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Loss Reduction on Enugu 24-bus 33KV Distribution Network Using Optimally Placed Distributed Generation

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ABSTRACT: Electric power generation in Nigeria stands at 30% less than the demand and of all the power generated, 50% is recorded as loss in the distribution networks. This ugly trend has severe socioeconomic implications on country, especially in the southeastern part of the country which receives only 9% of the total power generated through Enugu Electricity Distribution Company (EEDC). Against this backdrop, this paper focuses on the minimization of losses on the Enugu 24 bus distribution network using distributed generation (DG). The case study network was modeled and characterized on MATLAB/PSAT. Repeated power flow (RPF) and continuation power flow (CPF) were executed on the modeled network using SIMULINK/PSAT to determine the optimum location and optimum size of the DGs. Having optimally sized and placed the DGs on the identified vulnerable buses; the result shows that the real power loss was mitigated by 76.8% while 12 buses operating at under-voltage levels below 0.95PU were strengthened to the normal voltage level of $0.95pu \leq V \leq 1.05pu$. The implication of this result is that the high losses being recorded on Enugu 24 bus 33kV distribution network can be drastically minimized by using the method described by this paper.

KEYWORDS: Losses, Distributed Generation (DG), Voltage profile, Power flow

I. INTRODUCTION

Electrical energy is a fundamental necessity for the growth of any economy [8]. In recent years, the amount of electrical energy in the power grid of different States has been adopted as a viable yardstick for measuring the extent to which the States have developed [7], [4], [8]. Reference [9] observed that an increase in the amount of available electrical energy has led to a reduction in the number of working days, increased agro productivity, increased industrial output, better health conditions, improved transportation systems, and more nutritious meal. Thus, no state can witness tremendous development without a sufficient supply of electricity. Despite the indispensability of electricity, Nigeria is yet to meet the electrical energy demands of her citizens [3]. Presently, the power generation in Nigeria is 30% less than the demand and regrettably, 50% of this meager energy generated is said to be lost in the distribution network [12]. It is admissible that losses are inevitable in power systems even in states that have evolved the most sophisticated technologies for the generation, transmission, and distribution of electrical energy owing to the nature of electricity [11]. Nevertheless, a loss of 50% of total power generated is way too high to be acceptable. According to [11], only 9% of the total power generated in Nigeria is transmitted to the Enugu electricity distribution company (EEDC). This amount of power is too meager considering that the southeastern part of the country that EEDC supplies is the economic hub of Nigeria. To this end, this research is aimed at reducing the losses hindering the efficient distribution of the meager available energy within Enugu 24 bus 33kV/11kV distribution network using distributed generation technology.

1.1 Losses in Power Systems

According to WBGESS [17], losses from the viewpoint of electricity supply refer to the amount of electrical energy injected into the transmission and distribution lines which are not paid for by the consumers. Losses are classified into two broad categories; technical and non-technical losses [14], [8], [3], [2]. Technical losses have a natural occurrence



owing to some inherent weakness of the power systems components and accessories. Technical losses can be classified into three; variable losses (associated with loads), fixed losses (unconnected with load), and network services (uncontracted consumption of the network components) [11]. Variable losses are the losses that arise from heat dissipation in all the conductors associated with the system owing to their inherent internal resistance [6]. Fixed losses are losses that are caused by energy dissipation on the network components and equipment when energized [6]. These losses are not connected to the current flow in the network. Thus, they are not variable. They are always present whether there are loads or there are no loads. They are mostly associated with the transformers in the form of eddy current losses and hysteresis losses. Other causes of this fault type include corona effect and poor insulation which leads to current leakage [11]. Fixed losses are voltage-dependent. Network services are associated with the amount of energy consumed by the measuring devices and information systems deployed within the network. On the other hand, non-technical losses are orchestrated by agents that are external to the power systems and are loosely categorized into three; commercial, non-payment, and administrative losses [17].

One of the major causes of the technical losses being witnessed in the Enugu 24 bus 33kV/11Kv distribution network is the overloading of the network equipment. There are growing demands for electricity in newly constructed residential buildings, expansions of the grid to rural areas, erection of new industries, and urbanization. The distribution network is pressured to meet up these demands without any form of an increase in generation. This has brought about an unplanned increase in the feeder route length against the former length and has as well placed unanticipated pressure on the working distribution transformers [14].

1.2 Distributed Generations

Thomas et al. [18] coined a general definition of DG which seems now to be widely accepted as follows: “Distributed Generation is an electric power source connected directly to the distribution network or on the customer site of the meter” [19]. This definition excludes the type of DG technology and the size of the DG technology because different DG technologies abound and will continue to emerge. More so, the size of the DG varies from different regulatory bodies across different regions [20]. The placement of DG impacts the operation of the distribution network critically. If the DG is not placed appropriately, the condition of the distribution network may be worsened; that is the network losses may increase as well as the operating cost. On the other hand, Optimal DG placement (ODGP) can guarantee improved power factor, improved voltage profile of the feeder, power loss reduction, and increased available capacity of the feeder; improve power quality and reliability of supply [10].

REVIEW OF RELATED LITERATURE

Owing to the outrageously high losses being recorded on the distribution networks, many proposals have been made in the past to address the issue. Mohammed et al. [11] worked on challenges and panaceas to the power distribution losses in Nigeria. He identified the major causes of the high losses bedeviling distribution networks in Nigeria. However, this work focused mainly on non-technical losses and did not propose any means to reduce the technical losses. Similarly, Komolafe and Udofia [8] reviewed electrical energy losses in Nigeria. The authors compared the electrical energy losses in Nigeria for four different years with that of Ghana, South Africa, India, Brazil, UK, UAE, USA, and China. It was shown that for the four years chosen, Nigeria recorded the highest losses. Onodugo et al. [14] evaluated technical losses at the Enugu Metropolis network using the method of simulation and analysis with the help of the Electrical Transient and Analysis Program, ETAP. The results showed that the voltage levels at some feeders were below 0.95PU which translates to under-voltage. Two shunt capacitors were installed at the weakest feeders and the voltage was improved. Nevertheless, the study did not show how the sizes of the shunt capacitors were arrived at. Adesina and Ademola [3] suggested means through which power system losses can be effectively determined in Nigeria. They observed that the technical losses in developing countries are usually higher than that of developed countries. The study emphasized power flow studies as a potent tool to ascertain both the technical and non-technical losses. Moein et al. [10] noted that it is imperative to ascertain the exact line loss on a distribution network to assess the effectiveness of the distributed generation when eventually installed on the network. Thus, they proposed a new method through which an index quantifying the total line loss reduction can be achieved. Ade-Ikuesan et al. [2] investigated electric power loss in the primary distribution feeder in Ota distribution company Nigeria. It was revealed that most of the industries sited within the industrial area do not have capacitive load banks and inductive load banks and this caused a reduction in the power factor of the network resulting in critical power losses in the distribution network. This study identified key causes of losses that are often neglected. Ravi and Sonipat [15] observed that the placement of DG on the distribution system poses some potential problems to the distribution network since the distribution network is designed to be radial

and DG will invariably cause the network to be bidirectional. Given this, the thesis used IEEE 14 bus radial distribution system to investigate an effective means to properly size and place DG. The result shows that the impact DG has on a network will be positive if the DG is properly sized and placed, else it will be negative. Satish et al. [16] propose the application of Particle Swarm Optimization (PSO) technique to find the optimal size and optimum location for the placement of DG in the radial distribution networks seeking active power compensation by minimizing the real power losses and improving the voltage profile. It was shown that the optimal size of DG can be calculated using the exact loss formula while the optimal location can be found using the loss sensitivity factor. Acharya et al. [1] proposed a method to calculate the optimal size and location of the DG to achieve effective mitigation of loss using an exact loss formula. The work shows that this method is most useful in the deployment of a single DG unit that is to supply active power. More so, the loss sensitivity factor was employed to find the candidate locations for unit DG deployment to minimize the number of busbars taken into account in the search space.

III. METHODOLOGY

The case study network; Enugu 24 bus 33Kv/11KV distribution network was isolated from the entire southeast distribution network. This was done by performing load flow studies on the entire network to ascertain the value of the generators or loads to be placed at the coupling point between the case study network and the southeast distribution network. The network line data and bus data were the major inputs used to characterize the network. The Newton Raphson power flow method was adopted in this study.

3.1 FORMULATION OF POWER FLOW PROBLEM

Power flow analysis is essential in the coordination of power systems to guarantee that power systems are run properly. One advantage of the Newton-Raphson method (NR) is the speed of convergence, especially in very large power system networks. Another factor that makes Newton-Raphson method powerful is the adaptability of this method in most power system modeling software like MATLAB. The power flow equation is derived in polar form because, in the power flow problem analysis, real power and voltage magnitude are stated for the voltage-controlled buses. The expression for current flow in a power system network in polar form is thus formulated [5].

$$I_i = \sum_{j=1}^n |Y_{ij}| |V_j| \angle(\theta_{ij} + \delta_j) \quad (1)$$

To determine the real power at a given bus i is

$$P_i = V * I_i + jQ_i \quad (2)$$

Equation 2 can be rearranged in polar form using equation 1 as

$$P_i = |V_i| \angle(-\delta_i) \sum_{j=1}^n |Y_{ij}| |V_j| \angle(\theta_{ij} + \delta_j) + jQ_i \quad (3)$$

Equation 3 can be separated- the real and the imaginary portion for easy estimation in a network and are obtained in Equation 4 and 5 respectively.

$$P_i = \sum_{j=1}^n |Y_{ij}| |V_i| |V_j| \cos(\theta_{ij} + \delta_j - \delta_i) \quad (4)$$

$$Q_i = - \sum_{j=1}^n |Y_{ij}| |V_i| |V_j| \sin(\theta_{ij} + \delta_j - \delta_i) \quad (5)$$

The real and the reactive component of the power in equations (4) and (5) can be expanded using the Taylor series to produce a pattern of linear equations involving a Jacobian matrix which exhibits a clear link relating small variation real power with voltage angle and also the variation of voltage magnitude with variation in reactive power. This can be simplified as

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix} \begin{bmatrix} \Delta \delta \\ \Delta V \end{bmatrix} \quad (6)$$

ΔP and ΔQ represent differences between specified values and calculated values respectively, ΔV and $\Delta \delta$ represent voltage magnitude and voltage angle respectively in incremental forms and sub-matrices J_1 through J_4 from the Jacobian matrix

3.2 NETWORK CONFIGURATION AND SIMULATION

The result of the power flow performed on the entire southeast distribution network shows the power flow between the parent network and case study network. These values were used to configure a generator feeding the case study network since power is flowing into the case study network. The PSAT model of the case study network is as shown below.

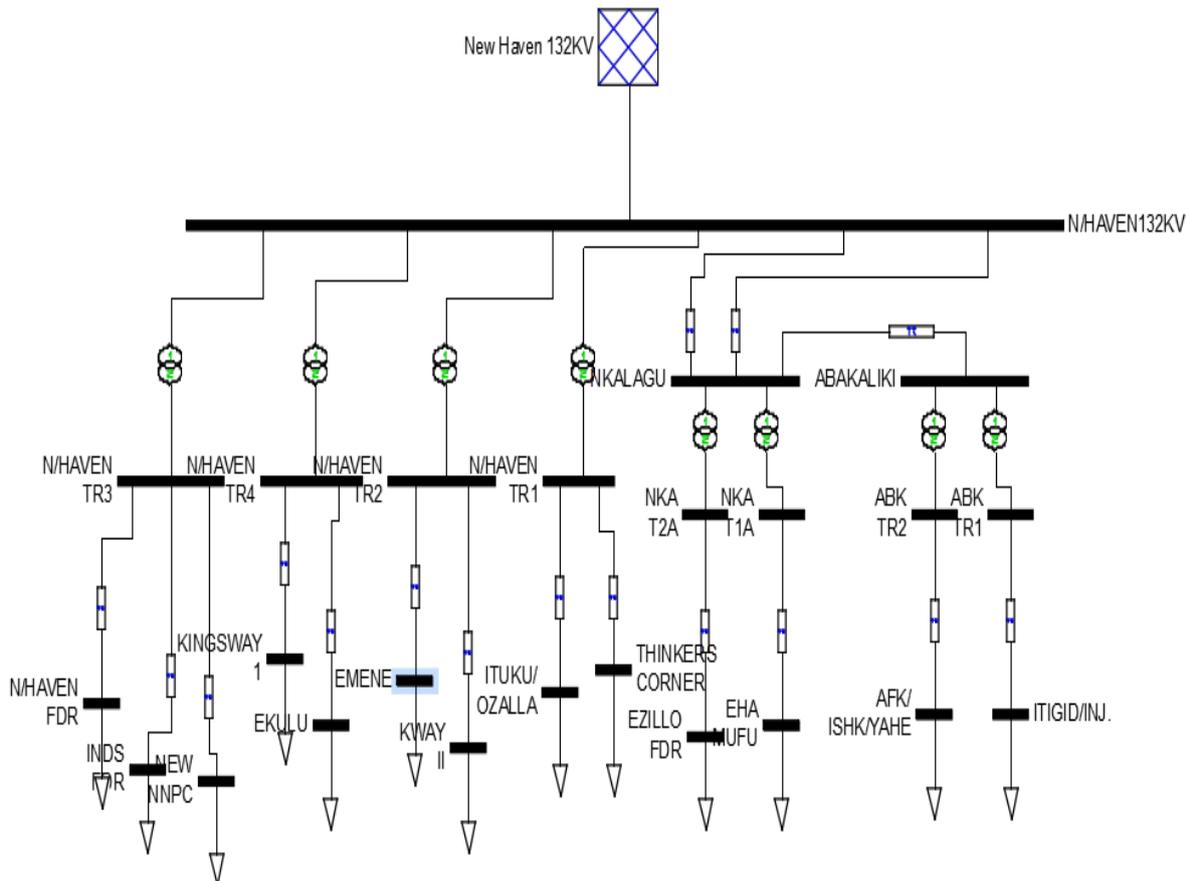


Figure 1: PSAT model of Enugu 24 bus 33kV distribution network

The case study network was loaded into PSAT on MATLAB and power flow was carried out on the network to ascertain the weakest buses. A DG with a real power rating of 5.5pu (on a 1MVA base) was placed at the weakest bus and power flow was run again to compare the new losses with the previous one. As expected, there was a reduction in the real power loss. The Per unit power rating of the DG was progressively increased at the same rate and in each time, load flow performed to ascertain the new losses. This process was continued till the optimum DG rating was reached. Beyond this rating, any additional increase in DG size will cause an increase in power loss. Continuation power flow (CPF) was then carried out to ascertain the next weakest bus having strengthened the former one by installing an optimally sized DG on it. This procedure is repeated to determine the optimum size of DG for the new weakest bus. The second optimally sized DG is then connected to its corresponding bus and load flow performed to determine the extent of loss reduction. This process is continued till the point where the installation of optimally sized DG fails to offer any additional total network loss reduction.

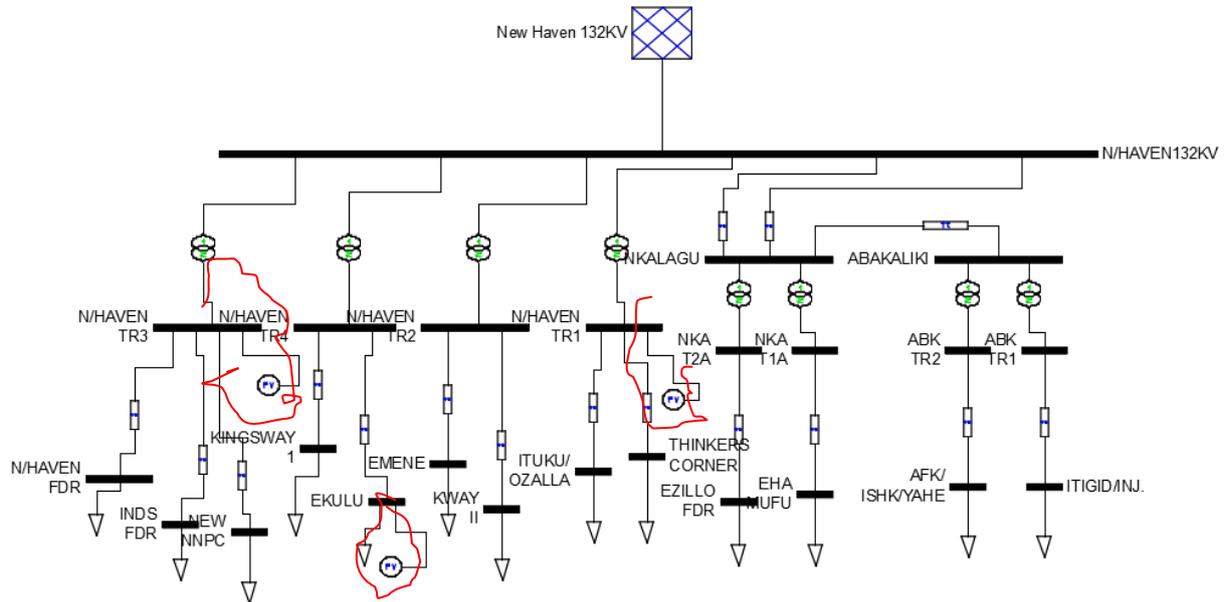


Figure 2: PSAT model of the case study network showing optimal locations of the DGs

IV. RESULTS AND DISCUSSION

Table 1. Continuation Power Flow Result

Bus	V	Phase	P gen	Q gen	P load	Q load
	[pu]	[rad]	[pu]	[pu]	[pu]	[pu]
INDS FDR	0.66435708	-0.40444	1.34E-10	4.49E-12	0.302477	0.027828
NEW NNPC	0.664357262	-0.40445	1.85E-10	3.27E-12	0.423468	0.024198
N/HAVEN FDR	0.664358128	-0.40442	4.05E-11	1.71E-12	0.090743	0.006957
N/HAVEN TR3	0.664358477	-0.40441	-2.9E-10	1.39E-11	0	0
THINKERS CORNER	0.683890908	-0.29606	1.23E-11	4.51E-12	0.393221	0.148819
ITUKU/ OZALLA	0.683896805	-0.29605	8.99E-12	-3.5E-13	0.302477	0.027828
N/HAVEN TR1	0.683898162	-0.29603	-1.3E-11	-3.9E-12	0	0
EKULU	0.748074448	-0.31504	3.71E-12	1.21E-12	0.423468	0.027828
KINGSWAY 1	0.748074448	-0.31503	2.72E-12	4.24E-12	0.302477	0.027828
N/HAVEN TR4	0.748075688	-0.31501	-9.8E-13	3.66E-12	0	0
EZILLO FDR	0.836905995	-0.21985	-1E-12	-4.6E-12	0.282312	0.018552
NKA T2A	0.836906734	-0.21984	1.24E-12	3.88E-12	0	0
AFK/ ISHK/YAHE	0.888682805	-0.15623	3.39E-13	2.51E-12	0.211734	0.013914
ABK TR2	0.888683327	-0.15622	2.95E-13	-3.3E-12	0	0
EHA MUFU	0.892129788	-0.14485	5.08E-13	-6E-13	0.201652	0.018552
NKA T1A	0.892130482	-0.14484	2.07E-13	4.35E-12	0	0
ITIGID/INJ.	0.906419446	-0.1307	2.02E-14	-6.1E-12	0.362973	0.027828



ABK TR1	0.90642047	-0.13068	1.27E-12	6.49E-12	0	0
KWAY II	0.916648919	-0.11569	1.02E-12	4.09E-12	0.181486	0.013914
EMENE	0.916648919	-0.11569	7.28E-13	7.87E-13	0.151239	0.013914
N/HAVEN TR2	0.916649425	-0.11568	-1.1E-12	-9.4E-12	0	0
ABAKALIKI	0.998292242	-0.00226	-3.4E-13	3.98E-13	0	0
NKALAGU	0.999169358	-0.00116	-7.2E-13	6.82E-13	0	0
N/HAVEN132KV	1	0	4.420472	1.836241	0	0

Table 2: Summary of Power flow of Enugu distribution network without DG and with DGs

(a) Before installation of DGs

(b) After installation of DGs

TOTAL GENERATION	
REAL POWER [p.u.]	1.924919
REACTIVE POWER [p.u.]	0.424593
TOTAL LOAD	
REAL POWER [p.u.]	1.800000
REACTIVE POWER [p.u.]	0.197350
TOTAL LOSSES	
REAL POWER [p.u.]	0.124919
REACTIVE POWER [p.u.]	0.227243

TOTAL GENERATION	
REAL POWER [p.u.]	1.829009
REACTIVE POWER [p.u.]	0.250207
TOTAL LOAD	
REAL POWER [p.u.]	1.8
REACTIVE POWER [p.u.]	0.19735
TOTAL LOSSES	
REAL POWER [p.u.]	0.029009
REACTIVE POWER [p.u.]	0.052857

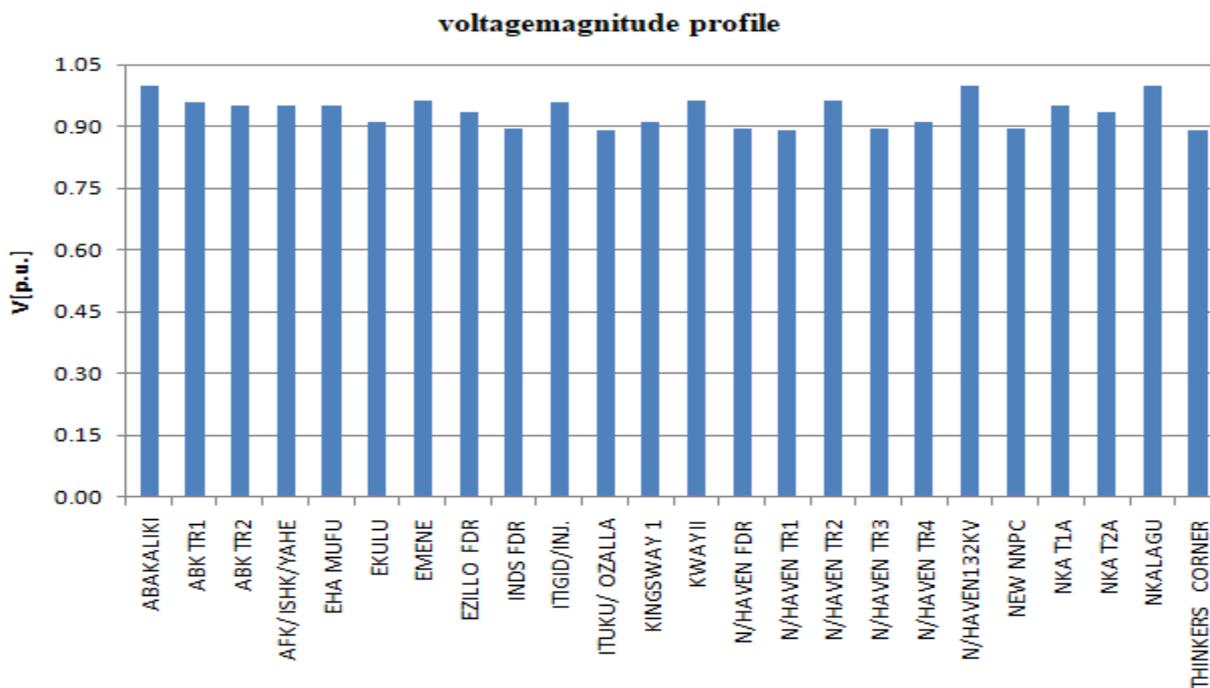


Figure 3: Voltage profile of Enugu Distribution Network before placement of DG on the network



In this work, continuation load flow was used to determine the weakest buses. These weakest buses are the preferred locations for the installation of DG's for optimum loss reduction. With continuation load flow, any bus with a voltage profile less than 0.95pu is a vulnerable bus. Also, the bus with the least voltage profile becomes the weakest bus. From continuation load flow result presented in table 1 it is clear that, INDS FDR, N/HAVEN FDR, NEW NNPC, N/HAVEN TR3 and THINKERS CORNER recorded a voltage profile of 0.66435708 after continuation power flow. As a result, these buses are the weakest buses.

Through repeated power flow, a DG with a real power rating of 40.5pu (on a base of 1MVA) was obtained as the optimum DG that will be placed at N/HAVEN TR3 to strengthen the bus.

Voltage profile afeter placement of DGs

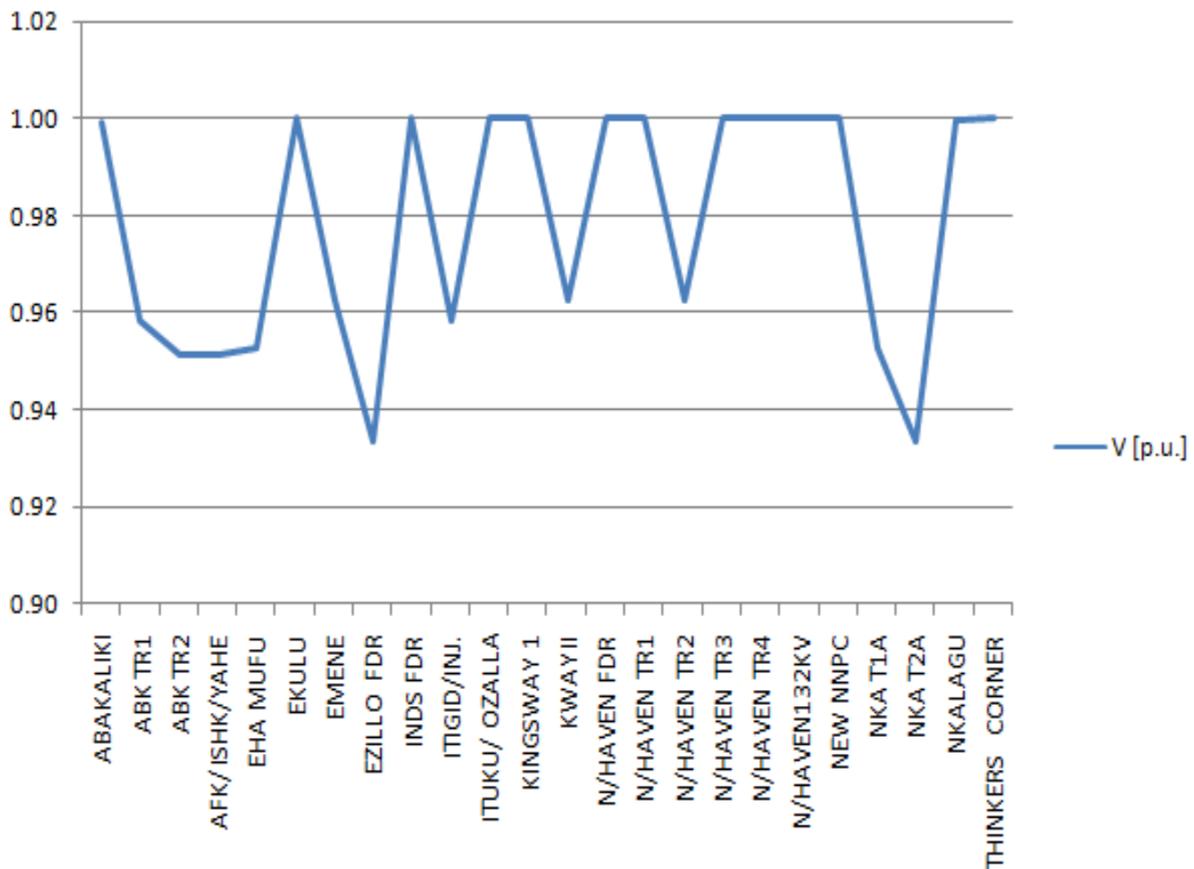


Figure 4: Voltage profile of the network after optimum sizing and optimum placement of DGs.

From figure 4, it is evident that out of the initial 12 buses operating at under-voltage (below voltage magnitude of 0.95pu), 10 have been increased to the normal voltage level of

$$0.95pu \leq V \leq 1.05pu \text{ leaving only two buses –EZEILO FDR and NKA T2A below 0.95PU.}$$

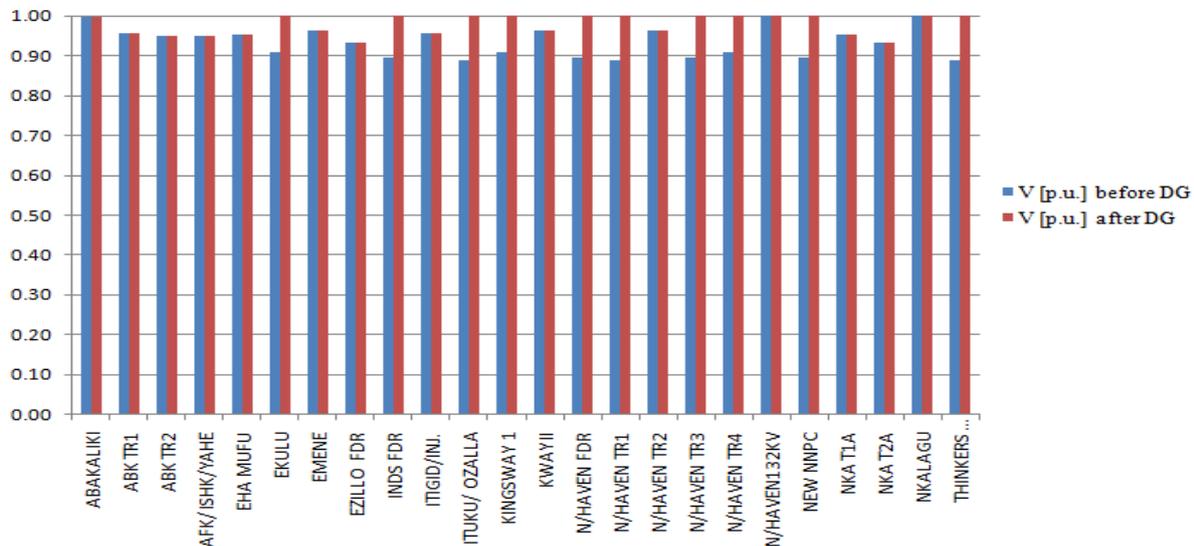


Figure 5: Voltage profile of the network before and after placement of DGs

The power flow result shows that the real power loss on the network has been reduced from the initial 0.124919pu to 0.02900pu. The percentage reduction in real power loss can be calculated thus;

$$\text{Percentage reduction in loss} = \frac{\text{Initial loss} - \text{final loss}}{\text{initial loss}} \times 100$$

$$\text{Therefore, the percentage reduction in loss} = \frac{0.124919 - 0.02900}{0.124919} \times 100 = 76.8\%$$

V. CONCLUSION

This research has demonstrated that the losses inhibiting the effective and efficient operation of Enugu 24-bus 33kV distribution network can be mitigated to a large degree using optimally sized and optimally placed distributed generation. From the simulation performed on the SIMULINK model of the case study network using power systems analysis toolbox PSAT on MATLAB/SIMULINK, it was established that N/HAVEN TR3, N/HAVEN TR1, and EKULU buses are the optimum locations to deploy the DGs. Also, the results obtained from repeated power flow show that the optimum real power ratings of the DGs on a base of 1MVA are 40.5pu, 35pu, and 36pu, respectively. The installation of 40.5pu DG at N/Haven TR3 reduced the real power loss from 0.124919pu to 0.08724pu, 35pu DG at N/Haven TR1 further reduced the real power loss to 0.057916pu, and 36pu DG at Ekulu finally brought the real power loss to 0.029009pu. The final power performed on the case study network shows that the real power loss has been reduced by 76.8%. This research, therefore, meets its objective of minimizing the technical losses militating against the efficient operation of Enugu 24 bus, 33kV distribution network.

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