

Teaching-Learning Based Optimization Approach for Determining Size and Location of Distributed Generation for Real Power Loss Reduction on Nigerian Grid

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Abstract: The ever increasing sensitization on the need for clean energies that are not only environmental friendly but also have comparative cost advantages encourages the use of distributed generation. Using distributed generation at the load ends or close to the load centers has not only reduced carbon emission, but also improves power system performances. Presented in this paper is the adoption of Teaching-Learning Based Optimization technique for determining the most suitable site and size of distributed generation for real power loss reduction on Nigerian power system. Backward/Forward Sweep technique was employed for the power flow analysis, while the suitable locations of the distributed generations were pre-selected using Voltage Stability Index and Teaching-Learning Based Optimization technique was employed to establish the optimal location and the optimum size of the required distributed generation. This approach was demonstrated on the IEEE 34-bus test system, with the placement of 1 kW DG at bus 11 of the system. The aggregate real power loss diminished from 571 kW to 208.5954 kW (63.5726% reduction), while Voltage Stability Index and voltage profile of the system also improved remarkably. Also, by placing distributed generation on typical Nigerian 11 kV feeder, the real power loss reduced from 1.1 kW to 0.75 kW while the magnitude of bus voltage increased from 0.8295 to 0.8456 p.u. Based on the results of this analysis, Teaching-Learning Based Optimization has demonstrated excellent performance on the two test cases and therefore would be a tool to adopt on the Nigerian radial distribution system.

Keywords: Distributed Generation, Loss Reduction, 11kV Feeder, Voltage Profile, Optimization, Voltage Stability Index

I. Introduction

The unplanned geometrical demand for electricity has direct effects on the orthodox power systems such as over-stretching of generation equipment beyond their maximum loadability and incessant blackout in major parts of the network axis due to acute supply of the needed energy. Power system planners are now pressurized to device alternative means of supplying energy to the end users in a manner that is both environmental friendly and cost-

effective. In view of environmental friendliness and cost implication in today's unwrapped electricity market, the need to strengthen the traditional power systems becomes obvious [1]. Distributed generation (DG) offers solution to these aforementioned issues [2]. In addition, the key potential attributes of DG include ecologically friendly technologies, techno-economic security, dependable operation, load demand compensation, losses reduction and voltage profile improvement among others [3, 4].

In this present time, according to authors in [5, 6], DG technologies have become the backbone of modern electric radial distribution networks in combating undue real power losses and severe deviation in bus voltage profile which are the key

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problems confronting radial distribution systems (RDSs). DG can be renewable energy source based or fossil fuels based, that are sited either very close to or at consumer's end. In terms of magnitude, DGs are relatively small when compared to the central grid systems [7]. Also, siting and sizing of DG is a constrained optimization problem that requires the use of appropriate optimization tools. If DG units are placed at non-optimal sites, consequences of such action include inherent possibilities for system losses to increase, occurrence of bi-directional power flow that can lead to the problems of protection current flow, deviation in system operating frequency and islanding difficulties among other anomalies [8-10].

Techniques and methods for siting and sizing of DGs are generally grouped as analytical method, classical optimization approaches and artificial intelligent techniques. The analytical approaches are mostly suitable for relatively small network; classical optimization approaches are more of analytical in nature with complex mathematical modeling and hardly guarantee optimal solution, most at time, they are trapped at local optimum solution; while the meta-heuristic swarm intelligence based optimization approaches are promising option for addressing issue relating to size as well as the site of DGs in RDS. Genetic algorithm, particle swarm optimization, mixed-integer nonlinear programming [11], evolutionary programming approach [12], gravitational search algorithm [13] and oppositional krill herd algorithm [14] among others, have been employed to evaluate optimum capacity and site of DGs. This work presents the use of TLBO technique for determining the optimum size and site of DG for real power loss reduction on Nigerian radial distribution system. Subsequent parts of this paper are as structured thus: the second section presents formulation of problem, while the third section provides detailed description of the 11 kV feeder of the Nigerian network employed in

the study, and the fourth section presents and discusses the result obtained from the study. The finishing comments are presented in the fifth section.

II. Problem Formulation

Optimal sizing and siting of DG is a constrained optimization problem that required excellent optimization tools. In this study, BFS technique was employed for the power flow analysis, while VSI was used to discover weakest nodes (buses) and TLBO was used as optimization tool to obtain the precise DG size and site required to diminish real power loss in order to enhance system voltage profile.

A. Formulation of Objective Function

At the branch connecting n and $n + 1$, the resulting real power loss is expressed as given by authors in [15] thus;

$$P_{Loss} = \left(\frac{P_n^2 + Q_n^2}{|V|^2} \right) \times R_n \quad (1)$$

The entire real power loss is given by [15];

$$P_{Tloss} = \sum_{k=1}^n \left(\frac{P_n^2 + Q_n^2}{|V|^2} \right) \times R_{n+1} \quad (2)$$

While the total voltage deviation [15] can be expressed as;

$$TVD = \sum_{k=1}^n |1 - V_n| \quad (3)$$

where; P_{Loss} = real power loss, $P_n = n^{th}$ bus real power loss, P_{Tloss} = system aggregate active power loss, Q_n = reactive power loss at n^{th} bus, R_n = resistance of the line section between buses n and $n + 1$ and TVD = total voltage deviation for $k = 1, 2, 3, \dots, n$; $V_n = n^{th}$ bus voltage magnitude(per unit).

If equation (2) is designated by f_1 and equation (3) is designated by f_2 , then using the weighted

approach to transform equations (2) and (3) into single objective function gives;

$$F = a_1 \times f_1 + a_2 \times f_2 \quad (4)$$

where; a_1 = weighted coefficient for the formulated power loss objective function and a_2 = weighted coefficient for the formulated for voltage deviation objective function.

Since the real power loss and voltage deviation are to be minimized, then equation (4) can be re-written as;

$$F_{min} = a_1 \times f_1 + a_2 \times f_2 \quad (5)$$

In this study, a_1 was assigned 0.8, a_2 was assigned 0.2 based on the significance of power loss to voltage deviation in this research. Hence,

$$a_1 + a_2 = 1; \quad 0 < a \leq 1 \quad (6)$$

B. The System Constraints

The equality (basic power flow equations) and inequality (voltage limits and DG sizes) constitute the constraints. The equality constraints are;

$$P_{gi} - P_{gj} = V_i \sum_{j=1}^n V_{ij} Y_{ij} \cos(\delta_i - \delta_j - \theta_{ij}) \quad (7)$$

$$Q_{gi} - Q_{gj} = V_i \sum_{j=1}^n V_{ij} Y_{ij} \sin(\delta_i - \delta_j - \theta_{ij}) \quad (8)$$

The inequality constraints are bus voltage limit, power limits of DG and distribution line absolute power limits as given by equations (9), (10), (11) and (12) respectively.

$$V_{min} \leq V_i \leq V_{max} \quad (9)$$

This places restriction on the system voltage profile, normally a margin $\pm 5\%$ is allowed.

$$\begin{aligned} P_{DGi}^{min} \leq P_{DGi} \leq P_{DGi}^{max} & \quad P_{DGi}^{min} = 0\text{kW}, \\ P_{DGi}^{max} = 5\text{kW} & \end{aligned} \quad (10)$$

$$Q_{DGi}^{min} \leq Q_{DGi} \leq Q_{DGi}^{max} \quad (11)$$

$$|P_{ij}^{Line}| \leq P_{ij,max}^{Line} \quad (12)$$

where; V_{min} = statutory minimal magnitude of the bus voltage, V_{max} = statutory maximal magnitude of the bus voltage, P_{DGi}^{min} and P_{DGi}^{max} stands for minimum and maximum injected active, Q_{DGi}^{min} and Q_{DGi}^{max} represent the i^{th} bus statutory minimal and maximal reactive power of DG components and $|P_{ij}^{Line}|$ and $P_{ij,max}^{Line}$ absolute and maximum statutory value of power flowing over the distribution line between the nodes i and j .

C. Backward/Forward Sweep Load Flow Technique

The radial nature and high reactance to resistance ratio of RDS renders traditional load flow techniques (Newton Raphson, Fast-decoupled and Gauss Seidel) inappropriate for carrying out distribution load flow analysis. Several literatures had presented BFS load flow technique as a promising alternative for distribution load flow analysis [16-19]. BFS does not require the formulation of Jacobian matrix and besides it can fully accommodate peculiar characteristics of distribution system. In BFS technique, two computational stages are executed in each iteration run, using two groups of recursive equations. Ideally, when the first groups of equations are utilized, power flow is thus computed. It usually starts from the last branch and en-route in backward course towards the root node. Also, when the second group of equations are engaged, the magnitude and phase angle of the voltage of each node are obtained, usually it starts from the root node and en-route in forward course towards the first node. The basic mathematical modelling is presented here:

1) Step 1: The backward Sweep

The current at each branch are totaled from loads to origin for each i^k iteration,

$$J^k = -T \times I^k \quad (12)$$

where; J^k is the branch current, I^k is the nodal current and T is the upper triangular matrix accompanying Kirchhoff current law.

Each element I_i^k of I^k linked to node i , and are usually estimated as function of applied complex powers S_i and V_k bus voltage profile;

$$I_k^k = \frac{S_i^*}{V_i^k} \quad (13)$$

2) Step 2: The Forward Sweep

At the forward sweep Kirchhoff voltage law is engaged to update nodal voltages using the earlier evaluated branch current vector J , branch impedances vector Z and TT (Transpose of matrix T);

$$V^{k+1} = V_0 - TT \times DZ \times J^k \quad (14)$$

where $DZ = V^k J^k$ is the branch impedance matrix, and V_0 is the swing node voltages.

Using the upper triangular matrix T ; the equation (14) becomes;

$$V^{k+1} = V_0 - TT \times DZ \times J^k \times T \quad (15)$$

3) Step 3: The Convergence Check

To perform the convergence check updated voltages are compared with previous voltages using equation (16);

$$\varepsilon \geq |V_i^{k+1} - V_i^k| \quad (16)$$

D. Optimal Siting of the Distributed Generation

Voltage stability index is one of the best indices employable in determining the pre-selected location where DG should be sited in a network. It is computed to determine the critical buses (weak buses) in the network. Siting DG at these weak buses does not only bring about reduction in real power losses but also enhance voltage stability of the whole distribution network. As obtained from authors in [15], VSI is obtained using equation (17) expressed thus;

$$VSI_{(i+1)} = |V_i|^4 - 4[P_{i+1,eff} \times X_i - Q_{i+1,eff} \times R_i]^2 - 4[P_{i+1,eff} \times R_i + Q_{i+1,eff} \times X_i]|V_i|^2 \quad (17)$$

where; $V_i = i^{th}$ bus voltage magnitude, $X_i =$ reactance of the line section between i and $i + 1$, $R_i =$ resistance of the line section between i and $i + 1$, $Q_{i+1,eff} =$ total effective reactance power load through the bus $i + 1$ and $P_{i+1,eff} =$ total effective real power load fed through the bus $i + 1$

E. Optimal Sizing of DG Using TLBO

TLBO being one of the state-of-the-art population based meta-heuristic algorithm was developed in 2011 [20]. The philosophy that brought to birth this algorithm was based on the effect of pressure of a tutor (i.e the teacher) on learners' output in a class room [20]. TLBO is comparatively better than many other population based optimization approaches. Many of these optimization tools have many essential parameters and the decision as regard what value to be chosen for these key parameters affects the convergence of these algorithms. TLBO on the other hand, has less specific

parameters, very simple to implement, and requires less computational time. The sizes of population coupled with the number of maximum iterations are its key parameters of interest [21]. Essentially, both the teacher's phase and learners' phase are the essential phases in the algorithm. In TLBO, learners being the initial solutions set are usually randomly generated; the value of the objective serves as bases to judge the possessed knowledge by each learner. The learner that has good possession of most knowledge (best objective function value) is considered to be the teacher, while other solutions are regarded as the students.

Modeling of the teacher phase which entails the flow of knowledge from teacher being the best solution to learners is given as;

$$Diff_{mean} = rand(X_{t,j} - T_f \times M_j) \quad (18)$$

$$X_{i,j}^{new} = X_{i,j}^{old} + Diff_{mean} \quad (19)$$

$$T_f = 0.5 * [1 + rand(0,1)] \quad (20)$$

$X_{i,j}^{old}$ is replaced with $X_{i,j}^{new}$ when gives better solution.

where; M_j = mean of variable considering all learners, $X_{i,j}$ = i^{th} learner's variable j^{th} ,

$X_{t,j}$ = Teacher's j^{th} variable and T_f is usually either 1 or 2.

The mathematical modelling for learners' phase in which each respective learner seeks to advance its previous knowledge via learning from the rest learners which he considered to be in good of possession of enhanced knowledge more than himself is given as;

$$\text{If } F(X_{i,j}) < F(X_{qj}) \quad (21)$$

Then

$$X_{i,j}^{new} = X_{i,j}^{old} + rand * (X_{i,j}^{old} - X_{qj}) \quad (22)$$

Otherwise, if

$$F(X_{i,j}) > F(X_{qj}) \quad (23)$$

Then;

$$X_{i,j}^{new} = X_{i,j}^{old} - rand * (X_{i,j}^{old} - X_{qj}) \quad (24)$$

$X_{i,j}^{new}$ is only acceptable if only and if equation (21) and (23) are satisfied.

where; X_{qj} = q^{th} learner's j^{th} , $F(X_{i,j})$ = objective function value for variable $X_{i,j}$ and q = randomly selected partner by each i^{th} learner.

The proposed approach is as shown in Figure 1 with the essential steps represented by each block.

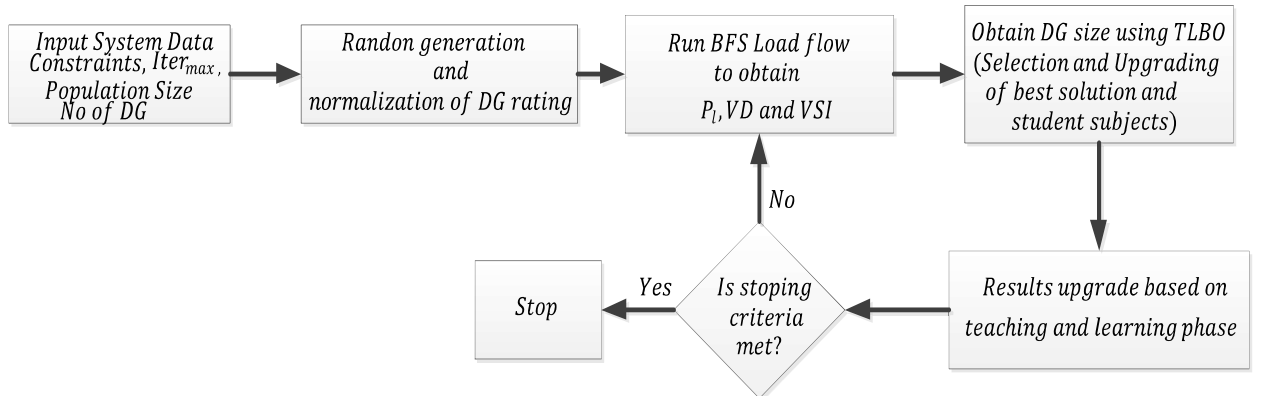


Figure 1: The Framework of the Proposed Approach

III. Description of Test Case Systems

The proposed approach was firstly implemented on a test system (IEEE 34-bus RDS), after which it was then implemented on a portion of the Nigerian network. The portion employed is the 11 kV 34-bus feeder in Ayepe area of Osogbo under Ibadan Electricity Distribution Zone in the South-West Nigeria. Detailed descriptions and corresponding line diagrams representation of proposed systems used for the analysis are as discussed in sub-sections 3.1 and 3.2.

A. The Test Case: IEEE 34 Bus System

The IEEE 34-bus RDS has 34 buses, 33 lines and 1 substation. Its real load stood at 4.636 MW, while its reactive load has been estimated to be 2.873 MVar. The one line diagram is as shown in Figure 2.

B. Ayepe 34-Bus Feeder Radial Distribution System

This feeder sprouts from Ayepe 15 MVA, 33/11-kV injection substation situated in Osogbo town. Characteristically, the feeder has 34 buses and 33 branches. The respective real and reactive power loads are 4.15 MW and 2.04 MVar. Figure 3 depicts the feeder's one line diagram.

IV. Results and Discussion

MATLAB 8.1.0.604 (R2013b) was used as the implementation software for this approach. The BFS was employed to compute the system power loss with and without DG installation. Then VSI was computed to pre-select the weak

buses, after which TLBO was employed to determine the optimal size and allocation of disperse generation on both systems. Table 1 presents the parameter values of TLBO, which gave the optimal results as control parameters.

A. Case I: IEEE 34-bus RDS

Voltage stability index is a viable tool for determining where DGs are to be sited; buses with the least value of VSI are the potentials

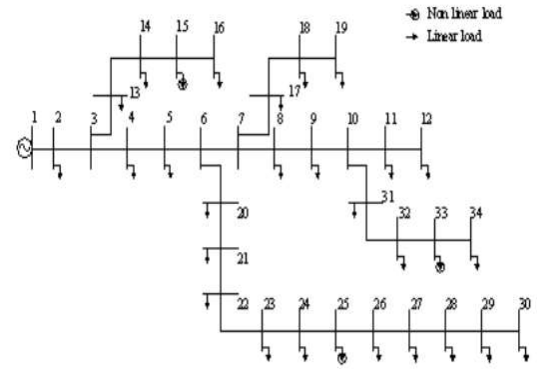


Figure 2: IEEE 34-Bus RDS; Line Diagram Representation

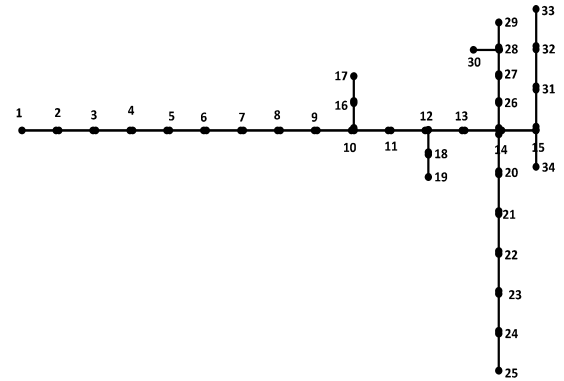


Figure 3: Ayepe 34-Bus Radial Distribution Network One Line Diagram

Table 1. Optimal Values of the TLBO Parameters

Parameters	Optimal Values
Value of Constant TF	1.0
No of subjects (Design variables)	20
Name of subject (Design variable; DG capacity size)	1kW
Population Size	50.0
Maximum Iteration	100.0

buses for siting DG. These buses are thus pre-selected with a view to reduce the algorithm exploration and exploitation of search space. Among the weak buses pre-selected from the computed value of the VSI, bus 11 was selected as the optimal location by TLBO and optimum DG size was found to be 1 kW. Immediately after the installation of this DG, the entire active power losses diminished from 571 kW to 208.5954 kW, this amounts to 63.5726% reduction. Figure 4 represents a comparison of the overall real power loss prior and immediately after the DG inclusion.

It was revealed that the voltage profile at each bus improved significantly as evidently seen in Figure 5, which compares the system voltage profile prior and immediately after sitting of disperse generation at the bus 11.

A good index to quantify the extent of voltage stability of the RDS is the VSI. The system's VSI was computed with and without DG installation. It was observed that the VSI at each bus improved remarkably as seen in Figure 6, which presented a line graph comparison of the VSI before and after including the DG.

B. Case 2: Ayepe 34- Bus RDS

The base case overall active power loss was established to be 1.1 kW and the minimum magnitude of bus voltage occurred at bus 25, which is 0.829482220 p.u. When the VSI was computed, the pre-selected locations for the integration of DG are bus 11 (0.8515), bus 22 (0.47897) and bus 23 (0.4769). However, TLBO selected bus 11 as the optimal site, while the optimal size of DG included was 1 kW showing that a micro DG [1] is required. The system's

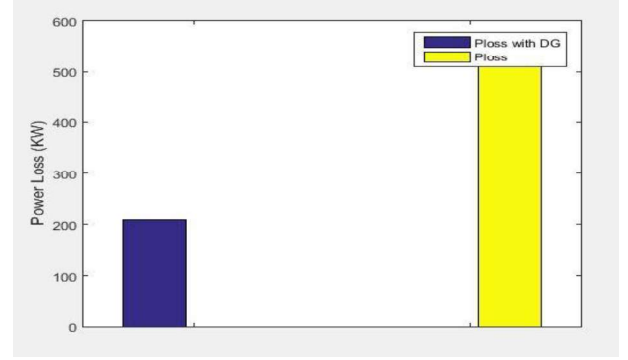


Figure 4: Comparison of Real Power Loss with and without DG

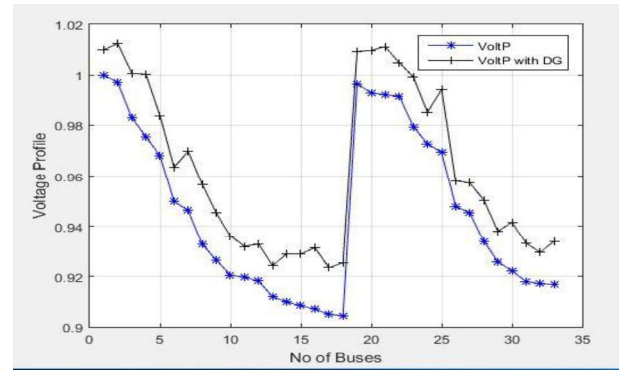


Figure 5: System Voltage Profile before and after DG installation

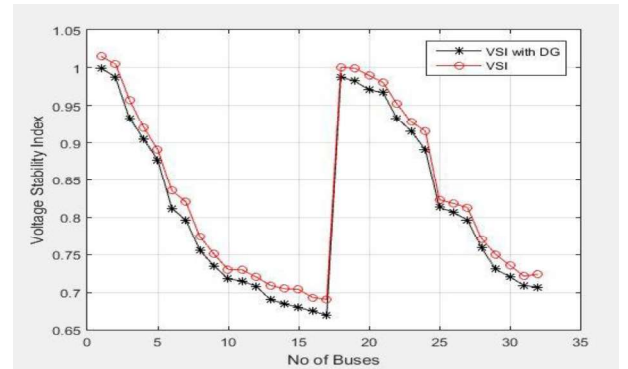


Figure 6: The System VSI with and without Installation of DG

Table 2. Summary of results on Ayepe 11 kV Feeder

Parameters of Interest	Without DG	With DG
Minimum Bus Voltage Magnitude (p.u)	(25) 0.8295	(25) 0.8456
Minimum VSI	(24) 0.4741	(24) 0.5120
Total Real Power Loss (kW)	1.100	0.750
Bus and Size of DG Installed	-	11(1kW)
Type of DG		Micro Distributed Generation

overall real power loss diminished appreciably with about 31.8% reduction (1.1kW to 0.75 kW).

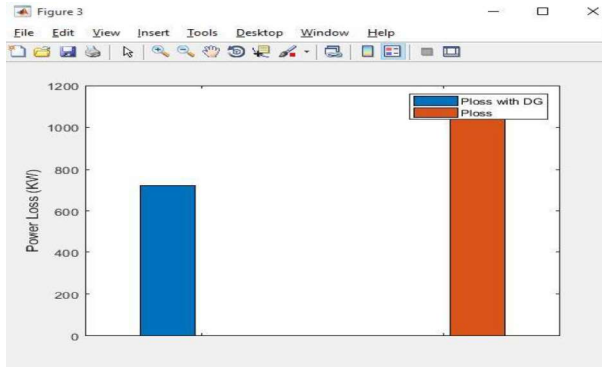


Figure 7: Comparison Real Power Loss with and without DG Installation

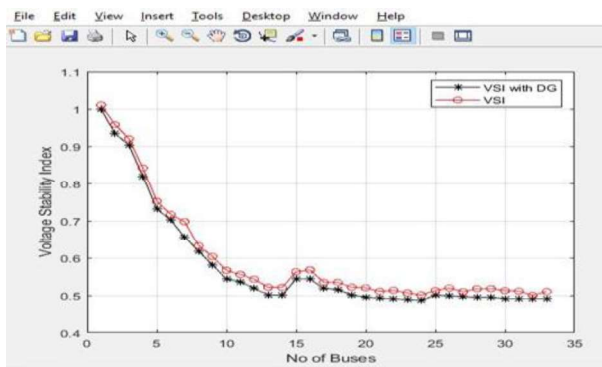


Figure 8: Comparison of VSI with and without DG Installation

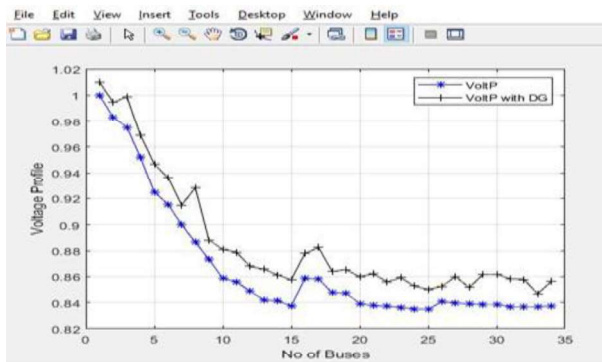


Figure 9: Comparison of System Voltage Profile with and without DG Installation

The stability of the system, as measured by the value of each VSI, was found to improve remarkably, most especially with the buses far from the sub-station. A comparison of the bus

VSI before and after the installation of micro DG is as shown in Figure 8.

The impact of the micro DG of size 1kW installed at bus 11 also raised the system voltage profile appreciably. It is a common knowledge that buses far away in RDS suffered severe bus voltage deviation. The DG installed at bus 11 raised the voltages of the far away buses remarkably. The comparison of bus voltage magnitude with and without DG installation is as shown in Figure 9.

The summary of the results obtained from the proposed method with respect to the size of DG integrated, optimal location, real power loss, the voltage magnitude as well as voltage stability index is presented in Table 2.

V. Conclusion

Presented in this study is the teaching-learning based optimization approach for sizing and siting of distributed generation for real power loss reduction on the Nigerian power grid. The results obtained show that the micro DG included in the network reflected a significant reduction in the system's real power loss, enhanced system voltage profile and provided appreciable improvement in the system's VSI. The proposed technique is therefore a promising optimization approach for addressing the two major problems (real power loss and voltage deviation) on the Nigerian radial distribution network.

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