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Optimal Distributed Generations Placement in Radial Distribution Network using Archimedes Optimisation Algorithm (AOA)

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ABSTRACT

The integration of distributed generation (DG) into the distribution network increases as the demand for power rises. Photovoltaic cell (PV) technology has progressed, becoming more affordable and widely available. The typical energy problems encountered in the past are resolved with the integration of PV in radial distribution networks. The efficiency and performance of the system can be impacted by the improper placement of DGs in the radial distribution network. Therefore, optimal placement of distributed generations in the radial distribution network is crucial to reduce power loss. The Archimedes Optimisation Algorithm (AOA) was employed for this study to determine the optimal location of DGs in the radial distribution network, considering system operational constraints such as power balance, voltage, and current. Using distribution load flow analysis based on the backward-forward sweep method, the original rate of power loss without the optimal placement of distribution generations in the IEEE 12-bus, 33-bus, and 69-bus test system was determined. Following this, the optimal placement of distributed generations in the radial distribution network was implemented using the Archimedes Optimisation Algorithm (AOA) in the IEEE 12-bus, 33-bus, and 69-bus test system. The results were analysed and compared to other algorithms, such as the Particle Swarm Optimisation Algorithm (PSO), in terms of consistency, convergence characteristics, and the optimal location of PV obtained.

1. Introduction

Our society today relies heavily on electricity, especially for powering servers and industrial machinery. This heightened dependence has led to a significant increase in electricity consumption over the past decade due to factors such as population growth, the Industrial Revolution (IR) 4.0, and technological advancements. It is projected that total energy generation will reach 272.8 TWh in 2040, representing a 60% increase from the 2020 levels [1]. In light of these trends, Malaysia is

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confronted with multiple challenges related to the supply and demand of electricity, including diminishing fuel supply, rising fuel acquisition costs, and concerns about transmission efficiency. To address these issues, Malaysia's Ministry of Energy and Natural Resources (KeTSA) has set a goal to achieve a 40% share of renewable energy in the country's installed capacity mix by 2035 [2]. This ambitious target is expected to drive substantial growth in renewable energy (RE) sources, particularly in distributed generation (DG). This initiative aims to produce cleaner energy with minimal distribution loss, aligning with the nation's commitment to a sustainable and resilient energy future.

Distributed generation (DG) refers to small-scale electric power generation, also known as dispersed generation in certain regions like Europe, typically ranging from 1 kW to 50 MW. According to the Institute of Electrical and Electronics Engineers (IEEE), DG involves the production of electricity by a facility small enough, usually 10 MW or less, to permit connection at almost any point in the power system. However, definitions may vary across regions and agencies. The International Energy Agency (IEA) characterizes DG as a generating plant that either serves customers on-site or provides support to distribution networks, being connected to the grid at the distribution stage voltage. Any generation or storage technology situated close to the load centre with a modular design fall under the category of a distributed energy source [3].

The radial distribution network benefits greatly in economic and environmental terms from distributed generation (DG) such as photovoltaic cells (PV), which minimises active power and distribution loss as well as the need for fossil fuels. Additionally, it reduces network dependency and improves the voltage profile of the network. However, improper DG placement in the network may reduce its effectiveness and overall performance [4, 5]. The total effectiveness and performance are also influenced by variables like the number of buses and PV. To accomplish the network's major objectives, optimal DG placement in the radial distribution network is a must. Although DG offers several advantages, the key to effective use of DG is to choose the optimal location and size of the DG unit [6].

In a distribution network, the selection of the most suitable location and size for distributed generations presents intricate optimisation challenges [7]–[11]. Various meta-heuristic optimisation techniques have been proposed to ensure the appropriate placement and sizing of DGs within the distribution network. For a real radial distribution system in Egypt, Crow Search Optimisation (CSO) was utilized to identify the optimal placement and size of distribution generation [12]. Additionally, the Hybrid Lightning Search Algorithm-Simplex Method (LSA-SM) [13] and Flower Pollination Algorithm (FPA) [14, 15] were applied to optimise distributed generation systems. Another approach to determine the ideal DG locations involved the use of the Firefly Algorithm (FA), which emulates the attractiveness of fireflies based on the light intensity observed by neighboring fireflies [16].

This study aims to determine the optimal placement of distributed generations in a radial distribution network using Archimedes Optimisation Algorithm, while considering the operational constraints of the system. The objective is to demonstrate the efficiency and performance of the proposed algorithm in minimising power loss for various radial distribution network, namely the IEEE 12-bus, 33-bus, and 69-bus systems. The simulation results obtained using Archimedes Optimisation Algorithm will be compared to those of other optimisation algorithms to assess its effectiveness and efficiency.

2. Methodology
2.1 Problem Formulation

This section presents detailed steps to determine the optimal placement of distributed generations in a radial distribution network using Archimedes Optimisation Algorithm (AOA). In the initial step, the backward-forward sweep method was employed to calculate the actual power loss, without considering the optimal location for distribution generations in the bus test system [17]. Archimedes Optimisation Algorithm was then utilised in the second stage to find the optimal distributed generation placement in the radial distribution network. Subsequently, the simulation results were analysed to assess the algorithm's efficiency and performance. MATLAB software was used for calculating the original rate of power loss and implementing the optimal distributed generation placement.

2.2 Objective Function and Constraints

Reducing power loss in a distribution network is crucial for ensuring the efficient functioning and optimal performance of the entire power system. To identify the optimal location DGs in a radial distribution network, a single-objective optimisation problem was formulated, considering system operating constraints for loss minimization. The calculation of real power loss in the system can be performed using (1) [18, 19].

$$P_{loss} = \sum_{i=1}^{N} \sum_{j=1}^{N} X_{ij}\left(P_i P_j + Q_i Q_j\right) + Y_{ij}\left(Q_i P_j + P_i Q_j\right) \tag{1}$$

$$X_{ij} = \frac{RL_{ij}\cos\left(\delta_i - \delta_j\right)}{V_i V_j} \tag{2}$$

$$Y_{ij} = \frac{RL_{ij}\,sin\left(\delta_i - \delta_j\right)}{V_i V_j} \tag{3}$$

where *Pi* is the active power injection at bus i, Q_i is the reactive power injection at bus i, RL_{ij} is the line resistance between bus i and j, V_i is the voltage at bus i and δ_i is the angle between bus i. The objective function to minimise the total real power loss in the radial distribution networks can be expressed as in (4).

$$OF_{min} = P_{loss} = \sum_{k=1}^{Ns} loss_k \tag{4}$$

where OF_{min} is objective function, P_{loss} is active power loss in system, $loss_k$ is loss of distribution at sections k dan N_s is the total number of sections. The objective function formulated is subjected to the following distribution system constraints.

Power balance constraint,

$$\sum_{i=1}^{N} P_{DG_i} = \sum_{i=1}^{N} P_{R_i} + P_{loss} \tag{5}$$

Voltage constraint,

$$|V_i|min \leq |V_i| \leq |V_i|max \tag{6}$$

Current limit,

$$|I_{ij}| \leq |I_{ij}|max \quad (7)$$

where P_{DG_i} is the active power generation of DG at bus i and P_{R_i} is the power request at bus i, $|V_i|min$ is 0.95 per unit and $|V_i|max$ is 1.05 per unit.

2.3 Archimedes Optimisation Algorithm for Optimal PV Location and Sizing

The Archimedes Optimisation Algorithm is grounded in the physics principle attributed to Archimedes. As per this principle, the buoyant force acting on an object immersed in a fluid equals the weight of the fluid displaced by the object [20]. In simpler terms, the upward force on an object submerged in a fluid is equivalent to the weight of the fluid that would fill the volume of the object, as illustrated in Fig. 1. By utilizing weight measurements in both air and liquids, this principle can be applied to calculate the buoyancy of objects in the fluid and determine their density.

If the object sinks half or completely in the fluid and weighs higher than the weight of the displaced fluid, the object will sink. Otherwise, the object will float. Individuals in a population are objects submerged in fluid in the AOA. The volume, density, and acceleration of objects all play an important role in the buoyancy of the object. The goal of the AOA is to achieve a neutral buoyancy state, where the net force of the fluid is equal to zero.

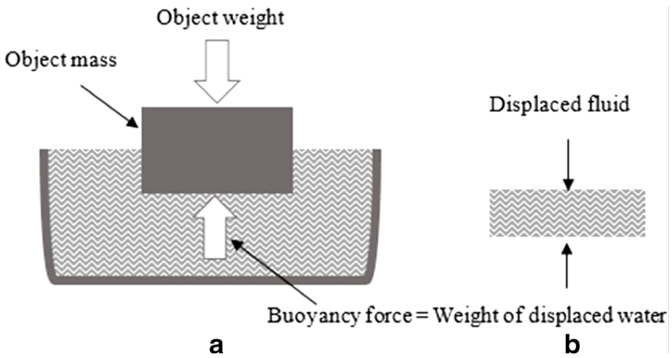

Fig. 1. Overview of Archimedes'principle

The Archimedes Optimisation Algorithm approach to minimising power loss by optimally placing distributed generations in a radial distribution network includes the following steps:

Step 1: Initialisation of the positions of all objects using (8).

$$O_i = lb_i + rand \times (ub_i - lb_i); i = 1, 2, \dots, N \quad (8)$$

where O_i is the i_{th} in a population of *N* objects, lb_i and ub_i is the lower boundary dan upper boundary of the search space respectively.

Step 2: Initialisation of volume (*vol*), density (*den*) and acceleration (*acc*) of each i_{th} object using (9), (10) and (11) respectively.

$$den_i = rand \quad (9)$$
$$vol_i = rand \quad (10)$$
$$pec_i = lb_i + rand \times (ub_i - lb_i) \quad (11)$$

where $rand$ is a dimensional vector, D that randomly generates number between [0,1] and acc_i is the i_{th} object's acceleration.

Step 3: Calculate the fitness value for each object and choose the best among all (best position, density, and acceleration).

Step 4: The density and volume of i_{th} object for iterations $i+1$ is updated using (12) and (13).

$$den_i^{t+1} = den_i^t + rand \times (den_{best} - den_i^t) \quad (12)$$
$$vol_i^{t+1} = vol_i^t + rand \times (vol_{best} - vol_i^t) \quad (13)$$

where vol_{best} and den_{best} are volume and density associated with the best object found so far and $rand$ is a random number that is uniformly distributed.

Step 5: Update the transfer function and density factor using equation 14 and 15.

$$TF = \exp(\frac{t-t_{max}}{t_{max}}) \quad (14)$$
$$d^{t+1} = \exp(\frac{t_{max}-t}{t_{max}}) \quad (15)$$

where t and t_{max} is the number of iteration and maximum iteration respectively.

Step 6: If TF ≤ 0.5, the exploration phase occurs (a collision between objects occurs). Update object acceleration, normalize acceleration and position updates using (16), (17) and (18) respectively.

$$accc_i^{t+1} = \frac{den_{mr} + vol_{mr} \times acc_{mr}}{den_i^{t+1} \times vol_i^{t+1}} \quad (16)$$

where den_i, vol_i, and acc_i are the density, volume, and acceleration of the i_{th} object. acc_{mr}, den_{mr} and vol_{mr} are the acceleration, density, and volume of random materials.

$$acc_{i-norm}^{t+1} = u \times \frac{acc_i^{t+1} - \min(acc)}{\max(accc) - \min(acc)} + l \quad (17)$$

where u and l are the normalized ranges and are set to 0.9 and 0.1 respectively.

$$x_i^{t+1} = x_i^t + C_1 \times rand \times acc_{i-norm}^{t+1} \times d \times (x_{rand} - x_i^t) \quad (18)$$

where x_i^{t+1} is the position of the i_{th} object for the next iteration $t+1$ and C_1 is constant equals to 2.

Step 7: If FP > 0.5, the exploitation phase occurs (no collisions between objects). Update object acceleration, normalize acceleration, position and directional flags using (19), (17), (20) and (22) respectively.

$$acc_i^{t+1} = \frac{den_{best} + vol_{best} \times acc_{best}}{den_i^{t+1} \times vol_i^{t+1}} \quad (19)$$

$$x_i^{t+1} = x_{best}^t + F \times C_2 \times rand \times acc_{i-norm}^{t+1} \times d \times (T \times x_{best} - x_i^t) \quad (20)$$

where C_2 is a constant equal to 6. Meanwhile, T is defined using (21).

$$T = C_3 \times TF \quad (21)$$

where C_3 is a constant equal to 3.

$$F = \begin{cases} +1 \; if \; P \leq 0.5 \\ -1 \; if \; P \geq 0.5 \end{cases} \tag{22}$$

where F is the directional flag. P can be defined using (23).

$$P = 2 \times rand - C_4 \quad (23)$$

where C_4 is a constant equal to 0.5.

Step 8: Evaluate each object and remember the best solution found to that extent. Assign x_{best}, den_{best}, vol_{best} and acc_{best}.

The flowchart of AOA for optimal location of DG installation is presented in Fig. 2.

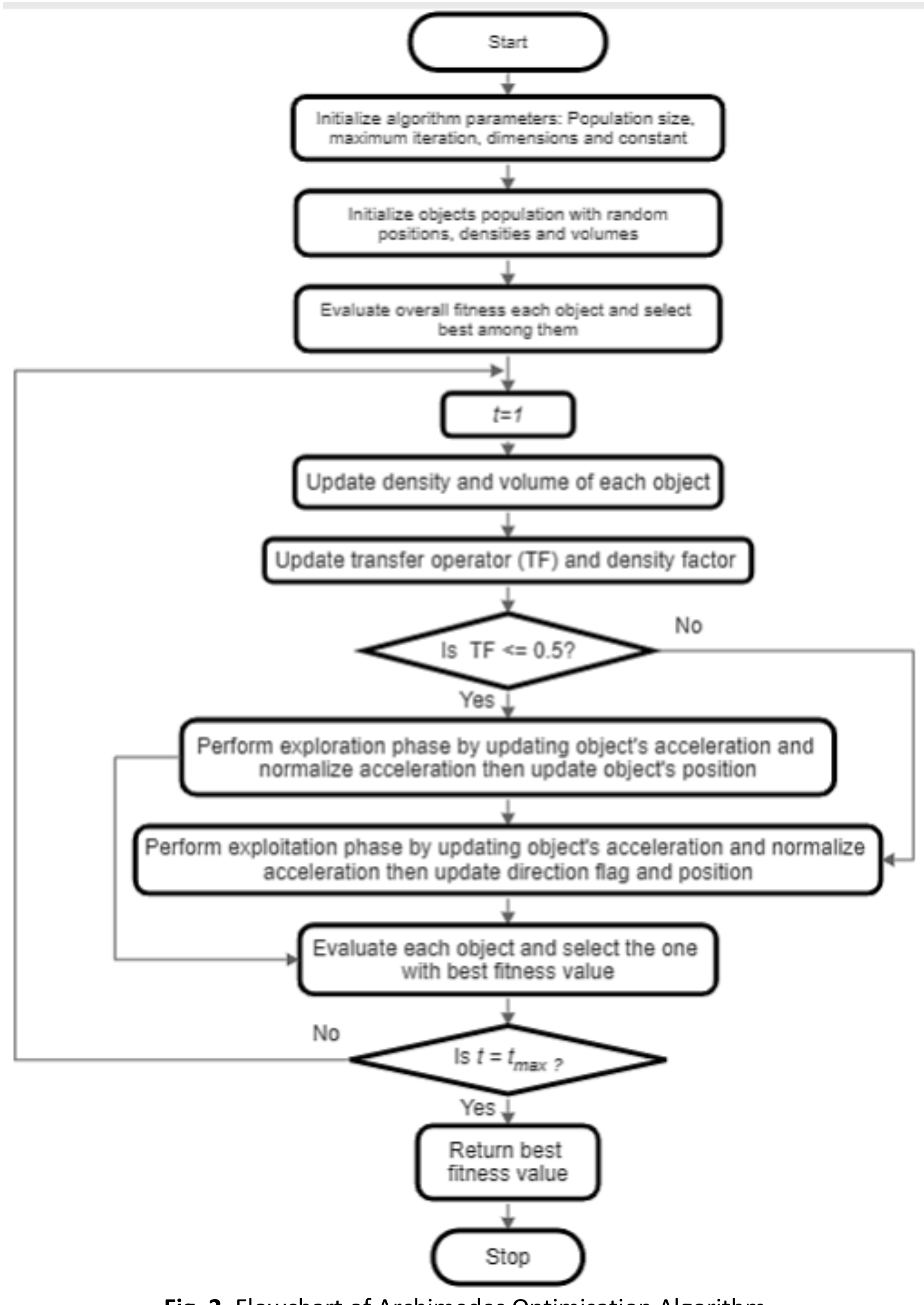

Fig. 2. Flowchart of Archimedes Optimisation Algorithm

3. Results and Discussion

The findings of the study include active power loss rate, voltage profile, and a comparison with PSO based on consistency characteristics, convergence characteristics, and optimal DG placement. These parameters were utilized to assess the performance of AOA for effective and efficient optimisation. The test systems employed in the study comprise the IEEE 12-bus, 33-bus, and 69-bus distribution networks, as depicted in Figs. 4, 5, and 6, respectively.

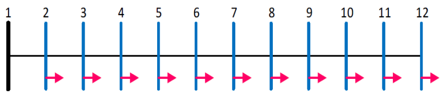

Fig. 3. IEEE 12-bus distribution network

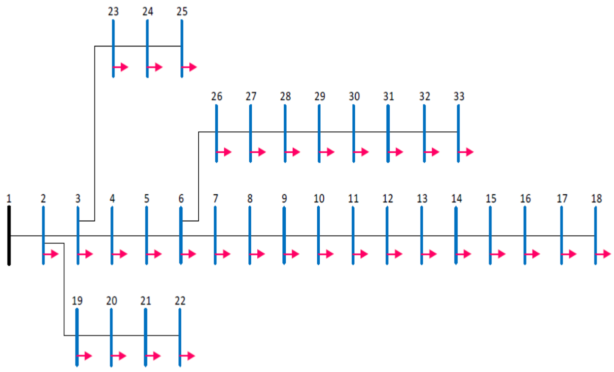

Fig. 4. IEEE 33-bus distribution network

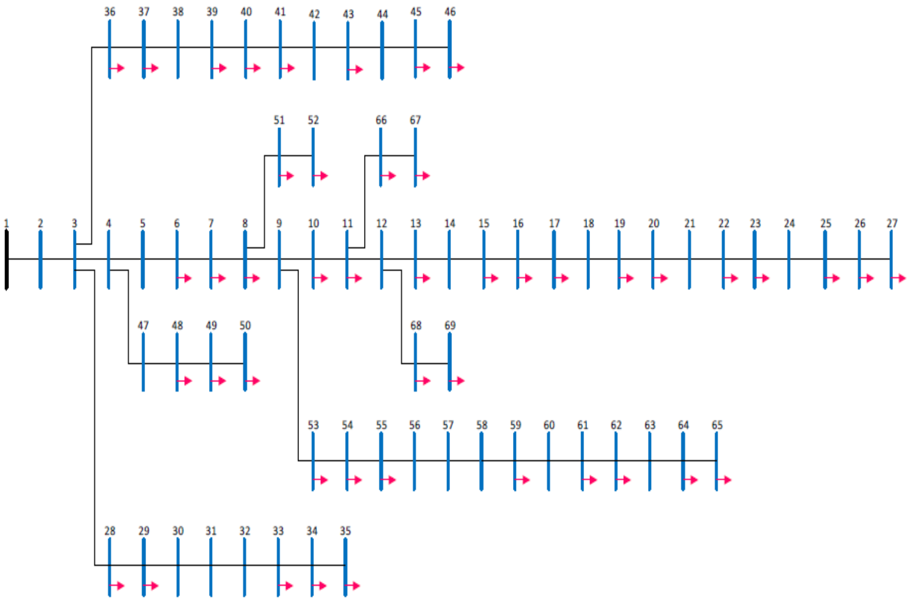

Fig. 5. IEEE 69-bus distribution network

Table 1 presents the results of DG placement optimisation for the IEEE 12-bus distribution system using AOA. The incorporation of a 2.36 MW DG in the IEEE 12-bus system leads to a substantial reduction in total active power loss, decreasing by 45.5299% from 23.1603 kW to 12.6129 kW, with the optimal placement identified on bus 9. The introduction of two, three, four, and five DGs further reduces total power loss to 11.7549 kW, 11.6005 kW, 11.5633 kW, and 11.5488 kW, respectively. Based on the simulation results analysis, it can be concluded that the optimal DG configuration for the 12-bus IEEE system involves five DGs of 0.472 MW each, positioned on buses 7, 8, 9, 10, and 11, resulting in a power loss reduction from 23.1603 kW to 11.5488 kW.

Table 1
Optimum DG Placement for IEEE 12-Bus System

Number of DG	Total active power loss (kW)	Percentage reduction of power loss (%)	Size per DG unit (MW)	Optimum DG placement
0	23.1603	-	-	-
1	12.6129	45.5299	2.360	Bus 9
2	11.7549	49.2454	1.180	Bus 7 Bus 10
3	11.6005	49.9121	0.787	Bus 7 Bus 9 Bus 11
4	11.5633	50.0729	0.590	Bus 7 Bus 8 Bus 10 Bus 11
5	11.5488	50.1353	0.472	Bus 7 Bus 8 Bus 9 Bus 10 Bus 11

Table 2 presents the optimal placement of DGs for the IEEE 33-bus system. When a 2.36 MW DG is integrated into the system, the total active power loss decreases from 203.0812 kW to 104.8059 kW, representing a reduction of 48.3921%, with the optimal placement identified on bus 6. The introduction of additional DGs in the IEEE 33-bus system further mitigates power loss. Analysis of the simulation results reveals that the optimal configuration for the 33-bus system involves six DGs, each with a capacity of 0.393 MW, installed on buses 7, 10, 16, 25, 30, and 32, resulting in a significant reduction in active power loss from 203.0812 kW to 69.7410 kW.

Table 2
Optimum DG Placement for IEEE 33-Bus System

Number of DG	Total active power loss (kW)	Percentage reduction of power loss (%)	Size per DG unit (MW)	Optimum DG placement
0	203.0812	-	-	-
1	104.8059	48.3921	2.360	Bus 6
2	87.8012	56.7655	1.180	Bus 10 Bus 30
3	75.3344	62.9043	0.787	Bus 7 Bus 9 Bus 11
4	71.6261	64.7303	0.590	Bus 7 Bus 14 Bus 25 Bus 31

5	70.1381	65.4630	0.472	Bus 8 Bus 15 Bus 25 Bus 29 Bus 32
6	69.7410	65.6586	0.393	Bus 7 Bus 10 Bus 16 Bus 25 Bus 30 Bus 32

Table 3 presents the optimal placement of DGs for the 69-bus IEEE system. Connecting a 2.36 MW DG to the system results in a substantial reduction in total active power loss, decreasing from 238.6734 kW to 95.6066 kW, representing a reduction of 59.9425%, with the optimal DG placement identified on bus 61. Increasing the number of DGs in the IEEE 69-bus system correlates with a decrease in power losses. As per Table 4.6, the optimal configuration for the 69-bus system involves installing seven DGs, each with a capacity of 0.337 MW, on buses 12, 21, 60, 61, 62, 63, and 64. This arrangement reduces active power loss from 238.6734 kW to 73.5559 kW.

Table 3
Optimum DG Placement for IEEE 69-Bus System

Number of DG	Total active power loss (kW)	Percentage reduction of power loss (%)	Size per DG unit (MW)	Optimum DG placement
0	238.6734	-	-	-
1	95.6066	59.9425	2.360	Bus 61
2	88.0188	63.1217	1.180	Bus 11 Bus 61
3	77.1414	67.6791	0.787	Bus 12 Bus 61 Bus 62
4	75.5769	68.3346	0.590	Bus 17 Bus 60 Bus 61 Bus 62
5	75.0343	68.5620	0.472	Bus 18 Bus 59 Bus 61 Bus 62 Bus 64

6	74.3088	68.8659	0.393	Bus 11 Bus 18 Bus 60 Bus 61 Bus 62 Bus 54
7	73.5559	69.1814	0.337	Bus 12 Bus 21 Bus 60 Bus 61 Bus 62 Bus 63 Bus 64

Fig. 6 depicts the voltage profile of the IEEE 12-bus system with varying numbers of DGs. The average voltage magnitude without PV is 0.99612 per unit, while the minimum voltage magnitude is 0.99345 per unit on bus 12. The system's performance is affected by the addition of one PV, resulting in an average voltage magnitude of 0.99862 per unit and a minimum voltage magnitude of 0.99808 per unit. With the installation of two, three, four, and five DGs, the average voltage magnitudes increase to 0.99826 per unit, 0.99826 per unit, 0.99840 per unit, 0.99839 per unit, and 0.99843 per unit, respectively. The minimum voltage magnitudes are 0.99808 per unit, 0.99728 per unit, 0.99768 per unit, 0.99763 per unit, and 0.99773 per unit for two, three, four, and five DGs, respectively.

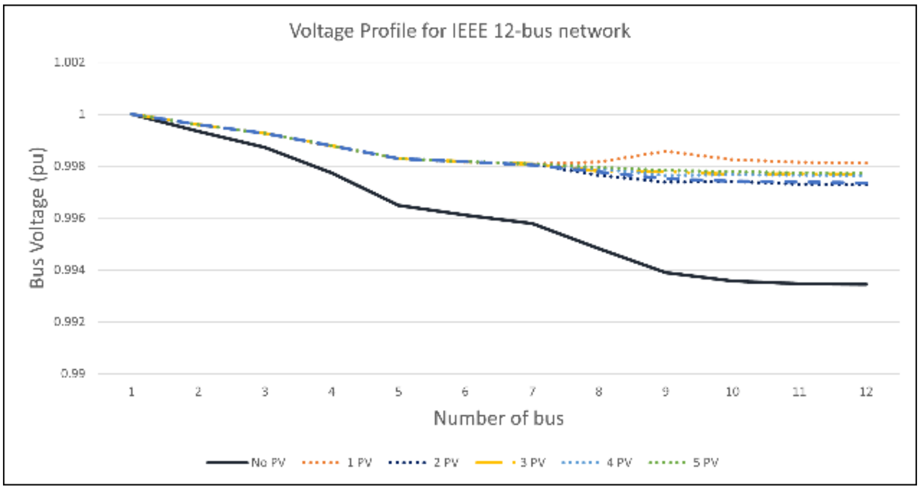

Fig. 6. Voltage profile for IEEE 12-bus network

According to Fig. 7, in the IEEE 33-bus system without DGs, the lowest voltage magnitude is 0.91293 per unit on bus 18, while the average voltage magnitude in the system is 0.94836 per unit. The installation of one DG increases the average voltage magnitude to 0.97269 per unit, with a minimum voltage magnitude of 0.94792 per unit. Subsequent installations of two, three, four, five, and six DGs lead to average voltage magnitudes of 0.97269 per unit, 0.98357 per unit, 0.97764 per unit, 0.97759 per unit, 0.97899 per unit, and 0.98017 per unit, respectively. The minimum voltage magnitudes for two, three, four, five, and six DGs are 0.94792 per unit, 0.97121 per unit, 0.95863 per unit, 0.96201 per unit, 0.96574 per unit, and 0.96731 per unit, respectively.

In the 69-bus IEEE system, as depicted in Fig. 8, the average voltage magnitude without DG is 0.97234 per unit, while the minimum voltage magnitude is 0.90338 per unit on bus 65. With one DG installed, the average voltage magnitude increases to 0.99077 per unit, and the minimum voltage magnitude is 0.97112 per unit. The average voltage magnitudes for two, three, four, five, six, and seven DGs further increase to 0.99077 per unit, 0.98855 per unit, 0.99046 per unit, 0.99310 per unit, 0.99231 per unit, 0.99192 per unit, and 0.99210 per unit, respectively. The minimum voltage magnitudes for two, four, five, six, and seven DGs are 0.95891 per unit, 0.97644 per unit, 0.97691 per unit, 0.97996 per unit, 0.97496 per unit, and 0.97697 per unit, respectively.

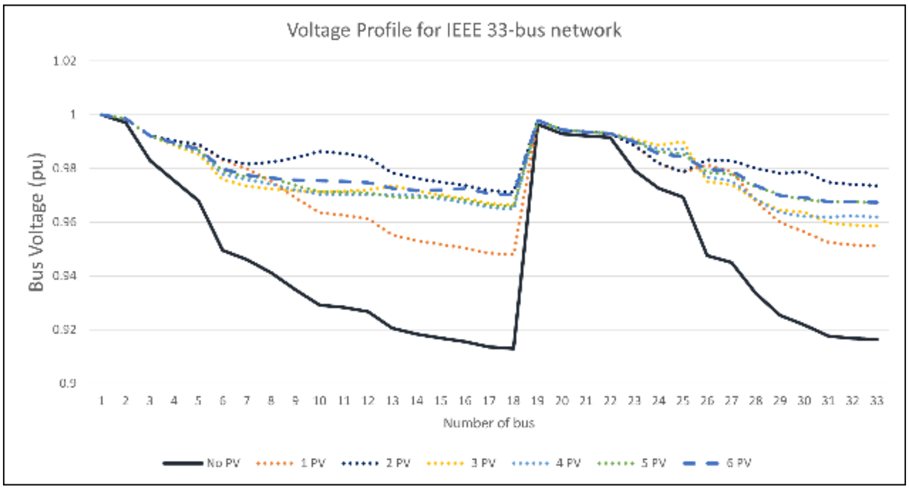

Fig. 7. Voltage profile for IEEE 33-bus network

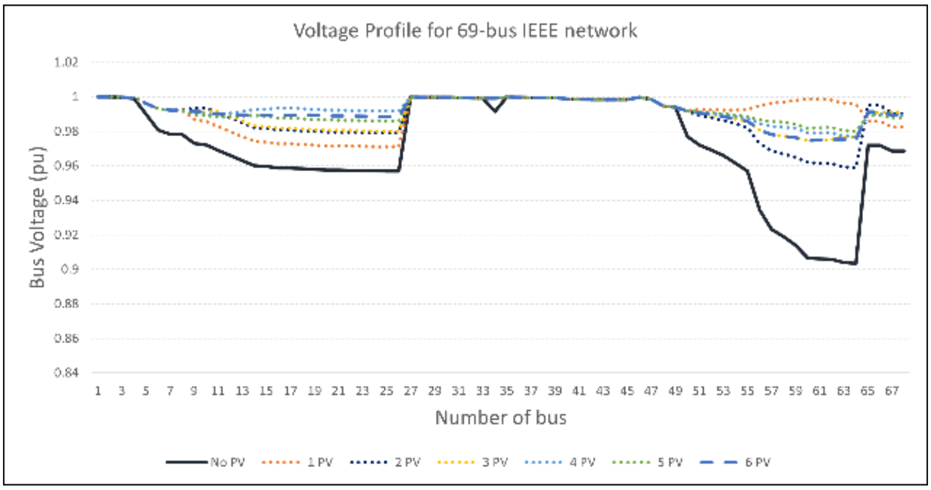

Fig. 8. Voltage profile for IEEE 69-bus network

The parameters used for the AOA and PSO comparison include 20 searching agents, 100 iterations, 3 DGs, and 20 runs. According to Fig. 9, both AOA and PSO consistently yield a minimum fitness value of 11.6005 kW per run, attributed to the convenient topology of the IEEE 12-bus system, making optimisation relatively straightforward with few local optima. Fig. 10 illustrates that AOA achieves the minimum active power loss at the 2nd iteration, while PSO reaches it at the 8th iteration for the IEEE 12-bus system.

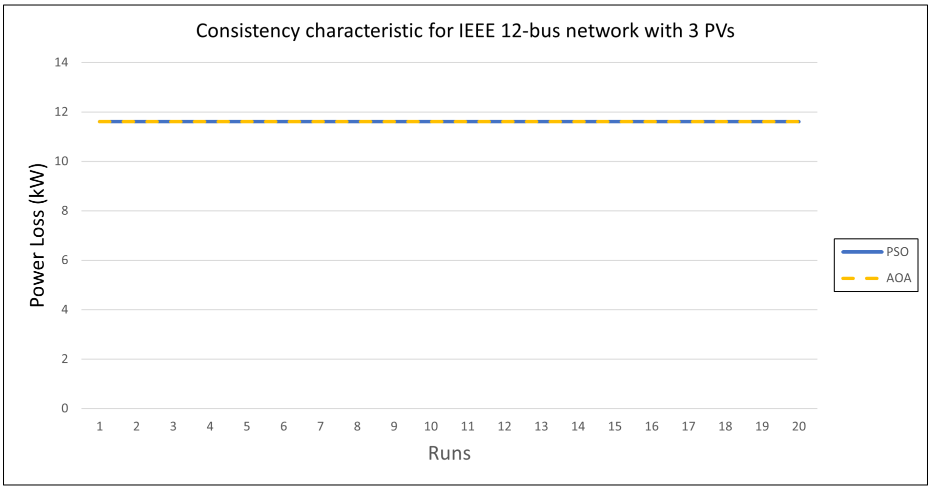

Fig. 9. Consistency characteristic for IEEE 12-bus network with 3 PVs

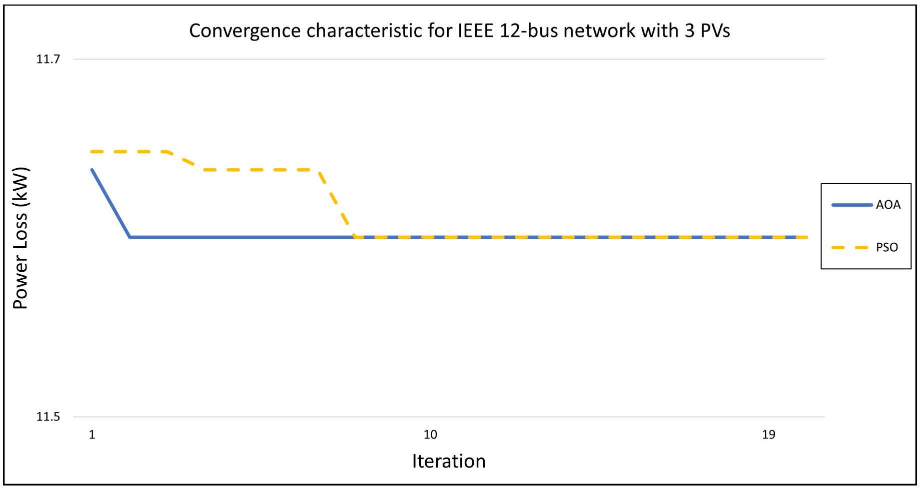

Fig. 10. Convergence characteristic for IEEE 12-bus network with 3 PVs

In Fig. 11, the optimal placement of three DGs in the IEEE 33-bus system results in a minimum fitness value of 75.3344 kW. AOA produces this minimum fitness value in 18 out of 20 runs, compared to PSO, which achieves it in 15 out of 20 runs. For the IEEE 33-bus system, Fig. 12 shows that AOA achieves the minimum active power loss total at the 8th iteration, while PSO reaches it at the 25th iteration.

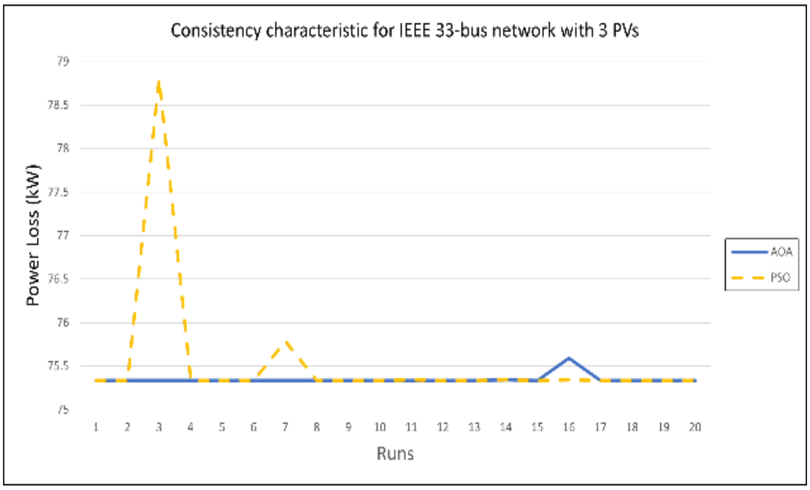

Fig. 11. Consistency characteristic for IEEE 33-bus network with 3 PVs

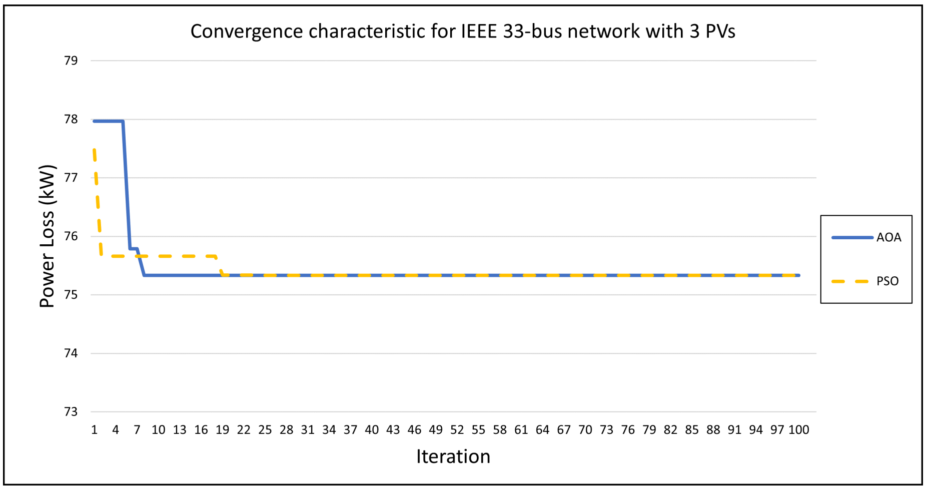

Fig. 12. Convergence characteristic for IEEE 33-bus network with 3 PVs

In Fig. 13, for the IEEE 69-bus system, AOA achieves a minimum fitness value of 77.1414 kW in 16 out of 20 runs, while PSO does so in 12 out of 20 runs. In Fig. 14, for the IEEE 69-bus system, AOA achieves the minimum active power loss at the 9th iteration, while PSO reaches it at the 20th iteration.

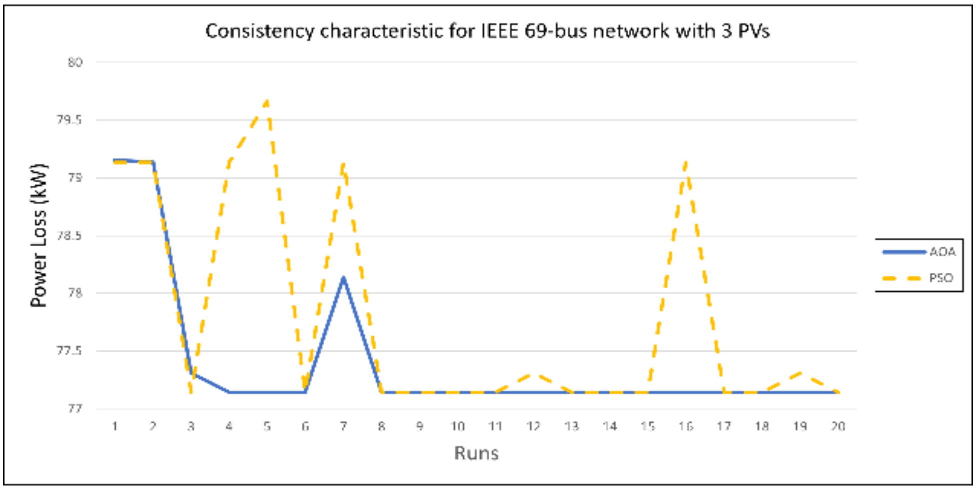

Fig. 13. Convergence characteristic for IEEE 69-bus network with 3 PVs

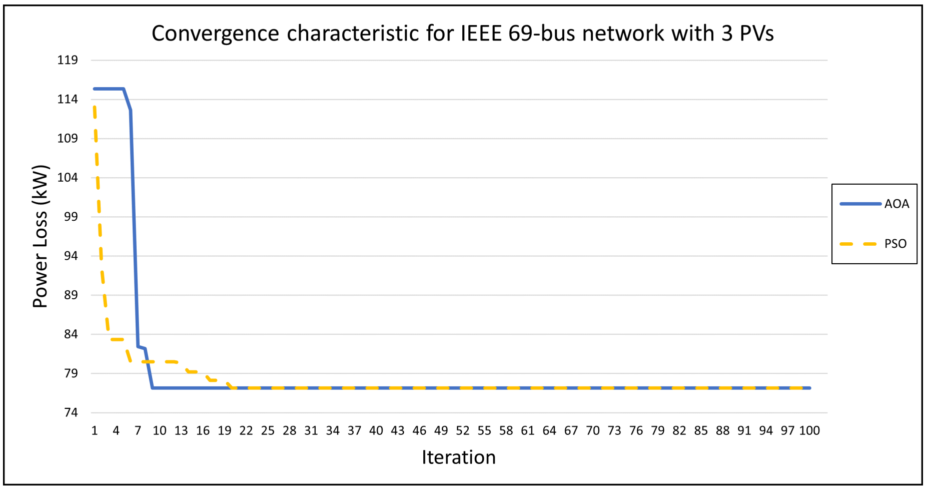

Fig. 14. Consistency characteristic for IEEE 69-bus network with 3 PVs

In Table 4, a comparison of the optimal placement of five DGs in the IEEE 12-bus system using AOA and PSO reveals identical minimum active power loss and DG locations. Notably, AOA demonstrates a faster calculation time of 11.1581 seconds, outperforming PSO's 14.6041 seconds.

Table 5 outlines a comparison between AOA and PSO for the IEEE 33-bus system with six DGs. AOA achieves a lower active power loss of 69.7410 kW compared to PSO's 70.8844 kW. Both algorithms identify the optimal DG placement at buses 7, 10, 16, 25, 30, and 32, with AOA boasting a quicker calculation time of 33.5668 seconds compared to PSO's 41.5684 seconds.

For the IEEE 69-bus system with seven DGs, AOA records a lower active power loss of 73.7428 kW, with an optimal DG placement at buses 12, 23, 59, 61, 62, 63, and 64. In contrast, PSO yields an active power loss of 74.0223 kW, with an optimal DG placement on buses 21, 59, 61, 62, 63, 64, and 69. AOA also exhibits a faster calculation time at 98.5286 seconds.

Table 4
Comparison Of Optimal Dg Placement for IEEE 12-Bus System

Algo.	No. of DG	Total active power losses (kW)	Percent reduction of power loss (%)	Size per DG unit (MW)	DG location	Time (s)
AOA	5	11.5488	50.1353	0.472	Bus 7 Bus 8 Bus 9 Bus 10 Bus 11	11.1581
PSO	5	11.5488	50.1353	0.472	Bus 7 Bus 8 Bus 9 Bus 10 Bus 11	14.6041

Table 5
Comparison Of Optimal Dg Placement for IEEE 33-Bus System

Algo.	No. of DG	Total active power losses (kW)	Percent reduction of power loss (%)	Size per DG unit (MW)	DG location	Time (s)
AOA	6	69.7410	65.6586	0.393	Bus 7 Bus 10 Bus 16 Bus 25 Bus 30 Bus 32	33.5668
PSO	6	70.8844	66.4035	0.393	Bus 7 Bus 10 Bus 16 Bus 25 Bus 30 Bus 32	41.5684

Table 6
Comparison Of Optimal Dg Placement for IEEE 69-Bus Systems

Algo.	No. of DG	Total active power losses (kW)	Percent reduction of power loss (%)	Size per DG unit (MW)	DG location	Time (s)
AOA	7	73.7428	69.1031	0.337	Bus 12 Bus 23 Bus 59 Bus 61 Bus 62 Bus 63 Bus 64	98.5286
PSO	7	74.0223	68.9860	0.337	Bus 21 Bus 59 Bus 61 Bus 62 Bus 63 Bus 64 Bus 69	112.6691

4. Conclusion

Archimedes Optimisation Algorithm was utilized in this study to identify the optimal placement of DGs in radial distribution networks, specifically the IEEE 12-bus, 33-bus, and 69-bus systems as test cases. The implementation of the algorithm resulted in a reduction percentage of active power loss of 50.1353%, 66.0442%, and 68.8659% for the respective IEEE 12-bus, 33-bus, and 69-bus systems. A comprehensive analysis and comparison of the study results were conducted to assess the effectiveness and performance of the developed algorithm, with a specific focus on its comparison with another algorithm, the Particle Swarm Optimisation Algorithm. The study reveals that AOA outperforms PSO across consistency characteristics, convergence characteristics, and computation time. This comparison establishes AOA as a good optimisation technique for solving the problem of optimal DG placement in radial distribution networks, ensuring power loss reduction while adhering to system constraints.

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References
[1] Azman, A. H., N. N. A. Tukimat, M. A. Malek, and R. F. Che. "Analysis of Malaysia Electricity Demand and Generation by 2040." In *IOP Conference Series: Earth and Environmental Science*, vol. 880, no. 1, p. 012050. IOP Publishing, October 2021. https://doi.org/10.1088/1755-1315/880/1/012050
[2] Ludin, N. A., H. Phoumin, F. S. M. Chachuli, and N. H. Hamid. "Sustainable Energy Policy Reform in Malaysia." In *Revisiting Electricity Market Reforms: Lessons for ASEAN and East Asia*, 251-281. Singapore: Springer Nature Singapore, 2022. https://doi.org/10.1007/978-981-19-4266-2_11
[3] Khetrapal, P. "Distributed Generation: A Critical Review of Technologies, Grid Integration Issues, Growth Drivers and Potential Benefits." *International Journal of Renewable Energy Development*, no. 2 (2020). https://doi.org/10.14710/ijred.9.2.189-205

[4] Prakash, P., and Khatod, D. K. "Optimal sizing and siting techniques for distributed generation in distribution systems: A review." *Renewable and sustainable energy reviews*, no. 57 (2016), 111-130.

[5] Meskin, M., Domijan, A., and Grinberg, I. "Impact of distributed generation on the protection systems of distribution networks: analysis and remedies–review paper." *IET Generation, Transmission & Distribution*, no. 14 (2020), 5944-5960.

[6] Shuaibu Hassan, A., Y. Sun, and Z. Wang. "Optimization Techniques Applied for Optimal Planning and Integration of Renewable Energy Sources Based on Distributed Generation: Recent Trends." *Cogent Engineering* 7, no. 1 (2020): 1766394. https://doi.org/10.1080/23311916.2020.1766394

[7] Suresh, M. C. V., and J. B. Edward. "A Hybrid Algorithm Based Optimal Placement of DG Units for Loss Reduction in the Distribution System." *Applied Soft Computing* 91 (2020): 106191. https://doi.org/10.1016/j.asoc.2020.106191

[8] Pham, T. D., T. T. Nguyen, and B. H. Dinh. "Find Optimal Capacity and Location of Distributed Generation Units in Radial Distribution Networks by Using Enhanced Coyote Optimization Algorithm." *Neural Computing and Applications* 33 (2021): 4343-4371. https://doi.org/10.1007/s00521-020-05239-1

[9] Elattar, E. E., and S. K. Elsayed. "Optimal Location and Sizing of Distributed Generators Based on Renewable Energy Sources Using Modified Moth Flame Optimization Technique." *IEEE Access* 8 (2020): 109625-109638. https://doi.org/10.1109/ACCESS.2020.3001758

[10] Pal, A., A. K. Chakraborty, and A. R. Bhowmik. "Optimal Placement and Sizing of DG Considering Power and Energy Loss Minimization in Distribution System." *International Journal on Electrical Engineering and Informatics* 12, no. 3 (2020): 624-653. https://doi.org/10.15676/ijeei.2020.12.3.12

[11] Karunarathne, E., J. Pasupuleti, J. Ekanayake, and D. Almeida. "Optimal Placement and Sizing of DGs in Distribution Networks Using MLPSO Algorithm." *Energies* 13, no. 23 (2020): 6185. https://doi.org/10.3390/en13236185

[12] Ismael, S. M., S. H. E. A. Aleem, and A. Y. Abdelaziz. "Optimal Sizing and Placement of Distributed Generation in Egyptian Radial Distribution Systems Using Crow Search Algorithm." In *Proceedings of the 2018 International Conference on Innovative Trends in Computer Engineering (ITCE 2018)*, vol. 2018-March, 332–337. https://doi.org/10.1109/ITCE.2018.8316646

[13] Chinnaraj, S. G. R., and R. Kuppan. "Optimal Sizing and Placement of Multiple Renewable Distribution Generation and DSTATCOM in Radial Distribution Systems Using Hybrid Lightning Search Algorithm-Simplex Method Optimization Algorithm." *Computational Intelligence* 37, no. 4 (November 2021): 1673–1690. https://doi.org/10.1111/coin.12402

[14] Abdelaziz, A. Y., E. S. Ali, and S. M. A. Elazim. "Flower Pollination Algorithm and Loss Sensitivity Factors for Optimal Sizing and Placement of Capacitors in Radial Distribution Systems." *International Journal of Electrical Power and Energy Systems* 78 (June 2016): 207–214. https://doi.org/10.1016/j.ijepes.2015.11.059

[15] Reddy, P. D. P., V. C. V. Reddy, and T. G. Manohar. "Application of Flower Pollination Algorithm for Optimal Placement and Sizing of Distributed Generation in Distribution Systems." *Journal of Electrical Systems and Information Technology* 3, no. 1 (May 2016): 14–22. https://doi.org/10.1016/j.jesit.2015.10.002

[16] Kamarudin, M. N., T. J. T. Hashim, and A. Musa. "Optimal Sizing and Location of Distributed Generation for Loss Minimization Using Firefly Algorithm." *Indonesian Journal of Electrical Engineering and Computer Science* 14, no. 1 (April 2019): 421–427. https://doi.org/10.11591/ijeecs.v14.i1.pp421-427

[17] Ouali, S., and Cherkaoui, A. "An improved backward/forward sweep power flow method based on a new network information organization for radial distribution systems." *Journal of electrical and Computer Engineering*, no. 1 (2020): 5643410. https://doi.org/10.1155/2020/5643410

[18] Kang, L. J., S. Abd Halim, H. M. Rosli, N. A. M. Kamari, and L. J. Awalin. "Optimal Distributed Generations Placement in Radial Distribution Network Using Whale Optimization Algorithm." *International Journal of Advanced Trends in Computer Science and Engineering* 9, no. 5 (2020): 7680-7689. https://doi.org/10.30534/ijatcse/2020/110952020

[19] Angalaeswari, S., Sanjeevikumar, P., Jamuna, K., and Leonowicz, Z. "Hybrid PIPSO-SQP algorithm for real power loss minimization in radial distribution systems with optimal placement of distributed generation." *Sustainability,* no. 12 (2020); 5787. https://doi.org/10.3390/su12145787

[20] Hashim, F. A., K. Hussain, E. H. Houssein, M. S. Mabrouk, and W. Al-Atabany. "Archimedes Optimization Algorithm: A New Metaheuristic Algorithm for Solving Optimization Problems." *Applied Intelligence* 51 (2021): 1531-1551. https://doi.org/10.1007/s10489-020-01893-z