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Optimal DG unit placement in distribution networks by multi-objective whale optimization algorithm & its techno-economic analysis

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ABSTRACT

In radial distribution networks, the appropriate placement of properly sized Distributed Generation (DG) units can significantly improve the performance of the system. The biggest techno-economic benefits can be obtained by reducing annual economic losses that include the expenses of deployment, operation and maintenance along with voltage variations and power loss across the buses. The current problem is examined in light of various multi-objective frameworks as well as the optimum compromise solution also termed the Pareto-optimal solution is presented. When dealing with a multi-objective optimization problem, certain constraints on equality and inequality are also examined. The focus of this paper is on a one-of-a-kind multi-objective whale optimization (MOWOA) algorithm for multi-objective problem-solving. To test its effectiveness, the method that was suggested is implemented on radial bus distribution systems IEEE-33 and IEEE-69. This paper also includes a comparison with other recent multi-objective algorithms such as opposition-based chaotic differential evolution (OCDE), Krill herd algorithm (KHA) and Power Loss Sensitivity Factor and Simulated Annealing (LSFSA). It has been discovered that the method proposed may improve power loss, annual economic loss mitigation and voltage profile improvement.

1. Introduction

he energy sector has been forced to consider small localized nonconventional energy sources due to fossil fuels being rapidly depleting, significant environmental ramifications, and increased T&D losses in traditional power systems. In addition, because too fast technological advancements in this area, the cost per unit of electricity generated by unconventional resources has decreased dramatically during the last two to three decades. As a result, these DG systems (distributed generation) units are becoming popular. DG units of small size should usually have a power capacity of less than 5 MW [1]. There are two types of DG units: intermittent and non-intermittent.

Several research studies in this area have been published in the literature in recent years. Different authors have used a variety of classical and heuristic strategies to address ODGP (optimal DG placement) issues. Previous research has developed an approach for the best size and placement of several kinds of DG units based on a genetic algorithm (GA) [2] to reduce daily average cumulative actual losses in power with improvements in the profile of voltage. The impact of several kinds of DGs running at varying power factors and with various models of load on placement was investigated by Singh et al. [3]. Vatani et al. [4] integrated analytical GA method to solve the problem of ODGP and reduce losses of the system while taking into consideration the DGs' operating power factor.

M. O. Okelola et al [5] has proposed a novel method called the Whale Optimization Algorithm (WOA) in order to evaluate how the amount of shunt capacitors that are properly assigned affects both the technical and economic benefits. Fadhel A. Jumaa et al [6] suggests the use of a technique for DG unit sizing and placement optimization termed particle swarm optimization (PSO).

In order to find the best position and sizing for shunt capacitors for reactive power compensation in power distribution systems with distributed generation, Surender Reddy Salkuti [7] presents a novel method. Here, the loss sensitivity factor technique is used to determine where the shunt capacitors should be installed.

A technique to optimize the size and location of DG in the distribution system to reduce power loss is presented by Thuan Thanh Nguyen et al. [8] and is based on Enhanced sunflower optimization (ESFO).

N. Karuppiah et al. [9] employ the voltage stability index to determine the best DG siting. In an attempt to decrease the gap between the

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amount of power produced and the amount that consumers need, Paul C. Maduforo et al. [10] present a sensitivity-based strategy for the distribution network allocation of distributed generation that improves voltage profile and reduces power loss. A 33-bus test system was used to evaluate the method's effectiveness. Ajit Pandharinath Chaudhari et al. [11] give an assessment of the ideal positioning and sizing of distributed generating in electrical energy distribution systems. The minimizing of active losses and the enhancement of the voltage profile has been taken into consideration in the problem of optimal location and dimensioning. The Grey Wolf Optimization Algorithm (GWO), the Whale Optimization Algorithm (WOA)and the Particle Swarm Optimization(PSO) were three optimization algorithms that Benalia M'hamdi et al. [12] attempted to investigate in order to determine the optimal sizes of decentralized production units in a power distribution network and evaluated on industry-standard IEEE 33-bus and IEEE 69-bus test systems.

In order to size and place DG, John Karis et al. [13] proposed an improved Newton Raphson approach on the IEEE 33 bus radial distribution system. The Whale Optimization Algorithm (WOA) was proposed by Lee Jin Kang et al. [14] and implemented on IEEE 28-bus, 33-bus, and 69-bus systems to optimize the placement of DG units.

Madihah et al. have suggested a novel method for optimal renewable energy-based DG allocation and sizing utilizing the clonal differential evolution technique, taking into account uncertainties as well as cost-cutting elements [15]. Several alternative techniques of soft-computing such as Algorithm for Krill Herds [16] (KHA), Tabu Search [17], Ant Colony Optimization [18] (ACO), Bacterial Foraging Optimization [19](BFO), Cuckoo Search [20] (CS), Augmented Lagrangian Genetic Algorithm [21](ALGA), Stud Krill Herd Algorithm [22] (SKHA), Whale Optimization Algorithm [23], oppostion based tuned chaotic differential evolution [24], Flower Pollination Algorithm [25], Ant-lion Optimization Algorithm [26], Elephant Herding Optimization algorithm [27], Modified Teaching Learning Based Optimisation [29], GA&PSO[31], Hybrid PSO[34], Improved PSO[35], Hybrid-GA/PSO[36], etc. have successfully employed by researchers to address the ODGP problem.Different approaches to techno-economic analysis were proposed by S. Dorahaki et.al [30], A.Asadi et.al[32], A. Ameli[33] et.al, Wu Ouyang [37] et.al, and Surender Singh Tanwar [40], R. Sivasangariet.al [41], R. K. Singh et.al [42], O. Penangsang et.al [43], Satish Kansal et.al [44]. R. Viral et.al [38] investigated a variety of DG-related topics, including the effects on distribution systems. For the best positioning and sizing of DGs, C. Tautiva et.al [39] presented a heuristic methodology.

The following are highlights of this work's contributions:

Ø In this paper, DG sources' ratings and locations are optimized and consequently the system's total cost and energy losses are reduced as bus voltages improve.

Ø In majority of the research on DG placement, Cost reduction, loss reduction, or voltage deviation reduction are all considered independently.

Ø Nevertheless, no one has ever evaluated all of the objectives at the same time including a maximum of economic advantages like minimizing of power loss and minimization of voltage deviation. However, under altered power conditions, consideration of the aforementioned objectives simultaneously is a requirement for corporate viability. When the system's lifespan is considered as well as the cost of energy distribution losses, the system's cost is directly related to the investment in DG sources.

Ø This work is unique in that it uses a multi-objective framework to consider all of the above goals. The novel Whale optimization algorithm is presented in this publication. The above-mentioned technique's effectiveness is evaluated using standard IEEE 33 as well as IEEE 69 bus test system.

Ø On comparison with other meta-heuristic techniques, the proposed technique appears to be able to produce better and satisfactory results.

Ø By balancing local and global search, this method is an example of a metaheuristic algorithm that seeks to solve optimization problems more quickly and effectively.

2. Problem articulation

The fundamental intent of multi-objective ODGP entails maximizing profit each year while minimizing power loss and increasing bus voltages, hence improving system efficiency and dependability. The total system cost is mostly determined by system network losses as well as the price of Distributed Generation (DG) units when they've been penetrated. As a result, one of the aims is to reduce power loss, while another is to reduce the system's annual economic loss (AEL).

The annual economic loss without DG (AELwoDG) reflects energy loss owing to power distribution costs; while the DG's annual economic loss (AELwDG) shows the annual economic loss as a result of the annual additional load due to DG integration as well as losses in DG power distribution. The distinction between AELwoDG and AELwDG indicates the entire annual cost savings as a result of optimal DG penetration. All of these goals are outlined in the subsequent sections:

Loss of Active power

In the distribution network, low voltage generates more losses than in the transmission system. The following equation can be used to calculate the most typical variable losses in the distribution systems:

$$P_{loss} = \sum_{i}^{n} I_i^2 R_i \tag{1}$$

Where 'I_i 'represents current, 'R_i 'represents resistance, 'n' is the number of buses. The goal of this paper is to reduce actual power loss. The limitation of voltage is set between 0.9 and 1.05. The maximum and minimum DG limits are 60 & 3000 respectively.

2.1. Annual economic loss(AEL)

When one or many DGs are connected to a network in comparison to when the network did not equipped with DGs, the overall loss of active power is reduced. As a result, the total economic loss for the year without any DG ($AELwo_{DG}$) is given by

$$\text{AEL}_{woDG} = P_L^{woDG} \times C_e \times 8760 \tag{2}$$

Where C_e= Cost of energy loss per kWh in \$, $P_L^{woDG}$is utter loss of real power without DG

The total economic loss for the year including DG cost (AEL_{wDG}), will be

$$\text{AEL}_{wDG} = P_L^{wDG} \times C_e \times 8760 + \frac{C_{DG}\sum_{i=1}^{N_{DG}} P_{DGi}}{L_{DG}} \tag{3}$$

Where

N_{DG}= Number of DGs installed

P_L^{wDG} is total real power loss with DG

C_{DG}= cost of DG per kW generated, including capital investment in DG as well as deployment, operation & maintenance costs

'L_{DG}' = Years of life span of DG

$$\text{Yearlysavings} = \text{AEL}_{woDG} - \text{AEL}_{wDG} \tag{4}$$

2.2. Multi-objective formulation

The incorrect location of DGs can have a severe influence on total cost, electricity quality and dependability. As a result, all of the above-mentioned objectives (P_L and AEL_{wDG}) can be considered simultaneously when optimizing the system as long as all limitations are met, such as Bus voltage limit, power balancing, line power flow & generator capacity. In general, a multi-objective issue can be expressed mathematically as

$$\begin{aligned} &\mathrm{Min}[f_1(x), f_2(x)...f_n(x)] \\ &\mathrm{relyingtoh}(x) = 0, g(x) \leq 0 \end{aligned} \tag{5}$$

Where the variable x's nth objective function is denoted by $f_n(x)$. While the accompanying h(x) and g(x) represents equality & inequality restrictions respectively. For this problem, two objectives (PL and YEL_{wDG}) are considered.

3. Whale optimization algorithm

Mirajalli and Lewis recently introduced a novel optimization technique named Whale Optimization Algorithm to the meta heuristic algorithms. Whales are regarded to be clever and mobile creatures. Humpback whales' peculiar hunting behaviour inspired the WOA algorithm. Humpback whales prefer krill or tiny fish as prey that live near the sea's surface. Bubble net feeding is a specific hunting technique used by humpback whales. Swimming around the prey while blowing bubbles in a circle or a 9-shaped pattern is aspect of this method.

The following sections describe the WOA mathematical model.

1 Surrounding(Encircling) the prey
2 Attacking using a bubble net
3 Look for the prey ie.,Search

3.1. Encircling (Surrounding) the prey

The target prey is assumed to be the best candidate solution at the moment by the WOA algorithm.

Other search engines strive to better their ranks in order to become the best search agent.

Equations are used to represent the behaviour

$$\underset{\rightarrow}{x}[n+1] = \left[\underset{\rightarrow}{x*}[n] - \underset{\rightarrow}{a} \cdot \underset{\rightarrow}{d}\right] \tag{6}$$

$$\underset{\rightarrow}{d} = \left|\underset{\rightarrow}{c} \cdot \underset{\rightarrow}{x*}[n] - \underset{\rightarrow}{x}[n]\right| \tag{7}$$

$$\underset{\rightarrow}{a} = 2\left(\underset{\rightarrow}{A} \cdot \overrightarrow{rand}\right) - \underset{\rightarrow}{A} \tag{8}$$

$$\underset{\rightarrow}{c} = 2 * \overrightarrow{rand} \tag{9}$$

$\underset{\rightarrow}{x*}[n]$- The best solution's position, which can be modified if a better solution is found.

$\underset{\rightarrow}{x}$ - the vector of position

n- the present iteration

$\underset{\rightarrow}{a}$, $\underset{\rightarrow}{c}$ - Vectors of coefficients

$\underset{\rightarrow}{A}$ - decreased linearly in the range (2,0)

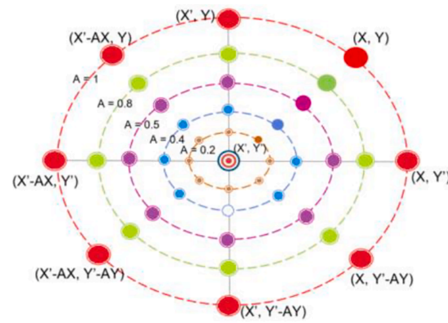
$\overrightarrow{rand}$- arbitrary vector between 0 and 1

3.2. Attacking using a bubble net Technique

There are two approaches to this hunting tactic.

i) **Encircling the prey shrinking**

Here's $\underset{\rightarrow}{a}$ a random number between -A and A. Where $\underset{\rightarrow}{A}$ is reduced from two to zero. Position $\underset{\rightarrow}{A}$ is changing at random between [-1, 1]. The new position $\underset{\rightarrow}{A}$ is obtained by comparing the original and current best agents.



Attacking using a bubble net method

i) **Updating the position Spirally**

To simulate the helix-structured movement between the locations of whales and prey, the following helix equation is employed:

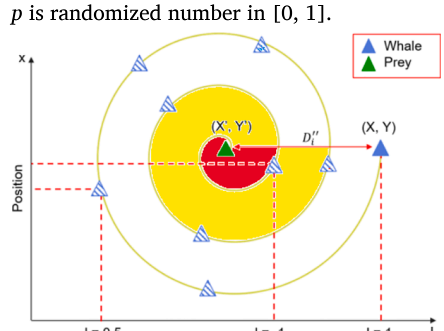
$$\underset{\rightarrow}{x}[n+1] = [\underset{\rightarrow}{d} \cdot e^{bl} \cdot \cos[2\pi l] + \underset{\rightarrow}{x*} \tag{10}$$

When the whale and the prey are separated by a significant distance (best solution) $d = |[\underset{\rightarrow}{x*} - \underset{\rightarrow}{x}[n]]|$. 'l' is a random value between -1 and 1 while b is a constant..

Whales hunt by swimming in a decreasing circle around their prey while also following a spiral pattern. Either diminishing encircling or the spiral model are given a 50% probability to keep track of whales' movements

$$\underset{\rightarrow}{x}[n+1] = \begin{cases} \underset{\rightarrow}{x*}[n] - \underset{\rightarrow}{a} \cdot \underset{\rightarrow}{d} & [p < 1/2] \\ \underset{\rightarrow}{d} \cdot e^{bl} \cdot \cos[2\pi l] + \underset{\rightarrow}{x*} & [p \geq 1/2] \end{cases} \tag{11}$$

p is randomized number in [0, 1].



Spiral Updating Mechanism

3.3. Locate (Search) the prey

When the search agent is greater than or less than one, the algorithm is updated according to a random selection search agent rather than the optimal search agent.

$$\underset{\rightarrow}{d} = \left|[\underset{\rightarrow}{c} \cdot \underset{\longrightarrow}{x_{rand}} - \underset{\rightarrow}{x}]\right| \tag{12}$$

$$\underset{\rightarrow}{x}[n+1] = (\underset{\longrightarrow}{x_{rand}} - \underset{\rightarrow}{a} \cdot \underset{\rightarrow}{d}) \tag{13}$$

$\overrightarrow{x_{rand}}$ - current iteration's scattered whales. The '||' indicates absolute values, Figure 1

4. Results and discussion

Bus systems IEEE-33 & IEEE-69 with varying levels of penetration are used to test the effectiveness of the suggested technique. To put it differently, for better economic and technological advantages, DGs have been deployed in one or more locations in each test systems. Except for

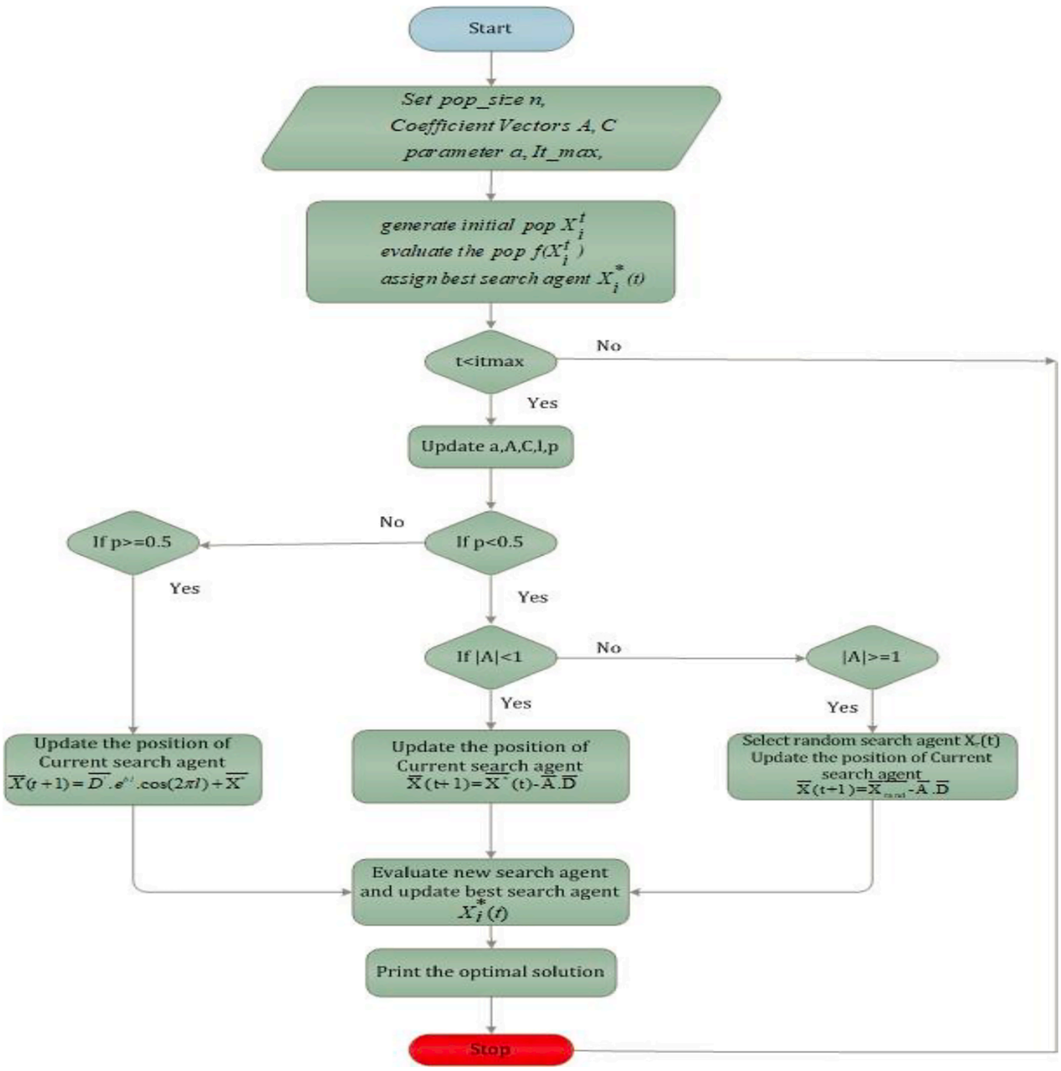


Fig. 1. Flow chart of whale optimization algorithm.

the slack bus, all of the buses are considered likely candidates for DG placement. 0.95 p.u & 1.05 p.u. are the lower and highest limits of bus voltages respectively. For maximum capacity utilization, The DGs are supposed to be operated at unity power factor resulting in the most possible gain from DGs.

Because the full life of DG is expected to be 10 years, the planning period for this unified system will also be ten years to illustrate the ODGP's long-term influence. The cost of power of DG injection is $30.00/ kW, which includes the cost of the DG units as well as deployment, operation & maintenance. The cost of energy loss is considered to be $0.05/ kWh [27]. NP is taken to be 50 in all cases. On the MATLAB R2020a edition, the algorithm proposed is implemented. In a multi-objective scenario, the proposed MOWOA is compared with other well-known algorithms.

4.1. IEEE-33 bus system (case study 1)

This scenario takes into account the IEEE-33 bus radial distribution network [24]. For this system, the substation base MVA and base voltage are 100 MVA & 12.66 KV respectively. Its overall active, reactive power demands are correspondingly 3.715 MW, 2.3 MVAr. Total losses in active and reactive power prior to DG installation for the standard system are observed to be 210.9970 kW and 143.0320 kVAr respectively. At bus number 18, the minimum voltage found is 0.9423 p.u. without any DG installation. The total loss of real power is converted to an annual economic loss (AEL_{woDG}) for cost analysis, which is 92,418 $.

4.1.1. P_L minimization (Case I)

For the sake of simplicity and comparison, the only objective function for DG allocation optimization is power loss minimization. Table 1 presents the findings obtained using the proposed WOA method. It also compares the results of existing approaches such as OCDE [27], KHA [16] and LSFSA [28] to the proposed method for a comparative study. When single DG is examined, the proposed method's optimal loss is 111.02 kW. When many DGs are placed, real power losses are also shown in Table 1. After installing three and four DGs, real power losses are decreased to 72.78 kW, 67.63 respectively. The losses are marginally better to those found in the literature using other methods. Table 2 shows cost study for various levels of penetration. Because higher penetration lowered power loss in the line, annual i.e. yearly economic losses decreased as well, resulting in a significant rise in annual total savings as shown in Table 2.

4.1.2. Case II: P_L minimization & AEL_{wDG}

P_L and AEL_{wDG} are considered to be objectives to be minimized in this case and the number of DGs is fixed to three. In the case II section of Table 3, the proposed MOWOA approach tabulates the best compromised solution for this case. According to this result, three DGs with

Table 1
33 bus system results for a single objective.

No. of DG(s)placement	Techniques	DG's placement (@Bus no.)	DG's @Size$_{[KW]}$	Voltage @bus[min] [V_{pu}]	The worst$_{Bus}$	Total active power loss $_{[KW]}$
1	**OCDE**[27]	6	2581.87	0.9423	18	110.85
1	**Proposed WOA**	6	2590.2	0.9425	18	111.02
3	**OCDE** [27]	13	801.84	0.9686	33	72.848
		24	1091.46			
		30	1046.58			
	KHA [16]	13	810.7	0.9610	18	75.412
		25	836.8			
		30	841.0			
	LSFSA [28]	6	1112.4	0.9677	14	82.03
		18	487.4			
		30	867.9			
	Proposed WOA	24	1091.3	0.9687	18	72.7861
		13	801.7			
		30	1053.6			
4	**OCDE** [27]	6	926.69	0.9702	18	67.735
		14	646.78			
		24	967.34			
		31	679.38			
	Proposed WOA	14	646.76	0.9703	18	67.63
		24	967.2			
		6	926.3			
		31	686.35			

Table 2
Cost analysis of 33 test bus system for single objective.

No. of DGs	Total yearly economic loss (USD)	Total yearly saving(USD)
0	92,418	0
1	56,402	36,016
3	40,720	51,698
4	39,302	53,116

capacities of 1091.3 kW, 801.7 kW and 1053.6 kW may be positioned at bus numbers 24, 13, and 30 for simultaneous P_L minimization and AEL_{wDG}. The value of AEL_{wDG} is decreased to USD 40,029 from USD 40,720 by sacrificing on P_L which is marginally enhanced from 72.78 kW to 74.45 kW with ideal placements. Savings are more when both objectives are consideredas shown in Fig. 2

Fig. 3 shows the 33 Bus system voltage profile with increasing DG units from 1, 3 and 4 respectively. With four DG units, the voltage profile is better when compared to others.

4.2. IEEE-69 bus system (Case study 2)

This case study takes into account the larger IEEE-69 bus radial distribution scheme. 12.66 kV is the system's substation base voltage. The real, reactive loads are 3.8022 MW, 2.6946 MVAr respectively. Load flow study shows reactive and active power losses with corresponding values of 102.1321 kvAr and 225 kW respectively. Total real power loss without DG is converted to its equal yearly economic loss for cost analysis (YEL_{woDG}) which in this case is 98,550$ (US). The bus minimum voltage is 0.9092 p.u. at bus number 65 when no DG is present.

4.2.1. P_L minimization (Case I)

For the sake of simplicity and comparative performance analysis, the only objective function in this case study is the loss of power. The proposed WOA approach can only reduce power loss of system and the outcomes are compared to those of other methods such as OCDE [27], KHA [16], LSFSA [28]. Tables 4 and 5 displays the outcomes of the proposed strategy. Before and after DG installation, Table 6 shows annual economic losses & overall annual savings. The overall annual savings increase as the penetration level increases, but the rate of increase slows after 2 to 3 DGs are installed.

4.2.2. Case II: P_L minimization & AEL_{wDG}

Three DGs were placed in this scenario so that the values of both PL and AEL_{wDG} reached simultaneously their minimum points. Because both objectives are inherently incompatible, we must choose the best compromise option for each.

After three DGs are installed, the loss is 70.52 kW, slightly greater than the value achieved in Case I. However, AEL_{wDG} falls from 38,285 USD to 37,891 USD, bringing total annual savings to 60,721 USD. Table 6 shows the best results together with the DG sizes and their positions. Savings are greater when both objectives are considered.as shown in Fig. 4.

Fig. 5 shows 69 bus system voltage profile with increasing DG units from 1, 2 and 3 respectively. The voltage profile with 3 DG units is better when compared to others. Figs. 6, 7 shows convergence characteristics of 33 and 69 bus systems.

5. Considering various loads

In studies of distribution systems with static load flow, the traditional model of constant power demand is frequently applied. Although the

Table 3
Results of 33 bus for multi-objective.

Technique	Case	DG no.s	Size of DG /Placement [Kw/Bus No.]	Voltage $_{@bus[min]}$ (V_{pu})/Worst bus	Loss of real power $_{[kw]}$	Total annual economic$_{[\$]}$ loss	Total annual saving $_{[\$]}$
OCDE[27]	Case: II (*Minimisation of P_L & YEL_{wDG}*)	3	758.39/14 986.52/24 1032.32 /30	0.9671/33	73.08	40,338.942	51,649.201
Proposed WOA	Case: II (*Minimization of P_L & YEL_{wDG}*)	3	707.6/25 748.9/14 1015.9/30	0.9653/30	74.45	40,029	52,389

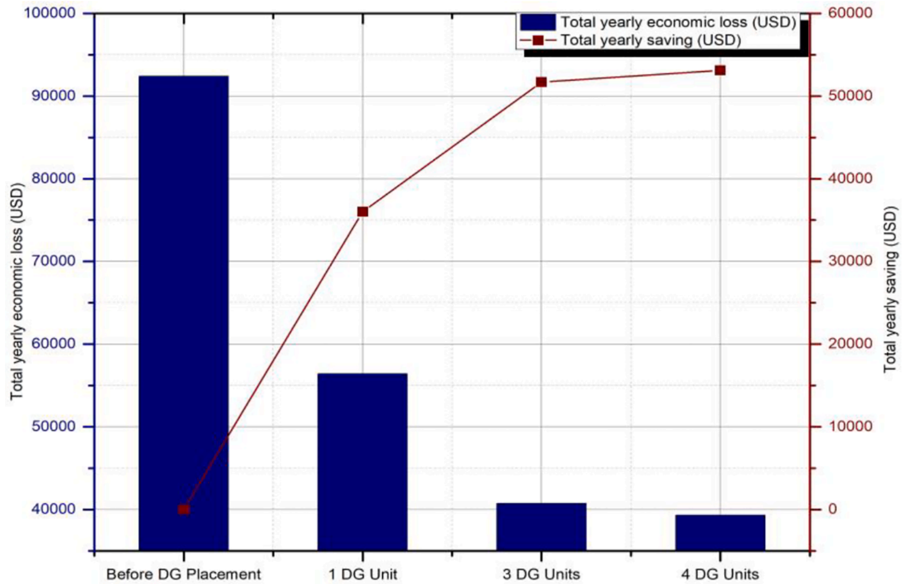


Fig. 2. Total yearly economic loss and savings for 33 bus system.

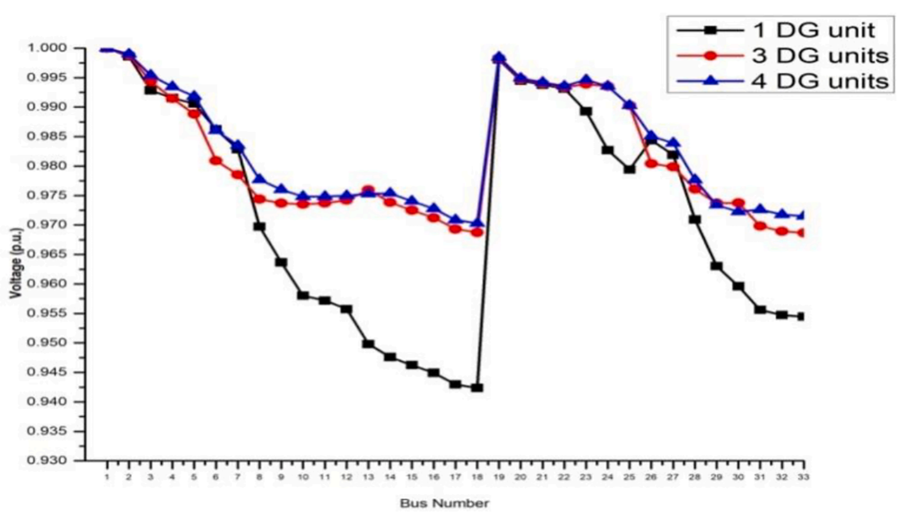


Fig. 3. 33 Bus system voltage profile.

Table 4
69 bus system results for single objective.

No. of DG(s) placement	Techniques	DG's placement (@Bus no.)	DG's @Size$_{[KW]}$	Voltage @bus[min][V$_{pu}$]	The worst$_{Bus}$	Total active loss $_{[KW]}$ of power
1	**OCDE** [27]	61	1872.43	0.9683	27	83.2
	Proposed WOA	61	1872.8	0.9683	26,27	83.2
2	**OCDE**[27]	17	530.99	0.9789	65	71.68
		61	1781.34			
	Proposed WOA	61	1781.6	0.9789	65	71.67
		17	531.5			
3	**OCDE** [27]	11	525.93	0.9790	65	69.436
		18	380.18			
		61	1718.96			
	KHA [16]	12	496.2	0.9790	65	69.563
		22	311.3			
		61	1735.4			
	LSFSA [28]	18	420.4	0.9811	61	77.1
		60	1331.1			
		65	429.8			
	Proposed WOA	66	459.8	0.9790	65	69.69
		18	399.6			
		61	1727			

Table 5
Cost analysis of 69 test bus system for single objective.

No. of DG	Total yearly economic loss (USD)	Total yearly saving (USD)
0	98,550	0
1	42,072	56,478
2	38,335	60,215
3	38,285	60,265

actual load on a distribution system must be modelled using constant impedance, exponential, constant current, or a combination of all of these loads, it cannot be modelled using constant power models alone.

The findings for IEEE bus systems 33 and 69 are compared before and after DG deployments taking into account various loads.

Comparing the preceding Tables 7 and 8 reveals that for both bus systems 33 and 69, the active power loss lowered after DG placement for the various loads as compared to the cases without DG placement.

Table 6
Results of 69 bus for multi-objective.

Technique	Case	DG no.s	Size of DG /Placement $_{[Kw/Bus\ No.]}$	Voltage $_{@bus[min]}$ (V_{pu})/ Worst bus	loss of real power $_{[kw]}$	Total annual economic$_{[\$]}$ loss	Total annual saving $_{[\$]}$
OCDE [27]	Case: II [*Minimizing* P_L & YEL_{wDG}]	3	406.46/12 314.68/21 1707.25/61	0.9775/65	69.78	37,847.325	60,672.2
Proposed WOA	Case: II (*Minimizing* P_L & YEL_{wDG})	3	462.4/66 399.6/18 1726.4/61	0.9790/65	70.52	37,891	60,721

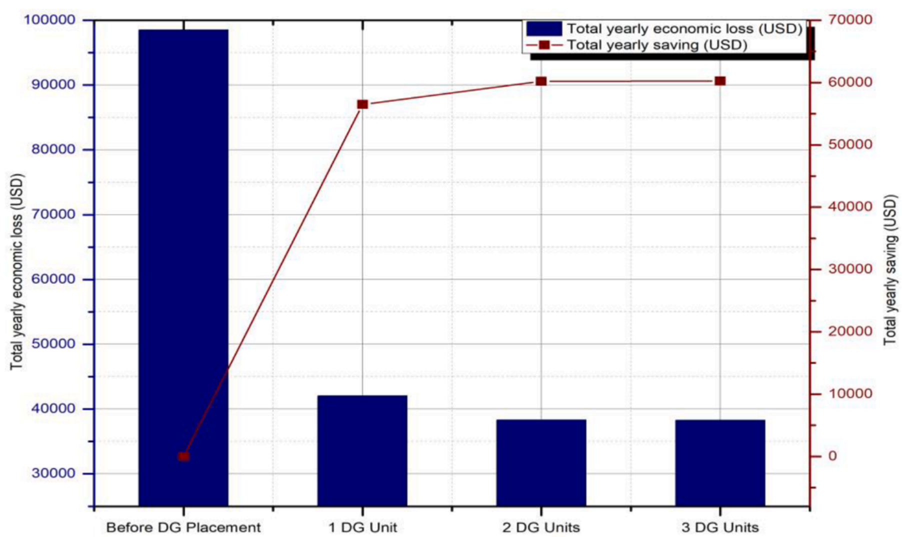


Fig. 4. Total yearly economic loss and savings for 69 bus system.

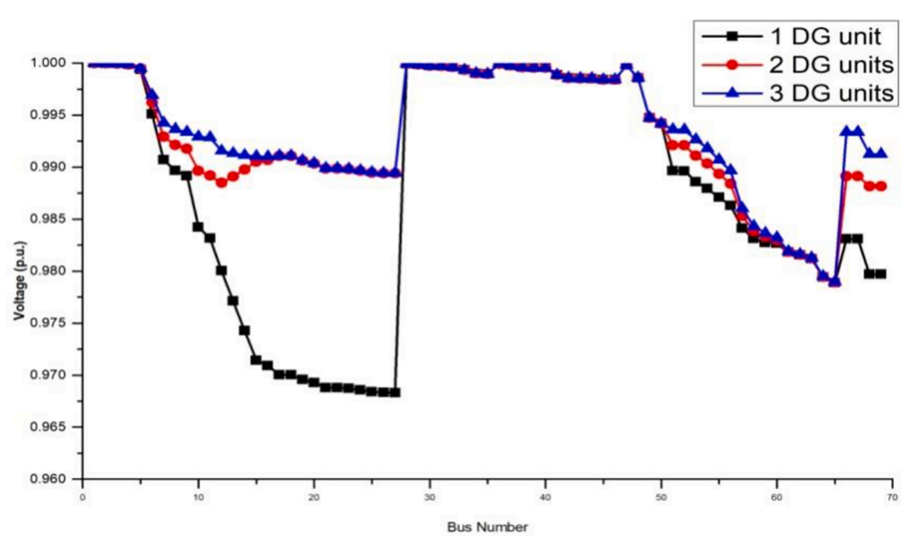


Fig. 5. 69 bus system voltage profile.

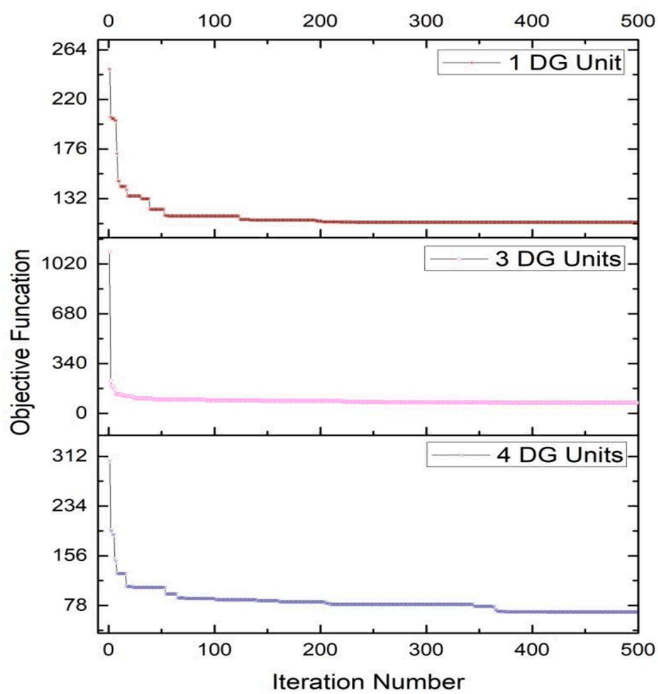


Fig. 6. Convergence characteristics of 33 bus system.

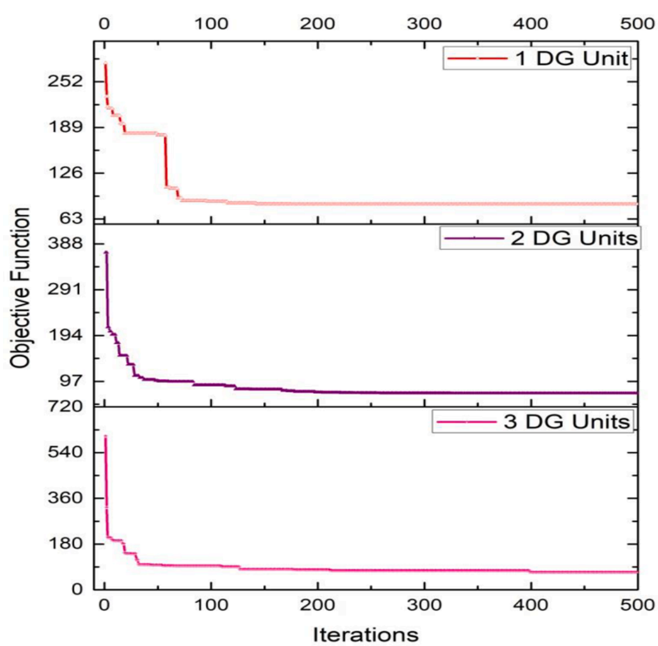


Fig. 7. Convergence characteristics of 69 bus system.

6. Computational complexity and performance analysis of the proposed algorithm

The proposed algorithm is implemented using MATLAB R2018a edition and it is run on an Intel Core TM i3 8th generation computer with 3.6 GHz processing speed and 8 GB of RAM.

Comparing the above Tables 9 and 10, for IEEE 33 bus sytem when single objective is considered (P_L *minimization)* the proposed algorithm CPU time for 1 DG,3 DG and 4 DG placement is 27.37 s,28.91 s and 26.45 s and when multi objective is considered (P_L *&* YEL_{wDG}) the CPU time is 39.11 s.

For IEEE 69 bus sytem, when single objective is considered(P_L *minimization)* the proposed algorithm CPU time for 1 DG,2 DG and 3 DG placement is 92.08 s,92.97 s and 96.33 s. and when multi objective is considered (P_L *minimization &* YEL_{wDG}) the CPU time is 110.2 s as shown in Tables 11 and 12.

Six benchmark test functions which are the combination of unimodal functions and multimodal functions are chosen to examine and assess the effectiveness of the WOA algorithm. Table 13 contains all of the parameters for the six test functions. Table 14 lists the experimental findings of those test functions to show the WOA's comprehensive performance.

7. Conclusion and future work

In this paper, presented an improved multi-objective method whale optimization (MOWOA) technique to position optimally sized DGs in optimal locations. To prove its effectiveness, the suggested method was tested on different test systems for radial distribution, including the bus systems IEEE-33 bus& IEEE-69. Two objectives namely loss of power, yearly (Annual) economic loss and a multi-objective framework are developed.

The primary objective of evaluating these objectives is to reduce annual economic loss total, minimise loss of real power and enhance profile of voltage to maximise overall annual savings. The annual economic loss and real power loss have both been significantly reduced when optimal-sized DGs are put in optimal locations, resulting in an improvement in voltage profile. The annual economic gain has increased considerably as a consequence of reduced yearly economic loss. When the results of the suggested approach are evaluated with those of other methods, it is seen that the proposed method provides better results. When comparing the proposed MOWOA method to existing algorithms such as OCDE, KHA and LSFSA, it can be concluded that it operates magnificently in all situations and can achieve greater precision and diversity.

The following conclusions can be made:

Ø The suggested approach is suitable for determining the best placements and DG sizes in a distribution network.
Ø The multi-objective whale optimization technique is used to integrate DGs optimally, reducing the overall real power losses and cost of energy losses.
Ø The proposed method performs better and satisfactory than other methods in the literature, according to numerical results.
Ø WOA has obtained a better solution for the ideal placement of multiple DGs in a radial distribution network by exhibiting high consistency and rapid convergence characteristics.

8. Future work

Future research can investigate into economic analysis to determine the minimum temporal link between profits from technical loss minimization and the expenses related to installing, running, and maintaining distributed generation units while taking various demand situations into consideration.

Distributed generators can also be integrated with electronic power converters that control the flow of active and reactive power. Technical losses may be further decreased as a result of the potential significant improvement in the voltage profiles.

Author's contribution statement

Hari Prasad Chella carried out literature survey and participated in optimal placing and sizing of Distributed Generation section. Hari Prasad C[HPC] and Prof. K. Subbaramaiah participated in the study of various nature- inspired algorithms for DG sizing. HPC carried out the DG sizing algorithm design and mathematical modelling. HPC, Prof. K. Subbaramaiah and Prof. P. Sujatha participated in assessment study and

Table 7
Results of 33 bus system with different load models.

Load model	Before DG placement Total active loss [kW] of power	After DG placement DG's placement (@Bus no.)			DG's @Size[kW] x10^3			Total active loss [kW] of power
Constant power	210.9986	30	24	13	1.0536	1.0913	0.8017	72.787
Constant current	182.7717	30	14	24	1.0544	0.7643	1.0856	64.956
Constant impedance	161.5944	14	24	30	0.7581	1.076	1.0463	58.6217
Incandescent	181.9316	24	33	13	1.1253	0.8336	0.8425	68.0813
Fluorescent	146.6016	14	30	24	0.7569	1.0649	1.0735	50.9935
A/C	185.7236	13	24	33	0.8436	1.1313	0.8318	68.4003
Dryer	153.8283	30	14	24	1.0467	0.7554	1.0732	55.8306
Freezer	175.1308	14	30	24	0.7622	1.0550	1.0838	62.1709
Heater	175.0989	24	14	30	1.0804	0.7634	1.0495	62.9156
Pump	193.6942	24	30	14	1.0918	1.0608	0.7668	67.6662
Computer	144.8297	14	24	30	0.7529	1.0700	1.0507	52.1758

Table 8
Results of 69 bus system with different load models.

Load model	Before DG placement Total active loss [kW] of power	After DG placement DG's placement (@Bus no.)			DG's @Size[kW] x 10^3			Total active loss [kW] of power
Constant Power	225.025	61	11	18	1.7191	0.5270	0.3804	69.4294
Constant current	191.516	61	66	18	1.7174	0.4575	0.3981	60.9246
Constant Impedance	167.061	61	18	66	1.7127	0.3969	0.4557	53.8901
Incandescent	186.738	2	61	17	3.0000	1.7705	0.5276	61.4835
Fluorescent	156.734	18	69	61	0.3980	0.3212	1.7590	48.2592
A/C	200.0499	69	2	61	0.6320	3.0000	1.7584	67.6249
Dryer	159.819	69	18	61	0.3227	0.3966	1.7348	51.9009
Freezer	186.046	18	61	69	0.3980	1.7399	0.3240	59.4742
Heater	178.23	69	61	18	0.3255	1.7370	0.3976	57.5381
Pump	208.664	61	11	18	1.7156	0.5238	0.3800	65.0516
Computer	151.363	17	61	2	0.5224	1.7704	0.0500	26.5782

Table 9
CPU timings for 33 bus system when single objective(P_L min.) is considered.

Technique	DG unit number (s)	DG's placement (@Bus no.)	DG's @Size$_{[KW]}$	Voltage @bus[min] [V_{pu}]	The worst$_{Bus}$	Total active power loss $_{[KW]}$	CPU Time (Sec)
Proposed WOA	1	6	2590.2	0.9425	18	111.02	**27.37**
	3	24	1091.3	0.9687	18	72.7861	**28.91**
		13	801.7				
		30	1053.6				
	4	14	646.76	0.9703	18	67.63	**26.45**
		24	967.2				
		6	926.3				
		31	686.35				

Table 10
CPU timings for 33 bus system when multi objective (P_L min. and Yearly economic savings) is considered.

Technique	Case	DG no.s	Size of DG /Placement $_{[Kw/Bus\ No.]}$	Voltage $_{@bus[min]}$ (V_{pu})/Worst bus	Real power $_{Loss\ [kw]}$	Total annual economic$_{[\$]}$ loss	Total annual saving $_{[\$]}$	CPU Time (Sec)
OCDE [27]	Case: II (*Min. of* P_L *&* YEL_{wDG})	3	758.39/14 986.52/24 1032.32 /30	0.9671/33	73.08	40,338.942	51,649.201	–
Proposed WOA	Case: II (*Minimization of* P_L *&* YEL_{wDG})	3	707.6/25 748.9/14 1015.9/30	0.9653/30	74.45	40,029	52,389	**39.11**

Table 11
CPU timings for 69 bus system when single objective (P_L min.) is considered.

Technique	No. of DG unit (s)	DG location (Bus no.)	DG size (kW)	Bus voltage(min) (p.u.)	Weakest bus	Total real power loss (kW)	CPU time(Sec)
Proposed WOA	1	61	1872.8	0.9683	26,27	83.2	**92.08**
	2	61	1781.6	0.9789	65	71.67	**92.97**
		17	531.5				
	3	66	459.8	0.9790	65	69.69	**96.33**
		18	399.6				
		61	1727				

Table 12
CPU timings for 69 bus system when multi objective (P_L min. and yearly economic savings) is considered.

Technique	Case	No. of DG	DG size/Location (kW/Bus no.)	Minimum bus voltage (p. u.)/Weakest bus	Real power loss (kW)	Total yearly economic loss ($)	Total yearly saving ($)	CPU Time (Sec)
OCDE [27]	Case: II (*Minimization of* P_L *&* YEL_{wDG})	3	406.46/12 314.68/21 1707.25/61	0.9775/65	69.78	37,847.325	60,672.2	–
Proposed WOA	Case: II (*Minimization of* P_L *&* YEL_{wDG})	3	462.4/66 399.6/18 1726.4/61	0.9790/65	70.52	37,891	60,721	**110.2**

Table 13
Description of six test functions.

Benchmark function(B)	Dimensions	Range of search	B_{min}	Iterations	Run times
$B_1(x) = \sum_{j=0}^{d} x_j^2$	30	[−100,100]	0	1000	20
$B_2(x) = \sum_{j=1}^{d-1} [100(x_{j+1} - x_j^2)^2 + (x_j - 1)^2]$	30	[−30,30]	0	1000	20
$B_3(x) = \sum_{j=1}^{d} [x_j^2 - 10\cos(2\pi x_j) + 10]$	30	[−5.12,5.12]	0	1000	20
$B_4(x) = \sum_{j=1}^{d} \lvert x_j \sin x_j + 0.1x_j \rvert$	30	[−10,10]	0	1000	20
$B_5(x) = [1 + (x_1 + x_2 + 1)^2(19 - 14x_1 + 3x_1^2 - 14x_2 + 6x_1x_2 + 3x_2^2)]$ $\times [(2x_1 - 3x_2)^2(18 - 32x_1 + 12x_1^2 + 48x_2 - 36x_1x_2 + 27x_2^2) + 30]$	2	[−2,2]	3	1000	20
$B_6(x) = -\sum_{j=1}^{10} [(x - a_j)(x - a_j)^T + c_j]^{-1}$	4	[0,10]	−10.5363	1000	20

Table 14
Performance evaluation of bench functions.

B	Best	worst	Average	SD
$\mathbf{B_1}$	2.71E+01	1.25E+02	6.58E+01	2.34E+01
$\mathbf{B_2}$	4.25E+01	1.60E+02	8.94E+01	2.65E+01
$\mathbf{B_3}$	1.04E+02	2.48E+02	1.62E+02	3.28E+01
$\mathbf{B_4}$	2.16E+01	3.04E+01	2.39E+01	2.16E+00
$\mathbf{B_5}$	9.07E+00	1.00E+01	9.49E+00	1.90E-01
$\mathbf{B_6}$	−1.15E+01	−1.14E+01	−1.14E+01	1.00E-02

performed the analysis. All three participated in sequence alignment and drafted the manuscript and approved the final manuscript.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

The authors do not have permission to share data.

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