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Improving the Performance of a Deficient 11 kV Distribution Network Using Distributed Generation

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Abstract **– With the inadequate generation, transmission and distribution capacities of the Nigerian Power System, the need to improve on the power that gets to the consumer via the distribution system cannot be overemphasized. Efforts should be made at ensuring a more robust and efficient distribution network in Nigeria. This study aims at improving the performance of a deficient distribution network using Distributed Generation (DG) units optimally placed and sized on the specific buses in the network. The Okada Community distribution network, located in Ovia North-East Local Government Area in Edo State, Nigeria, was used as a case study. Relevant data collected from Benin Electricity Distribution Company (BEDC) was used to carry out load flow study on the network using Newton-Raphson iteration technique in ETAP 16.0 environment to ascertain the state of the network under base, minimum and maximum loading conditions. DG units were optimally placed in specific buses using loss sensitivity factor and load flow analysis was then repeated on the enhanced network. Results obtained show that the voltage profile of the network improved drastically after it was enhanced, as all the bus voltages were within the acceptable voltage range unlike the condition before enhancement, where none of the bus voltages was within the acceptable range. The total power loading of the system also improved from 4968 kW and 1633 KVAR to 5398.63 kW and 1774.51 KVAR for base loading condition, from 4094 kW and 1345 KVAR to 4372 kW and 1437 KVAR for minimum loading condition and from 5985 kW and 1967 KVAR to 6647.02 kW and 2184.7 KVAR for maximum loading condition.**

Keywords-Distributed Generation (DG); Newton-Raphson; ETAP; Loss Sensitivity Analysis; Voltage profile; Enhancement

I. INTRODUCTION (HEADING 1)

The Power Sector is a very vital part of a country's economy. This is due to the fact that electricity is very essential for human existence. A direct correlation exists between a country's electric load growth rate with its Gross Domestic Product (GDP). This is reflected in the fact that the United States of America consumes well over one billion, one hundred thousand megawatts of electric power while Nigeria struggles with about five thousand megawatts. If the economic growth challenge in Nigeria is to be resolved, the electricity supply industry must be fixed [1].

A major problem facing the Nigerian Power System is insufficient generation and transmission capacity. The demand is much higher than the generation and this has led to constant load shedding and erratic power supply [2]. The distribution system is another weak link. It is characterized by a lot of losses, thus reducing its efficiency. The transmission and distribution losses in the Nigerian Power System amounts to about 40% [3]. These losses increase the cost of operating electric utilities, thereby resulting in high cost of electricity. Therefore, the need to reduce system losses cannot be overemphasized because of its financial, economic and socio-economic importance to the utility company, the consumers and the country in general [3].

Epileptic and unstable power supply have been the order of the day in Nigeria for the past two decades [3] with an average of about six hours of electricity per day supplied to homes [4]. The number of power outages in a given locality per year is an indication of the efficiency of power supply even as consumer dissatisfaction with electricity service is often linked to high level of outages [5,6]. Since the more the number of power outages, the less efficient the power system, it follows that given higher system losses (technical and non-technical losses), there would be more power outages indicating the inefficiency of the system.

Serious efforts need to be made to improve the efficiency of the distribution system (not neglecting the generation and transmission system) so as to improve the power situation in the country. One of the methods of improving the system losses as well as the bus voltage profile in the distribution system is the use of Distributed Generation (DG) units. In this study, DG units were added to the 11 kV Okada distribution network in Benin City, Edo State, Nigeria, so as to enhance the performance of the network, which is highly deficient as it is characterized by voltage instability and high losses. Thus, Loss Sensitivity Factor technique was used to determine the candidate buses where the DG units will be placed so as to enhance the network

II. USE OF DGs FOR DISTRIBUTION SYSTEM ENHANCEMENT

Distributed generation (DG) 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 maybe even in the same vicinity [7]. DGs have found increased usage in the power distribution system. Some of the merits of installation of DG units in distribution level are peak load saving, enhancement of system security and reliability, voltage stability improvement, strengthening of the grid, reduction in the on-peak operating cost, losses reduction in the network, enhances voltage profile and power quality, etc. [8,9,10]. The main reason for applying DGs in the power distribution are an energy efficiency or rational use of energy, deregulation or competition policy, diversification of energy sources, availability of modular generating plant, ease of finding locations for smaller generators, shorter construction time and lower capital costs for smaller plants, and closeness of the generation plant to heavy loads, which can reduce the cost of transmission/distribution [11].

There are various techniques of improving distribution system voltage profile like installation of shunt capacitor banks, etc. it is available from literature that in some cases, addition of these capacitor banks can lead to resonance in the network [12] and this is undesirable. This is one of the reasons distributed generation is preferred for network compensation

Some of the technologies that are employed for DG sources include photo voltaic cells, wind generation, combustion engines, fuel cells etc, depending on the resources that are available in the geographical area [13,14]. Usually, DGs are integrated with the existing distribution system and lot of studies are done to find out the best position to locate them as well as the size of DGs to produce utmost benefits [7,15]. The main characteristics that are considered for the identification of an optimal DG location and size are the minimization of transmission loss, maximization of supply reliability, maximization of profit of the distribution companies (DISCOs), etc [16]. Due to extensive costs, the DGs should be properly placed with optimal size 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 [17].

III. LOSS SENSITIVITY ANALYSIS

Loss sensitivity factors are calculated for determining the candidate nodes for placement of enhancement devices. Estimation of these sensitive nodes helps in reducing the search space [18].

The active power loss in a distribution network can be found out by the equation:

$$P_{line\,los}(q) = \frac{[P_{eff}(q)^2 + Q_{eff}(q)^2]R_k}{V_q^2} \tag{1}$$

here P_(eff) (q) and Q_(eff) (q) are the effective active and reactive power flows supplied beyond the node ‘q’

$$\frac{\partial P_{lineloss}(q)}{\partial P_{eff}(q)} = \frac{2^*P_{eff}(q)^*R_k}{V_q^2} \tag{2}$$

$$\frac{\partial P_{lineloss}(q)}{\partial Q_{eff}(q)} = \frac{2^*Q_{eff}(q)^*R_k}{V_q^2} \quad [16] \tag{3}$$

Equation (2) and (3) are used to find the sensitivity factors of the buses and they are ranked in value. The buses having high value of LSF is considered as highest priority one. It is necessary to consider LSF based on both priority and proximity of buses towards load and generation. Because, considering LSF based priority list alone may indicate nearby buses as optimal site for placing DGs which makes the identified sites ineffective to satisfy the objectives [19].

The exact loss formula for finding the active power loss of the system is derived from the active power injected based loss sensitivity factor.

$$P_L = \sum_{i=1}^{N}\sum_{i=j}^{N}\alpha_{ij}\left(P_iP_j + Q_iQ_j\right) + \beta_{ij}\left(Q_iP_j - P_iQ_j\right) \tag{4}$$

Where,

$$\alpha_{ij} = \frac{r_{ij}}{V_iV_j}\cos\left(\delta_i - \delta_j\right);\ \beta_{ij} = \frac{r_{ij}}{V_iV_j}\sin\left(\delta_i - \delta_j\right) \tag{5}$$

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

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

IV. METHODOLOGY

The study was carried out in Okada Community, Ovia North-East Local Government Atea, Edo State, Nigeria. The distribution network has 27 buses, each bus corresponding to the low voltage sides of the various 11/0.415 kV distribution transformers. Field data was used for this study and it was collected from Benin Electric Distribution Company, Edo State, Nigeria. Data collected include the network diagram, transformer ratings, the line parameters like impedance, route distances from one transformer to the other, load on each of the transformers, cables types and diameters etc. The collected data were from the low voltage side of the various 11/0.415 kV transformers. The network was modeled in the ETAP 16.0 environment and then load flow analysis was done using Newton-Raphson iteration technique as shown in figure 1. The simulation was carried out under base, minimum and maximum bus loading conditions respectively as shown in figures 2 - 4. The performance of the network under these conditions were noted. Parameters like the bus voltages, percentage loading, etc. were taken into consideration. The loss sensitivity analysis was then used to optimally place and size DGs in deficient buses in the network so as to enhance it. The simulation procedure under base, minimum and maximum bus loading conditions were repeated for the enhanced network as shown in figures 5 – 7 and the performance of the enhanced network was then compared to that of the original network.

Figure 1. Okada Distribution Network as Modeled on ETAP 16

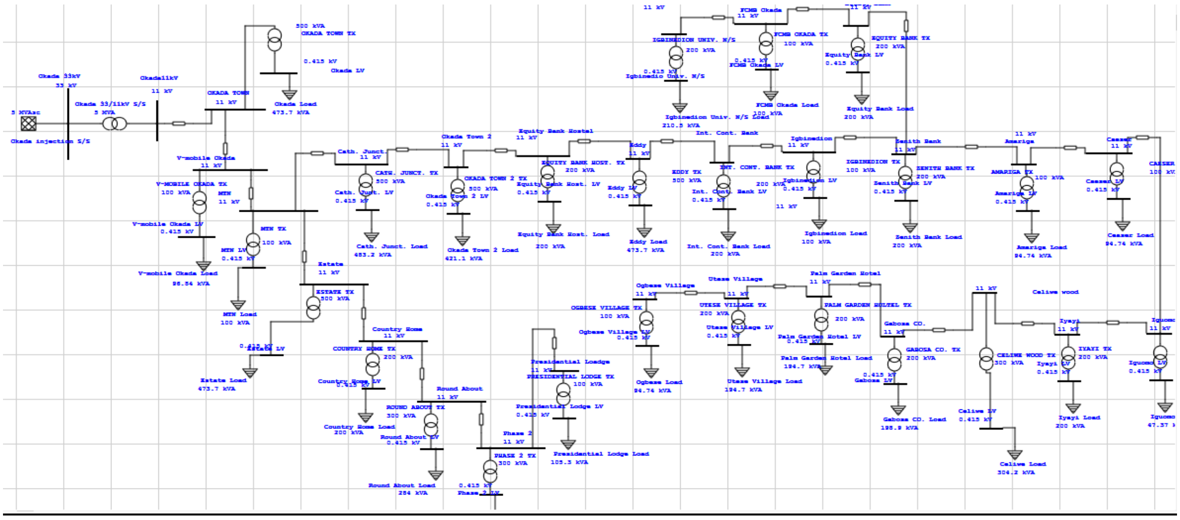


Figure 2. Base Bus Loading of the Network on Run Mode

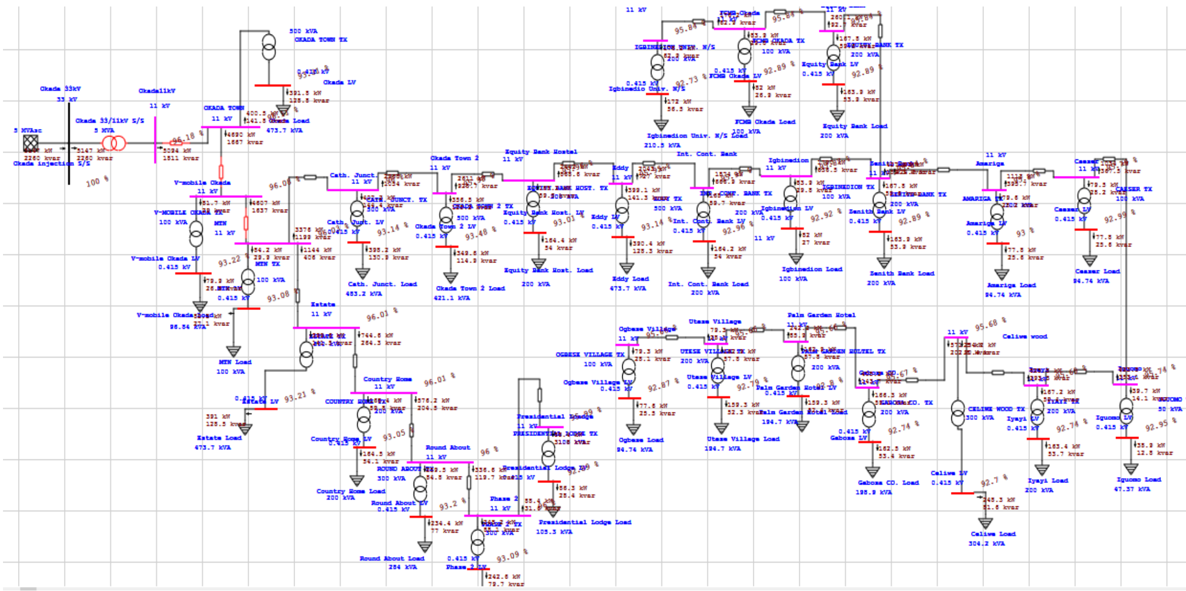


Figure 3. Minimum Bus Loading of the Network on Run Mode

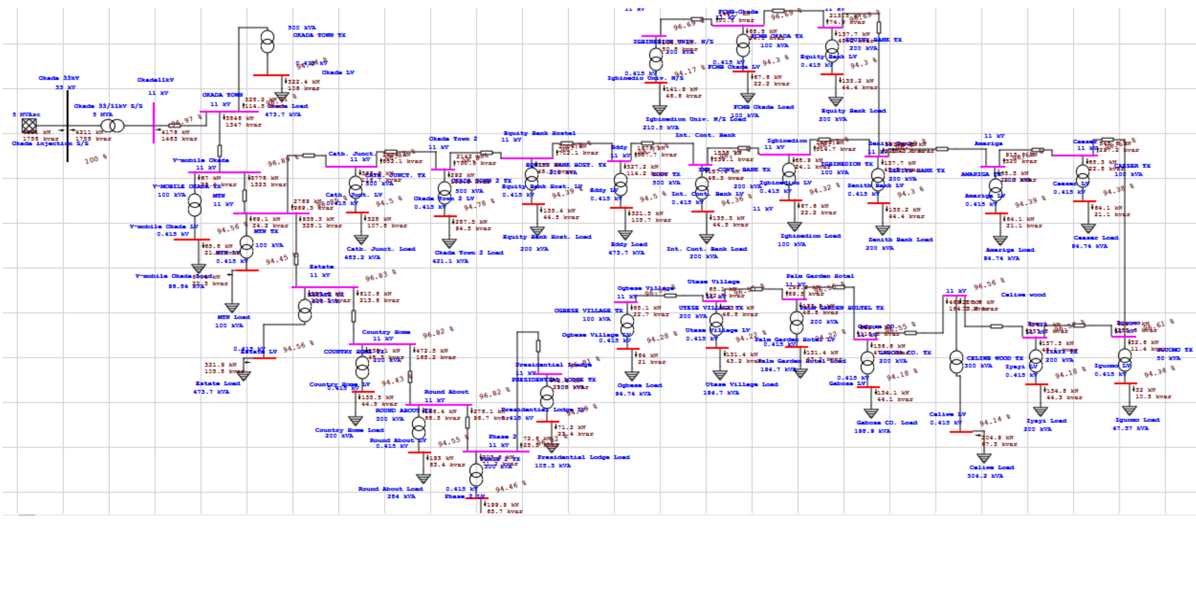


Figure 4. Maximum Bus Loading of the Network on Run Mode

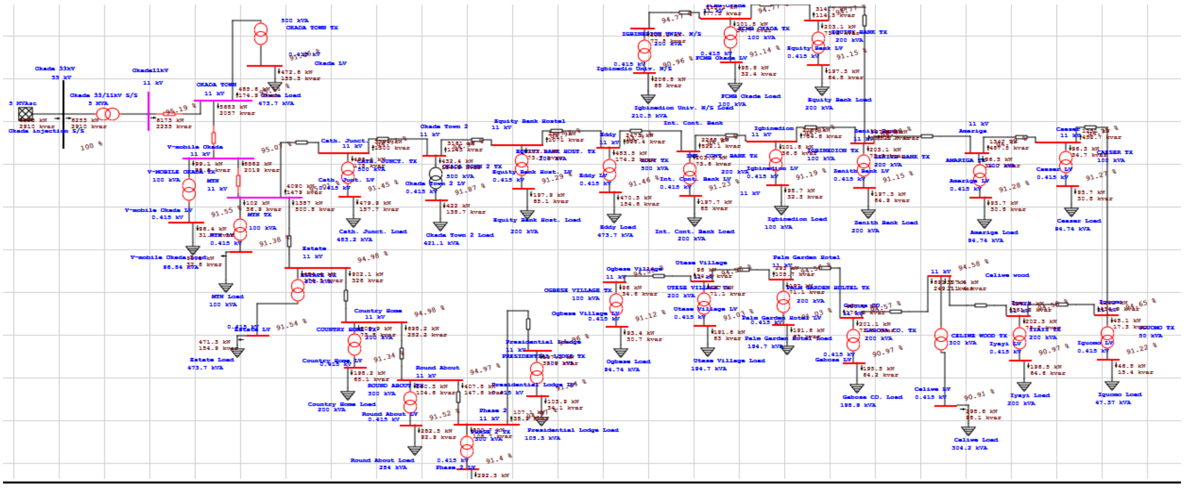


Figure 5. Network With DG Under Base Loading on Run Mode

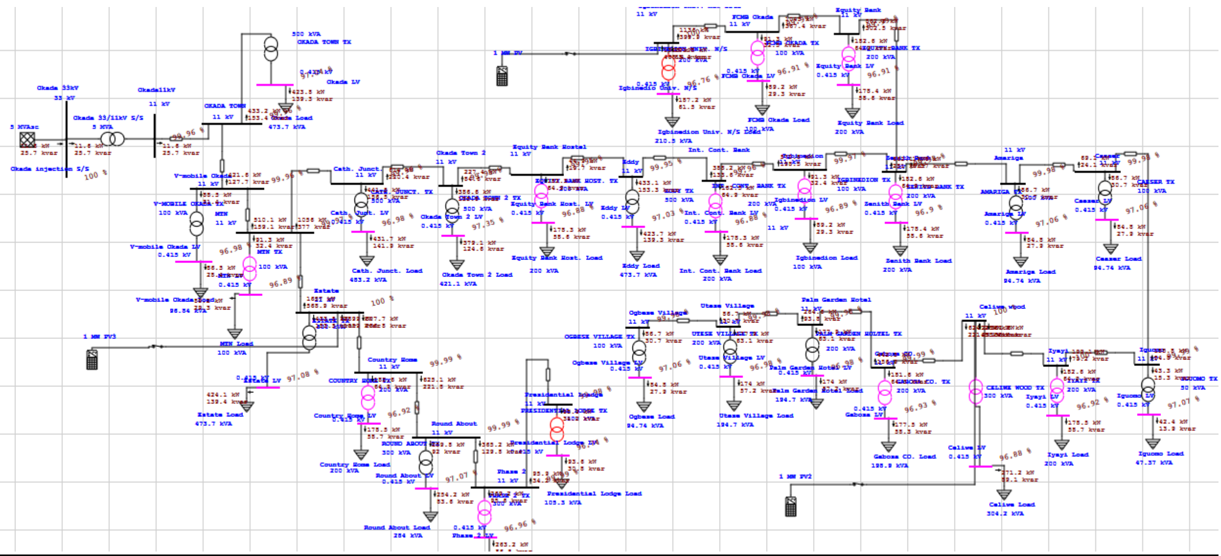


Figure 6. Network with DG Under Minimum Loading on Run Mode

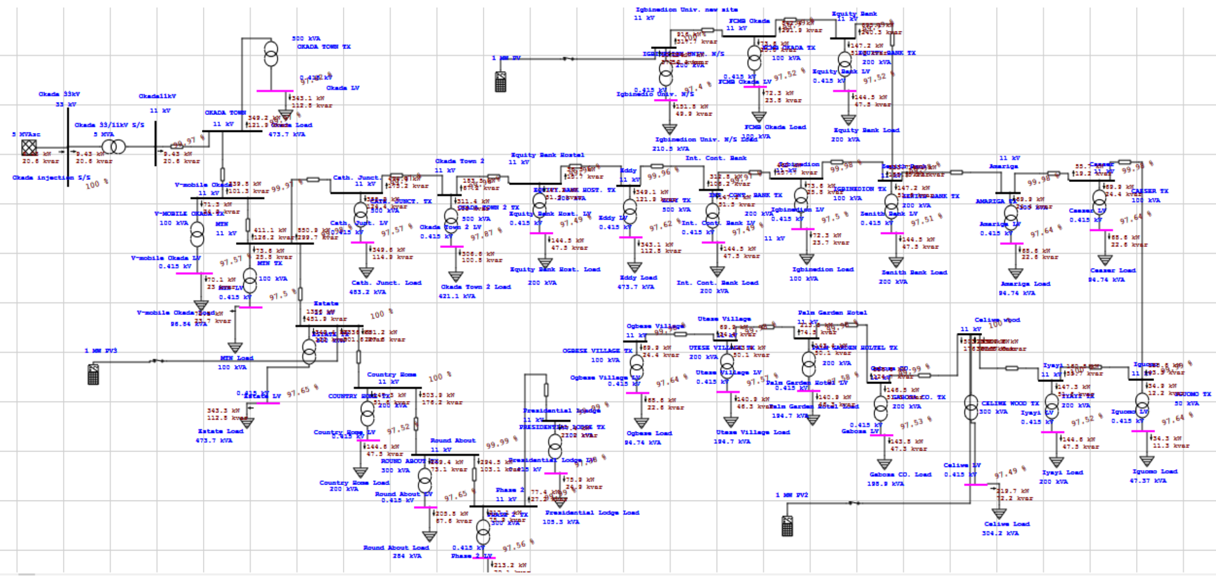
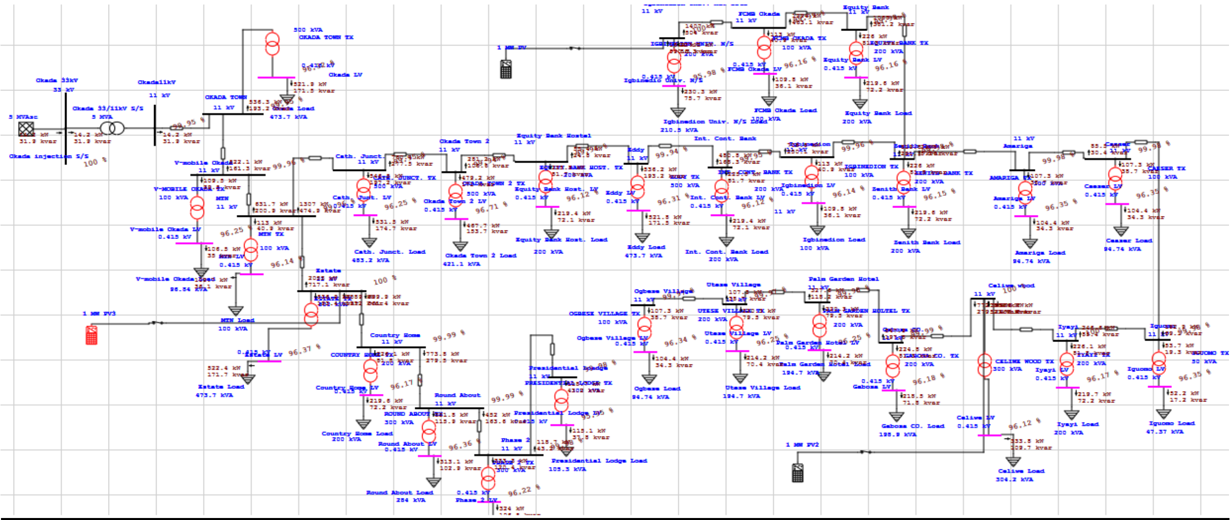


Figure 7. Network with DG Under Maximum Bus Loading on Run Mode



A. Optimal Location of Distributed Generators

The following steps were followed for the optimal allocation of Distributed generators in the network:

1. Run the Base case power flow distribution network and find out the voltage magnitude of each bus.

2. Identify the prospective buses by their location, reactive power drawn, voltage magnitude and distance from the injection substation.

3. Determine the size of DGs that need to be placed for the transforming the distribution network.

4. Find out the Loss sensitivity factors based on (2), (3) and (6) for all buses.

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 are considered for placing the multiple DG units for the distribution network.

B. Optimal Sizing of Distributed Generators

The procedure for finding the optimal size of DGs is described in detailed below:

1. Input the number of DGs, optimal sites found for DG allocation.

2. Run the Base case power flow distribution network and find out the voltage magnitude of each bus.

3. The optimal size of DG can be calculated using the following steps:

a) Place a DG in the optimal site found through the LSF based optimal allocation method.

b) The size of DG is changed in small steps and the voltage magnitude of each cases considered are compared.

c) Compare and select the size of the DG that contributes less to the network.

4. Fix the DG size if any one of the conditions mentioned in step 6 violates.

5. The load data should be updated after fixing each DG and continue with step 3 finding the size of next DG.

6. The procedure can be stopped if any of the following occurs:

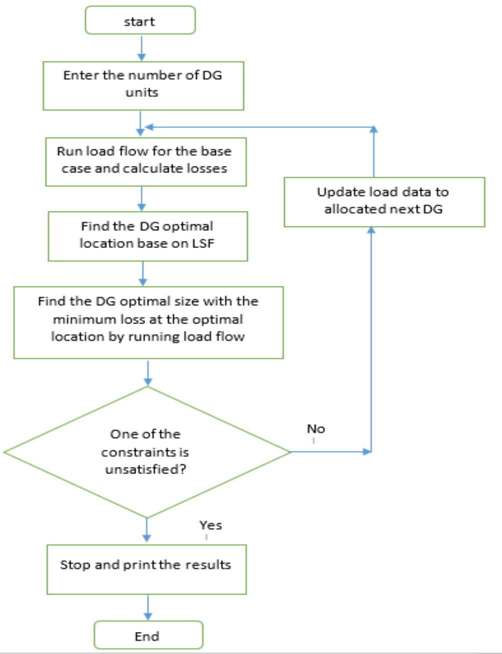
a) When upper limit of the voltage is violated.

b) When total size of DG is more than that of total load plus loss.

c) When DG sizing has been done for all Number of DG units.

The flow chart showing the aforementioned procedures is shown in figure 8.

Figure 8. Flow Chart of Optimal Location and Sizing Based on LSF



V. RESULTS AND DISCUSSION

A. *Results Before Enhancement of the Network*

As stated earlier, load flow analysis was carried out using Newton-Raphson iteration technique in ETAP 16.0 environment for both the original and the enhanced networks. Tables 1 to 3 show the results obtained from the analysis of the original network under base, minimum and maximum loading conditions respectively. A close look at table 1 shows that under base load condition, all the buses violate the acceptable voltage limit with the percentage loadings of about 93% for each of the buses. The total loading of the network stood at 4968 kW and 1633 KVAR for real and reactive power respectively. This shows that the network is very unstable and poor under base loading condition. From table 2, under minimum loading condition, it was observed that the voltages of most of the buses were still below the acceptable limit, except for about seven of the buses whose voltages fall close to within the acceptable lower limit while the total loading of the network stood at 4094 kW and 1345 KVAR for real and reactive power respectively. For the case of the maximum loading condition as shown in table 3, the network was quite unstable. The percentage loading exceeded 100 and the bus voltages were far below the acceptable lower limit when compared with the previous loading conditions. The total loading stood at 5985 kW and 1967 KVAR for real and reactive power respectively. The network is quite unhealthy under this condition. There is thus need for enhancement.

TABLE I. RESULTS FOR BASE BUS LOADING CONDITION OF THE ORIGINAL NETWORK

Terminal Bus	Rating/Limit	Rated kV	kW	KVAR	Amp	Loading (%)	Voltage (%)
Cath. Junt.	483.2 kVA	0.415	398.2	130.9	626.1	93.1	93.14
Okada	473.7 kVA	0.415	391.8	128.8	614.9	93.3	93.31
Estate	473.7 kVA	0.415	391	128.5	614.3	93.2	93.21
Eddy	473.7 kVA	0.415	390.4	128.3	613.8	93.1	93.14
Okada Town 2	421.1 kVA	0.415	349.6	114.9	547.6	93.5	93.48
Celiwe	304.2 kVA	0.415	248.3	81.62	392.3	92.7	92.7
Phase 2	294.7 kVA	0.415	242.6	79.75	381.7	93.1	93.09
Round About	284 kVA	0.415	234.4	77.03	368.2	93.2	93.2
Igbinedio Univ. N/S	210.5 kVA	0.415	172	56.52	271.6	92.7	92.73
Country Home	200 kVA	0.415	164.5	54.07	258.9	93.1	93.05
Equity Bank Host.	200 kVA	0.415	164.4	54.02	258.8	93	93.01
Int. Cont. Bank	200 kVA	0.415	164.2	53.97	258.7	93	92.96
Zenith Bank	200 kVA	0.415	163.9	53.89	258.5	92.9	92.89
Equity Bank	200 kVA	0.415	163.9	53.88	258.5	92.9	92.89
Iyayi	200 kVA	0.415	163.4	53.71	258	92.8	92.74
Gabosa	198.9 kVA	0.415	162.5	53.42	256.6	92.7	92.74
Palm Garden Hotel	194.7 kVA	0.415	159.3	52.35	251.3	92.8	92.79
Utese Village	194.7 kVA	0.415	159.3	52.35	251.4	92.8	92.8
Presidential Lodge	105.3 kVA	0.415	86.31	28.37	136.1	92.9	92.89
MTN	100 kVA	0.415	82.3	27.05	129.5	93.1	93.08
Igbinedion	100 kVA	0.415	82.03	26.96	129.3	92.9	92.92
FCMB Okada	100 kVA	0.415	81.97	26.94	129.2	92.9	92.89
V-mobile Okada	96.84 kVA	0.415	79.94	26.28	125.6	93.2	93.22
Caeser	94.74 kVA	0.415	77.83	25.58	122.6	93	92.99
Amariga	94.74 kVA	0.415	77.84	25.58	122.6	93	93
Ogbese Village	94.74 kVA	0.415	77.62	25.51	122.4	92.9	92.87
Iguomo	47.37 kVA	0.415	38.88	12.78	61.25	92.9	92.95
Total			4968	1633			

TABLE II. RESULTS FOR BASE BUS LOADING CONDITION OF THE ORIGINAL NETWORK

Terminal Bus	Rating/Limit	Rated kV	kW	KVAR	Amp	% Loading	Voltage (%)
Cath. Junt.	483.2 kVA	0.415	328	107.8	508.2	75.6	94.5
Okada	473.7 kVA	0.415	322.4	106	498.9	75.7	94.64
Estate	473.7 kVA	0.415	321.9	105.8	498.5	75.6	94.56
Eddy	473.7 kVA	0.415	321.5	105.7	498.2	75.6	94.5
Okada Town 2	421.1 kVA	0.415	287.5	94.49	444.2	75.8	94.78
Celiwe	304.2 kVA	0.415	204.9	67.34	318.7	75.3	94.14
Phase 2	294.7 kVA	0.415	199.9	65.69	309.8	75.6	94.46
Round About	284 kVA	0.415	193	63.42	298.9	75.6	94.55
Igbinedio Univ. N/S	210.5 kVA	0.415	141.9	46.63	220.6	75.3	94.17
Country Home	200 kVA	0.415	135.5	44.55	210.2	75.6	94.43
Equity Bank Host.	200 kVA	0.415	135.4	44.51	210.1	75.5	94.39
Int. Cont. Bank	200 kVA	0.415	135.3	44.48	210	75.5	94.36
Zenith Bank	200 kVA	0.415	135.2	44.43	209.9	75.5	94.3
Equity Bank	200 kVA	0.415	135.2	44.42	209.9	75.4	94.3
Iyayi	200 kVA	0.415	134.8	44.31	209.6	75.4	94.18
Gabosa	198.9 kVA	0.415	134.1	44.07	208.5	75.3	94.18
Palm Garden Hotel	194.7 kVA	0.415	131.4	43.18	204.2	75.4	94.22
Utese Village	194.7 kVA	0.415	131.4	43.18	204.2	75.4	94.22
Presidential Lodge	105.3 kVA	0.415	71.16	23.39	110.5	75.4	94.29
MTN	100 kVA	0.415	67.8	22.28	105.1	75.6	94.45
Igbinedion	100 kVA	0.415	67.62	22.22	105	75.5	94.32
FCMB Okada	100 kVA	0.415	67.58	22.21	104.9	75.4	94.3
V-mobile Okada	96.84 kVA	0.415	65.82	21.63	101.9	75.7	94.56
Caeser	94.74 kVA	0.415	64.14	21.08	99.52	75.5	94.38
Amariga	94.74 kVA	0.415	64.14	21.08	99.52	75.5	94.39
Ogbese Village	94.74 kVA	0.415	64	21.04	99.41	75.4	94.28
Iguomo	47.37 kVA	0.415	32.04	10.53	49.74	75.5	94.34
Total			4094	1345			

TABLE III. RESULTS FOR MAXIMUM BUS LOADING CONDITION OF THE ORIGINAL NETWORK

Terminal Bus	Rating/Limit	Rated kV	kW	KVAR	Amp	% Loading	Voltage (%)
Cath. Junt.	483.2 kVA	0.415	479.9	157.7	768.5	114.3	91.45
Okada	473.7 kVA	0.415	472.6	155.3	755	114.6	91.66
Estate	473.7 kVA	0.415	471.3	154.9	754	114.4	91.54
Eddy	473.7 kVA	0.415	470.5	154.6	753.4	114.3	91.46
Okada Town	421.1 kVA	0.415	422	138.7	672.8	114.8	91.87
Celiwe	304.2 kVA	0.415	298.6	98.13	480.9	113.6	90.91
Phase 2	294.7 kVA	0.415	292.3	96.08	468.4	114.2	91.4
Round About	284 kVA	0.415	282.5	92.86	452	114.4	91.52
Igbinedio Univ. N/S	210.5 kVA	0.415	206.8	67.97	333	113.7	90.96
Country Home	200 kVA	0.415	198.2	65.13	317.7	114.2	91.34
Equity Bank Host.	200 kVA	0.415	197.9	65.06	317.5	114.1	91.29
Int. Cont. Bank	200 kVA	0.415	197.7	64.98	317.3	114.1	91.23
Equity Bank	200 kVA	0.415	197.3	64.85	317	113.9	91.15
Zenith Bank	200 kVA	0.415	197.3	64.85	317	114	91.15
Iyayi	200 kVA	0.415	196.5	64.6	316.4	113.7	90.97
Gabosa	198.9 kVA	0.415	195.5	64.24	314.6	113.7	90.97
Palm Garden Hotel	194.7 kVA	0.415	191.6	62.97	308.2	113.8	91.03
Utese Village	194.7 kVA	0.415	191.6	62.97	308.2	113.8	91.03
Presidential Lodge	105.3 kVA	0.415	103.9	34.14	166.9	113.9	91.14
MTN	100 kVA	0.415	99.15	32.59	158.9	114.2	91.38

Terminal Bus	Rating/Limit	Rated kV	kW	KVAR	Amp	% Loading	Voltage (%)
Igbinedion	100 kVA	0.415	98.74	32.45	158.6	114	91.19
FCMB Okada	100 kVA	0.415	98.65	32.42	158.5	113.9	91.14
V-mobile Okada	96.84 kVA	0.415	96.38	31.68	154.2	114.5	91.55
Amariga	94.74 kVA	0.415	93.74	30.81	150.4	114.1	91.28
Caeser	94.74 kVA	0.415	93.72	30.8	150.4	114.1	91.27
Ogbese Village	94.74 kVA	0.415	93.41	30.7	150.1	113.9	91.12
Iguomo	47.37 kVA	0.415	46.8	15.38	75.14	114	91.22
Total			5985	1967			

B. Use of Loss Sensitivity Factor to Determine Candidate Bus for Possible Enhancement

Using loss sensitivity factor, buses are identified as prospective candidate buses base on their location, reactive power drawn and losses, voltage magnitude and distance from the injection substation. LSF is able to predict which bus will have the highest loss reduction when a DG is placed in the network. Hence, the sensitive buses can serve as locations for the DG placement.

The sensitivity equation is given by:

$$\varphi = \frac{\partial P_{Loss}}{\partial Q} = \frac{2QR}{V^2} \tag{7}$$

φ = loss sensitivity factor

Q = Reactive power drawn
V = Voltage
R = Total route resistance

With the criteria listed previously for determining candidate buses for DG placement, the buses that met these criteria for base, minimum and maximum loading conditions are shown in Tables 4 to 6 respectively and their respective loss sensitivity factors are shown when loss sensitivity analysis was carried out on them.

TABLE IV. CANDIDATE BUSES MEETING THE CRITERIA FOR DG PLACEMENT UNDER BASE LOADING CONDITION

S/N	Bus Name	KVAR	Voltage Magnitude (V)	Total Route Resistance	LSF
1	Celiwe	81.62	385	0.6128	0.000674876
2	Igbinedion Univ.	56.52	385	0.5138	0.000391836
3	Cabosa	53.42	385	0.61371	0.00044236
4	Cath. Junct.	130.9	387	0.44257	0.000773624
5	Estate	128.5	387	0.2218	0.000380603
6	Eddy	128.3	387	0.44257	0.000758257

TABLE V. CANDIDATE BUSES MEETING THE CRITERIA FOR DG PLACEMENT UNDER MINIMUM LOADING CONDITION

S/N	Bus	KVAR	Voltage Magnitude (V)	Route Resistance	LSF
1	Celiwe	67.34	391	0.6128	0.00054
2	Igbinedion Univ.	46.63	391	0.5138	0.000313
3	Iyayi	44.31	391	0.61371	0.000356
4	Cath. Junct.	107.8	392	0.44257	0.000621
5	Estate	105.8	392	0.2218	0.000305
6	Eddy	105.7	392	0.44257	0.000609

TABLE VI. CANDIDATE BUSES MEETING THE CRITERIA FOR DG PLACEMENT UNDER MAXIMUM LOADING CONDITION

S/N	Bus	KVAR	Voltage Magnitude (V)	Route Resistance	LSF
1	Celiwe	98.13	377	0.6128	0.000846
2	Igbinedion Univ.	67.97	377	0.5138	0.000491
3	Iyayi	64.24	378	0.61371	0.000552
4	Cath. Junct.	157.7	380	0.44257	0.000967

S/N	Bus	KVAR	Voltage Magnitude (V)	Route Resistance	LSF
5	Estate	154.9	380	0.2218	0.000476
6	Eddy	154.6	380	0.44257	0.000948

It was observed from simulation results that the DG had its best performance at the Igbinedion Univ., Estate and Celiwe buses so the DG units of 1 MW each were placed on these buses to enhance the network.

C. Results After Enhancement of the Network

The results of the enhanced network are shown in tables 7 to 9 for base, minimum and maximum loading conditions respectively. It can be observed from table 7 that the performance of the network improved drastically when compared with table 1. All the bus voltages were within the acceptable limit and the total loading increased (as expected because the network has been enhanced by DG placement) from 4968 kW and 1633 KVAR to 5398.63 kW and 1774.51 KVAR for real and reactive power respectively. The same can also be said for the results obtained from the enhanced network under minimum loading conditions as shown in table 8. When compared with table 2, it is observed that all the bus voltages fell within the acceptable range and the total loading of the network also increased from 4094 kW and 1345 KVAR to 4372 kW and 1437 KVAR for real and reactive power respectively. But for the case of the enhanced network under maximum loading condition as shown in table 9, when compared with table 3, it can be observed that the bus voltages improved and fell within the acceptable limit unlike in table 3. The total loading also improved from 5985 kW and 1967 KVAR to 6647.02 kW and 2184.7 KVAR for real and reactive power respectively but the percentage loading also exceeded 100 as is the case in table 3. Thus, the network, whether original or the enhanced, should never be made to operate under maximum loading condition.

TABLE VII. RESULTS FOR BASE BUS LOADING CONDITION OF THE ENHANCED NETWORK

Terminal Bus	Rating/Limit	Rated kV	kW	KVAR	Amp	% Loading	Voltage (%)
Amariga	94.74 kVA	0.415	84.79	27.87	127.9	97.1	97.06
Cath. Junt.	483.2 kVA	0.415	431.7	141.9	651.9	97	96.98
Caeser	94.74 kVA	0.415	84.79	27.87	127.9	97.1	97.06
Celiwe	304.2 kVA	0.415	271.2	89.15	410	96.9	96.88
Country Home	200 kVA	0.415	178.5	58.66	269.7	96.9	96.92
Eddy	473.7 kVA	0.415	423.7	139.3	639.5	97	97.03
Equity Bank Host.	200 kVA	0.415	178.3	58.61	269.5	96.9	96.88
Equity Bank	200 kVA	0.415	178.4	58.65	269.6	96.9	96.91
Estate	473.7 kVA	0.415	424.1	139.4	639.8	97.1	97.08
FCMB Okada	100 kVA	0.415	89.23	29.33	134.8	96.9	96.91
Gabosa	198.9 kVA	0.415	177.5	58.35	268.2	96.9	96.93
Igbinedion	100 kVA	0.415	89.19	29.31	134.8	96.9	96.89
Igbinedio Univ. N/S	210.5 kVA	0.415	187.2	61.54	283.4	96.8	96.76
Iguomo	47.37 kVA	0.415	42.4	13.94	63.97	97.1	97.07
Int. Cont. Bank	200 kVA	0.415	178.3	58.61	269.6	96.9	96.88
Iyayi	200 kVA	0.415	178.5	58.66	269.7	96.9	96.92
MTN	100 kVA	0.415	89.19	29.31	134.8	96.9	96.89
Ogbese Village	94.74 kVA	0.415	84.78	27.87	127.9	97.1	97.06
Okada	473.7 kVA	0.415	423.8	139.3	639.5	97	97.04
Okada Town 2	421.1 kVA	0.415	379.1	124.6	570.3	97.4	97.35
Palm Garden Hotel	194.7 kVA	0.415	174	57.18	262.7	97	96.98
Phase 2	294.7 kVA	0.415	263.2	86.51	397.5	97	96.96
Presidential Lodge	105.3 kVA	0.415	93.63	30.77	141.7	96.7	96.74
Round About	284 kVA	0.415	254.2	83.56	383.5	97.1	97.07
Utese Village	194.7 kVA	0.415	174	57.18	262.7	97	96.98
V-mobile Okada	96.84 kVA	0.415	86.53	28.44	130.7	97	96.98
Zenith Bank	200 kVA	0.415	178.4	58.64	269.6	96.9	96.9
Total			5398.63	1774.51			

TABLE VIII. RESULTS FOR MINIMUM BUS LOADING CONDITION OF THE ORIGINAL NETWORK

Terminal Bus	Rating/Limit	Rated kV	kW	KVAR	Amp	% Loading	Voltage (%)
Amariga	94.74 kVA	0.415	68.64	22.56	103	78.1	97.64
Cath. Junt.	483.2 kVA	0.415	349.6	114.9	524.7	78.1	97.57
Caeser	94.74 kVA	0.415	68.64	22.56	103	78.1	97.64
Celiwe	304.2 kVA	0.415	219.7	72.23	330.1	78	97.49
Country Home	200 kVA	0.415	144.6	47.51	217.1	78	97.52
Eddy	473.7 kVA	0.415	343.1	112.8	514.6	78.1	97.62
Equity Bank Host.	200 kVA	0.415	144.5	47.48	217	78	97.49
Equity Bank	200 kVA	0.415	144.5	47.51	217.1	78	97.52
Estate	473.7 kVA	0.415	343.3	112.8	514.8	78.1	97.65
FCMB Okada	100 kVA	0.415	72.28	23.76	108.5	78	97.52
Gabosa	198.9 kVA	0.415	143.8	47.26	215.9	78	97.53
Igbinedion	100 kVA	0.415	72.25	23.75	108.5	78	97.5
Igbinedio Univ. N/S	210.5 kVA	0.415	151.8	49.88	228.2	77.9	97.4
Iguomo	47.37 kVA	0.415	34.32	11.28	51.48	78.1	97.64
Int. Cont. Bank	200 kVA	0.415	144.5	47.49	217	78	97.49
Iyayi	200 kVA	0.415	144.6	47.52	217.1	78	97.52
MTN	100 kVA	0.415	72.25	23.75	108.5	78	97.5
Ogbese Village	94.74 kVA	0.415	68.64	22.56	102.9	78.1	97.64
Okada	473.7 kVA	0.415	343.1	112.8	514.7	78.1	97.62
Okada Town 2	421.1 kVA	0.415	306.6	100.8	458.7	78.3	97.87
Palm Garden Hotel	194.7 kVA	0.415	140.9	46.31	211.4	78.1	97.58
Phase 2	294.7 kVA	0.415	213.2	70.06	320	78	97.56
Presidential Lodge	105.3 kVA	0.415	75.89	24.95	114.1	77.9	97.38
Round About	284 kVA	0.415	205.8	67.64	308.6	78.1	97.65
Utese Village	194.7 kVA	0.415	140.9	46.3	211.4	78	97.57
V-mobile Okada	96.84 kVA	0.415	70.07	23.03	105.2	78.1	97.57
Zenith Bank	200 kVA	0.415	144.5	47.5	217.1	78	97.51
Total			4372	1437			

TABLE IX. RESULTS FOR MAXIMUM BUS LOADING CONDITION OF THE ORIGINAL NETWORK

Terminal Bus	Rating/Limit	Rated kV	kW	KVAR	Amp	% Loading	Voltage (%)
Amariga	94.74 kVA	0.415	104.4	34.32	158.7	120.4	96.35
Cath. Junt.	483.2 kVA	0.415	531.5	174.7	808.8	120.3	96.25
Caeser	94.74 kVA	0.415	104.4	34.32	158.7	120.4	96.35
Celiwe	304.2 kVA	0.415	333.8	109.7	508.5	120.2	96.12
Country Home	200 kVA	0.415	219.6	72.19	334.5	120.2	96.17
Eddy	473.7 kVA	0.415	521.8	171.5	793.4	120.4	96.31
Equity Bank Host.	200 kVA	0.415	219.4	72.12	334.3	120.2	96.12
Equity Bank	200 kVA	0.415	219.6	72.18	334.4	120.2	96.16
Estate	473.7 kVA	0.415	522.4	171.7	793.9	120.5	96.37
FCMB Okada	100 kVA	0.415	109.8	36.09	167.2	120.2	96.16
Gabosa	198.9 kVA	0.415	218.5	71.82	332.7	120.2	96.18
Igbinedion	100 kVA	0.415	109.8	36.07	167.2	120.2	96.14
Igbinedio Univ. N/S	210.5 kVA	0.415	230.3	75.68	351.3	120	95.98
Iguomo	47.37 kVA	0.415	52.22	17.17	79.37	120.4	96.35
Int. Cont. Bank	200 kVA	0.415	219.4	72.13	334.3	120.2	96.12
Iyayi	200 kVA	0.415	219.7	72.2	334.5	120.2	96.17
MTN	100 kVA	0.415	109.7	36.07	167.2	120.2	96.14
Ogbese Village	94.74 kVA	0.415	104.4	34.32	158.7	120.4	96.34
Okada	473.7 kVA	0.415	521.9	171.5	793.5	120.4	96.32
Okada Town 2	421.1 kVA	0.415	467.7	153.7	708.2	120.9	96.71

Terminal Bus	Rating/Limit	Rated kV	kW	KVAR	Amp	% Loading	Voltage (%)
Palm Garden Hotel	194.7 kVA	0.415	214.2	70.4	325.9	120.3	96.25
Phase 2	294.7 kVA	0.415	324	106.5	493.1	120.3	96.22
Presidential Lodge	105.3 kVA	0.415	115.1	37.84	175.7	119.9	95.95
Round About	284 kVA	0.415	313.1	102.9	475.9	120.4	96.36
Utese Village	194.7 kVA	0.415	214.2	70.4	325.9	120.3	96.25
V-mobile Okada	96.84 kVA	0.415	106.5	35.01	162.1	120.3	96.25
Zenith Bank	200 kVA	0.415	219.6	72.17	334.4	120.2	96.15
Total			6647.02	2184.7			

CONCLUSION

It has been shown from the study that the Okada town distribution network is quite deficient as can be seen from the bus voltages and percentage loading obtained under base, minimum and maximum loading conditions. With the enhancement carried out by optimally placing three (3) DG units of 1 MW each at Igbinedion University, Estate and Celiwe buses, it was observed that the performance of the distribution network improved drastically for base, minimum and maximum bus loading conditions. But it is worthy of note that as can be seen from the percentage loading of the buses under maximum loading condition, the network should never be made to operate under maximum condition as the buses will be overloaded. It is thus recommended that the network should be enhanced. The lines should be replaced with ones having higher current carrying capacity so as to be able to evacuate more power and more DG units should be introduced into the network should there be need for expansion in the near future.

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