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A Genetic Algorithm Approach to Optimal Sizing and Placement of Distributed Generation on Nigerian Radial Feeders

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ABSTRACT

Mitigating power loss and voltage profile problems on radial distribution networks has been a major challenge to distribution system operators. While deployment of distributed generation, as compensators, has made a suitable solution option, optimum placement and sizing of the compensators has been a concern and it has thus been receiving great attention. Meta-heuristic algorithms have been found efficacious in this respect, yet the use of the algorithms in addressing problems of radial feeders is still comparatively low in Nigeria where analytical and numerical programming methods are common. Hence; the use of genetic algorithm to site and size distributed generator for real-time power loss reduction and voltage profile improvement on the Nigerian secondary distribution networks is presented. Backward-forward sweep load flow analysis, together with loss sensitivity factor, is deployed to identify the buses suitable for the installation of the distributed generation, while the algorithm is employed in estimating the optimum size. This approach is tested on the standard IEEE 15-bus system and validated using a Nigerian 11 kV feeder. The result obtained on the IEEE test system shows 183 kW loss using the compensator, as compared to 436 kW loss without the compensator; while on the Nigerian network the loss with the compensator was 4.99 kW, in comparison with no-compensation loss of 10.47kW. By the approach of this study, real power loss on the Nigerian feeder decreased by 52.3% together with energy cost reduction from N658,789.12 to N314,227.38. Likewise the minimum bus voltage magnitude and the voltage stability index of the network are improved to acceptable limits. This approach is therefore recommended as capable of strengthening the performance of the Nigerian radial distribution system.

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INTRODUCTION

Distribution system operators are challenged in maintaining correct voltage profiles across distribution networks. For the widespread socio-economic development, power demand at distribution ends increases; for which the ability of radial distribution networks to have faithful accountability for the power input from upstream transmission operators is jeopardized. Basically, four important parts which the power system network is made up comprises: generation, transmission, distribution, and utilization; that need to be efficiently planned and securely operated to maintain a required standard of voltage level and frequency. Various devices, that include on-load tap changers and static Volt-Ampere Reactive (VAR) compensators, are traditionally deployed in controlling and keeping the voltage in distribution systems within a specified range. Operations of the devices are well coordinated to ensure proper performances (Hadjsaid et al., 2013). But with the continuously increasing demand for electric power owning to population expansion and speedy economic ballooning, distribution systems operations, particularly in developing nations, have been approaching the peak in reference to power carrying capacity and voltage stability.

Since the recent past, distributed generation (DG) has been deployed as compensator on power system networks. It has been submitted by Islam *et al.* (2012) that distribution sub-systems are switching to active from passive networks due to the growing penetration rate of DG. The increasing connection of DG to power system networks is accompanied by several adverse effects including voltage dissimilarities, impaired protection, revamped transient stability limits, bi-directional power flows and augmented MVA fault level. Voltage dissimilarities has been undertaken as the most prepotent impact with DG (Xu and Taylor, 2018). When DG sources are added to a power system, the base case operation scenarios are varied that, as a result, calls several factors to be addressed at the design phase of DG installations. Factors like: which technology should be used? How many DG units and of what capacity should be installed? Where should they be situated, and what connection type should be used?; Require careful considerations. Caution is therefore necessary in approaching DG allocation and sizing on power systems as inappropriate and inefficient connection may make the system liable to loss increase and, consequently higher costs (Arorede *et al.*, 2014). To this end, several methods are being evolved and employed to optimally place and size DG.

In Viral and Khatod, (2015), an analytical approach is used for DG sizing and siting in a balanced radial distribution network for loss minimization. The method was tested on 15-bus IEEE test system with about 42% reduction in loss. It is, however, noted that the loss could be further reduced for better performance of the distribution system by implementing a more robust technique. Gopiya Naik (2013) presents an analytical approach to prune the actual power loss in a distribution network, a sensitivity analytic technique to identify the optimal location for placement of both DG and capacitor and then a heuristic curve fitting technique for obtaining their optimal capacity. However, the DG model considered a fixed power factor controllable synchronous generator with actual and reactive power delivery. Authors in Win and Swe (2015) used the exact loss formula to figure the optimal size and corresponding optimum location of DG, with 4 DG types considered. Gross reactive and real power losses was curtailed, while the voltage profile is also ameliorated. But though Newton-Raphson's approach to power flow was adopted yet the drawbacks of the method is that an earlier study that used 3 DG and supplied both real and reactive power was discovered to be more trenchant in reducing the total power loss in the system. A steady voltage distribution with respect to constructive reconfiguration algorithm has been proposed to reconfigure simultaneously with sizing and siting in distribution network with the view of achieving maximal reduction in the loss (Bayat *et al.*, 2016). A bi-directional progression of current that emerges as a result of the newly installed DGs in various parts of the circuit is considered in (Sivakumar *et al.*, 2021) and multiple DG capacity is sized by utilizing real power sensitivity in large size distribution network at a time to achieve loss minimization and nodal voltage improvement. The study makes use of up-down sizing (UDS) based on the load distribution downward the feeder, and sensitivity sizing (SS) based on the real power loss sensitivity calculations, for the sizing of the DGs. Nevertheless, the proposed method did not look into location and was not practically evaluated.

Heuristic methods have been found to be more superior to analytical approaches. Reference Jamian *et al.* (2002) combined three varieties of particle swarm optimization to size DG, while (Antony and Baby, 2013) also used particle swarm optimization for optimal placement of DG. In Kumari *et al.* (2017) is presented a new particle swarm optimization (NPSO) with its performance compared to ordinary PSO and tested it on IEEE 15-bus system with a percentage loss reduction of 41%. Authors in Yammani *et al.* (2016) considered various load models for the mitigation of cost, power loss and voltage deviation where a shuffled bat algorithm (SBA) was proposed. Nevertheless, the convergence criteria were not preferable compared with shuffled frog leap algorithm (SFLA). Thangaraj and Kuppan (2017) allocated DG and distribution static synchronous compensators DSTATCOM simultaneously using lightning search algorithm (LSA) to solve the multi objective function and linearly varying the feeder loads. However, sizing was not addressed in the work. Cuckoo search algorithm was deployed to size compensators in (Uchendu, 2020) that individually and simultaneously placed shunt capacitor banks and DG on a distribution network to ascertain the behavior of the network, as well as to minimize the power loss and maximize the system voltage stability. Merits of backward forward sweep method over others like Gauss-Seidel and Newton-Raphson are highlighted in the report. Authors in Ullah *et al.* (2019) proposed a phasor particle swarm optimization on a practical radial distribution feeder. Power loss attenuation is the objective function rather than optimizing the annual energy loss. However, vital aspects of power system as stability, reliability and power quality, are not addressed. Authors in Abou El-Ela *et al.* (2018) approached a multi objective task in light of economic, environmental as well as technical benefits associated with optimal sizing of both DG and capacitor bank in distribution system by emulating the water flow cycle to sea from rivers form streams (water cycle algorithm), which achieved a more flexible result with DGs of controllable power factor rather than those with fixed power factor. However, by reducing the production cost, the goal was achieved economically. Presented in Kamarudin *et al.* (2019) is simulated swarm-based optimization application, firefly algorithm (FA), to suitably locate and size DG in order to achieve loss minimization and voltage profile improvement in a radial distribution network. However, refinement of objective function and problem formulation is possible for improvement. Proposed in Kamarudin *et al.* (2020) is a combination of particle swarm optimization (PSO) with ant lion optimization (ALO) and fuzzy logic controller (FLC). The elitism phase of the ALO is improved by the PSO, while training the parameter and data set with the FLC to locate DGs optimally. In Haider *et al.* (2021) is employed, branch and bound as well as classical method to solve the location while proposed a second order cone relaxation of the optimal power flow in solving the size which was combined to form the proposed methodology mixed integer second order cone programming MI-SOCP. However, the method was not capable of operating optimally with battery packages in the AC distribution network in exploring the optimal size and location.

Meta-heuristic methods have been adjudged to be more superior to analytical and numerical programming approaches, but it is submitted in the report on the findings in (Olabode *et al.*, 2018) that the use and the knowledge of the method is still relatively low in tackling power system problems in Nigeria. There have been some instances of deployment of heuristic techniques on the Nigerian radial distribution system (RDS), though. In Olabode *et al.* (2019a), is presented the application of FA on Nigerian 11 kV feeder as a good optimal sizing and siting shunt capacitor stratagem for actual power loss reduction when combined with voltage stability index (VSI) and with backward-forward sweep (BFS) load flow technique. Presented in Okelola *et al.* (2019) is teaching-learning based optimization technique, which together with BFS and VSI, was deployed for placement and sizing of DG for active power loss on Nigerian 11 kV secondary distribution network. A combination of BFS, loss sensitivity factor (LSF) and cuckoo search algorithm (CSA) has also been deployed in a two-stage approach for installation of shunt capacitor on a 17-bus Nigerian 11 kV feeder (Olabode *et al.*, 2020).

In a review paper by Olabode *et al.* (2019b), the authors acknowledge that there is research gap for further investigation on the use of heuristic-based approach of addressing the problem of reactive power supports on Nigerian electric grid system, hence; this study presents optimal sizing and sitting of DG for voltage profile improvement and actual power loss reduction on radial distribution system utilizing GA, and with a Nigerian 11 kV feeder employed as a case study.

MATERIALS AND METHODS

Essential steps involved in this work are: performance of the load flow study of the feeder using the backward-forward sweep technique, followed by finding the potential location and determining the size of the DG using GA, then installation of the chosen (optimal) size on the candidate bus, and finally, running the load flow studies.

Description of the case study feeder

The approach presented in this study was first validated on IEEE 15-bus radial feeder before implementing it on a typical Nigerian 11 kV 15-bus feeder as a case study. Figure 1 is the single line diagram of the IEEE test system, while the network's line and bus data is as available in (Das *et al.*, 1995).

The one-line Figure of the 11 kV distribution feeder, which is situated at Oluode Area of Osogbo in the southwestern region of Nigeria is shown in Figure 2 together with the line and load data as presented in Table 1 and Table 2 respectively. The Nigerian 15-bus feeder has a maximum load of 5 MW and 3.094 kVAR with operating voltage of 11 kV, while the geographical coverage supplied by the feeder is one of the largest commercial areas in the state capital city. Commercial activities that involve some industrial load, in addition to the large residential consumers connected along the length of the feeder, makes it worthy of concern for this investigation. Over the recent past years, the feeder has been cumbered with serious challenges like overloading, outages, loss of supply, to mention but few.

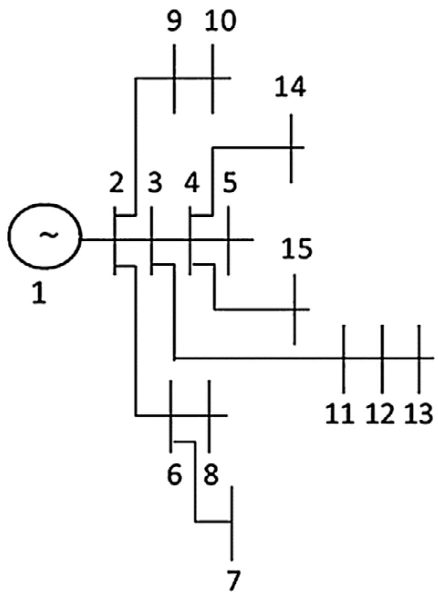

Figure 1: One line diagram of IEEE 15-bus RDS.

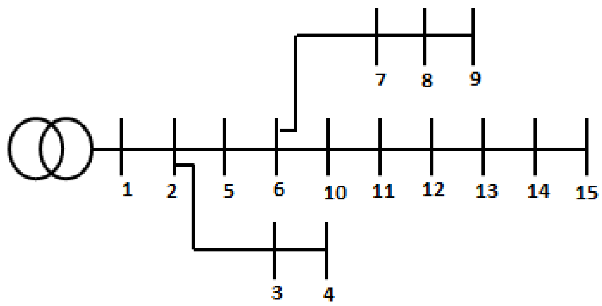

Figure 2: One line diagram of the Nigerian 11 kV network.

Table 1: Line Data

S/N	From Bus	To Bus	L (km)	R (Ω)	X (Ω)
1	1	2	0.7200	0.0155	0.2261
2	2	3	0.3600	0.0167	0.1130
3	3	4	0.9000	0.0419	0.2826
4	4	5	0.7200	0.0155	0.2261
5	2	9	0.7450	0.0346	0.2159
6	9	10	0.5400	0.0251	0.1696
7	2	6	0.2700	0.0126	0.0848
8	6	7	0.7250	0.0157	0.2277
9	6	8	0.2250	0.0105	0.0707
10	3	11	0.2250	0.0105	0.0707
11	11	12	0.5450	0.0253	0.1711
12	12	13	0.5000	0.0215	0.1570
13	4	14	0.9000	0.0419	0.2826
14	4	15	0.7200	0.0155	0.2261

Table 2: Load data

Bus No.	Bus Type	S (kVA)	P (kW)	Q (kVAR)
1	1	-	-	-
2	2	500.057	425.000	263.500
3	2	300.034	255.000	158.100
4	2	500.057	425.000	263.500
5	2	500.057	425.000	263.500
6	2	500.057	425.000	263.500
7	2	300.034	255.000	158.100
8	2	50.006	42.500	26.350
9	2	200.023	170.000	105.400
10	2	200.023	170.000	105.400
11	2	300.034	255.000	158.100
12	2	500.057	425.000	263.500
13	2	300.034	255.000	158.100
14	2	500.057	425.000	263.500
15	2	300.034	255.000	158.100

Load flow analysis

The backward sweep starts with branches in the last layer, moving towards the root node branches. The effective power flow in each branch is obtained by considering the node voltages of the previous iteration. The voltages obtained during the forward sweep are held constant during this step, and updated power flows in each branch are transmitted backwards along the feeder using the backward path. The backward-forward sweep is carried out iteratively until a convergence criterion is met. This criterion is set in the program such that if the solutions obtained in the subsequent iterations are consistently similar, the program stops execution (Olabode *et al.*, 2020; Okeloa *et al.*, 2019; Olabode *et al.*, 2019a)

Calculate the current of each load using equation (1).

$$i_n = \left(\frac{s_n}{v_n}\right) \tag{1}$$

where, i_n the load current at bus n.

s_n is the apparent power load at bus n.

v_n is bus voltage at node n.

Calculate the current of each line beginning form the tail of the feeder (2).

$$I_{n-1} = i_n + \sum_{k=n} i_k^{line} \tag{2}$$

where, i_{n+1} is the branch current at bus n from the end of the feeder.

i_n is the current at bus n

i_k is line current at bus *n*.

Calculate the voltage of each bus starting from the source (3).

$$v_{n+1} = v_n - i_n^{line} z_n^{line} \tag{3}$$

where, v_{n+1} is the voltage at bus n

v_n is the load voltage at bus n.

i_n is current at bus n.

z_n is impedance at bus n

The flow chat of the backward forward sweep load flow is as shown in Figure 3. forward sweep load flow is as shown in Figure 3.

Optimization procedure

Improvement of the voltage profile of the feeder, with a reasonable amount of reduction in power loss by optimally placing and sizing of DG is the main objective of this work. The placement problem's objective function is based on the VSI presented in (Chakravorty and Das, 2001) that describes placing of DGs on RDS to enhance voltage stability. The function to be maximized is:

$$f(VSI) = \sum_{i=2}^{n} VSI_i \qquad (4)$$

where,

$$VSI_i = |V_s|^4 - 4V_s^2(R_i P_{Li} + X_i Q_{Li}) - 4(X_i P_{Li} - R_i Q_{Li})^2 \qquad (5)$$

and

i = 2, 3, 4, …, n. Representing the total number of buses.

V_s is the source voltage, Q_{Li} is the total reactive power fed through node *I*, P_{Li} is the total active power fed through node *i*

- V_s depicts voltage at the source
- Q_{Li} depicts absolute KVAR power fed along node *i*
- P_{Li} depicts absolute real power fed along node *i*
- R_i depicts resistance within node *i* and source bus
- X_i depicts reactance within node *i* and source bus

Equation (4) was maximized subject to the following load flow equations and operational constraints.

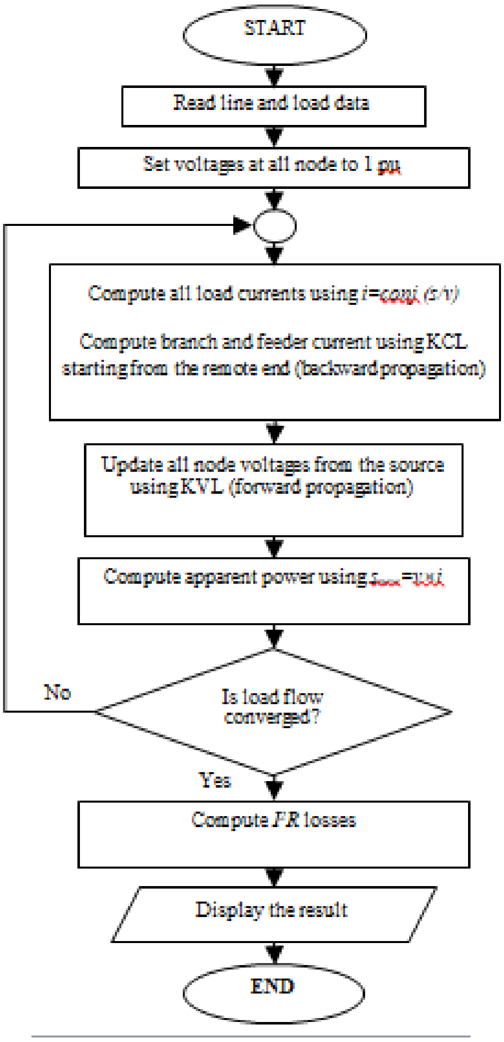

Figure 3: Flowchart of backward-forward sweep load flow algorithm.

(i) Equality constraints

The equality constraints include non-linear recursive power flow equations formulated as follows:

$$P_{i+1} = \left[P_{i,i+1} - \left\{R_{i,i+1}\frac{P_{i,i+1}^2 + Q_{i,i+1}^2}{|V_i|^2}\right\} - P_{i+1}^L + \alpha_{P_{DG}} p_{i+1}^{DG}\right] \qquad (6)$$

$$Q_{i+1} = \left[Q_{i,i+1} - \left\{X_{i,i+1}\frac{P_{i,i+1}^2 + Q_{i,i+1}^2}{|V_i|^2}\right\} - Q_{i+1}^L + \alpha_{Q_{DG}} Q_{i+1}^{DG}\right] \qquad (7)$$

$$|V_{i+1}|^2 = |V_i|^2 - 2(P_{i,i+1}R_{i,i+1} + Q_{i,i+1}X_{i,i+1}) + (P_{i,i+1}^2 Q_{i,i+1}^2)\left[\frac{R_{i+1}^2 + X_{i+1}^2}{|V_i|^2}\right] \qquad (8)$$

where,

P_{i+1} is active power through node $i+1$; Q_{i+1} is reactive power through node $i+1$; $|V_i|$ is the voltage magnitude at node i; $P_{i,i+1}$ is active power flow in the branch between node *i* and *i*+1; $Q_{i,i+1}$ is reactive power flow in the branch between node *i* and *i*+1; $X_{i,i+1}$ the reactance of branch between node *i* and *i*+1; $R_{i,i+1}$ the resistance of branch between node *i* and *i*+1; $\alpha_{P_{DG}}$ is the DG active power multiplier set to 1 where there is a DG and 0 where there is none.

$P^{L}{}_{i+1}$ is the active power load at node i+1; $Q^{L}{}_{i+1}$ is the reactive power load at node i+1; $\alpha_{Q_{DG}}$ is the reactive power multiplier set to 1 where there is a DG and 0 where there is none. Lastly, $Q^{L}{}_{i+1}$ is the DG reactive power load at a node; p^{DG}_{i+1} is DG real power at node i+1; Q^{DG}_{i+1} is DG KVAR power at node i+1

(ii) Inequality constraints

The inequality constraints include:

The operational voltage limits were set using (9) as follows:

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

The thermal capacity limits were set using (10) as:

$$|I_{i,i+1}| \leq |I_{i,i+1}|_{max} \quad (10)$$

Static stability of a distribution system is only improved when the DG penetration level is below 50% (Bawazir and Cetin, 2020; Impram *et al.*, 2020) Therefore, Equation (11) is used to limit the penetration level.

$$\frac{\sum_{i=1}^{n} P_{i+1}^{DG}}{P_{Load}} \leq \eta \quad (11)$$

The DG active power limits were set using (12).

$$0 \leq P_i^{DG} \leq P_{DGmax} \quad (12)$$

The total number of buses for DG placement was determined using (13).

$$No. of\ Locations = \frac{maximum\ DG\ penetration}{maximum\ DG\ size} \quad (13)$$

The inequality constraint was enforced using the penalty function shown in (14).

$$pf = \left[\sum_{i=1}^{n} h(V_i) + \sum_{i=1}^{n} h(P_i^{DG}) + \sum_{i=1}^{n} h(Q_i^{DG}) + \sum_{i=0}^{n-1} h(|I_{i,i+1}|)\right] \quad 14)$$

where, *PF* depicts penalty function and *h* is the penalty coefficient

$$h(x) = \begin{cases} (x - x^{max})^2, & if\ x > x^{max} \\ (x^{min} - x)^2, & if\ x < x^{min} \\ 0, & if\ x^{min} \leq x \leq x^{max} \end{cases} \quad (15)$$

where, x^{min} is the lower limit of the variable x

x^{max} is the upper limit of the variable x

x variable contains the number of DG installed.

The penalty coefficient is usually between 10^3 and 10^5 (Polprasert *et al.*, 2016).

The objective function, therefore, becomes Equation (16), from Equation (4) to (15).

$$f(VSI) = \sum_{i=2}^{n} VSI_i + pf \quad (16)$$

The convergence criteria for the power

$$P_{gi} - P_{di} - \sum_{i=1,j=2}^{N} V_i V_i Y_j \cos(\theta_i - \delta_i + \delta_j) = 0 \quad (17)$$

$$Q_{gi} - Q_{di} - \sum_{i=1,j=2}^{N} V_i V_i Y_j \sin(\theta_i - \delta_i + \delta_j) = 0 \quad (18)$$

where,

P_{gi} real power generated at the bus i^{th}

P_{di} real power demand at the bus i^{th}

Q_{gi} reactive power generated at the bus i^{th}

Q_{di} reactive power demand at the bus i^{th}

V_i voltage magnitude at the i^{th} bus

V_j voltage magnitude at the j^{th} bus

θ_i is the angle of the ij^{th} element in the admittance matrix,

δ_i and δ_j voltage angle at the i^{th} and j^{th} bus

While the procedure for execution of the GA is as follows, the flowchart of the procedure is presented in Figure 4.

- Start.
- The initialization of the definition of parameters.
- Create a loop for 50 iterations.
- Accept dataset using parallel search to reduce iteration time.
- Run load flows.
- Calculate power loss and voltage at each bus.
- Test if voltage constraints have been satisfied.
- If six is not satisfied, step 4 is repeated.
- Solve the Multi-objective function.
- Apply cross over function and mutation function

- Determine the number of locations.
- Create a new population.
- Calculate total active and reactive power losses using the load flow method.
- Calculate the minimal system voltage as well as the associated node.
- Install DG at each node, with the capacity of each DG varying from 10% to 100% in 10% increments of total DG capacity.
- Save the DG size that corresponds to the lowest loss from each node.
- Evaluate each node's loss.
- The optimal site for DG installation is the node with the lowest losses.
- Repeat the load flow method, this time locating the best DG capacity at the best location and calculating total active and reactive power losses. Determine the system's minimum voltage as well.
- Increment iteration.
- Test if max. iteration < 50.
- End.

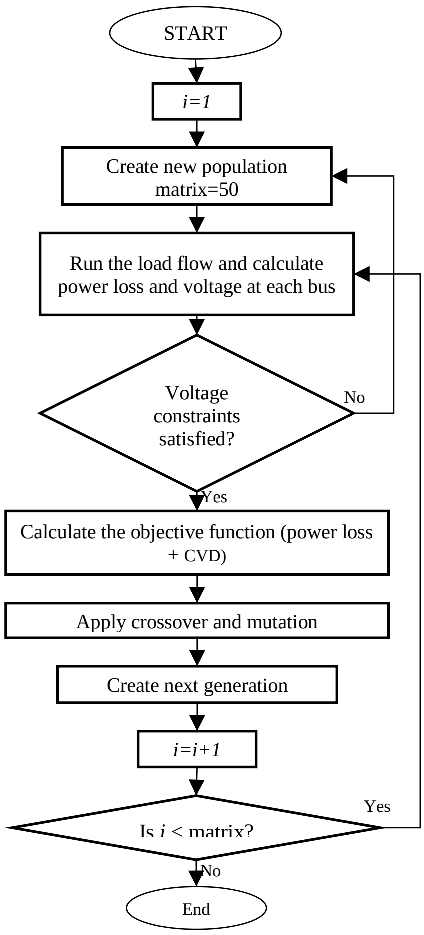

Figure 4: Genetic algorithm flow chart.

RESULTS AND DISCUSSION

In this study, *P+jQ* kind of DG was used because as compared to other types it has significant influence on real power loss reduction and improves voltage profile due to its convergence. Figure 5 that shows the convergence of the GA for multi-objective function reveals that there is fitness for the genetics function as seen at 0.231 and 0.21, while Figure 6 presents the rate of convergence considering 2 objective cases.

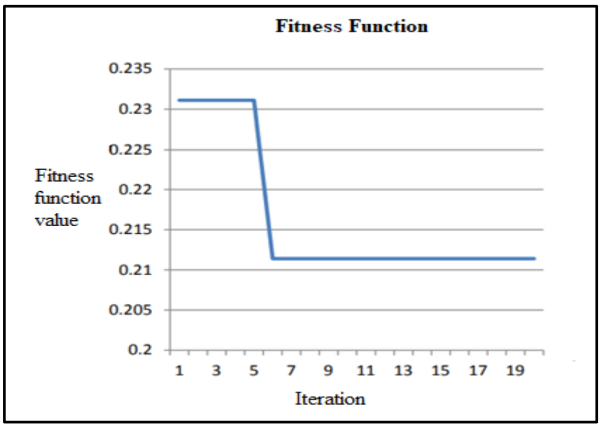

Figure 5: Convergence of GA for multi-objective function.

The approach of this study was firstly demonstrated using the standard IEEE 15-bus RDS. On this test system, DG of 1 MW size at 0.85 pf is connected at Bus 4, and the losses were computed using the power flow method. Presented in Table 3 is the result of the test, which shows 52.3% loss reduction. Compared to 42% obtained in (Viral and Khatod, 2015) using analytical method and 41% obtained in (Kumari *et al.*, 2017) using PSO and NPSO, it is established that there is an improvement using the method of this study as Figure 7 presents.

Table 3: Result on the IEEE-15 bus radial distribution system

Size of DG added	1 MW at 0.85 pf
Location of the DG	Bus 4
Losses without DG	436109.8 W
Losses with DG	183113.3 W

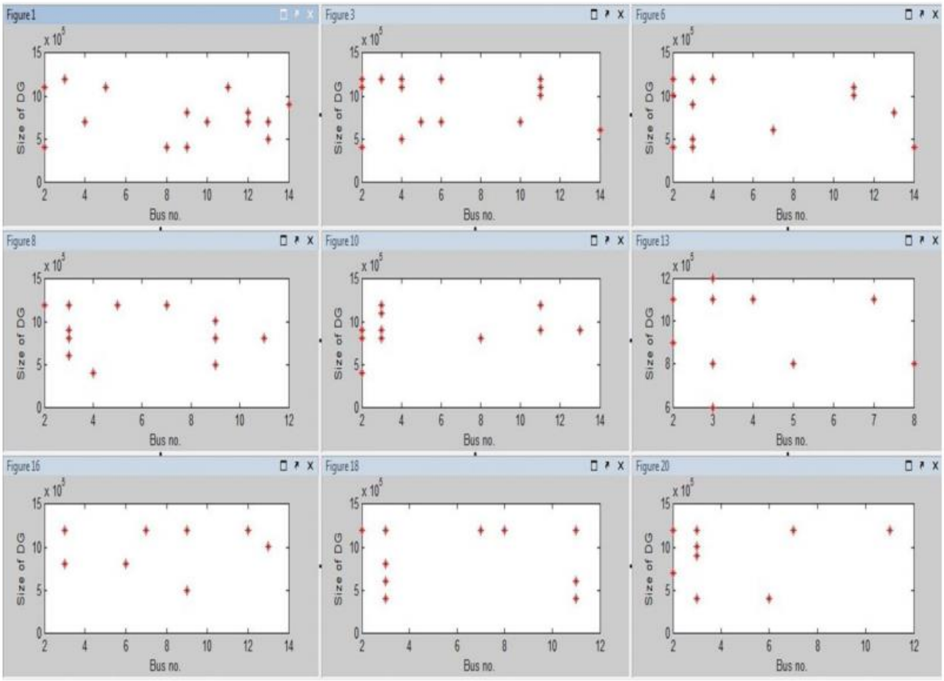

Figure 6: Convergence of GA with iterations considering 2- objective case.

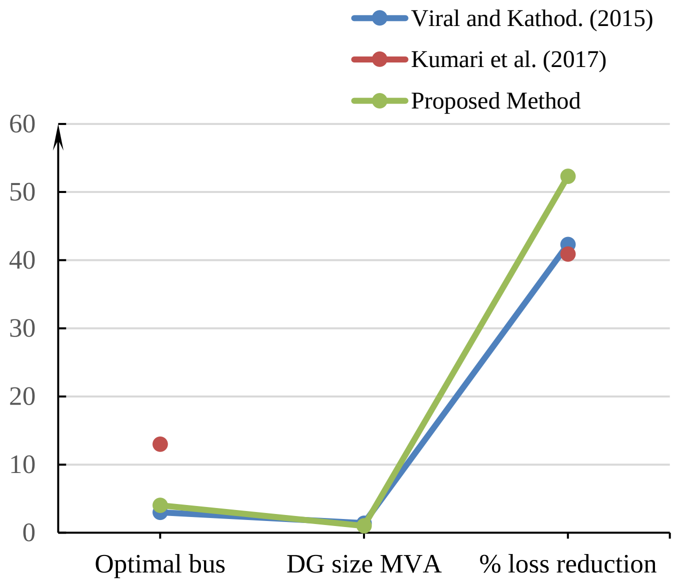

Figure 7: Comparison with results of other studies.

In the case of the Nigerian system, Figure 8 compares the voltages at various buses of the feeder, with and without DG connection. It can be seen that at the connection of the DG, the voltages at all the nodes of the feeder improved. This came with considerable reduction in losses as presented in Tables 3 and 5. Power injections from DGs alter networks power flows that results in reduction in energy losses. Due to this, reduction in energy cost may be achieved if DG is utilized to deliver energy locally to the load. Figure 9 shows 52.29% cost reduction as the energy cost reduced from ₦658,789.12 to ₦314,227.38 with the connection of the DG.

Table 4: Summary of the result on the Nigerian 11 kV feeder

Size of DG added	1 MW at 0.85 pf
Location of the DG	Bus 4
Losses without DG	10.4702658 kW
Losses with DG	4.9940781 kW

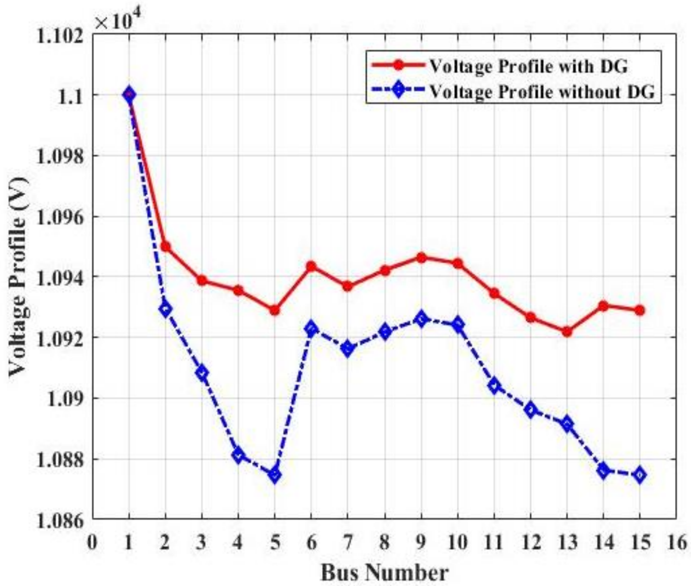

Figure 8: Comparison of voltage profiles of the buses.

Table 5: Comparison of losses at the buses of the Nigerian 11 kV feeder

Bus No.	Current without DG (A)	Current with DG (A)	Power loss without DG (W)	Power loss with DG (W)
1.	Slack Bus	Slack Bus	Slack Bus	Slack Bus
2.	472.5	159.9	7477.7	3870.2
3.	284.8	153.5	1354.2	393.5
4.	147.1	17.1	907	12.3
5.	46	45.5	70.8	69.2
6.	27.6	27.3	31.9	31.2
7.	46	45.5	70.8	69.2
8.	91.8	90.9	88.5	86.8
9.	73.4	72.7	136.5	115.8
10.	45.9	45.5	49.1	48.2
11.	22.9	22.7	18.1	17.9
12.	18.3	18.2	8.4	8.3
13.	27.5	27.3	7.9	7.8
14.	45.8	45.5	70.7	69.6
15.	119.1	118.2	178.6	176
Total	**1468.7**	**889.8**	**10470.27**	**4974.08**

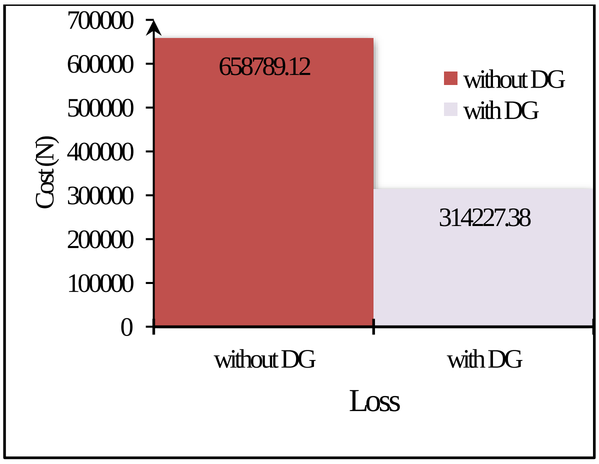

Figure 9: Cost comparison.

CONCLUSION

Use of genetic algorithm to determine the appropriate size and position of distributed generation for active power compensation on Nigerian radial distribution networks is presented in this study. By this optimization approach, reduction in actual power losses and improvement in voltage profile was achieved. A better system performance was obtained with the algorithm implemented on typical Nigerian 11 kV feeder. Power loss on the network reduced from the pre-implementation value of 10470.2658 W to 4994.0781 W on connecting the distributed generation. The voltage profile of the network was also enhanced appropriately.
Minimizing power losses and enhancement of voltage profiles are very crucial to the performances of radial distribution systems. As this study has shown genetic algorithm as providing an optimal means of siting and sizing distributed generation on radial networks for power compensation, the approach of the study is therefore recommended as capable of strengthening the performance of the Nigerian radial distribution system. Thus, it should be adopted as substitute to the use of analytical and numerical programming approaches that is currently prevalent.

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