. An approach to simultaneously minimise real power loss and net reactive power flow by optimally placing distributed

generation(DGs) and shunt capacitors (SCs) is presented in [11]. A multi-objective evolutionary algorithm based on decomposition (MOEA/D) was adopted to select the optimal sizes of DGs and SCs. Sensitivity factor approach was not adopted because it reduces the search space. Exploring the entire search space by the MOEA/D algorithm provided a more accurate analysis and thus the most optimum location and rating of both DG and SC.

III.   METHODOLOGY

Distributed generation was optimally sized and positioned to improve the performance of 11KV distribution network. This was achieved by first obtaining relevant information from the Port Harcourt Electricity Distribution Company (PHEDC). Newton Raphson load flow analysis was then implemented with the aid of Electric Transient Analyser Program (version 1.6) software to determine the bus voltages and losses. The procedural steps associated with this work can be summarised as follows:

(i)   Model the network, run the base-case load flow analysis
(ii)   Implement Loss Sensitivity technique to determine the possible buses for DG placement
(iii)   Rank the determined buses in order of priority based on their loss sensitivity value and their Normalised Voltages.
(iv)   Implement Particle Swam Optimization technique to determine the optimal size(s) corresponding to each determined bus
(v)   Integrate determined size(s) of DG at their respective buses.
(vi)   Run the load flow analysis of upgraded network and
(vii)   Compare pre-upgrade and post-upgrade results to determine the impact of integrating DG

3.1   Description of Ikwerre Road 11kV Distribution Network

The existing 1` road distribution network consist of 1x15MVA, 33/11kV injection substation with two (2) feeders located at the premises of Silverbird Cinema Port Harcourt. Power supply to the network is through a 33kV feeder (Silverbird) at Port Harcourt Town Sub-Transmission Station with installed capacity 165MVA,132/33kV. Table 3.1 shows the installed capacity of Silverbird injection substation.

Table 3.1 Installed capacity of Ikwerre Road Injection Substation

Transformer		Rated Voltage	No of Feeders
ID	MVA	KV	
T1	15	33/11	Ikwerre Road
			Abonnema Wharf

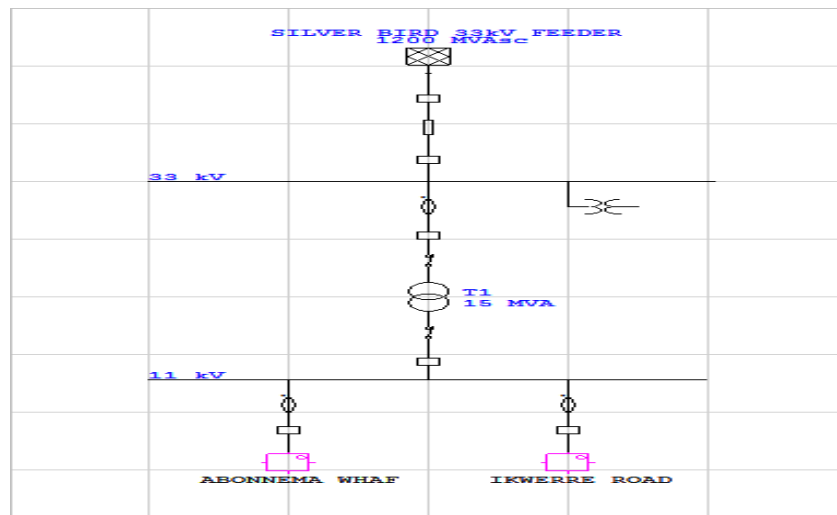Source: Port Harcourt Electricity Distribution Company (PHEDC)

Figure 3.1 Single Line Diagram of SilverBird Injection Substation

Source: Port Harcourt Electricity Distribution Company (PHEDC)

IV.   RESULTS AND DISCUSSIONS

4.1 Pre-Upgrade Network Simulation
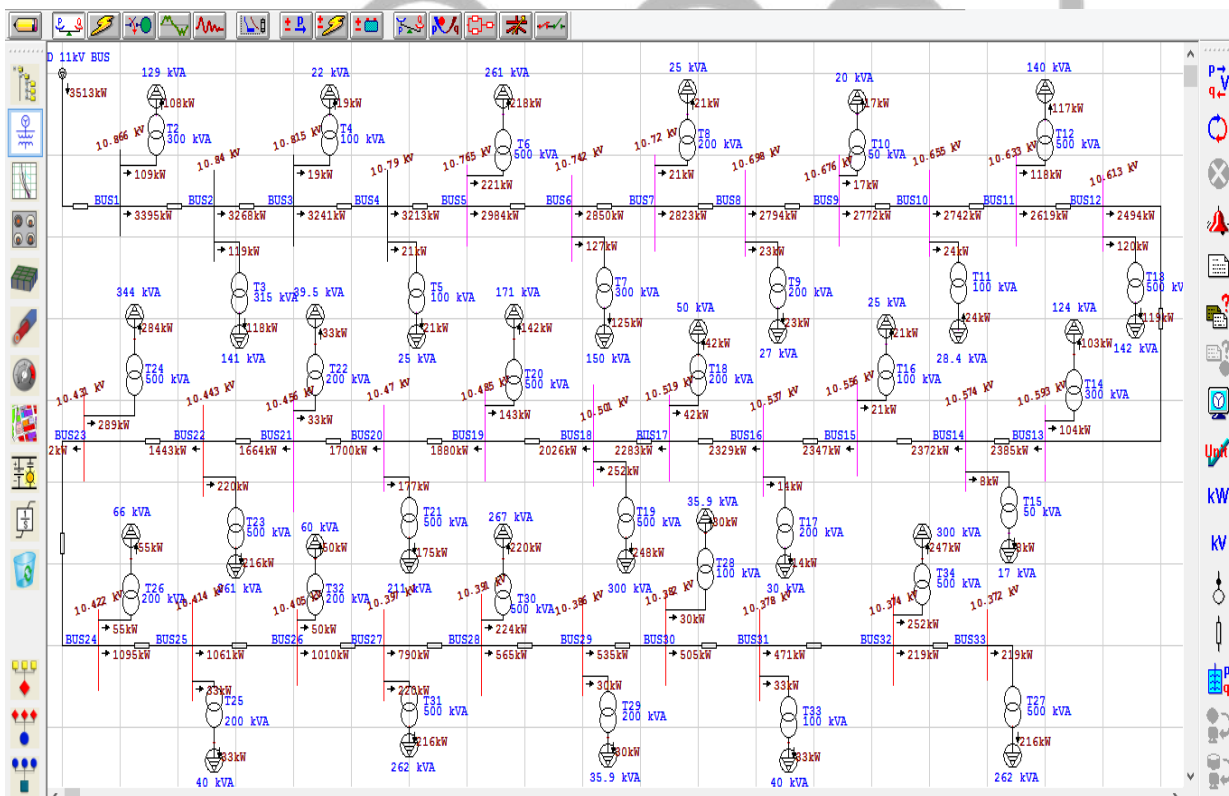
Figure 4.1 Simulation of Existing Ikwerre-Road 11kV Distribution Network without DG

Figure 4.1 shows the existing Ikwerre-Road 11kV distribution system without DG connected to the network. Power flow analysis using Newton-Raphson method was performed to examine the state of the distribution system. For each bus, the voltage profile is calculated. The red and the pink colour indicates buses with critical and marginal operating condition respectively.

Table: 4.1 Bus Operating Voltage without DG

Bus	Bus	Nominal	Operating

No	Name	Voltage (kV)	Voltage (p.u)
1	Anokkwuru	11	0.988
2	R/S Tide	11	0.985
3	FCMB	11	0.983
4	Airtel	11	0.981
5	Education	11	0.979
6	NYSC	11	0.977
7	First Bank	11	0.975
8	Access Bank	11	0.973
9	MTN	11	0.971
10	Airtel	11	0.969
11	MileOne Market1	11	0.967
12	MileOne Market2	11	0.965
13	Police	11	0.963
14	PHED	11	0.961
15	UBA Bank	11	0.960
16	Heritage Bank	11	0.958
17	Polaris Bank	11	0.956
18	Egede Str	11	0.955
19	Timber Str	11	0.953
20	Gambia Str	11	0.952
21	Mr Biggs	11	0.951
22	St Thomas1	11	0.949
23	St Thomas2	11	0.948
24	Zenith Bank	11	0.947
25	Keystone Bank	11	0.947
26	Peco	11	0.946
27	Umuduru Str	11	0.945
28	Owhonda Str	11	0.945
29	CoinnOil	11	0.944
30	MTN	11	0.944
31	Eco Bank	11	0.943
32	Ikokwu Str	11	0.943
33	Chibu Str	11	0.943

Table 4.1 shows the pre-upgrade nominal and operating values at each bus in the distribution network. A cursory look at the voltage profile in table 4.1 shows that bus number 22,23,24,25,26,27,28,29,30,31,32 and 33 violated the lower voltage statutory limit of 0.95 pu and are taking as candidate buses for optimum DG location.

Table: 4.2 Optimum Location and Size of DG

Bus ID	R(j)	V(j)	Q(j)	LSF	Ranking	Vnorm
1	0.35	0.988	3513	2519.198	3	1.04
2	0.37	0.985	3395	2589.399	2	1.04
3	0.36	0.983	3268	2435.048	4	1.03
4	0.39	0.981	3241	2626.852	1	1.03
5	0.33	0.979	3213	2212.531	7	1.03
6	0.30	0.977	2984	1875.689	14	1.03
7	0.38	0.975	2850	2278.501	5	1.03
8	0.37	0.973	2823	2206.566	8	1.02
9	0.32	0.971	2794	1896.566	12	1.02
10	0.35	0.969	2772	2066.540	9	1.02
11	0.38	0.967	2742	2228.579	6	1.02
12	0.33	0.965	2619	1856.200	15	1.02
13	0.35	0.963	2494	1882.530	13	1.01
14	0.34	0.961	2385	1756.105	17	1.01
15	0.32	0.96	2372	1647.222	19	1.01
16	0.35	0.958	2347	1790.112	16	1.01

17	0.38	0.956	2329	1936.722	10	1.01
18	0.38	0.955	2283	1902.448	11	1.01
19	0.37	0.953	2026	1650.765	18	1.00
20	0.32	0.952	1880	1327.590	21	1.00
21	0.35	0.951	1700	1315.788	22	1.00
22	0.38	0.949	1664	1404.218	20	1.00
23	0.33	0.948	1443	1059.726	23	1.00
24	0.35	0.947	1152	899.188	24	1.00
25	0.34	0.947	1095	830.277	25	1.00
26	0.32	0.946	1061	758.775	27	1.00
27	0.35	0.945	1010	791.691	26	0.99
28	0.35	0.945	790	619.244	28	0.99
29	0.37	0.944	565	469.176	29	0.99
30	0.36	0.944	535	432.257	31	0.99
31	0.39	0.943	505	442.958	30	0.99
32	0.33	0.943	471	349.576	32	0.99
33	0.30	0.943	219	147.765	33	0.99

Table 4.2 shows the sensitivity analysis performed on each bus using the values obtained from power flow analysis. The optimal location for DG placement is determined by the normalized voltage magnitudes and the loss sensitivity factors. The normalized voltage decides the requirement for compensation while the loss sensitivity factors give the order of priority. Buses with normalized voltages less than or equal to 1.01pu and high LSF value ranked in ascending order are selected as the candidate buses for DG placement. A quick look at table 4.2 shows that [Bus4, Bus2, Bus1, Bus3, Bus7 Bus11, Bus5, Bus8, Bus10] violated the normalized voltage condition therefore cannot be used because it will have a negative impact on the distribution system. Bus 17 is seen to have the highest loss sensitivity factor and its normalized voltage falls within acceptable limits. It is therefore selected as the best suitable locations for the placement of DGs in order to reduce the real power losses and improve the voltage profile simultaneously so that the power delivering capacity is enhanced.

The choice of Bus 17 as our best position for integrating our DG is further verified by our results from the PSO algorithm. Buses 13, 14, 16, 17 and 18 were identified as possible optimal locations for DG integration. Should our choice of implementation was to integrate multiple DGs, the optimal sizes suited for each bus would have been integrated and results noted. But for the reason of practical application and economic feasibility, a single DG of 2MW is installed at bus 17.

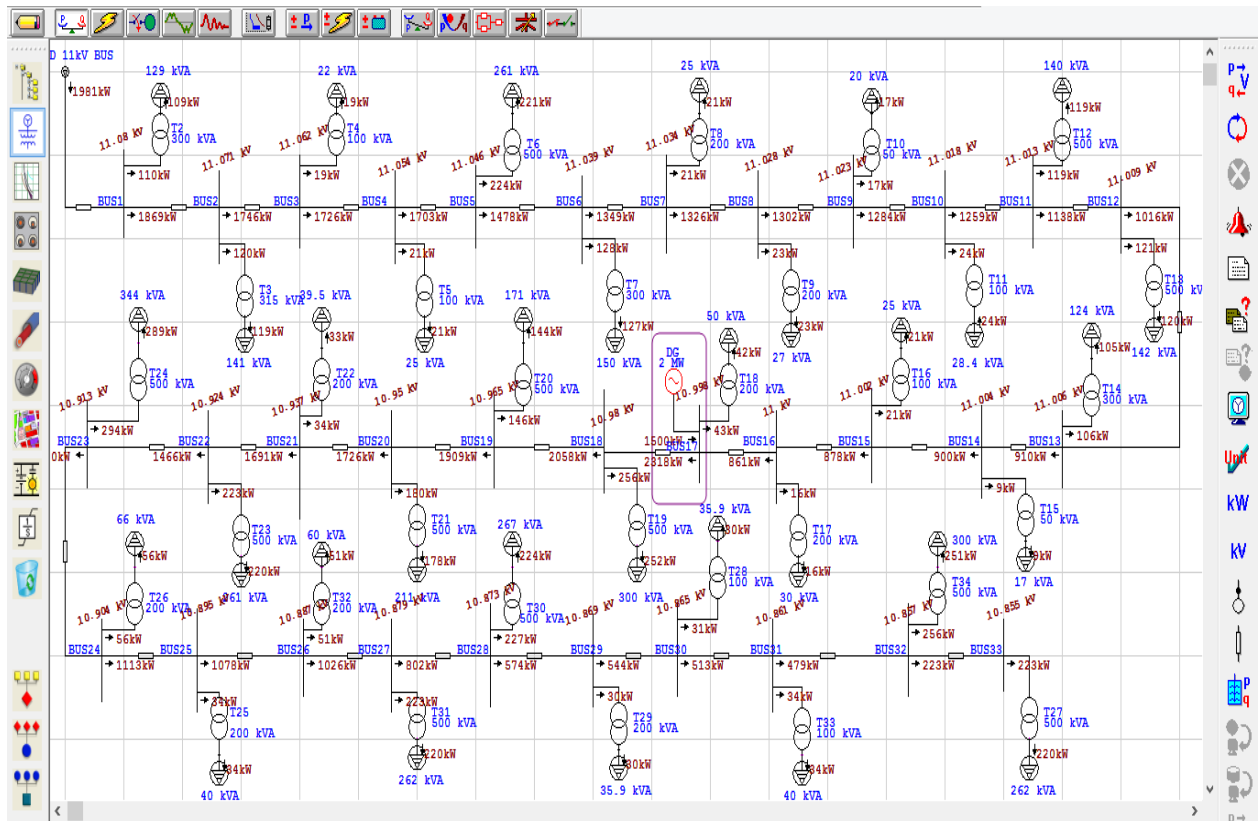**4.3   Post-Upgrade Network Simulation**

Figure 4.2 Simulation of Improved Ikwerre-Road 11kV Distribution Network

Table4.3: Bus Operating Voltage with DG

Bus No	Bus Name	Nominal Voltage (kV)	Operating Voltage (p.u)
1	Anokkwuru	11	1.003
2	R/S Tide	11	1.002
3	FCMB	11	1.001
4	Airtel	11	1.000
5	Education	11	0.999
6	NYSC	11	0.998
7	First Bank	11	0.998
8	Access Bank	11	0.997
9	MTN	11	0.996
10	Airtel	11	0.996
11	MileOne Market1	11	0.995
12	MileOne Market2	11	0.994
13	Police	11	0.994
14	PHED	11	0.994
15	UBA Bank	11	0.993
16	Heritage Bank	11	0.993
17	Polaris Bank	11	0.993
18	Egede Str	11	0.992
19	Timber Str	11	0.992
20	Gambia Str	11	0.992
21	Mr Biggs	11	0.992
22	St Thomas1	11	0.992
23	St Thomas2	11	0.992
24	Zenith Bank	11	0.993
25	Keystone Bank	11	0.993

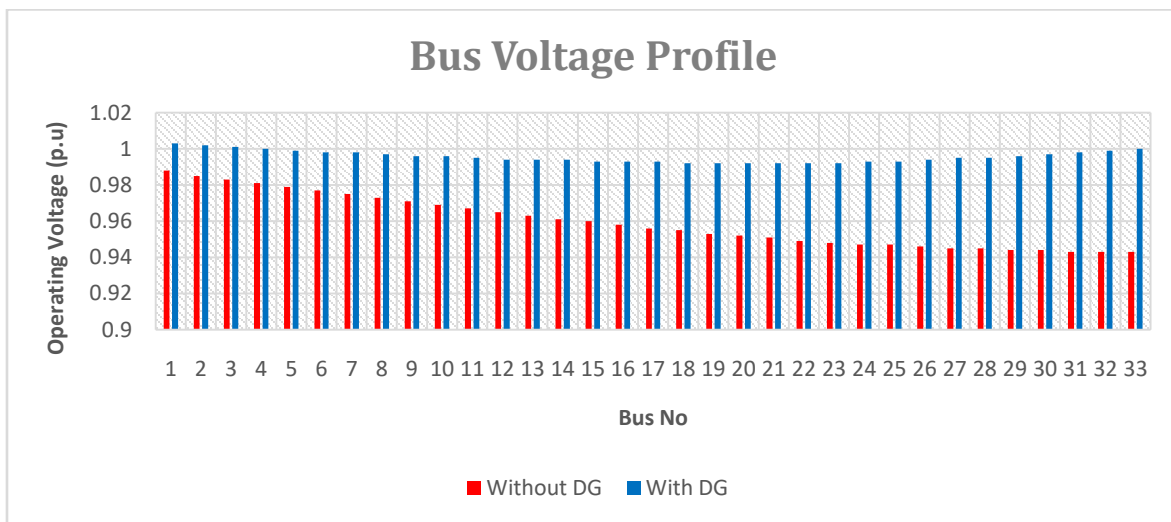| 26 | Peco | 11 | 0.994 |
27	Umuduru Str	11	0.995
28	Owhonda Str	11	0.995
29	CoinnOil	11	0.996
30	MTN	11	0.997
31	Eco Bank	11	0.998
32	Ikokwu Str	11	0.999
33	Chibu Str	11	1.000

Figure 4.3 Voltage Profile of Ikwerre-Road 11kV Distribution Network

Table 4.3shows the post-upgrade nominal and operating values at each bus in the distribution network. A quick look at the voltage profile in table 4.3 shows that there was no violation of bus voltage statutory limit when DG of 2MW was added to the system

Figure 4.3 shows the voltage profile of the distribution system with and without DG integration. The red colour indicates the voltage profile when no DG was connected to the system. Similarly, the blue colour indicates the voltage profile when DG is connected. A cursory look at the figure shows that the voltage profile of the system improved significantly when DGs were connected to the system.

Table 4.4 Result of Line Power Losses

Line ID	From Bus	To Bus	Without DG		With DG	
			kW Losses	Kvar Losses	KW Losses	Kvar Losses
Line1	BUS1	BUS2	8.232	4.954	1.741	1.048
Line2	BUS2	BUS3	7.662	4.611	1.547	0.931
Line3	BUS3	BUS4	7.574	4.559	1.519	0.914
Line4	BUS4	BUS5	7.476	4.499	1.487	0.895
Line5	BUS5	BUS6	6.478	3.899	1.192	0.717
Line6	BUS6	BUS7	5.936	3.573	1.053	0.634
Line7	BUS7	BUS8	5.849	3.52	1.033	0.621
Line8	BUS8	BUS9	5.755	3.464	1.011	0.608
Line9	BUS9	BUS10	5.686	3.422	0.995	0.599
Line10	BUS10	BUS11	5.588	3.363	0.974	0.586
Line11	BUS11	BUS12	5.118	3.08	0.88	0.529
Line12	BUS12	BUS13	4.661	2.805	0.805	0.484
Line13	BUS13	BUS14	4.279	2.575	0.756	0.455
Line14	BUS14	BUS15	4.249	2.558	0.753	0.453
Line15	BUS15	BUS16	4.175	2.512	0.745	0.448

| Line16	BUS16	BUS17	4.124	2.482	0.74	0.445
Line17	BUS17	BUS18	3.977	2.393	1.875	1.128
Line18	BUS18	BUS19	3.144	1.892	1.482	0.892
Line19	BUS19	BUS20	2.715	1.634	1.279	0.770
Line20	BUS20	BUS21	2.227	1.34	1.049	0.632
Line21	BUS21	BUS22	2.141	1.289	1.009	0.607
Line22	BUS22	BUS23	1.613	0.971	0.760	0.458
Line23	BUS23	BUS24	1.029	0.619	0.485	0.292
Line24	BUS24	BUS25	0.933	0.562	0.440	0.265
Line25	BUS25	BUS26	0.877	0.528	0.413	0.249
Line26	BUS26	BUS27	0.796	0.479	0.375	0.226
Line27	BUS27	BUS28	0.488	0.293	0.230	0.138
Line28	BUS28	BUS29	0.25	0.151	0.118	0.071
Line29	BUS29	BUS30	0.224	0.135	0.106	0.064
Line30	BUS30	BUS31	0.2	0.12	0.094	0.057
Line31	BUS31	BUS32	0.174	0.105	0.082	0.050
Line32	BUS32	BUS33	0.038	0.023	0.018	0.011
			113.668Kw	**64.41Kvar**	**27.046Kw**	**16.41Kvar**
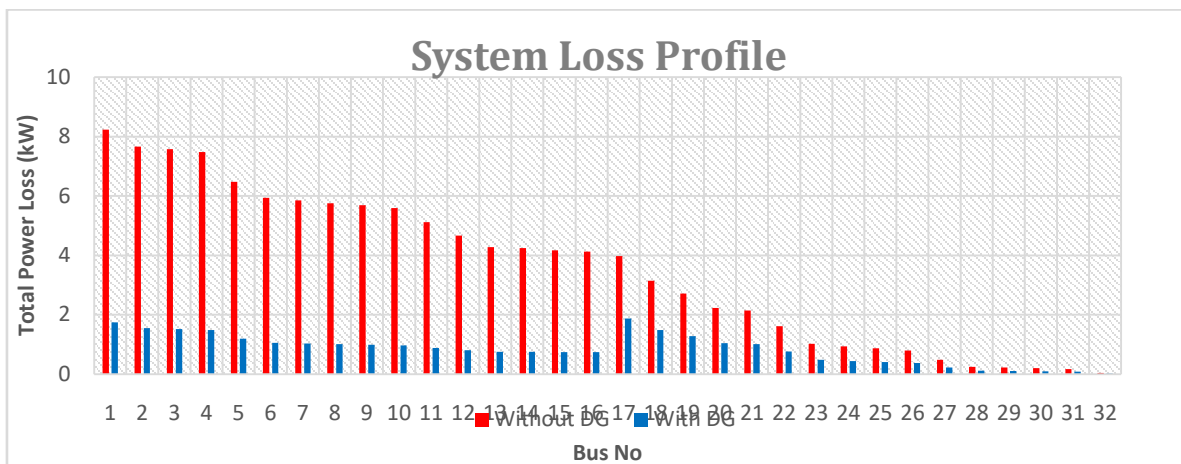
Figure 4.4 Real Power Loss in Ikwerre-Road 11kV Distribution Network

Table 4.4 and Figure 4.4 show the Impact of DG Penetration in the system losses. The real and reactive power losses on the distribution system without DG is calculated as 113.668 kW and 68.41kvar. However, when a DG of 2MW was connected to the system, the real and reactive power loss on the system was reduced to 27.046 kW and 16.277kvar with a maximum saving of 86.622kW and 52.133kvar respectively.

V.   CONCLUSION

This study inspected the existing 11Kv Ikwerre Road distribution network in Port Harcourt. This research work aimed at enhancing the performance of the network by optimally sizing and placing Distributed Generation (DG) into the network. Care was taken to ensure the form was DG was both practically application to the network and also economically feasible to implement. By modelling the existing network (pre-upgrade state) in ETAP using Newton-Raphson power flow technique, it was realised that the network suffers from considerable

level of power loss while the voltage level at some busses was below the statutory level. Post-upgrade simulation was conducted on the network to ascertain the impact the choice of DG gad on the network and the results were significantly positive.

Determination of under voltage was hinged on the provision of Nigerian Electricity Regulatory Council Distribution Code which provides that for an 11Kv line, voltages below .95pu are considered under voltage. Transformers loaded above 60% were also considered to be overloaded.

Based on the results obtained, it can be concluded that load flow analysis is very vital for understanding the operational nature of a network and that optimally sizing and integrating distributed generation into a network could significantly enhance the performance of the network through loss reduction and voltage profile enhancement. It could also be said that though solar energy may be a very favourable source of power, it is often not the best for every application. For an urban area like Ikwerre Road, a gas powered generator has been seen to be the most practical and economic alternative.

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