

APPLICATION OF ARTIFICIAL BEE COLONY FOR OPTIMAL SITING AND SIZING OF SINGLE DISTRIBUTED GENERATION FOR REAL POWER LOSS MINIMIZATION: A CASE STUDY OF NIGERIAN 11KV FEEDER

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ABSTRACT

Distributed Generation (DG) is one of the emerging technologies for combating the problems of power loss at distribution end of power systems. This paper presents application of DG using Artificial Bee Colony (ABC) as optimization algorithm to diminish active power loss on Nigerian 11kV feeder. In this work, backward- forward sweep load flow technique was employed for the load flow analysis; the weak buses were identified via voltage stability index (VSI) and ABC decides both the optimal site and size of DG integrated. IEEE 34-bus network was used to validate this technique, while it was implemented on Ayepe 11kV feeder Nigeria practical network. With placement of 1MW DG at bus 20 on IEEE 34- bus network, 34.25557 % reduction was achieved for the aggregate real power loss while both VSI and voltage profile improved remarkably. On Ayepe feeder, 71.4 % reduction in aggregate real power was recorded aside appreciably improvement in system VSI and voltage profile. The proposed approach is therefore a promising approach for optimal location and sizing of DG on a practical 11kV feeders.

Keywords: Artificial Bee Colony, Ayepe Feeder, Distributed Generation, Real Power Loss Reduction, System Voltage Profile

1. INTRODUCTION

The role of distribution system in energy management system cannot be over-emphasized; it linked and served the generated energy to final consumers (Ade-Ikuesan *et al.*, 2018). The topological structure of distribution system is usually radial most especially in a densely populated area (Rao and Ravindra, 2013). Distribution systems (DS) are known to be ill-conditioned with peculiar characteristics such as high resistance to reactance ratio (R/X ratio), un-transpose or rarely transposed lines, unbalanced single-phase and double-phase loads among others (Smarajit and Karma, 2008; Joydeep *et al.*, 2004). The distribution system experiences mammoth active power loss compared to transmission system, and over time, researchers' attention has been drawn explicitly towards reduction of active power loss on transmission system. DS is responsible for loss of about 5 to 13% of the aggregate power generated. (Ramakrishnan and Pushparajan, 2018). The need to minimize this loss is imperative, if the distribution systems will faithfully deliver the power received to the ultimate consumers.

Several attempts has been made by different researchers over time to allay losses in distribution system to appreciable level and one of such approaches is the use of distributed, dispersed or embedded generation. DG is a viable emerging technique for coping with increased energy-demand in this modern day (Ajenikoko *et al.*, 2017). It is an electrical source which is usually connected to the power systems, either very close to or at end-user's site. It is comparatively smaller in relation to national grid generating plants (Ajenikoko *et al.*, 2017). Notable among the compelling factors that encouraged rapid integration of DG within DS includes global surge in electrical power demand, fossil fuel natural depletion, desire for clean energy, economical consideration, technological innovations and current policy on power system deregulation (Oladepo and Hasimah, 2019; Linh and Dong, 2013). In this regard, DGs integration is gaining popular attention as a viable alternative option for enhancing the performance of distribution systems (Bhullar and Ghosh, 2018). Different authors had suggested sizes of DG to be between 500 kW to 1 MW; 25 kW to 25 MW and few kW to 100 MW (Kumawat and Singh, 2016; Thomas *et al.*, 2001).

DG either employs renewable or non-renewable energy sources to generate power with minute emission of gases. Its technologies comprise any of photovoltaic, wind turbine, fuel cells, small and micro-sized turbine packages, internal combustion engine generators, and reciprocating engine generators (Savya and Padmavathy, 2016). The specific benefits of DG among others include nearness of the generation plants to consumers heavy loads, elimination of costs incurred in the transmission energy over a relatively long distance, efficient use of energy, diversification of sources of energy, availability of modular generating plant, ease of finding sites for smaller generators and relatively shorter construction

times in addition to lesser capital costs involvement for procurement of smaller plants (Lalitha et al., 2017; Chiradeja and Ramakumar, 2004). As beneficial as DG is to distribution system, if not correctly sized and placed in the system, it increases the system losses appreciably and leads to bidirectional current flow. To avert these scenarios; several population based optimization algorithms have been employed for its optimal sizing and siting. The Artificial Bee Colony (ABC) optimization algorithm belongs to the family of meta-heuristic algorithms that mimics honeybee foraging attributes. The core merits of ABC algorithm among others include exclusion of external parameters, possession of excellent global search ability due to introduction of neighborhood source production mechanism which is relatively akin to mutation technique in GA, more so the computational time is lesser (Tan *et al.*, 2012). This paper presents ABC optimization approach for minimizing active power loss on a typical Nigerian 11kV feeder via optimal siting and sizing of DG.

2. PROBLEM FORMULATION

Optimal siting and sizing of DGs is a constrained-optimization problem, it can be formulated either as single or multi-objective functions. In this study, the objective functions of interest comprise power losses minimization and voltage profile enhancement. To ease the implementation stage, weighted approach was engaged to convert the formulated objectives into single objective function. The basic advantages of weighted technique are stated in the work of Tan *et al.*, (2012).

The aggregate real power loss is modelled using equation (1) as given thus;

$$P_{Loss} = \sum_{i=0}^n \left(\frac{P_i^2 + Q_i^2}{V_i^2} \right) \times r_{i+1} \quad (1)$$

where; n = Bus number, P_i = Real power flows, Q_i = Reactive power flows, V_i = Bus voltage at bus i , r = line resistance

Also, the total voltage deviation can be expressed as;

$$TV D = \sum_{n=1}^n 1 - V_n \quad (2)$$

If $f_1 \wedge f_2$ represent the total real power loss and total voltage deviation and $w_1 \wedge w_2$ are the weighted value assigned to equations (1) and (2) based on the relative importance. Equation (3) modeled the objective function set out for this research;

$$F = w_1 f_1 + w_2 f_2 \quad (3)$$

The aim of this research is to minimize both the real power loss and system voltage deviation. This is achieved by minimizing Equation (3) as given by equation (4) thus;

$$F_{min} = w_1 f_1 + w_2 f_2 \quad (4)$$

As a rule guiding the choice of weighted values for the formulated objective functions;

$$0 \leq w_i \leq 1 \wedge \sum_{i=1}^k w_i = 1 \quad (5)$$

In this work, equation (1) was assigned a weighting coefficient of 0.6 while equation (2) was assigned 0.4 weighting coefficient due to its power quality impacts. The objective function in equation (4) is subjected to active power losses constraint, voltage constraint and DG size constraint. The equality constraints are given as;

$$\sum_{i=1}^n P_{Gi} = P_D + P_L \quad (6)$$

$$\sum_{i=1}^n Q_{Gi} = Q_D + Q_L \quad (7)$$

where; P_{Gi} and Q_{Gi} = active and reactive power generation at node i , P_D and Q_D = active and reactive power of demand respectively. $P_L \wedge Q_L$ = active and reactive power losses.

The inequality constraints are bus voltage limit, power limits of DG and distribution line absolute power limits as given by equations (8), (9), (10) and (11) respectively.

$$V_{min} \leq V_i \leq V_{max} \quad (8)$$

$$P_{DG_i}^{min} \leq P_{DG_i} \leq P_{DG_i}^{max} \quad (9)$$

$$Q_{DG_i}^{min} \leq Q_{DG_i} \leq Q_{DG_i}^{max} \quad (10)$$

$$P_{ij}^{Line} \leq P_{ij,max}^{Line} \quad (11)$$

where; V_{min} and V_{max} = minimum and maximum bus voltage magnitude, $P_{DG_i}^{min}$ and $P_{DG_i}^{max}$ = minimum and maximum injected active power of DG, $Q_{DG_i}^{min}$ and $Q_{DG_i}^{max}$ = minimum and maximum reactive power of DG components at the i^{th} bus and P_{ij}^{Line} and $P_{ij,max}^{Line}$ absolute power and its corresponding maximum allowable value expected to flow over the distribution line between the nodes i and j .

The optimal location of DG can be pre-selected to conserve the solution search space using VSI computed from base case power flow for the concerned network. Equation (12) modelled the VSI;

$$VSI_{(m+1)} = V_m \sqrt{1 - 4[P_{m+1,eff} \times X_m - Q_{m+1,eff} \times R_m]^2 - 4[P_{m+1,eff} \times R_m + Q_{m+1} \times X_m]} \quad (12)$$

When $VSI > 0$ for $i = 2, 3, \dots, n$, then a possible solution exist. Inspecting the VSI performance exposes buses susceptible to huge voltage drop, these buses are tagged potential buses needing reactive power compensation (Tan *et al.*, 2012).

3. ARTIFICIAL BEE COLONY OPTIMIZATION

The ABC belongs to the family of population based meta-heuristics optimization algorithms, its birth modelled intuitive behaviour of honeybee based on the food searching (foraging) strategies. In the colony of honeybee, three distinctive groups can be identified; employed bees, onlookers and scouts bee. The basic functions of each group and how each group performs its primary responsibility are vividly stated in (Lalitha *et al.*, 2017). Onlookers bees select a food source i using a probability function modelled by equation (13);

$$P_i = \frac{fitness(i)}{\sum_{i=1}^N fitness(i)}$$

(13)

where; $fitness(i)$ = fitness value of a solution, and N = aggregate number of food-source positions.

The onlooker bees evaluate the most viable food source among all the neighboring food sources, this formed the new location of the food source i and once this is determined then another ABC algorithm cycle begins, then the cycle is repeated until the stopping criteria (Maximum Fitness – Average Fitness) $< 10^{-12}$ are satisfied (Savya and Padmavathy, 2016; Lalitha *et al.*, 2017). The procedural steps used by Lalitha *et al.*, (2017) were adopted in this research.

3.1 Description of IEEE 34 bus System

This standardized network has 34 buses, 33 lines, 1 substation, a total real and reactive load of 4.636 MW and 2.873 MVar, respectively. Figure 1 depicts its one line diagram.

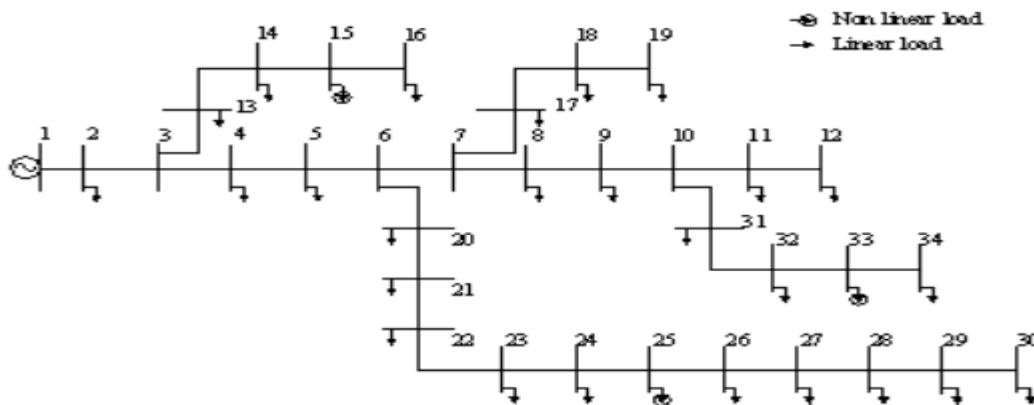


Figure 1: Figure 1: One Line Diagram of IEEE 34-Bus

3.2 The Ayepe 34-Bus Feeder; Real Nigerian Radial Distribution System

Ayepe 11-kV feeder is an outgoing feeder from Ayepe 15MVA, 33/11-kV injection substation located at Osogbo, Osun State. Ayepe 11-kV feeder has 34- buses, 33 branches; a total real power loads 4.15 MW and reactive power of 2.04 MVar respectively. One line diagram of the Ayepe 34-Bus feeder in Figure 2

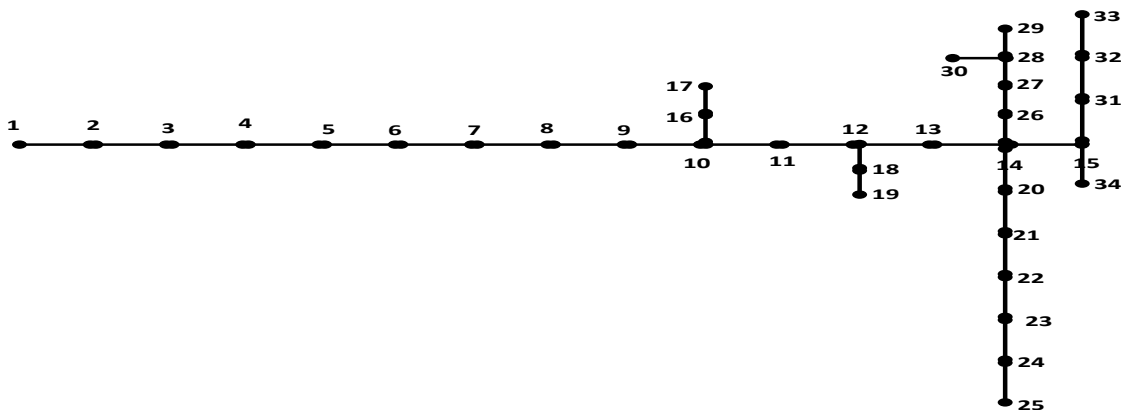


Figure 2: One Line Diagram of Ayepe 34-Bus RDS

4. RESULTS AND DISCUSSION

ABC was employed for the optimal sizing and siting of DG on IEEE and a typical Nigerian 11kV feeder. The effectiveness of this approach was firstly validated on IEEE 34-bus standardized RDS and thereafter applied to address the power loss and voltage profile enhancement on a typical Nigerian RDS. The parameters of ABC that gave optimal results is tabulated in Table 1.

Table 1: Optimal Values used for ABC Parameters

ABC Parameters	The Optimal Values
Employed Bees	14
Onlookers	10
Scout Bees	10
Total No of Bees (Population Size)	34
Maximum No of Iteration	50

Case I: IEEE 34-bus RDS

The load flow analysis was carried out using BFS technique; the result of line losses for the base case of IEEE 34-bus system is presented using Table 2.

Table 2: Line Loss on IEEE 34- Bus RDS

Line No	Loss (kW)	Loss (kVAr)
1.0000	12.1967	6.3100
2.0000	51.5862	26.2744
3.0000	19.8120	10.0901
4.0000	18.6145	9.4807
5.0000	38.0757	32.8688
6.0000	1.9208	6.3493
7.0000	11.7055	8.4477
8.0000	4.2012	3.0183
9.0000	3.5640	2.5359
10.0000	0.5562	0.1839
11.0000	0.8850	0.2926
12.0000	2.6773	2.1064
13.0000	0.7321	0.9636
14.0000	0.3583	0.3189
15.0000	0.2825	0.2063
16.0000	0.2525	0.3371
17.0000	0.0533	0.0418
18.0000	0.1609	0.1535
19.0000	0.8319	0.7496
20.0000	0.1007	0.1177
21.0000	0.0436	0.0577
22.0000	3.1732	2.1682
23.0000	5.1297	4.0507
24.0000	1.2838	1.0046
25.0000	2.5698	1.3089
26.0000	3.2885	1.6743
27.0000	11.1610	9.8405
28.0000	7.7356	6.7391
29.0000	3.8466	1.9593
30.0000	1.5729	1.5545
31.0000	0.2104	0.2452
32.0000	0.0130	0.0202

33.0000

1.2838

1.0046

On IEEE 34- bus RDS the aggregate real power loss was obtained to be 208.5954MW and the aggregate reactive power loss stood at 141.4698 kVAr for the base case without integration of DG. With installation of DG of size 1kW at bus 20 selected by the ABC, an appreciable improvement was observed as in the system VSI and system voltage profile shown in Figure 3 and 4 respectively.

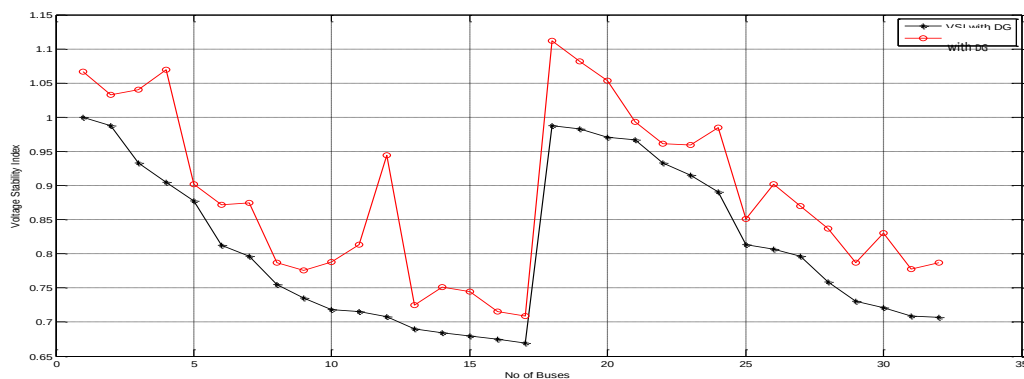


Figure 3: The System VSI with and without Integration of DG

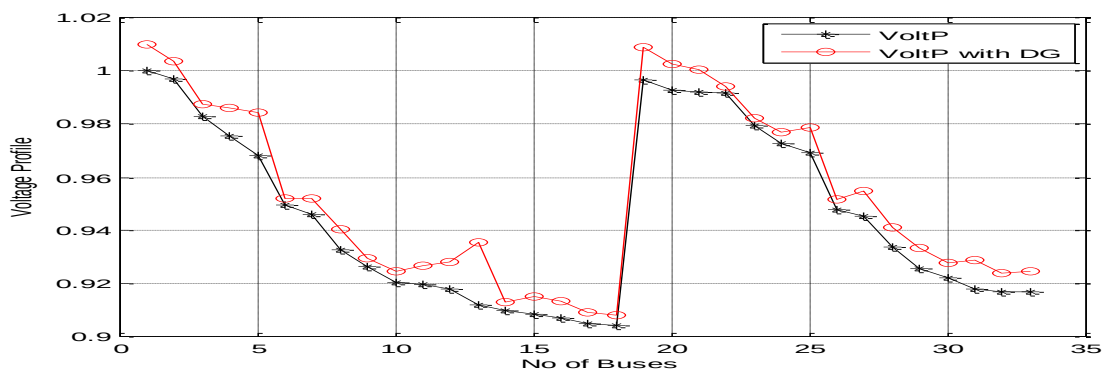


Figure 4: Bus Voltages Magnitude Prior and after DG Integration.

Also, it was observed that the voltage at each bus experienced a noticeable rise in the presence of DG installed at bus 20. It could be inferred that the optimal bus to site the DG is 20 and the optimal size is 1kW as determined by the ABC. A significant reduction in aggregate active power loss was recorded; it reduced the initial real power loss from 208.59 to 137.1394 MW which amounts to 34.26% reduction. Figure 5 represents comparison of aggregate real power loss prior and after integration of DG at bus 20.



Figure 5: Real Power Loss Prior and after DG Integration

Case 2: Ayepe 34- Bus RDS

Having observed the excellent performance of this approach on standardized IEEE 34-bus RDS; it was then adopted to solve the problem of power loss and voltage profile enhancement on a typical Nigerian 11kV feeder. The ABC parameters presented in Table 1 was still used on Ayepe feeder and 1MW size of DG was installed at bus 20. The system VSI obtained is as shown in Figure 6. From Figure 6; it was observed that the system voltage stability index at each bus approaches unity which give an indication of stable system. Also, the VSI at each bus improved significantly in comparison with the base case without DG.

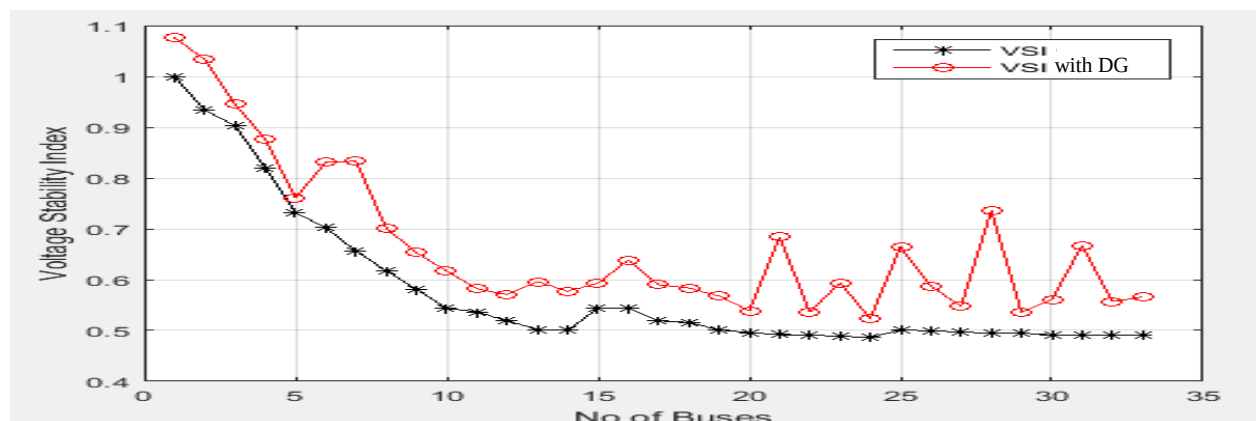


Figure 6: VSI on Ayepe feeder prior and after DG integration

The system voltage profile with and without DG is as shown in Figure 7; it can be observed that after the installation of DG at the optimal bus selected by ABC, an appreciable enhancement was evidently noticeable at each bus as depicted by Figure 7.

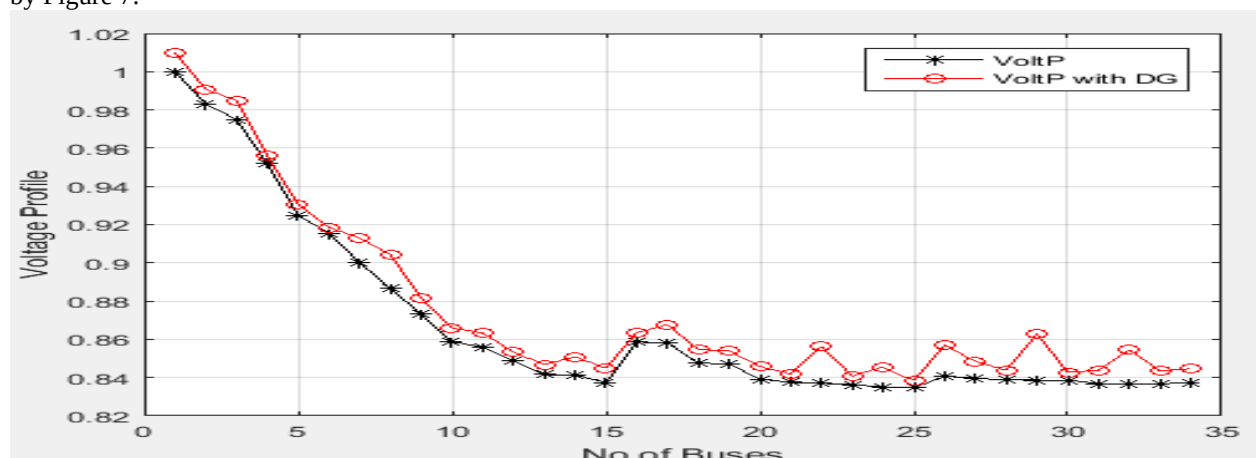


Figure 7: Voltage Profile on Ayepe Feeder

Figure 8 compares the aggregate real power loss prior and after DG integration, the total power loss for the base case was found to be 7 MW and in the presence of DG, it reduced appreciably to 2.0 MW, which amount to 71.4% reduction.

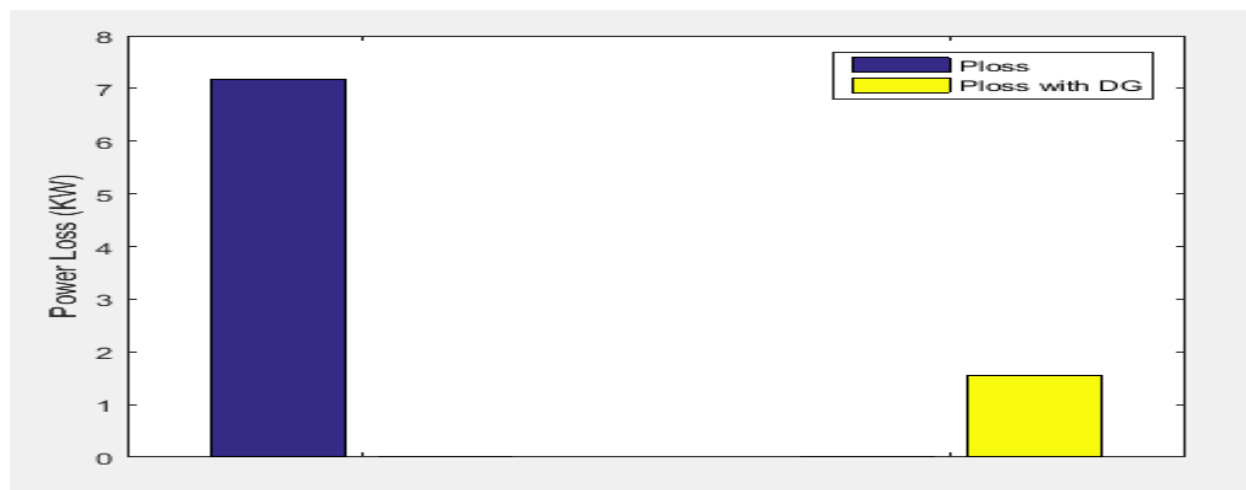


Figure 8: Real power loss on Ayepe feeder prior and after DG integration

5. CONCLUSION

This paper presents real power loss minimization on a typical Nigerian 11kV feeder using ABC as optimization technique. The approach was validated on IEEE 34-bus RDS and thereafter employed to solve the problem of real power loss and voltage deviation on a typical Nigerian 11kV feeder. ABC was employed to optimally sized and placed DG in the candidate location chosen. The integration of DG at the potential locations chosen by optimization algorithm enhanced system stability substantially based on the values obtained for VSI. Also, the aggregate real power loss in the system reduced significantly while the voltage profile of the system improved remarkably. The results obtained with this approach forms a basis for comparison when other population based optimization algorithms are used on same network.

6. REFERENCES

- Ade-Ikuesan, O. O., Okakwu, I. K., Osifeko, M. O., and Olabode, O. E. (2018). Investigation of Electric Power Losses on Primary Distribution Feeder: A Case Study of Sango - Ota Distribution Company, Ogun State, Nigeria. *International Journal of Applied Engineering Research*, 13(7), 5000-5003
- Ajenikoko, G. A., Olabode, O. E., and Olayanju, O. W (2017). Distributed generation (DG) integration on utilities distribution system: a survey. *International Journal of Advanced Engineering and Technology*, 1(4), 1-10
- Bhullar, S., and Ghosh, S. (2018). Optimal integration of multi distributed generation sources in radial distribution networks using a hybrid algorithm. *Energies*, 11, 628-643.
- Chiradeja P., and Ramakumar R., (2004). An approach to quantify the technical benefits of distributed generation,” *IEEE Trans Energy Conversion*, 19(4), 764-773
- Farhoodne, M., Mohamed, A. and Shareef, H. (2014). Identification of multiple harmonic sources in power systems using independent component analysis and mutual information. *Generation, Transmission and Distribution, IEEE Proceedings*, 146, 7–12
- Joydeep, M., Mohammed, B., and Salem, E (2004). A three-phase power flow solution method for unbalanced distribution networks. three-phase power-flow analysis of unbalanced distribution systems. *IEEE Proc.-Gener., Transm., Distrib.*, 151(5), 568-574.
- Kumawat, A. and Singh, P. (2016). Optimal placement of capacitor and DG for minimization of power losses using genetic algorithm and artificial bee colony algorithm. *International Research Journal of Engineering and Technology*, 3(4), 2482- 2488
- Lalitha, M. P., Reddy, V. C. V. and Reddy, N. S (2017). Application of Fuzzy and ABC algorithm for dg placement for minimum loss in radial distribution system. *Iranian Journal of Electrical & Electronic Engineering*, 6(4), 248- 256.
- Linh, N. T and Dong, D. X. (2013). Optimal location and size of distributed generation in distribution system by artificial bees colony algorithm. *International Journal of Information and Electronics Engineering*, 3(1), 63- 67
- Oladejo, O., and Hasimah, A. (2019). Allocation of distributed generation and capacitor banks in distribution system. *Indonesian Journal of Electrical Engineering and Computer Science*, 13(2), 437-446
- Ramakrishnan, D., and Pushparajan, S (2018). “Simultaneous Placement of Distributed Generation and Reconfiguration in Distribution Networks using Unified Particle Swarm Optimization”. *International Journal on Future Revolution in Computer Science & Communication Engineering*, 4(3), 41-49
- Rao, R. S and Ravindra, K (2013). Power Loss Minimization in Distribution System using Network Reconfiguration in the Presence of Distributed Generation. *IEEE Transactions on Power Systems*, 28(1):103-109

- Savya, S and Padmavathy, N. (2016). Optimal allocation and sizing of distributed generation using artificial bee colony algorithm. *International Research Journal of Engineering and Technology*, 3(2),1244-1251
- Smarajit G., and Karma, S.S (2008). An Efficient Method for Load-Flow Solution of Radial Distribution Networks. *World Academy of Science, Engineering and Technology*, 701-707
- Tan, W. S., Hassan, M. Y., Majid, M. S. and Rahman, H. A (2012). Allocation and sizing of DG using cuckoo search algorithm. IEEE International Conference on Power and Energy (PECon), 2-5 December 2012, Kota Kinabalu Sabah, Malaysia
- Thomas A, Goran A and Lennart, S. (2001). Distributed generation: a definition, Elsevier Science, 3(2), 217-223

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