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# Optimal Placement and Sizing of Distributed Generator in the Makurdi Medium Voltage Distribution Network using a Genetic Algorithm

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***Abstract:*** *The Nigerian power sector is currently dealing with a range of issues, including shortages in electricity generation, inefficiencies in the system and major power losses along the long stretches of transmission and distribution lines. This paper aims to improve the performance of the underperforming distribution network by strategically adding Distributed Generation (DG) units, carefully positioned and sized within the grid. The North-Bank feeder of Makurdi's medium voltage distribution system was chosen as a case study because it experiences persistent supply shortages and voltage drop problems more than other feeders in the network. This feeder, which consists of a 10-bus system running over a long route with increasing load demands, was initially modeled and tested using MATLAB/Simulink environment. The initial results showed a total real power loss of 0.089 MW and line losses of 0.090 MW, with about 90% of the buses showing voltages below the required range of 0.95 pu to 1.05 pu. To mitigate these problems, a combination of Genetic Algorithm (GA) and the Newton-Raphson method was utilized to find the best size and placement for the DG units in the network. After running the simulations with the optimized DG setup, the results were quite promising. Active power losses dropped significantly from 0.089 MW to 0.00013 MW, which is roughly a 99.89% reduction. The voltage levels across all buses improved considerably, with buses 5 and 9 seeing voltage increases of 75% and 38.2%, respectively. Therefore, it is obvious from the results that the main goal of improving the distribution network's efficiency was successfully achieved.*

***Key Words:*** *Distribution networks, Power loss, Distributed Generation, Genetic Algorithm, optimization*

## I. INTRODUCTION

As the world's demand for electricity continues to grow especially in developing countries like Nigeria, so does the need to cut down greenhouse gas emissions, reduce active power losses, improve voltage stability, and boost overall power system reliability. This has sparked increased interest in incorporating Distributed Generation (DG) into Medium Voltage (MV) distribution networks. According to [1], DG refers to the generation of electrical power closer to where it's actually utilized, often blending renewable and non-renewable sources. In many cases, DG doesn't require transmission lines for connection, which is known as off-grid DG [2]. Figuring out the best way to place and size DG units in a MV distribution network is quite tricky. It involves balancing numerous technical, economic, and environmental factors. That's why, to make the most of DG, its placement must be carefully planned. If the DG is placed poorly—either in the wrong spot or at an unsuitable size—it can lead to increased system losses, voltage swings, flickering, protection issues, harmonic distortion, system instability, and wasted investment [3]. This paper aims to determine the best placement and size of a distributed generator in the North-Bank feeder of the Makurdi medium voltage distribution network.

Many studies have been conducted to figure out the best way to place and size distributed generation (DG) units to make power systems more efficient. These efforts focus on reducing active power losses, improving voltage stability, and other benefits [4, 5, 6, 7]. When it comes to finding the optimal DG placement and sizing, researchers have used a variety of optimization techniques. These methods can be classified into different categories, such as deterministic approaches like analytical methods or Sequential Quadratic Programming (SQP), and heuristic methods like Genetic Algorithms (GA), Particle Swarm Optimization (PSO), or Artificial Bee Colony (ABC). Also, these optimization strategies can be either single-objective or multi-objective, depending on how many goals they aim to achieve. The main goals in most of the literature for DG placement are to minimize power losses and enhance voltage profiles.

[8] posited an optimal placement of distributed generation using genetic algorithm. The proposed algorithm was applied on a 33-bus and 69-bus systems. The obtained results showed 62.52% of improvement in power loss after placement of DG for 33 bus test system and 64.9% of improvement in power loss after placement of DG for 69 bus test system. [9] used an objective function considering power losses, voltage profile, and pollution emission, which was solved by equilibrium optimizer (EO). Finally, the effectiveness of the proposed

strategy was verified based on IEEE 33 and 69-bus distribution networks. [10] presented an improved multi-objective whale optimization (MOWOA) technique to position and optimally sized DGs in optimal locations. To prove its effectiveness, the suggested method was tested on different test systems for radial distribution, including the bus systems IEEE-33 bus and IEEE-69. [11] presented an improved analytical technique to solve the problem of optimal location and sizing of distributed generation for distribution systems.

## II. MATERIAL AND METHODS

**Description of the Case Study Feeder**

The North Bank feeder is a 10-bus feeder consisting of 33 kV and 11 kV buses. The single line diagram of the North-Bank feeder network is presented in Figure.1, The feeder network has a maximum load of 14.9 MW and 11.8 kVAR with operating voltages of 33/11 kV. The feeder is located in the state capital city supplying some industrial loads, commercial centers and residential consumers connected along the length of the network. In the recent years, the feeder has been cumbered with serious challenges like overloading, outages, loss of supply, etc.

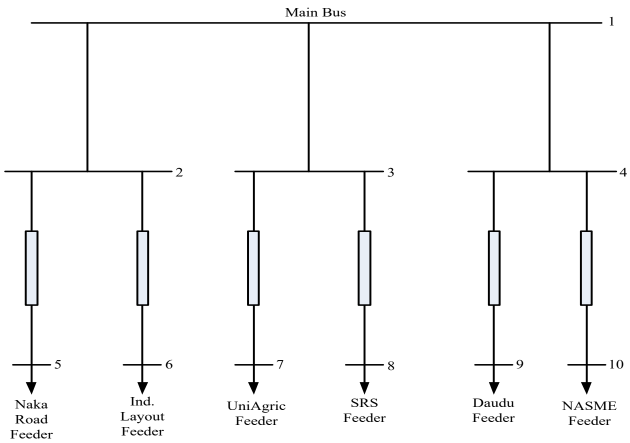


**Figure 1: Single Line Diagram of the 10-Bus 33/11 kV North-Bank Feeder**

**Optimization Techniques.**

Optimization techniques are methods used to find the best solution among a set of possible solutions, given a specific objective function and constraints. Optimization techniques for Distributed Generation (DG) placement refer to methods used to determine the optimal location, size, and type of DG units (e.g., solar, wind, or energy storage) in a power distribution system. The goal is to minimize costs, maximize benefits, and ensure reliable operation. The combination of two algorithms was used in this study: the Newton-Raphson algorithm obtained from [12] as presented in Figure 2 for load flow analysis and genetic algorithm as presented in Figure 3 for optimization.

**Newton–Raphson (NR) Method of Power Flow Analysis.**

Newton–Raphson is usually very efficient and a preferred method for load flow analysis due to its ability to handle complex power systems with multiple voltage-dependent loads and generators. It converges rapidly, especially for small to medium-sized systems. NR provides highly accurate results for voltage magnitude and phase angle. However, Newton–Raphson method requires good initial guesses and may diverged if Jacobian matrix is singular or ill-conditioned. The calculation of the load flow analysis starts by describing Kirchhoff Current Law (KCL), which states that the sum of currents flowing into a node equals the sum of currents flowing out of the node as shown in Figure 2.

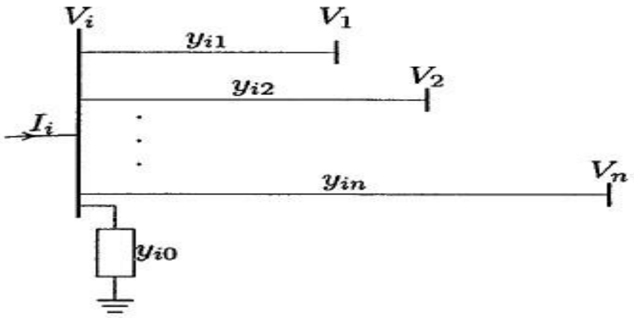


**Figure 2: A Typical Bus of the Power System [12]**

The current flow out from bus i can be described in the equation (1),

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

where:
$I_i$: current injected from bus i in pu.
$Y_{ij}$: mutual admittance between bus i and j in pu.
$V_j$: voltage of bus j in pu.
$\theta_{ij}$ : angle of mutual admittance between bus i and j in radian.
$\delta_j$: voltage angle of bus j in radian.
Meanwhile, real and reactive power injection are described using the equation below,

$$P_i - jQ_i = V^*{}_i I_i \quad (2)$$

where:
$P_i$: active power injected from bus i in pu.
$Q_i$: reactive power injected from bus i in pu.
$V_i$: voltage of bus i in pu.
$I_i$: current injected from bus i in pu.
Substituting for Ii yields,

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

The algorithm for Newton-Raphson load flow method can be summarized in the following steps [12]:

1. Initialization: for load buses, the active and reactive power are known; the voltage and angle must be estimated. For the slack bus, the voltage and angle are known, so set the voltage magnitude to 1 and the angle to $0^{\circ}$.
2. Calculate power mismatch: calculate P and Q injection for load buses using the given values and the estimated values of voltage magnitudes and phase angles, while, for generator bus, P injection is calculated. After that power mismatch $\Delta P$ and $\Delta Q$ can be found.
3. Jacobian matrix is formed using the partial derivative equations which are in terms of voltage magnitude and angle.
4. Then, solve the equation by either inversing the Jacobian matrix and multiplying it by the power mismatch or using Gaussian elimination for the Jacobian matrix so as to find $\Delta\delta$ and $\Delta|V|$ values.
5. New estimated values are found for voltage magnitude and angle.
6. These steps are repeated until the power mismatch is less than the specified accuracy.

**Voltage Stability Index**

A system experiences a state of voltage instability when there is a progressive or uncontrollable drop in voltage magnitude following a disturbance, increase in load demand, or change in operating condition. It is usually identified by an index called the steady-state voltage stability index, evaluated using sensitivity analysis. Sensitivity analysis is the computation of the voltage stability index of all the nodes in RDS.

The SI Index, proposed by [13], was utilized to find the weakest voltage bus in the power system. This index will find the most optimum weakest link in the system, which could lead to voltage instability in the future when there is an increase in load. The value of the index is given by equation (4).

$$SI = |V_s|^2 - 4 \times [P_r x_{ij} - Q_r r_{ij}]^2 - 4 \times [P_r x_{ij} - Q_r r_{ij}] \times |V_s|^2 \quad (4)$$

where,
$SI$ = stability index,
$V_s$ = sending bus voltage,

$P_r$ = active load at the receiving end,
$Q_r$ = reactive load at the receiving end,
$r_{ij}$ = resistance of the line i-j and
$x_{ij}$ = reactance of the i-j.
Under stable operation, the value of $SI$ should be greater than zero for all buses. When the value of $SI$ becomes closer to one, all buses become more stable. In the proposed algorithm, $SI$ value is calculated for each bus in the network and sorted from highest to lowest value. The bus having the lowest value of $SI$ will be considered in fitness function

**Genetic Algorithm (GA).**

Genetic algorithms (GAs) are stochastic global search and optimization methods that mimic the metaphor of natural biological evolution. Genetic algorithms work with a group of candidate solutions using the concept of survival of the fittest to iteratively generate improved approximations to the optimal solution. The advantages of using GA are that it requires no knowledge or gradient information about the response surface; it is resistant to becoming trapped in local optima, and it can be employed for a wide variety of optimization problems.

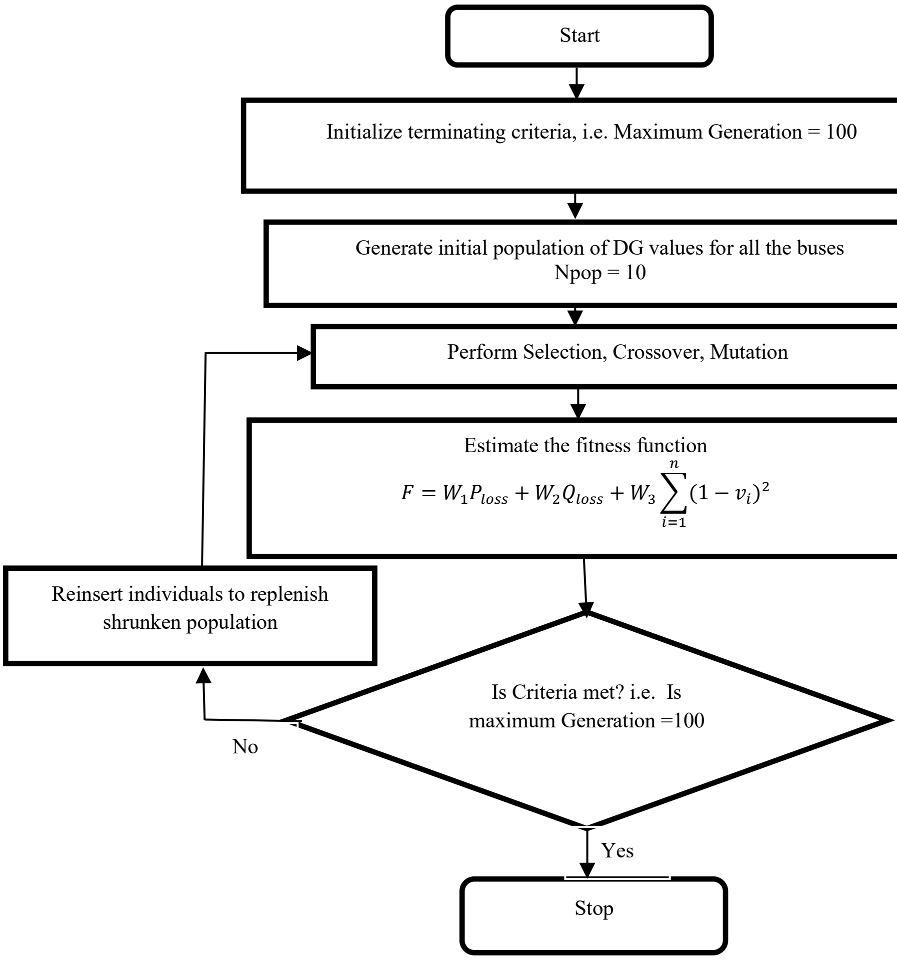


**Figure 3: Flow Chart for Optimal Size and Placement of DG using Genetic Algorithm**

**Solution Methodology**

To achieve the optimization problem of active power loss reduction and voltage profile improvement by optimal placement and sizing of DG in the North Bank feeder of Makurdi medium voltage distribution network, certain procedures as described here were followed. The data for North Bank feeder which consisted of load bus, line resistance and reactance, used in this work was obtained from Energy Trading Unit (ETU), Jos Electricity Distribution Company Plc, Makurdi Business Unit. The data collected were organized and used to perform power flow analysis for the base case network, using the Newton-Raphson technique to determine the amount of power loss and voltage profile of all the buses. After power flow analysis, the Voltage Stability Index was employed to select the weaker buses as the most appropriate candidate buses for the placement of the DG unit based on their voltage profile problem.

Genetic algorithm optimization technique was then implemented to find the optimal sizing of DGs. By applying these methods to interact with Newton-Raphson programmed in MATLAB 2015a, the power flow analysis of the North-Bank feeder with the installation of DG was performed. Finally, the results of power flow analysis with and without DG installation was compared and the optimization problem was solved.

## III. RESULTS AND DISCUSSION

**Simulation Results**

The data used for simulation in this study was retrieved from Energy Trading Unit (ETU), Jos Electricity Distribution Company Plc, Makurdi Business Unit. The results obtained during simulation are presented and discussed.

**Table 1: Load Flow Result of North-Bank 10-bus Feeder without DG**

| Bus No. | Vp | Angle | Injection | | Generation | | Load | |
|---|---|---|---|---|---|---|---|---|
| | (pu) | (Deg) | MW | Mvar | MW | Mvar | MW | Mvar |
| 1 | 1.0000 | 0.0000 | 14.989 | 22.485 | 14.989 | 22.485 | 0 | 0 |
| 2 | 0.7351 | -11.6476 | 0 | 0 | 0 | 0 | 0 | 0 |
| 3 | 0.8938 | -6.4100 | 0 | 0 | 0 | 0 | 0 | 0 |
| 4 | 0.7982 | -11.4763 | 0 | 0 | 0 | 0 | 0 | 0 |
| 5 | 0.5717 | -25.4043 | -4.65 | -3.72 | 0 | 0 | 4.65 | 3.72 |
| 6 | 0.7174 | -13.3068 | -1.5 | -1.2 | 0 | 0 | 1.5 | 1.2 |
| 7 | 0.8866 | -6.9743 | -0.45 | -0.36 | 0 | 0 | 0.45 | 0.36 |
| 8 | 0.8543 | -9.4267 | -2.9 | -2.32 | 0 | 0 | 2.9 | 2.32 |
| 9 | 0.7232 | -17.6854 | -2.4 | -1.92 | 0 | 0 | 2.4 | 1.92 |
| 10 | 0.7900 | -12.1958 | -3 | -2.4 | 0 | 0 | 3 | 2.4 |
| **Total** | | | **0.089** | **10.565** | **14.989** | **22.485** | **14.9** | **11.92** |

**Table 2: Line Flows and Losses for North-bank 10-bus Feeder without DG Installation**

| From Bus | To Bus | P MW | Q Mvar | From Bus | To Bus | P MW | Q Mvar | Line Losses MW | Mvar |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 6.205 | 11.476 | 2 | 1 | -6.17 | -7.341 | 0.0350 | 4.1350 |
| 1 | 3 | 3.359 | 3.7 | 3 | 1 | -3.352 | -2.951 | 0.0060 | 0.7490 |
| 1 | 4 | 5.425 | 7.309 | 4 | 1 | -5.405 | -4.856 | 0.0210 | 2.4530 |
| 2 | 5 | 4.67 | 6.067 | 5 | 2 | -4.65 | -3.72 | 0.0200 | 2.3470 |
| 2 | 6 | 1.501 | 1.273 | 6 | 2 | -1.5 | -1.2 | 0.0010 | 0.0730 |
| 3 | 7 | 0.45 | 0.367 | 7 | 3 | -0.45 | -0.36 | 0.0000 | 0.0070 |
| 3 | 8 | 2.902 | 2.584 | 8 | 3 | -2.9 | -2.32 | 0.0020 | 0.2640 |
| 4 | 9 | 2.404 | 2.393 | 9 | 4 | -2.4 | -1.92 | 0.0040 | 0.4730 |
| 4 | 10 | 3.001 | 2.463 | 10 | 4 | -3 | -2.4 | 0.0010 | 0.0630 |
| **Total** | | | | | | | | **0.0900** | **10.5640** |

**Table 3: Voltage Profile of all the Buses without DG**

| Bus No. | Voltage profile | Angle |
|---|---|---|
| | (pu) | (Deg) |
| 1 | 1.0000 | 0.0000 |
| 2 | 0.7351 | -11.6476 |
| 3 | 0.8938 | -6.4100 |
| 4 | 0.7982 | -11.4763 |

| | | |
|---|---|---|
| 5 | 0.5717 | -25.4043 |
| 6 | 0.7174 | -13.3068 |
| 7 | 0.8866 | -6.9743 |
| 8 | 0.8543 | -9.4267 |
| 9 | 0.7232 | -17.6854 |
| 10 | 0.7900 | -12.1958 |

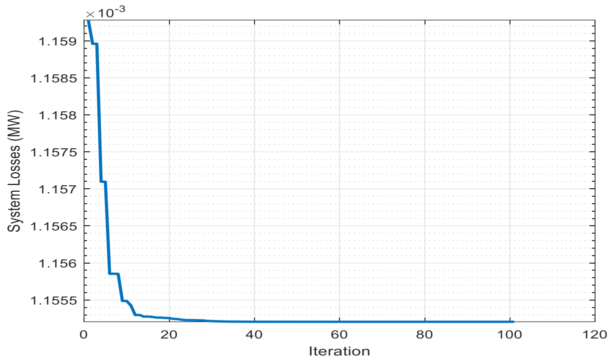


**Figure 4: GA Convergence Characteristics for North-Bank Feeder**

**Table 5: Comparison of Load Flow Results Summaries of North-Bank Feeder with/without** DG

| **Without DG** | | **With DG** | |
|---|---|---|---|
| Active Power Loss (MW) | Reactive Power Loss (MVar) | Active Power Loss (MW) | Reactive Power Loss (MVar) |
| **0.089** | **10.565** | **0.00013** | **0.0015** |

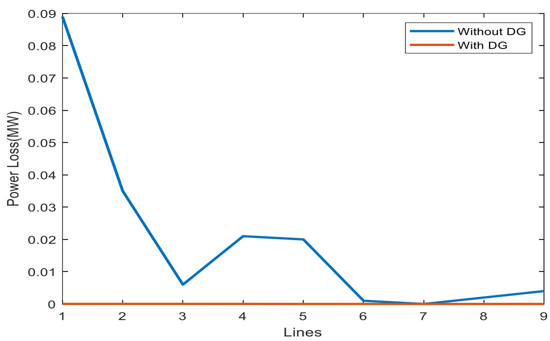


**Figure 5: Active Power Loss of North-Bank feeder with/without DG**

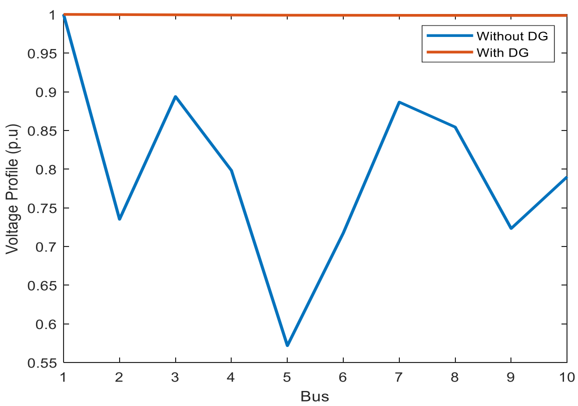


**Figure 6: Voltage Profile of North-Bank Feeder with/without DG installation**

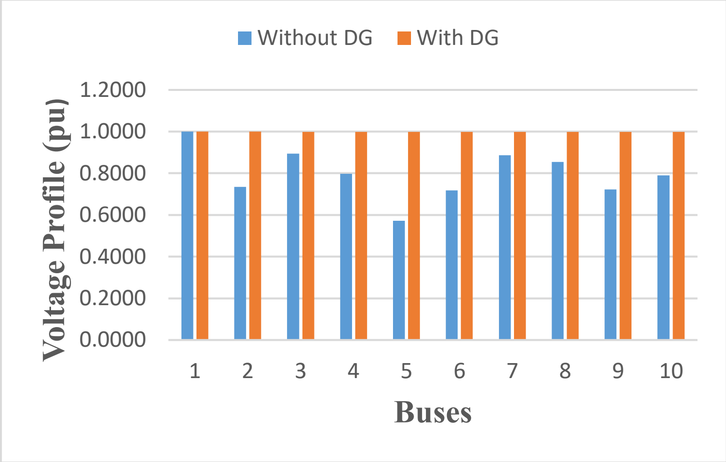


**Figure 7: Bar Chart showing Voltage Profile of North-Bank feeder with/without DG**

**Load flow analysis of 10-bus North-Bank feeder without DG Installation**

Load flow analysis of the North Bank feeder was carried out without DG installation in the network using the Newton-Raphson iterative technique in MATLAB 2015a software. Table 1 shows the results obtained from the analysis of the base case network. It was observed from the results that active and reactive power losses of the network were 0.089 MW and 10.565 MVar, respectively. Also, according to the results in Table 2, the active and reactive losses on the line without DG were recorded as 0.0900 MW and 10.5640 MVar, respectively. For a statutory voltage limit between 0.95 pu and 1.05 pu, which is the considerable voltage limit for the Nigeria distribution network. Only 10% out of the ten (10) buses in the network were within the statutory voltage limit; 90% of the buses in the network were below the statutory voltage limit of 0.95 pu to 1.05 pu before DG was placed on the network. It can be inferred that the network is very weak and needs enhancement to make it more efficient.

**Location and Sizing of Distributed Generation.**

The optimum size and location of DG for the case study network were determined using the Voltage Stability Index (VSI) as stated in equation 4. The result in Table 3 showed that bus 5 and bus 9 had the poorest voltage profile values of 0.5717 pu and 0.7232 pu, respectively. These two buses were considered weaker buses and the best location for placement of DG. Hence, two DGs of 8 MW capacity each were placed at these locations.

**Load flow analysis of 10-bus North-Bank feeder with installation of DG**

Load flow analysis of the North Bank feeder was repeated when DGs were installed at their respective sized locations. Simulation was carried out by the implementation of the genetic algorithm optimization technique. Figure 4 shows the convergence characteristics of power loss over iteration for the North Bank feeder. Table 4 presented a summary of results obtained from load flow analysis carried out on the North Bank Feeder. The results present an active power loss of 0.00013 MW when the DG was installed and a reactive power loss of 0.0015 MVar without DG connection to the network.

**Power Losses Reduction**

Figure 5 shows the graphical representation of load flow analysis obtained with and without installation of DG in the network. The graph shows that the incorporation of DG in the network minimized power losses significantly. Comparatively, the total active and reactive power losses of the network before and after DG installation were reduced significantly, from (0.089 MW, 10.565 MVar) without DG to (0.00013 MW, 0.0015 MVar) with DG. These represent about 99.85% active power loss reduction and 99.89% reactive power loss reduction.

**Voltage Profile Improvement**

The percentage voltage losses before DG installation were more than those recorded after DG installation. About 90% of buses were operating below the permissible voltage limit when the load flow analysis was carried out on North Bank Feeder without DG installation. However, after the incorporation of the DG and simulation, there was an improved voltage profile in all buses of the network. Hence, the effect of DG integration on the network for voltage profile improvement was achieved as shown in Figure 5 and Figure 6.

## IV. CONCLUSION

With the aim to reduce active power loss and improve the voltage profile of the distribution network, the North Bank feeder of the Makurdi medium voltage distribution network was chosen owing to its large loss and voltage drop problem compared to the rest of the feeders. The selected feeder has a long route and experiences significantly increasing loads. It is evidently clear from the simulation results that the decreases in the total real and reactive power losses and the improvement in bus voltage profiles are a function of the optimal location and size of the DG unit. The results also revealed that the use of genetic algorithm optimization with Newton-Raphson to size and place the DG on the network contributes to an active power loss reduction from 0.089 MW to 0.00013 MW, which represents a 99.89% reduction in active power loss. The voltage profiles of all the buses were improved to 1.00 pu, with bus 5 and bus 9 having a voltage profile improvement of 75% and 38.2%, respectively. Therefore, the optimization of DG will increase the efficiency of the distribution system without the need to expand the existing power system.

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