

Optimal location and sizing of distributed generation to minimize losses using whale optimization algorithm

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ABSTRACT

The conventional power plants often bring in power quality concerns for instance high power losses and poor voltage profile to the network which are caused by the locations of power plants that are placed a distance away from loads. With proper planning and systematic allocation, the introduction of distributed generation (DG) into the network will enhance the performance and condition of the power system. This paper utilizes the optimization approach named whale optimization algorithm (WOA) in the search of the most ideal location and size of DG while ensuring the reduction of power losses and the minimization of the voltage deviation. WOA implementation is done in the IEEE 33-bus radial distribution system (RDS) utilizing MATPOWER and MATLAB software for no DG, one DG and two DGs installation. The outcome obtained from using WOA was compared to other well-known optimization methods and WOA has shown its competency after comparison; the optimal location of WOA with other methods showing almost the same result. The best result presented was the system with two DGs installed due to the losses of the system was recorded to be the least compared to one DG or no DG installation.

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1. INTRODUCTION

In the era of industrialization, the need for advancement and improvement of the power network rise as the demand for stable electricity accelerate. The utility companies will opt for an optimized network to provide users with undistruptive electricity yet be cost-effective to the company. Usage concerning distributed generation (DG) mainly within the distribution network has various benefits such as the minimization of power loss and voltage drop, reduction in long term investment to upgrade the network, as well as the reliability and stability of the power system [1] only with suitable location and perfect capacity of DG. The implementation of DG that is located near loads changes the flow of the typical electrical network. Hence, the placement of DG near loads eliminates the long-distance power delivering process thus helps minimize losses [2]. The formation of DG units into different forms and capacities contribute to the power system enhancement and are converting the classic plans of an electrical network [3].

The proper allocation and size of DG must be taken into consideration during planning. This is due to the inaccurate position and size of DG integrated into the network might produce even higher losses than before. The objective of this paper is to find the most suitable location and size of DG in the IEEE 33-bus radial distribution system (RDS) utilizing whale optimization algorithm (WOA) to lower power losses and minimize

voltage deviation. An organized power network with the integration of DG units at suitable locations and size is extremely important as the impact of DG on loss reduction changes when the DG location changes.

Numerous methods had been used by various researchers to achieve the most ideal position and size of DG with low losses and are classified into two big groups; the classic approach and the Artificial Intelligence (AI) approach [4]. Three sub-categories of the AI approach consist of society inspired, nature-inspired and also hybrid that uses two techniques. The effective approaches in finding the most ideal location and size of DG must be able to improve DG capabilities while maintaining power system efficiency [5]. A few well known AI approaches are the particle swarm optimization (PSO), the genetic algorithm (GA), and artificial bee colony (ABC) algorithm, grey wolf optimization (GWO) algorithm [6], artificial algae algorithm [7], embedded adaptive mutation evolutionary programming [8] and artificial fish swarm optimization (AFSO) algorithm [9].

Throughout the years, AI methods have been extensively used with regards to discover the most ideal location and size of DG to obtain the maximized benefits from the insertion of DG units in the power system. From the work done by authors in [10]–[12] using PSO, the total losses of the system with DG installed were found to have a major reduction at approximately 67% from the initial losses without DG. The ideal allocation of DG was obtained through simulation of PSO with the least losses. Next, in [13] the combination of analytical techniques with genetic algorithm was utilized in the IEEE 33-bus and 69-bus distribution system in examining the most ideal location and size of multiple DGs. The hybrid technique was found to be capable of obtaining the DGs allocation with low losses when compared to other non-hybrid techniques.

This paper applied the WOA to find the optimal allocation of DG with the appropriate size in the IEEE 33-RDS for power loss and voltage deviation curtailment. The inspiration of WOA comes from the natural phenomenon of the hunting behaviour of humpback whales [14] thus falls under the sub-category of nature-inspired techniques from the AI approach. The advantages of using WOA for optimization problems were identified in [15]; simple application as the parameters settings is rather easy due to the minimal amount of variables and simple computation with a high level of precision. WOA has shown its high competency in solving the DG allocation within the distribution system. Based on authors in [15], WOA has the ability to identify the ideal location of DG and the outcome resulted in a positive voltage profile and low power losses. Several IEEE test systems were tested by applying WOA and the results were convincing. Also, WOA was simulated in IEEE 33-bus and 69-bus RDS for the purpose of obtaining the most ideal allocation of DGs for multi-objective [16]. The WOA simulated outcome was put in comparison to other optimization techniques and WOA shown to be more suitable for multi-objective optimization resulted in low power loss, low operating cost and an enhanced voltage profile.

In this paper, the simulation was done in the IEEE 33-bus test system by employing the MATPOWER and MATLAB software. The load flow analysis using the Newton Raphson method was carried out to identify the base case scenario without the insertion of DG units. The load flow analysis was done by the MATPOWER software to first identify the weakest bus and to obtain the values for power loss and voltage of the base case. Then, with DG units inserted in the system, the WOA was utilized in MATLAB with the objective to secure the most ideal location and size of DG while ensuring the system has the least losses. In section 2 below, the problem formulation, the mathematical model and equations were provided. Whereas section 3 displayed the results based on the simulations done as well as the analysis and discussion of the results. Lastly, section 4 presented the conclusion of this paper.

2. RESEARCH METHOD

The problem formulation such as the constraints, the equations of the objective function to compute power loss and voltage deviation of the system are presented in this subsection. The mathematical model of the optimization approach using WOA are also elaborated. Other than that, the flowchart of the proposed work to present the flow and steps which has been implemented in this work is displayed in this section.

2.1. Power loss objective function

One of the objectives of this paper is to obtain the power loss minimization in the 33-bus test system. The losses for each bus of the test system was obtained through the power flow calculation using MATPOWER. Firstly, the line and load data [17] were inserted into the MATPOWER/MATLAB software. Then, the load flow is calculated using the Newton Raphson method and then the results are displayed. The bus voltage limits and the DG capacity limits are the two constraints needed to be taken into consideration for the optimization simulation process. The voltage regulation limits of bus voltage between 0.95 p.u. and 1.05 p.u. of voltage had to be met for all the bus voltages [18].

$$V_{min} \leq V_p \leq V_{max} \quad (1)$$

where V_p is the node voltage at bus p. Also, V_{min} and V_{max} represent the minimum and maximum voltage complying with the regulation limits.

The constraints of the input DG capacity in this paper must follow the allowable inserting limit of DG into the IEEE 33-bus RDS.

$$V_{min} \leq V_p \leq V_{max} \tag{2}$$

where P_{DG} is the input DG size, $P_{DG min}$ and $P_{DG max}$ are the valid DG limit of minimum and maximum size respectively. The minimum size of DG is 0 MW. Based on [19], the maximum DG size restriction must be smaller than 3.715 MW which is the total active power load of the 33-bus test system. In order to maximize the DG capability in the network, the maximum allowable limit of DG into the 33-bus test system must be observed.

The summation of the power losses of the system without the insertion of DG can be obtained through (3).

$$V_{min} \leq V_p \leq V_{max} \tag{3}$$

Where,

n - number of branches in the 33-bus test system

P_p - active power flow from bus p

Q_p - reactive power flow from bus p

R_i - resistance of the i th branch

With the DG inserted into the distribution system, the summation of power loss is calculated by applying (4).

$$P_{total loss with DG} = \sum_{i=1}^n \left(R_i * \frac{(P_{DG p}^2 + Q_{DG p}^2)}{|V_p|^2} \right) \tag{4}$$

Where,

$P_{DG p}$ - active power flow from bus p with the presence of DG.

$Q_{DG p}$ - reactive power flow from bus p with the presence of DG.

$$f_1(x) = \min \frac{P_{total loss (with DG)}}{P_{total loss (base)}} \tag{5}$$

The power loss objective function for power loss minimization is specified as (5) where $f_1(x)$ is the objective function one in this paper.

2.2. Voltage deviation objective function

Voltage deviation of the system is obtained through the total voltage differences between each bus and the reference voltage [19], [20]. The formulation for the reduction of voltage deviation is indicated as (6).

$$f_2(x) = \sum_{i=1}^n |V_i - V_{ref}| \tag{6}$$

where $f_2(x)$ is the objective function two in this paper, n represents the total amount of load bus, V_i represents the actual voltage at load bus i , and V_{ref} shows the reference voltage of 1.0 p.u. WOA problem formulation was inspired by the unique hunting technique of humpback whales which was subsequently represented into mathematical formulas [14] given in subsection 2.3 to 2.5.

2.3. Searching randomly for prey

Humpback whales will hunt for food by chance, without planning, depending on the location during the exploration phase [19], [21]. As a result, when vector \vec{A} has a value bigger than one, the location of a search agent is updated based on the previous randomly selected agent. This method enables WOA to do a broad variety of searches using (7) and (8).

$$\vec{D} = \vec{C} \cdot \vec{X}_{random} - \vec{X} \tag{7}$$

$$\vec{X}(t+1) = \vec{X}_{random} - \vec{A} \cdot \vec{D} \quad (8)$$

where \vec{X}_{random} is a position vector selected randomly among the initial population. Coefficient vectors \vec{A} and \vec{C} have to be calculated utilizing (9) and (10). Also, Vector \vec{a} can be reduced linearly from 2 to 0 while vector \vec{r} is a value chosen randomly within 0 to 1.

$$\vec{A} = 2\vec{a} \cdot \vec{r} - \vec{a} \quad (9)$$

$$\vec{C} = 2 \cdot \vec{r} \quad (10)$$

Coefficient vectors \vec{A} and \vec{C} are considered the two main internal parameters to be modified and tailored accordingly. The varying values of \vec{A} and \vec{C} showed the several locations around the best agent that can be obtained in relation to the current position. In this paper, the vector \vec{a} was set to a constant number 2, in order to contribute to exploration and enable the WOA algorithm to execute a global hunt.

2.4. Encircling and shrinking mechanism

In this phase, humpback whales are now preparing to trap the prey after the exploration phase. Humpback whales will surround the prey within loops with bubbles blown on an upward spiral pattern. This hunting strategy of humpback whales is with the name of bubble-net feeding behaviour [22]. WOA approach suggests that the best agent is either the chosen prey or the closest match to the ideal solution:

$$\vec{D} = \vec{C} \cdot \vec{X}^*(t) - \vec{X}(t) \quad (11)$$

$$\vec{X}(t+1) = \vec{X}^*(t) - \vec{A} \cdot \vec{D} \quad (12)$$

where t represents the current iteration, \vec{X} is the position vector, and \vec{X}^* is the vector that indicates the position of the best agent discovered up until now. When a better search agent is discovered, vector \vec{X}^* must be updated and replaced after each iteration. This is to ensure that the best solution of the placement and size of DG stored and checked among all the search agents.

The utilization of either equation of the random search mechanism in 2.3 or the shrinking mechanism in 2.4 to determine the position vector is depending on the value of vector \vec{A} . The algorithm chooses (8) for the value of $A \geq 1$, and (12) for $A < 1$. This is because the humpback whales have already found their target and are prepared to attack it.

2.5. Spiral updating position

The spiral formula is formed between the position of humpback whales with the prey and (13) is utilized to update the position.

$$\vec{X}(t+1) = \vec{D}' \cdot e^{bl} \cdot \cos(2\pi l) + \vec{X}^*(t) \quad (13)$$

$$\vec{D}' = \vec{X}^*(t) - \vec{X}(t) \quad (14)$$

Vector \vec{D}' is used to represent the distance between the whale and the prey, also indicating the optimal solution found so far. Whereas b is a constant that specifies the shape of the spiral and l will be chosen randomly of value -1 to 1 in the software.

Humpback whales, on the other hand, swim around their prey in an encircling manner while also following a spiral-shaped route. Based on this feeding method, there is a 50% possibility of selecting either the encircling or the spiral equations as (15).

$$\vec{X}(t+1) = \begin{cases} \vec{X}^*(t) - \vec{A} \cdot \vec{D} & \text{if } p < 0.5 \\ \vec{D}' \cdot e^{bl} \cdot \cos(2\pi l) + \vec{X}^*(t) & \text{if } p \geq 0.5 \end{cases} \quad (15)$$

where p is chosen randomly in the software between the number of 0 to 1.

The WOA algorithm is used to find the best solutions for the size and location of either one or two DG that fully fulfilled the objective functions. The steps for carrying out the simulation process in achieving the optimal location and size of DG using WOA are described in a flowchart in Figure 1.

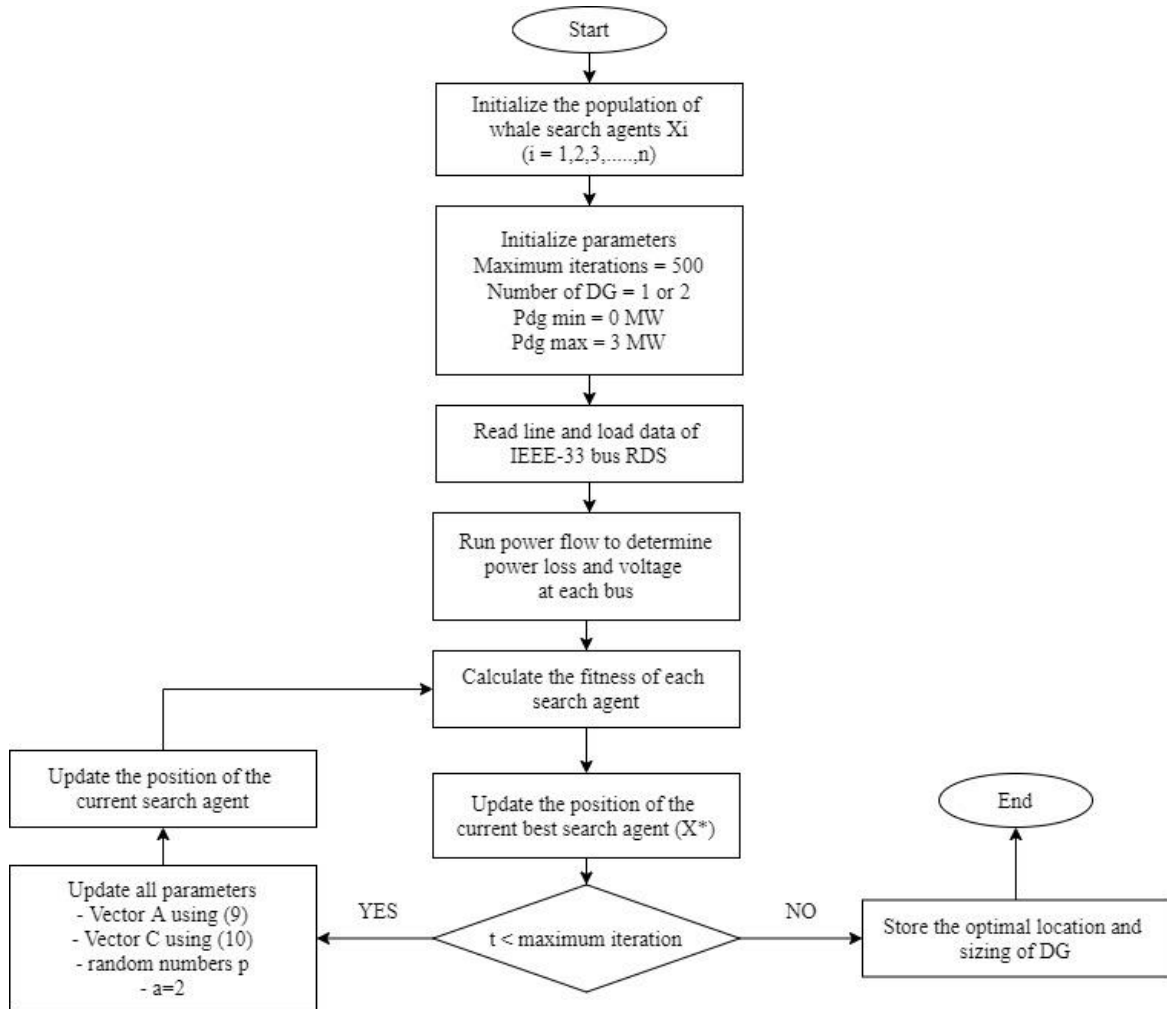


Figure 1. Flowchart to obtain the optimal location and size of DG utilizing WOA

2.6. Implementation of whale optimization algorithm in 33-bus radial distribution system

WOA the optimization technique with the Newton Raphson load flow technique was used to search for the optimum placement and size of DG in various case studies utilizing MATLAB and MATPOWER software. The simulation in this paper was done on IEEE 33-bus test system displayed as in Figure 2. The line and load values of the test system were obtained from [17] with 12.66 kV and 100 MVA of voltage level and base apparent power respectively. The WOA parameters value used to conduct the simulation was listed in Table 1.

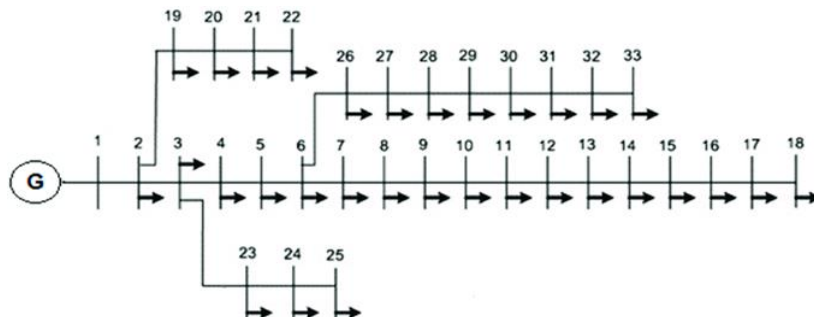


Figure 2. IEEE 33-bus radial distribution system

Table 1. The whale optimization algorithm variables and values

WOA parameters	Values
Number of whale search agents	200
Maximum iterations	500
Number of DG	1 and 2
DG lower input size	0 MW
DG upper input size	3 MW

3. RESULTS AND DISCUSSION

Three case studies have been tested and compared to verify the accuracy of WOA in the search of the most ideal location and size of DG for loss reduction and voltage deviation minimization.

Case 1: The base case where the test system is with no insertion of DG.

Case 2: Test system with one DG inserted.

Case 3: Test system with two DGs inserted.

Table 2. The three case studies optimization results of whale optimization algorithm

	Number of DG	Total active power loss (kW)	Loss reduction (%)	Minimum bus voltage (V p.u.) @ bus 18	Total voltage deviation (p.u.)	Optimal location and size of DG		
						Optimal location @ bus number	DG power (MW)	Total DG power (MW)
Case 1	0	202	-	0.9134	1.6964	-	-	-
Case 2	1	103	49	0.9523	0.7928	6	2.589	2.589
Case 3	2	83	59	0.9697	0.5794	13 30	0.850 1.192	2.042

For case 1, the simulation was run without any DG inserted into the system. Thus, active power loss of 202kW and voltage deviation of 1.6964 p.u. were simulated to be the losses of the base case. From the data listed in Table 2, Case 2 with the insertion of one DG has shown improvement in the losses of the system. The power loss for Case 2 was found to be 103kW which was reduced by about 49% when compared to Case 1. Also, the voltage deviation obtained was found lesser than in Case 1 at 0.7928 p.u. For all cases, bus 18 which is the weakest bus will have the minimum voltage when compared to the voltage of other buses. This is due to bus 18 is placed furthest away from the source thus having the least bus voltage. From (1), the minimum voltage must be kept within the regulation limit of at least 0.95 p.u and above. Thus, the minimum voltage at bus 18 was improved from 0.9134 V p.u. to 0.9523 V p.u. for Case 2 with one DG inserted. In Case 3, all losses had been further reduced; 83kW for active power loss with 59% of loss reduction compared to Case 1 with 0.9754 p.u. for voltage deviation. The minimum bus voltage at bus 18 for Case 3 with two DGs inserted into the system was observed at 0.9697. With this, all bus voltages for Case 2 and Case 3 comply with the regulation limit and fulfilled the constraints set.

Figure 3 represented the voltage profile for the three case studies; Case 1 of no DG, Case 2 of one DG, and Case 3 of 2 DGs. Case 3 with 2 DGs inserted into the system exhibited the best voltage profile among all. The percentage of loss reduction for Case 2 and Case 3 when put into comparison with the value in Case 1 can be calculated using (16). This is to ensure that when one DG or two DGs is added to the network, a positive loss reduction occurs.

$$\% \text{ Loss Reduction} = \frac{P_{\text{loss base}} - P_{\text{loss with DG}}}{P_{\text{loss base}}} \times 100\% \quad (16)$$

By using WOA, the most ideal location for 1 DG was obtained at bus 6 with the DG size of 2.589MW. Then, with 2 DGs, the best location was found to be bus 13 and 30, with the DG size of 0.85 MW and 1.192 MW respectively, having a total DG capacity of 2.042MW.

The WOA findings were compared to different optimization algorithms employed by other researchers in papers [20], [21], [23], [24] in order to evaluate the accuracy of WOA in the search of the optimal location in the IEEE 33-bus system. The algorithms used for comparison include PSO [23], the combined analytical and genetic algorithm (A/GA) technique [13], bacterial foraging optimization algorithm (BFOA) [24] and ant lion optimization algorithm [25].

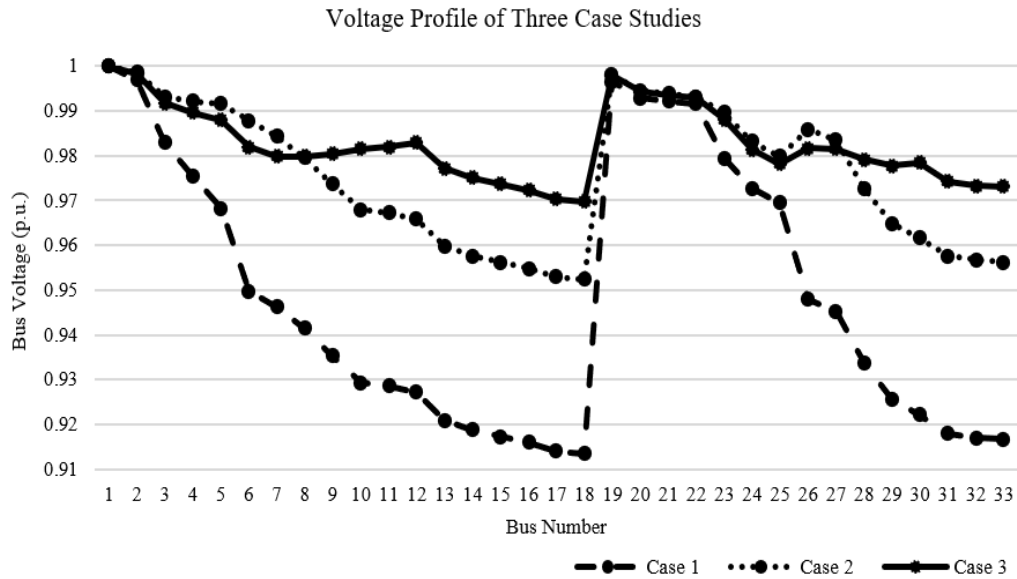


Figure 3. Voltage profile of three case studies

Table 3. Comparison of the optimal location produced by WOA and other optimization methods

	Number of DG	Optimization method	Optimal location @ Bus number	
			DG location 1	DG location 2
Case 2	2	PSO [23]	6	-
		A/GA [13]	6	-
		BFOA [24]	6	-
		Proposed method WOA	6	-
Case 3	2	PSO [23]	12	30
		A/GA [13]	13	30
		BFOA [24]	14	30
		Proposed method WOA	13	30

Based on Table 3, the comparisons demonstrated that the proposed method WOA in this paper was found to have nearly equivalent results to the other methods listed and this showed that WOA is reliable and accurate in the search of optimal location of DG.

4. CONCLUSION

This paper presents the optimal location and size of DG utilizing the WOA to achieve power loss reduction and voltage deviation minimization in the IEEE 33-bus radial distribution system. Both the power loss and voltage deviation which are the two objectives in this paper has been successfully achieved where the losses were reduced significantly from the base case after the DG incorporation into the system. However, among all cases, Case 3 (the test system of two DGs inserted) offered the best results. Case 3 was chosen to be the best instead of Case 2 despite produced a smaller output size because Case 3 generated the least losses that benefited the long-term sustainability of the power system. This is due to the fact that significant losses in the power network must be avoided in order to prevent poor performance and failure of the electrical power system. To conclude, the insertion of DG using WOA was capable and effective in finding the most appropriate location and sizing of DG which the outcome produced minimal active power loss and achieved voltage deviation reduction.




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