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Power losses reduction by optimal allocation of renewable distributed generation in distribution networks

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Abstract – *The electrical energy demand is increasing dramatically in many countries around the world due to population growth. As a result of this significant increase in demand, electricity distribution companies are seeking to promote distributed generation (DG). With the growing integration of decentralized renewable power generation into the distribution network, it becomes an active circuit where power flows and voltages are influenced not only by loads but also by sources. In distribution networks (DN), the optimal allocation of Renewable Distributed Generation (DG) units can significantly improve system performance by reducing power losses and enhancing the voltage profile and stability of the radial distribution network. The main objective of this paper is to apply the marine predator algorithm (MPA) to optimize the siting and sizing of DG units in the DN. The objective function considered is the minimization of active power losses. The proposed algorithm is tested on the IEEE 33-bus and 69-bus DN. The simulation results demonstrate that the MPA algorithm outperforms other optimization algorithms in terms of perform.*

Keywords: *Distribution network, Renewable distributed generation, Marine predator algorithm, Power losses.*

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I. Introduction

The term "distributed generation" (DG) is commonly used to refer to electrical energy sources that are directly connected to the distribution network. DG can be categorized into three groups: renewable energy sources (such as wind, solar, hydro, geothermal, and biomass), non-renewable energy sources (including small gas turbines, combustion turbines, and microturbines), and storage systems (such as batteries, flywheels, super-capacitors, compressed air energy storage, and pumped storage) [1, 2].

The integration of these energy sources into the distribution network brings numerous benefits, particularly with the incorporation of renewable energy sources. These benefits encompass power loss reduction, network reinforcement, improved reliability and security, reduction in greenhouse gas emissions, minimization of system costs, and more [3].

However, the improper allocation of DGs can have a significant impact on power flow, power losses, voltage profile, and system stability [4, 5]. The integration of distributed generation (DG) into distribution networks offers several advantages, including the reduction of power losses, improvement of voltage profile along feeders, and increased maximum power transmission capacity in cables and transformers [6]. However, the installation of DG in distribution systems requires careful consideration of their optimal locations and sizes. Choosing a suboptimal location with an optimal size or vice versa can lead to increased system losses and costs, as well as deterioration in voltage profile, protection, and stability. Therefore, simultaneous optimization of both location and sizing of DGs in distribution systems can prove highly beneficial for the overall performance of the distribution power system [7].

Meta-heuristic optimization techniques have been extensively investigated for the allocation and sizing of different types of DGs in distribution networks. These techniques employ iterative procedures to search for optimal or sub-optimal solutions to the optimization problem. Several meta-heuristic methods have been employed in this context, including Genetic Algorithm (GA), Simulated Annealing (SA), Tabu Search (TS), Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), Non-dominated Sorting GA-II (NSGA-II), Plant Growth Simulation Algorithm (PGSA), Artificial Bee Colony Algorithm (ABC), Bacterial Foraging Algorithm (BFA), Cat Swarm Optimization (CSO), Grey Wolf Optimization (GWO), Krill Herd Algorithm (KHA), and Invasive Weed Optimization (IWO) [8-10]. Among these approaches, the Marine Predator Algorithm (MPA) is specifically utilized for addressing the optimal placement and sizing problem of DGs in radial distribution networks [11].

The primary focus of this study is to achieve the minimization of real power losses in distribution networks. To evaluate the effectiveness of the marine predator algorithm (MPA) method, extensive assessments are conducted using the well-known IEEE 33-bus and IEEE 69-bus test systems. Through these evaluations, the aim is to establish the validity and performance of the MPA approach in addressing real power losses.

II. Methodology

II.1. Minimization of total active power loss

The main objective of DG siting and sizing in the distribution network is to minimize network active power losses while satisfying some operating constraints. The objective function for the minimization of active power loss is described as:

$$F = \min\left(P_{loss}\right) = \min\left(\frac{r_{ij}}{V_i V_j}\left(\sum_{i=1}^{N}\sum_{j=1}^{N}\cos\left(\delta_i-\delta_j\right)\left(P_iP_j+Q_iQ_j\right)+\sin\left(\delta_i-\delta_j\right)\left(Q_iP_j+P_iQ_j\right)\right)\right) \quad (1)$$

where P_i, P_j and Q_i, Q_j are the total active and reactive power at buses i and j; r_{ij} is the resistance of the branch ij; V_i, V_j and δ_i and δ_j are the voltage magnitudes and the voltage angles at buses i and j, respectively.

P_{loss} can be represented in percentage (%) while doing comparison as:

$$P_{loss}(\%) = \frac{P_{loss\_base} - P_{loss\_DG}}{P_{loss\_base}} \times 100 \quad (2)$$

where P_{loss_base} denoted the total power losses in the base case, while P_{loss_DG} represents the total power losses in the presence of DG units.

II.2. Constraints

Some constraints in the distribution network must be addressed while determining the best placement and sizing of DGs. They are explained as follows.

- *Equality constraint*

In the optimal allocation of DGs, active and reactive power balance equations are defined as equality constraints. These constraints are expressed by:

$$P_{G,i} - P_{l,i} = |V_i|\sum_{j=1}^{N_{bus}}|Y_{ij}||V_j|\cos\left(\delta_i-\delta_j-\theta_{ij}\right) \quad (3)$$

$$Q_{G,i} - Q_{l,i} = |V_i|\sum_{j=1}^{N_{bus}}|Y_{ij}||V_j|\sin\left(\delta_i-\delta_j-\theta_{ij}\right) \quad (4)$$

where $P_{G,i}$ and $Q_{G,i}$ are, respectively, the active and reactive power outputs of the ith generator; $P_{L,i}$ and $Q_{L,i}$ are, respectively, the active reactive powers of ith load bus; θ_{ij} are the angle of ith element in the admittance matrix of the system related to buses i and j.

- *Inequality constraints*

The inequality constraints subjected to DG setting and sizing problem include [11]:

Bus voltage:

$$V_{\min} \le |V_i| \le V_{\max} \qquad i = 1, 2, \ldots, N_{bus} \quad (5)$$

Branch current:

$$I_i \le I_{i\_\max} \qquad i = 1, 2, \ldots, N_{br} \quad (6)$$

Size of DG:

$$P_{DG}^{\min} \le |P_{DGi}| \le P_{DG}^{\max} \quad (7)$$

Position of DG:

$$2 \le |DG_{bus}| \le N_{bus} \quad (8)$$

where V_{min} and V_{max} are taken as 0.95 and 1.05 (p.u.), respectively; N_{bus} is the total number of buses; DG_{bus} is the bus number of the DG installation; V_i is the bus voltage; I_i is the current of the branch i; P_{DG} is the total power of DG and N_{br} is the total number of branches.

II.3. Marine Predator Algorithm (MPA)

MPA is a new swarm intelligence-based algorithm, proposed by a search [12]. This algorithm is mainly inspired by the hunting mechanism of marine predators, which is displayed in two strategies, namely, Lévy and Brownian motion. These two strategies depend on the shortage or abundance of prey in the defined areas. The MPA optimization procedure is divided into three essential stages considering different velocity ratios:

- high-velocity ratio, or when the target is moving quicker than the predator;
- unit velocity ratio, or when both predator and target move at about the same speed; and

- low-velocity ratio, or when a target is moving slower than the predator. These three stages mimic the step size of a predator's movements when catching prey. Based on these three steps and marine memory ability, the fitness of each solution for the current iteration is compared to its counterpart in the previous iteration, and the best solution is chosen. This process ameliorates the solution quality throughout the number of iterations.

II.4. Implementation of MPA in DG siting and sizing

This procedure can also be summarized in the following steps.

- **Step 1:** Read branch data and bus data for the network.
- **Step 2:** Read DG data.
- **Step 3:** Set the parameters of algorithm MPA and the limits of decision variables (siting and sizing of DG).
- **Step 4:** Generate the initial population for the decision variables (DG siting's and sizes).
- **Step 5:** Run backwards and forward to sweep power flow, incorporating DG.
- **Step 6:** Compute the active power loss (P_{loss}).
- **Step 7:** Compute the objective functions represented by Eq. (1).
- **Step 8:** Update the fitness of the objective function.
- **Step 9:** Repeat steps 5–8 until the maximum number of iterations.
- **Step 10:** Print the optimal solution (optimal siting and sizing of DG).

The other control parameters are set up according to the recommendation of the author in their original paper, as shown in Table 1. [12]

Table 1. Settings of the MPA parameters

Algorithm	Parameter settings	Value
MPA	Population size	50
	Maximum number of	200
	iterations	0.5
	P	≥ 10
	High-velocity ratio	1
	Unit-velocity ratio	0.1
	Low-velocity ratio	0.2
	FADs	

III. Simulation Results and Discussion

In this section, the performance of the aforementioned algorithm is evaluated using the IEEE 33-bus and IEEE 69-bus radial distribution networks. Figure 1 illustrates the diagram of the IEEE 33-bus system, which comprises main feeders and three laterals. The system operates at a voltage level of 12.66 kV and has a total load of 3720 kW and 2300 kVAr. The system data can be referred to in [13]. Figure 2 displays the diagram of the IEEE 69-bus system, consisting of 69 buses, 7 feeders, and 68 branches. This system operates at 12.66 kV and has a total load of 3800 kW and 2690 kVAr. The relevant system data is provided in [14].

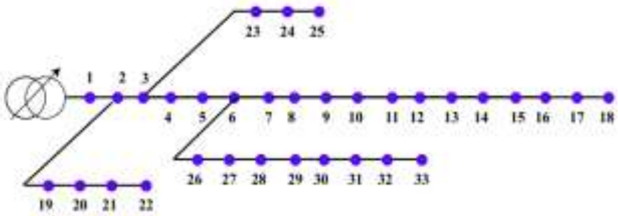

Figure 1. IEEE 33-bus distribution test system.

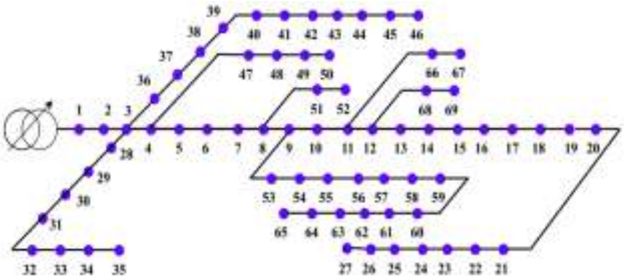

Figure 2. IEEE 69-bus distribution test system.

The optimal location and sizing of DGs in the RDN is determined with the objectif of reducing active power losses. The convergence characteristic of the MPA technique is depicted in Figure 3 and Figure 4 MPA technique converged to the optimal solution in a small number of iterations.

Figure 4 and Figure 6 show how the voltage profile was improved in the IEEE 33-bus system and IEEE69-bus system.

The optimal allocation results of three DGs are shown in Table 2 and Table 3.

The obtained results reveal that the MPA algorithm outperforms other existing methods such as opposition-based tuned-chaotic differential evolution technique (OTCDE) [15], manta ray foraging optimization (MRFO) algorithm [16], chaotic maps integrated stochastic fractal search (CMSFS) [17] and hybrid CBGA-VSA [18].

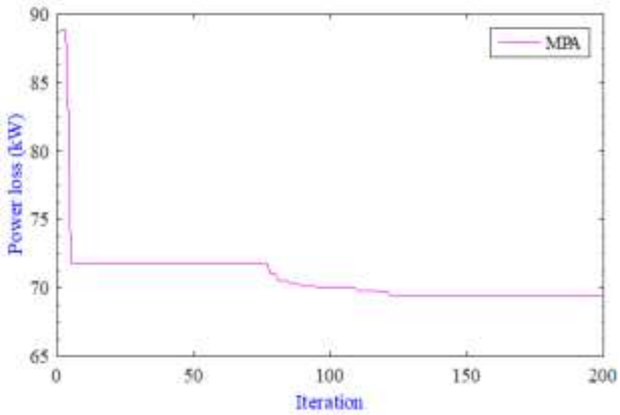

Figure 3. Convergence curve of MPA for the 33-bus network

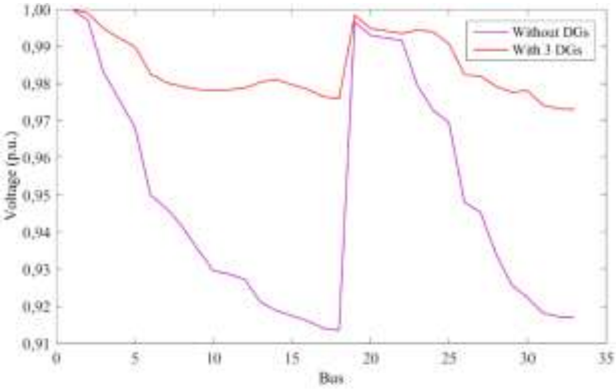

Figure 4. Bus voltage profile of IEEE 33-bus system

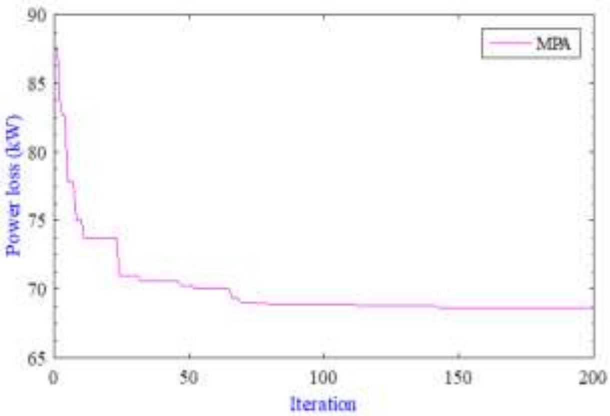

Figure 5. Convergence curve of MPA for the 69-bus network

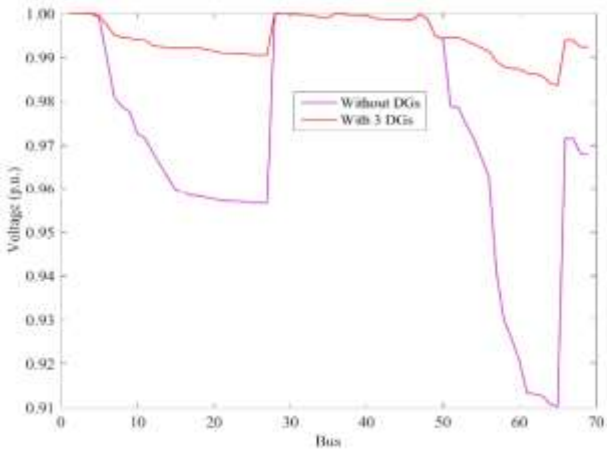

Figure 6. Bus voltage profile of IEEE 69-bus system

Table 2. Results for installing DGs in the 33-bus system

Algorithm	P_L without DG (kW)	With 3 DGs			
		Bus no.	*DG size (kW)*	*P_L (kW)*	*P_L reduction (%)*
MPA	201.89	14 24 30	759.0859 1071.1 1099.9	**69.3833**	**65.6335**
OTCDE [15]	210.98	13 24 30	801.8 1091.31 1053.6	72.785	65.5000
MRFO [16]	210.98	13 24 30	788.276 1017.1 1035.3	72.876	65.4583
CMSFS [17]	210.98	13 24 30	802 1091 1054	72.785	65.5000
CBGA-VSA [18]	210.98	13 24 30	801.8 1091.3 1053.6	72.785	65.5000

Table 2. Results for installing DGs in the 69-bus system

Algorithm	P_L without DG (kW)	With 3 DGs			
		Bus no.	*DG size (kW)*	*P_L (kW)*	*P_L reduction (%)*
MPA	224.55	11 18 61	472.3495 387.9321 1738.3	**68.661**	**69.423**
OTCDE [15]	224.95	12 22 61	379.26 328.39 1746.46	69.761	68.99
MRFO [16]	224.95	11 18 61	524.23 369.12 1713.4	69.426	69.14
CMSFS [17]	225.00	11 18 61	527 1719 380	69.428	69.14
CBGA-VSA [18]	225.00	11 18 61	526.8 380.1 1710.9	69.408	69.15

IV. Conclusion

The placement and sizing of renewable distributed power generation (DGs) in a distribution network play a vital role in enhancing network performance. This study focuses on the optimal allocation of DG units in a distribution network using the marine predator algorithm (MPA). The objective is to minimize power losses in the radial distribution network by selecting the optimal locations and sizes for the DGs. The effectiveness of the proposed method is demonstrated through its application to the IEEE 33-bus and IEEE 69-bus systems. Comparative analysis with other existing methods, including OTCDE, MRFO, CMSFS, and CBGA-VSA, showcases the superior performance of the MPA algorithm in achieving the desired objectives.

Declaration

- The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper.
- The authors declare that this article has not been published before and is not in the process of being published in any other journal.

The authors confirmed that the paper was free of plagiarism.

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