Nodal Electricity Price Based Optimal Size and Location of DGs in Electrical Distribution Networks Using ANT LION Optimization Algorithm

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Abstract

Distribution system has been the weakest link in the entire power system supply chain. It is also one of the most vital parts of the power system. However, a lot of methods have been developed to improve the condition of the distribution system. The use of distributed generations (DGs) is one such method where the generated power is closer to the load center, and the DG is also providing ancillary services to the grid. The nodal electricity price for DGs location is determined based on the Locational Marginal Price (LMP). LMP implies the price to buy and sell power at each node within electrical distribution markets. In the nodal electricity market (EM), the cost of energy is determined by the location of DG to which it is provided. This paper presents a novel approach that utilizes nodal electricity price for optimal sizing and location (OSL) of DGs. A multi-objective ANTLION optimization (MOALO) has been utilized as an optimization approach to compute the OSL of DGs units. ANTLION optimization (ALO) is based on the unique hunting

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behaviour of antlions. Optimization has been done for social welfare maximization, loss minimization, and voltage profile improvement in distribution networks (DNs). The results of the proposed technique have been evaluated for IEEE 33 bus DNs.

Keywords: Distributed generation (DG), locational marginal price (LMP), distribution network (DN), electricity market (EM), antlion optimization (ALO), optimal size and location (OSL).

1 Introduction

Optimal DG size and placement is a vital tasks for distribution companies to keep the electrical DN running smoothly. DG has recently attracted more attention, especially in light of increased consumer awareness about environmental concerns, electricity market restructuring, sophisticated power electronics devices, and the need for important energy storage technologies. DG has a broad range of applications and shows a significant role in the recent electrical distribution system. DG is defined by the International Energy Agency as an electrical source that is directly associated with the electrical DN delivered to local customers with the small generating units located near end-users [1]. The term 'DG' refers to a variety of locally placed power generating units, i.e., both renewable and conventional. An electricity market (EM) is a place where electricity buying and selling agreements are framed, as well as price trade-offs and trade transactions are executed [2]. EMs all across the globe mostly adapt to the nodal EM. The nodal EM includes the generation cost as well as the energy distribution cost [3]. The role of the nodal market is to adapt to the new challenges and analyze the passive customers that will transform into active customers. In a nodal EM, the locational marginal price (LMP) model gives the meritorious solution by optimizing total costs [3].

The inappropriate positioning and sizing of DG units cause unpredicted difficulties, such as voltage flicker, voltage sag, fault current, power loss, stability problems, etc. These parameters will increase in the electrical system [4]. DG with appropriate position and sizing installed in an electrical network can provide numerous advantages to the system including cost savings, reduced total power loss, improvement of reliability, and better power quality features such as voltage profile [4].

Most of the research articles have been published in recent years to solve the ideal location of DG and sizing problems in the DNs for maximizing their benefit by different techniques such as Particle swarm optimization (PSO) [5], Genetic algorithm (GA) [6], Genetic Moth Swarm Algorithm [7], & Multi-objective PSO [8]. These methods have been presented to deal with the problem of power loss reduction. Rudresh et al. [9] proposed the fuzzy logic algorithm for optimal DG placement to reduce power losses. The presented technique was tested on a 24-bus system. An analytical method-based technique is used by Navdeep et al. [10] to compute the OSL of DG to reduce the losses. The work is applied to IEEE 33 and 69 bus radial DNs. The power loss minimization problem was solved by Emad et al. [11] using a genetic month swarm algorithm (GMSA). The recommended technique is applied to IEEE 33 and 69 bus systems. The Firefly algorithm was proposed by Muhamad et al. [12] for OSL of DG to reduce the losses and voltage profile enhancement on IEEE 33 bus system. A novel methodology-based harris haws optimizer has been suggested to calculate the OSL of DG in DNs to decrease the power losses, voltage deviation, and enhancement of voltage stability index by Ali et al. [13]. The suggested algorithm is being tested on 33 and 69 bus radial DNs. Fine-tuned PSO has been applied in Ehsan et al. [14] to calculate the OSL of DG for loss reduction. The recommended method is evaluated on IEEE 33, 69, and real network. Adel et al. [15] presented a complete review of the ALO algorithm and its most recent versions that are modified to hybrid and multi-objective ALO. The suggested algorithms have been applied in various fields such as power, engineering, medical, and machine learning, etc.

The majority portion of the literature survey emphasizes to find out the OSL of DG or multiple DGs to reduce the losses. However, the OSL of DGs in the nodal EM has not been incorporated into the electrical DN for social welfare maximization (SWM). A novel algorithm, MOALO (Multi-objective Ant Lion Optimisation) technique has been proposed in this paper to optimize the objective function containing minimization of line losses, sizes of DGs, social welfare, and voltage profile in the nodal EM. The MOALO used here, is a metaheuristic algorithm that has numerous advantages like requirement of lesser parameters, ease of implementation, robustness, and fast convergence [15, 16]. Additionally, the summary of the comprehensive reviews and comparison of numerous approaches for optimal DG sizing and position has been shown in Tables 1 and 2. respectively.

Table 1 Comprehensive reviews for OSL of DG in the DNs

References	Publication Year	Metrics	Algorithm	Test System	Effectors/Attributes: Minimization of the Loss Function	Effectors/Attributes: Enhancement of Voltage Profile	Effectors/Attributes: Minimization of the Cost Function	Effectors/Attributes: Enhancement of Reliability
[17]	2021	OSL of DG	Hybrid Genetic Dragonfly	15 and 69	✓			
[8]	2021	OSL of DG in reconfigured network	Multi-objective PSO	33	✓	✓		
[18]	2020	OSL of DG	Binary PSO and shuffled frog leap (BPSO-SLFA)	33 and 69	✓	✓		
[19]	2020	OSL of DG units	Grasshopper optimization algorithm and Cuckoo search technique	33 and 69	✓	✓		✓
[20]	2019	OSL of DG	Phasor particle swarm optimization (PPSO)	33	✓	✓		✓
[7]	2019	OSL of renewable DG sources	GMSA	33 and 69	✓			
[21]	2018	Optimal location of protection devices and DG	Cuckoo Search	69				✓
[22]	2018	Optimal placement of energy storage system	Artificial bee colony (ABC)	33	✓	✓		
[23]	2017	OSL of DG	Decision-making algorithm	33	✓	✓		
[24]	2017	Optimal DG and capacitor placement	PSO	33 and 69		✓	✓	
[25]	2016	Optimal placement of multiple DGs	PSO	33 and 69	✓	✓		
[26]	2016	OSL of DG	Strength Pareto Evolutionary Algorithms	33	✓	✓		
[27]	2015	Optimal position, & sizing of DG	GA	14	✓			
[28]	2015	OSL of DG	Weighted Sum method	15	✓		✓	

Table 2 Various approaches for optimal DG placement comparison

References	Methods	Merits	Demerits
[21, 29]	Cuckoo Search	• Easier to implement. • Fewer tuning parameters.	• Falling into local optimal solutions is simple process. • Slow Convergence rate.
[22, 30, 31]	ABC	• Simplicity, flexibility, and robustness. • Fewer Control Parameters. • Ability to handle the objective cost.	• Slow convergent speed. • Search speed slows down later.
[25, 32]	PSO	• To maximize the power Quality. • Less computing space (memory). • High convergence compared to GA.	• Difficult to design initial parameters. • Premature convergence and trapped to local minima.
[20, 33]	PPSO	• Efficient performance in real parameter global optimization.	• Weak local searchability.
[27, 34]	GA	• Performance is good for a complicated problem. • The global optimum is a simple task to accomplish. • Parallelism.	• Need Tune Parameters. • Time-consuming algorithm. • Premature Convergence
[7]	GMSA	• Simple and flexible. • Avoid the trap of local minima. • Fast convergence characteristics.	• More time-consuming.
[17, 35]	Hybrid Genetic Dragonfly	• High accuracy. • Quick Convergence.	• No internal memory. • Loosened network constraints.
[26, 36]	Strength Pareto Evolutionary Algorithms	• Extreme solutions are preserved.	• More time-consuming.

1.1 Motivation

To the author's knowledge, MOALO has not been implemented in the literature so far to solve DG size and placement issues in the nodal electrical distribution system. MOALO has fast convergence and wide search space. So, it has inspired us to solve multiple issues such as SWM, losses, and voltage profile improvement with the help of MOALO methodology.

1.2 Contributions

The paper important contributions are as follows: –

- The mathematical modeling of nodal EM as an additional benefit has been developed.
- Social welfare maximization, loss minimization, voltage profile enhancement of electrical DN in nodal EM has been considered which has never been done before for the DG placement.
- The optimization issues have been solved with the development of Multi-objective ALO.
- Another superiority of the employed methodology results in 6, 1, 14, 13, and 12% improvement in social welfare.
- Also, the results show that the 5% enhancement in voltage profile and 146.98 kW and 100.6179 kVAR reduction in losses (i.e., active and reactive power).
- Finally, social welfare has been improved by 9.4% using MOALO whereas 5% improvement using GA.

1.3 Organization of the Paper

The rest sections of the paper are written as follows: – Section 2 depicts the advantages of employing DG while Sections 3 and 4 describe the DG location problem formulation and its objective function respectively. In Section 5, the methodology has been described. Section 6 presents the MOALO algorithm and its advantages. Section 7 illustrates the results and discussion. Finally, Sections 8 and 9 show the conclusion and future scope & references respectively.

2 Technical, Economical, and Environmental Advantages of Employing DG

The majority of the advantages of employing DG in DNs have technical, economical, and environmental inferences and they are interconnected.

So, here the advantages of DG are divided into three categories: – technical, economical, and environmental.

The main technical advantages of DG are [37, 38]: –

1. Improved voltage profile
2. Reduced line losses
3. Improved energy efficiency
4. Improved system dependability and security
5. Improved power quality
6. Reduced transmission and distribution congestion

The main economical advantages of DG are [37, 39]: –

1. Reduced operation and maintenance cost
2. Lower fuel costs as a result of improved overall efficiency
3. Operating costs reduced due to peak saving
4. Improved productivity

The main environmental advantages of DG are [4]: –

1. Lowers expenses in health care as a result of a better environment
2. Lower pollutants emissions

3 Problem Formulation

The formulation of the DG size and position problem is proposed based on three objective functions, i.e., SWM, power loss reduction, and voltage profile improvement. The classical optimal power flow (OPF) cost reduction algorithm is reformed to combine both the demand bids as well as generation bids. In OPF, LMP is calculated as a Lagrangian multiplier of the power balance equation. $\mathrm{LMP_k}$ depicts the marginal location price at node k, also known as nodal electricity price, is composed of three components as follows: –

$$\mathrm{LMP_K} = \lambda_\mathrm{K}^\mathrm{E} + \lambda_\mathrm{K}^\mathrm{C} + \lambda_\mathrm{K}^\mathrm{L} \tag{1}$$

- Energy component ($\lambda_\mathrm{K}^\mathrm{E}$): – It refers to the marginal cost of generating one extra megawatt-hour. It represents the cost of energy at the reference bus.
- Loss component ($\lambda_\mathrm{K}^\mathrm{L}$): – It represents the active power loss marginal cost in DNs.
- Congestion component ($\lambda_\mathrm{K}^\mathrm{C}$): – It refers to the congestion marginal cost in DNs.

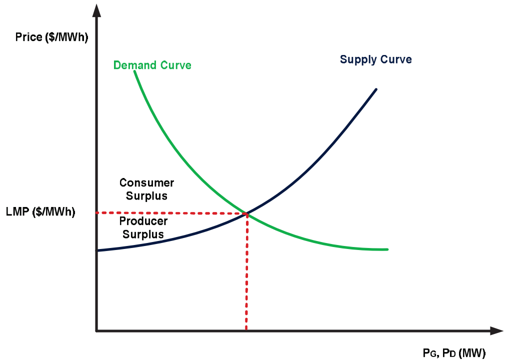

Figure 1 The social surplus with quadratic supply and demand curve.

OPF utilizes the generator and consumer bids as inputs. In the base scenario, the OPF is utilized to evaluate the dispatch, demands, and pricing at each node of the system. The OPF utilizes a social welfare maximization approach. Social welfare refers to the difference between the profit of the consumers and the total production cost [40]. The total of the producers' and consumers' surplus costs, as depicted in Figure 1. In general, social welfare is maximized when the EM price is equal to the marginal cost [40]. The nodal electricity prices have been used as an indicator for finding the candidates nodes for DG location. The main aim of the DG location is to satisfy the demand at a lower cost by altering the dispatch situation. The AC (alternating current) OPF approach is considered because it is more accurate than DC (direct current) OPF in terms of accuracy. AC OPF plays a significant role in the electricity market.

4 Objective Function

The formulation of DG size and position issue is proposed based on the three objective functions are as follows: –

4.1 Social Welfare Maximization

The objective function of the proposed work is expressed as demand curves given by the customers minus the bid curve supplied by the GENCO and DG owners.

$$\mathrm{Max}^{\mathrm{m}} \sum_{\mathrm{i}=1}^{\mathrm{N}} (\mathrm{B_i}(\mathrm{P_{Demi}}) - \mathrm{C_i}(\mathrm{P_{Geni}})) - \mathrm{C_i}(\mathrm{P_{DGi}}) \tag{2}$$

Otherwise, the maximization problem can be expressed into the minimization problem by multiplying (-1) in Equation (2).

$$\mathrm{Min}^{\mathrm{m}} \sum_{\mathrm{i}=1}^{\mathrm{N}} (\mathrm{C_i}(\mathrm{P_{Geni}}) - \mathrm{B_i}(\mathrm{P_{Demi}})) + \mathrm{C_i}(\mathrm{P_{DGi}}) \tag{3}$$

N depicts the total number of buses, $\mathrm{P_{Geni}}, \mathrm{Q_{Geni}}$ depicts real and reactive power generation at bus i, $\mathrm{P_{Demi}}, \mathrm{Q_{Demi}}$ depicts real and reactive power demand at bus i, $\mathrm{P_{DGi}}, \mathrm{Q_{DGi}}$ depicts the real and reactive power supplied by the DG at bus i.

4.2 Minimization of Losses

The primary objective of assigning DGs in the DN is improving the system efficiency through power loss reduction. The objective of reducing power losses (i.e., active & reactive power) may be represented mathematically as follows:

$$\text{Minimize } \mathrm{P_{Losses}} = \sum_{\mathrm{i}=1}^{\mathrm{N_{br}}} \mathrm{I^2_{branch,i}} \times \mathrm{R_i} \quad \text{for } \mathrm{i} = 1, 2, 3, \ldots \mathrm{N} \tag{4}$$

$$\text{Minimize } \mathrm{Q_{Losses}} = \sum_{\mathrm{i}=1}^{\mathrm{N_{br}}} \mathrm{I^2_{branch,i}} \times \mathrm{X_i} \quad \text{for } \mathrm{i} = 1, 2, 3, \ldots \mathrm{N} \tag{5}$$

Where, $\mathrm{I_{branch,i}}$, $\mathrm{R_i}$ depicts the $\mathrm{i^{th}}$ branch current and resistance. $\mathrm{P_{Losses}}$, $\mathrm{Q_{Losses}}$, and $\mathrm{N_{br}}$ represent active, reactive power losses and the number of branches respectively.

4.3 Voltage Profile Enhancement

DG units are essential for improving the voltage amplitude in the distribution system. The voltage drops per unit are computed using Equation (6) and when DG inserts power at node i, the reformed equation has been depicted in Equation (7) [8].

$$\mathrm{V_i} - \mathrm{V_{i+1}} = \mathrm{P_{(i,i+1)}} \mathrm{R_{(i,i+1)}} + \mathrm{Q_{(i,i+1)}} \mathrm{X_{(i,i+1)}} \tag{6}$$

$$\mathrm{V_i} - \mathrm{V_{i+1}} = (\mathrm{P^{load}_{i+1}} - \mathrm{P^{DG}_{i+1}}) \mathrm{R_{(i,i+1)}} + (\mathrm{Q^{load}_{i+1}} - \mathrm{Q^{DG}_{i+1}}) \mathrm{X_{(i,i+1)}} \tag{7}$$

V, R, and X stand for Voltage, resistance, and reactance between the lines i and $\mathrm{i} + 1$.

Equality Constraints: –

The DN of electrical energy is modeled by the power balance equations (i.e., active & reactive) at every node of the network. It is essential that the summing of inserted and extracted power throughout the network match at any point in the distribution grid. LMP is the double variable of real power balance limitation, that is calculated in Equation (8) [41].

$$\begin{aligned} \mathrm{P_i} &= \mathrm{P_{Geni}} + \mathrm{P_{DGi}} - \mathrm{P_{Demi}} \\ &= \sum_{\mathrm{j=1}}^{\mathrm{N}} |\mathrm{V_i}||\mathrm{V_j}|\{\mathrm{G_{ij}Cos}(\delta_{\mathrm{i}}-\delta_{\mathrm{j}}) + \mathrm{B_{ij}Sin}(\delta_{\mathrm{i}}-\delta_{\mathrm{j}})\} \end{aligned} \tag{8}$$

$$\begin{aligned} \mathrm{Q_i} &= \mathrm{Q_{Geni}} + \mathrm{Q_{DGi}} - \mathrm{Q_{Demi}} \\ &= \sum_{\mathrm{j=1}}^{\mathrm{N}} |\mathrm{V_i}||\mathrm{V_j}|\{\mathrm{G_{ij}Sin}(\delta_{\mathrm{i}}-\delta_{\mathrm{j}}) - \mathrm{B_{ij}Cos}(\delta_{\mathrm{i}}-\delta_{\mathrm{j}})\} \end{aligned} \tag{9}$$

$\mathrm{G_{ij}}$, $\mathrm{B_{ij}}$ depicts the conductance and susceptance from bus i to j. δ_{i}, δ_{j} depicts the voltage angle for bus i and j respectively.

Inequality Constraints: –

Inequality constraints such as generator's active & reactive power, voltage amplitude, voltage angle and line flow capacity are also the part of the OPF used in the problem formulation. In the following equations, bands are established for the mentioned variable in the appropriate manner. The main constraints that were utilized are as follows: –

$$\mathrm{P_{DGi}^{min}} \le \mathrm{P_{DGi}} \le \mathrm{P_{DGi}^{max}} \tag{10}$$

$$\mathrm{Q_{DGi}^{min}} \le \mathrm{Q_{DGi}} \le \mathrm{Q_{DGi}^{max}} \tag{11}$$

$$\mathrm{V_i^{min}} \le \mathrm{V_i} \le \mathrm{V_i^{max}} \tag{12}$$

$$\delta_{\mathrm{i}}^{\mathrm{min}} \le \delta_{\mathrm{i}} \le \delta_{\mathrm{i}}^{\mathrm{max}} \tag{13}$$

$$\mathrm{S_{ij}} \le \mathrm{S_{ij}^{max}} \tag{14}$$

Where, $\mathrm{V_i^{min}}$, $\mathrm{V_i^{max}}$ depicts the minimum and maximum voltage bounds for the bus i. $\mathrm{S_{ij}}$ depicts the line flow capacity from bus i to j.

5 Methodology

This paper proposes a methodology considering $\mathrm{i^{th}}$ and $\mathrm{j^{th}}$ bus line flow capacity through a market operation when two microgrids ($\mathrm{MG_1}$ and $\mathrm{MG_2}$) participate as distribution loads. The proposed ideal DG location in the DN employs the LMP idea, which is implemented using MOALO. The LMP presents an accurate indicator of each node in the DNs ability to provide electricity. LMP is a valid criterion that correlates the actual energy value of each bus. LMP based ranking is used to find the candidates' nodes for DG location.

LMP based Ranking: – The LMP index is an important tool for ranking the electrical network buses. As a result, the load buses are ranked from highest to lowest of LMPs, with the 1^{st} node in the sequence being the best candidate of DG location, are given below:

$$\mathrm{LMP_K} = \begin{bmatrix} \mathrm{LMP_1} \\ \mathrm{LMP_2} \\ \mathrm{LMP_3} \\ \vdots \\ \mathrm{LMP_i} \end{bmatrix} \tag{15}$$

$\mathrm{i} = 1, 2, 3 \ldots \mathrm{n}$ bus.

Best location = index $\{$maximum (LMP)$\}$

6 Multi-Objective Ant Lion Optimization (MOALO)

MOALO is a novel metaheuristic technique for solving several engineering optimization issues introduced by Mirjalili [42]. The basic ALO algorithm is still prone to get trapped in the local optimum and shows slow convergence in the later period. Therefore, the proposed algorithm uses novel MOALO which enhances the global search space and local exploration in solving multi-objective problems and it gives a higher convergence rate. The ALO mimics the hunting behavior of ant lions. The predator (ant lions) interactions with their prey(ants) are used to solve optimization issues. ALO is a global optimizer because of its ability to balance exploration and exploitation for many applications. There are five phases in the hunting behavior of ant lions: agent random walk, building ant traps, ant entrapment, prey capture, and trap rebuilding. ALO's random ant walks and roulette wheel may remove local optima. The mathematical modeling of the ALO algorithms of several stages is given below:

6.1 Random Walk of Ants

Ants generally travel randomly around the natural world to find food. Thus, ant movement may be depicted as the random walk as given below:

$$\mathrm{X(t)} = [0, \mathrm{cusum}(2\mathrm{r}(\mathrm{t}_1) - 1), \mathrm{cusum}(2\mathrm{r}(\mathrm{t}_2) - 1), \ldots, \mathrm{cusum}(2\mathrm{r}(\mathrm{t}_\mathrm{n}) - 1)] \tag{16}$$

cusum is used to compute the cumulative sum, n is the number of iterations, t denotes the step of random walk, and stochastic function r(t) may be represented as follows:

$$\mathrm{r(t)} = \begin{cases} 1 & \text{if rand} \geq 0.5 \\ 0 & \text{if rand} < 0.5 \end{cases} \tag{17}$$

According to Equation (17), rand indicates the random number amongst 0 and 1. A random walk is used to update the location of the ants in each optimization phase. Due to the search space boundary constraints, Equation (16) cannot be utilized to update ant positions. Thus, ants' positions are normalized using Equation (18) to ensure that they are inside the limit condition.

$$\mathrm{X}_\mathrm{i}^\mathrm{t} = \frac{(\mathrm{X}_\mathrm{i}^\mathrm{t} - \mathrm{a}_\mathrm{i}) \times (\mathrm{d}_\mathrm{i}^\mathrm{t} - \mathrm{c}_\mathrm{i}^\mathrm{t})}{(\mathrm{b}_\mathrm{i} - \mathrm{a}_\mathrm{i})} + \mathrm{c}_\mathrm{i}^\mathrm{t} \tag{18}$$

$\mathrm{a_i}$, $\mathrm{b_i}$ signifies the minimum and maximum values of random walk of $\mathrm{i^{th}}$ variable and $\mathrm{c_i^t}$, $\mathrm{d_i^t}$ signifies the minimum and maximum value of the $\mathrm{i^{th}}$ variable at $\mathrm{t^{th}}$ iteration respectively.

The position of the ants, as well as fitness function matrix, are shown below: –

$$\mathrm{M_{ant}} = \begin{bmatrix} \mathrm{A_{ant1,1}} & \mathrm{A_{ant1,2}} & \cdot & \mathrm{A_{ant1,h}} \\ \mathrm{A_{ant2,1}} & \mathrm{A_{ant2,2}} & \cdot & \mathrm{A_{ant2,h}} \\ \cdot & \cdot & \cdot & \cdot \\ \mathrm{A_{antn,1}} & \mathrm{A_{antn,1}} & \cdot & \mathrm{A_{antn,h}} \end{bmatrix} \tag{19}$$

$$\mathrm{M_{OA}} = \begin{bmatrix} \mathrm{f(A_{ant11}, A_{ant12}, \ldots, A_{ant1h})} \\ \mathrm{f(A_{ant21}, A_{ant22}, \ldots, A_{ant2h})} \\ \cdot \\ \cdot \\ \cdot \\ \mathrm{f(A_{antn1}, A_{antn2}, \ldots, A_{antnh})} \end{bmatrix} \tag{20}$$

Where the fitness values of the ant position matrix $\mathrm{M_{ant}}$ are represented by $\mathrm{M_{OA}}$ matrix. The associated position and fitness matrices for ants and ant lions hidden in the search region are provided by

$$\mathrm{M_{antlion}} = \begin{bmatrix} \mathrm{A_{antlion1,1}} & \mathrm{A_{antlion1,2}} & \cdot & \mathrm{A_{antlion1,h}} \\ \mathrm{A_{antlion2,1}} & \mathrm{A_{antlion2,2}} & \cdot & \mathrm{A_{antlion2,h}} \\ \cdot & \cdot & \cdot & \cdot \\ \mathrm{A_{antlionn,1}} & \mathrm{A_{antlionn,1}} & \cdot & \mathrm{A_{antlionn,h}} \end{bmatrix} \tag{21}$$

$$\mathrm{M_{OAP}} = \begin{bmatrix} \mathrm{f(A_{antlion11}, A_{antlion12}, \ldots, A_{antlion1h})} \\ \mathrm{f(A_{antlion21}, A_{antlion22}, \ldots, A_{antlion2h})} \\ \cdot \\ \cdot \\ \cdot \\ \mathrm{f(A_{antlionn1}, A_{antlionn2}, \ldots, A_{antlionnh})} \end{bmatrix} \tag{22}$$

6.2 Building Trap

A roulette wheel operator simulates the ant lions hunting behavior. The roulette wheel selection operator has been used to choose the ant lions based on their fitness value throughout the optimization procedure. The ant lions will have a better chance of catching their prey if they choose this method.

6.3 Ant Entrapment

The mathematical representation of the influence of antlions traps on the random path of ants are as follows: –

$$\mathrm{c_i^t = Antlion_j^t + c^t} \tag{23}$$

$$\mathrm{d_i^t = Antlion_j^t + d^t} \tag{24}$$

Where, the minimum and maximum of all variables at $\mathrm{i^{th}}$ ants are $\mathrm{c^t}$, $\mathrm{d^t}$ respectively. $\mathrm{Antlion_j^t}$ depicts the location of $\mathrm{j^{th}}$ ant lion at $\mathrm{t^{th}}$ iteration.

6.4 Sliding Ants Towards Antlions

When random ants are captured near the traps, ant lions start shooting sands outward from the trap's core. This ensures that no ants will be able to get out of the trap. Using the following equations, we can represent the process mathematically.

$$\mathrm{c^t = \frac{c^t}{I}} \tag{25}$$

$$\mathrm{d^t = \frac{d^t}{I}} \tag{26}$$

$\mathrm{I = 10^W \frac{t}{T}}$ t denotes the present iteration, T is the total number of iterations, and w is a constant of present iteration t.

6.5 Prey Capture and Trap Rebuilding

The last step of ant lions is capturing an ant at the bottom of the pit, after which ant lion must update its position using the following equations: –

$$\mathrm{Antlion_j^t = Ant_i^t \quad if\ f(Ant_i^t) > f(Antlion_j^t)} \tag{27}$$

Where, $\mathrm{Ant_j^t}$ shows the location of $\mathrm{j^{th}}$ ant lion at $\mathrm{t^{th}}$ iteration.

6.6 Elitism

It is an evolutionary algorithm to maintain the optimal solution. Mathematically, the elitism process may be shown as follows:

$$\mathrm{Ant_i^t = \frac{R_A^t + R_E^t}{2}} \tag{28}$$

Where, $\mathrm{R_A^t}$, $\mathrm{R_E^t}$ represents the random walk of ants around the ant lions selected by the roulette wheel and elite at $\mathrm{t^{th}}$ iteration.

6.7 Advantages of MOALO

This MOALO has numerous advantages as follows [15, 16]:

- Easy implementation
- Few tuning parameters
- Wide search space
- Robustness
- Fast convergence

6.8 Employment of MOALO

The stepwise algorithm for finding the OSL of DGs in a DNs is as follows:

Step 1: Read the data of distribution line, load bus, DGs supply offer, and demand bids.
Step 2: Compute the best position for DG units.
Step 3: Initialize the ALO parameters that are the population size, the maximum number of iterations, minimum and maximum DG sizes (given in Table 3).
Step 4: Create a random population of DG sizes using Equation (29)

$$\mathrm{Population} = (\mathrm{DG}_{\mathrm{max}} - \mathrm{DG}_{\mathrm{min}}) \times \mathrm{rand}() + \mathrm{DG}_{\mathrm{min}} \tag{29}$$

Step 5: Calculate the social welfare, active & reactive power losses, and voltage profile from Equations (3), (4), (5), and (7) respectively for the population generated.
Step 6: Select the DG sizes which give the best solution.
Step 7: Equations (16)–(18) is used to update the location of ant lions.
Step 8: Execute OPF analysis again and calculate the social welfare, power losses, and voltage profile for the updated population size.
Step 9: If the solution achieved is less than the present best solution, replace it; else move to step 7.
Step 10: Print the results if the maximum iteration is reached.

7 Result and Discussions

The generator at bus number 1 has been supposed as the reference bus that transmits a flat bid of 20 $ for the reformed IEEE 33 bus represented in Figure 2. The maximum line flow capacity of all lines' is 1.5 MW, with a voltage amplitude range of 0.95 to 1.01 pu. In addition, two microgrids were placed at bus 18 and 33 to meet the demands of simulating a double auction scenario. The line and load data of the IEEE 33 bus system were taken from the reference [23]. The specifications of the proposed work, which are mentioned in this paper (see Table 3).

7.1 Scenario 1

Furthermore, it is anticipated that each player in the competitive market scenario sends three zones of actual power quantities with their bidding rates to the market operator for consideration. There are two microgrids placed at bus 18 and 33, which are far away from the reference bus. Figures 3 and 4 show the demand bids submitted by these microgrids in response to the demand auction.

Table 3 Specification for the proposed work

Parameters	Value
Base kV	12.66 kV
Base MVA	100 MVA
No. of Initial Population	20
Power factor	0.8
DG Size Minimum	300 kW
DG Size Maximum	1 MW
Maximum iteration	150

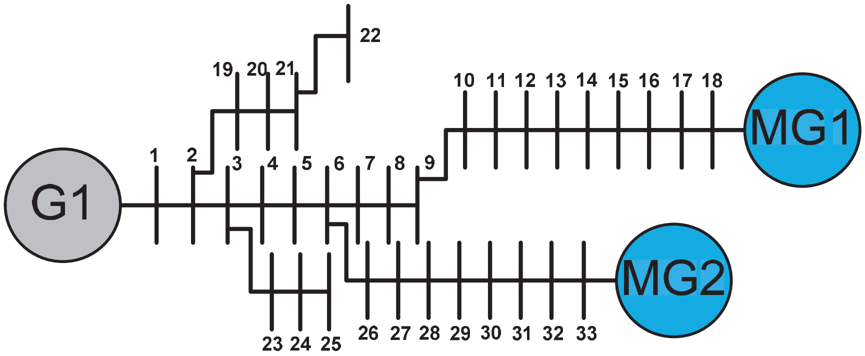

Figure 2 Reformed IEEE 33 bus system.

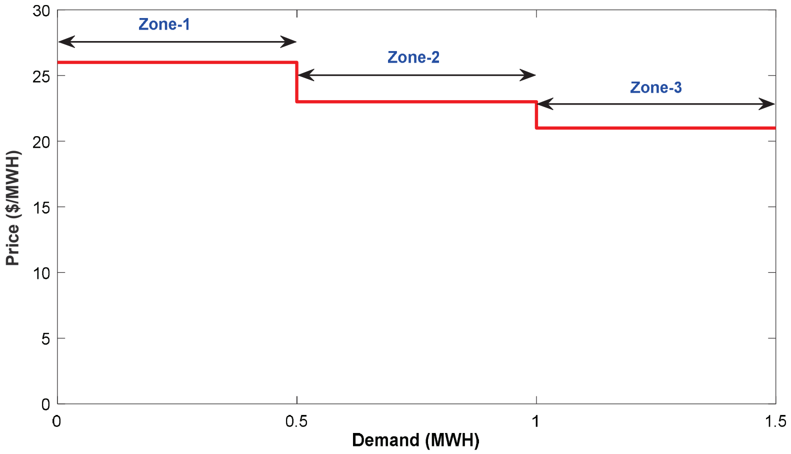

Figure 3 Demand bid microgrid in 33 bus system.

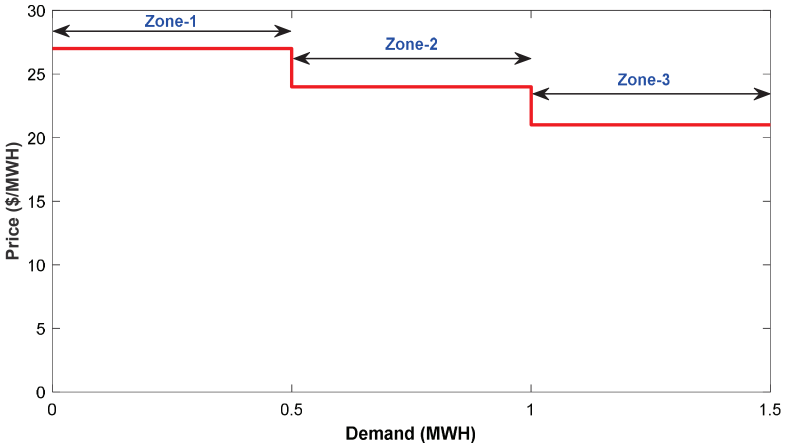

Figure 4 Demand bid microgrid in 18 bus system.

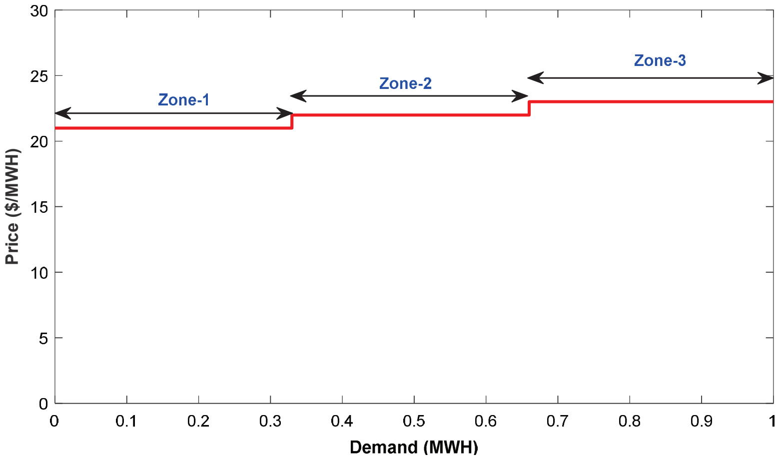

Figure 5 Demand bid microgrid in five identical DG.

Figures 3 and 4 depict the demand bids, which consist of three zones in decreasing order. The assumption has been made that there are five identical DGs with the same manufacturing methodology. The market operator receives offers from these five identical DGs in increasing order as shown in Figure 5. It has been proposed that the size of potential DGs lie between 330 kW and 1 MW to meet the DGs capacity limit. Table 4 presents information on supply and demand bids in a detailed manner.

Table 4 Supply and demand bids sent to the EM operator

EM Participants	Zone-1	Zone-2	Zone-3
Five identical DGs	21$ (0–330 kWh)	22$ (330–660 kWh)	23$ (660–1000 kWh)
18	27$ (0–0.5 MWH)	24$ (0.5–1 MWH)	21$ (1–1.5 MWH)
33	26$ (0–0.5 MWH)	23$ (0.5–1 MWH)	21$ (1–1.5 MWH)

Table 5 Ranking of an electrical distribution network based on LMP index

LMP Ranking	Bus Number	LMP($/MWH)
1	33	22.8134
2	32	22.8132
3	31	22.8117
4	30	22.7946
5	29	22.7351

7.2 Present LMP Ranking and Systematic Approach

The next section describes the two approaches for DG placement and size applied to standard 33 bus systems, which have an inaccuracy in the radial distribution system. As a result, the novel approach has been introduced.

Higher the LMP, the more difficult it is to deliver an extra unit of power at a particular node. As a result, there may be a lot of power being transferred from generators to meet the needs of heavy loads or congestion or losses [43]. Gautam and Mithulanathan used LMP ranking to place the DGs in decreasing order list, which is shown in Table 5 [43]. OPF will compute the optimal DG size once the candidate list has been determined.

It is clear that LMP based ranking in the radial DN is not precise since the location of the 1^{st} DG at the 1^{st} rank bus, significantly modifies the network scenario. Because of this, placing the next DG at the second rank bus based on the predetermined list is no longer optimal. At first glance, utilizing OPF after locating the first generator and re-creating the LMP rank list, seems to be a novel way to deal with this problem every time. Therefore, in this scenario the feasible set gradually decreases and as a result, it will have sufficient accuracy.

In the same way, this paper's novel approach is preferred over an analytical approach to OSL of the DGs provided in Kayal et al., [44] wherever in the first phase OSL of DGs is achieved to decrease loss and maximize voltage amplitude. The appropriate DG size will be calculated in the second phase of the procedure.

7.3 Proposed Method

An innovative method for the OSL of DGs in the radial DNs is presented in this paper. With LMP, this meta-heuristic technique is capable of obtaining the best possible DG placement and size. MOALO simultaneously offers the positions of the predefined five DGs by searching each possible combination of positions. In an EM, MOALO attempts to maximize social welfare and voltage profile by calculating the fitness of each population member. Figure 6 shows the final optimal DG location on a reformed IEEE 33 bus-system with five identical DGs installed. DGs are positioned at bus 6, 12, 20, 25, 31 in the optimal solution. Moreover, an OPF execution is used to determine the appropriate size for DG candidates while they are being evaluated in the fitness calculation process. Table 6 shows the LMP and social welfare maximization parameters produced by every DG at the optimal placement. A nearby evaluation of LMP before and after optimizing DG position and size has been shown in Figure 7. The red color line represents the IEEE 33-bus system while the blue color line represents the OSL of DGs. It is evident from Figure 8 that the optimal chosen DGs have resulted in a large decrease in the LMP as shown in the graph. As a result, social welfare has been improved to 6, 1, 14, 13, and 12% at the respective placing of DGs shown in Figure 6 by employing the proposed method.

The active and reactive power losses for each branch, are shown in Figures 9, and 10 respectively. It is evident from Table 7 that the total active

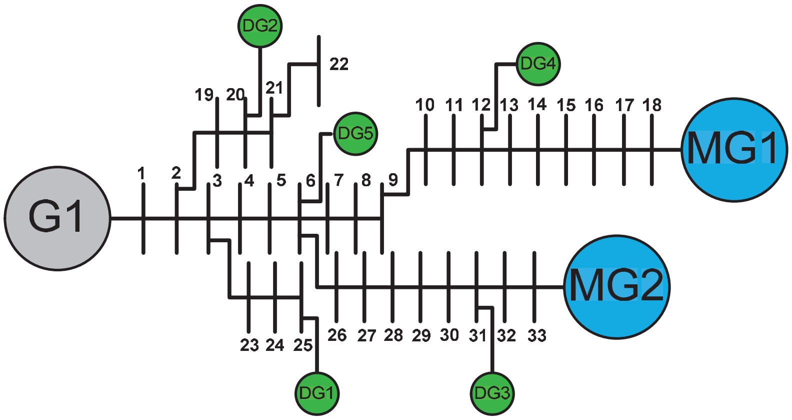

Figure 6 Dual auction OSL of DG in IEEE 33 bus system.

Table 6 OSL of DGs and their corresponding LMP

DG Number	DG Location	DG Size (KW)	LMP ($/MWH)	Social Welfare Maximization
DG1	25	910	20.0731	6%
DG2	20	459	20.0187	1%
DG3	31	736	20.0819	14%
DG4	12	571	20.0363	13%
DG5	6	546	20.0109	12%

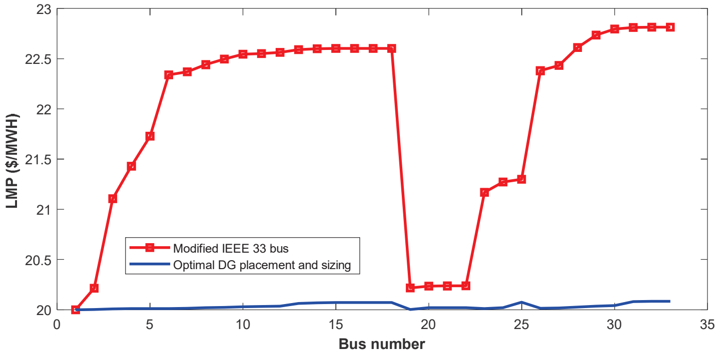

Figure 7 LMP comparison between the base and optimal scenario.

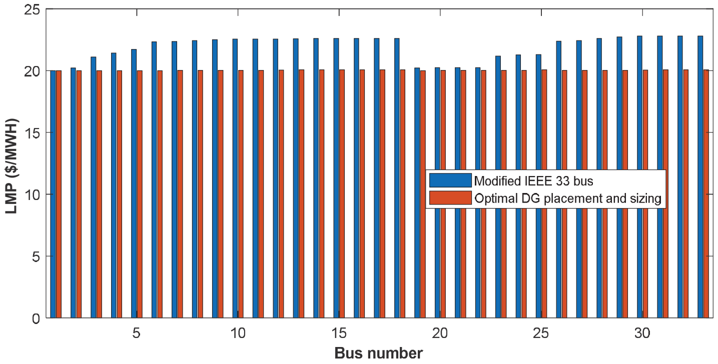

Figure 8 LMP of IEEE 33 bus system.

power losses are reduced by 146.98 kW from 164.6452 kW to 17.6652 whereas, the total reactive power losses are reduced by 100.6179 kVAR from 108.7772 kVAR to 8.1593 kVAR.

The voltage amplitude of each bus has been compared in both the scenario that is reformed IEEE 33 bus-system and optimal solution shown in

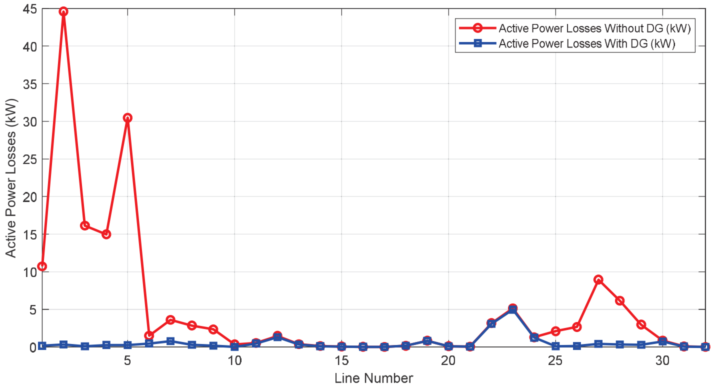

Figure 9 Active power losses with and without DG.

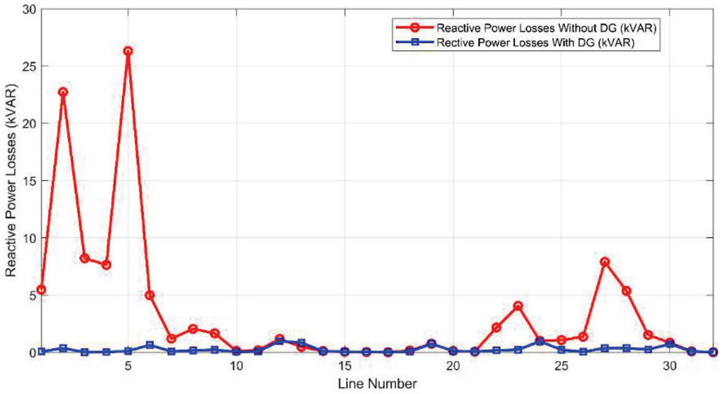

Figure 10 Reactive power losses with and without DG.

Figure 11. Voltage amplitude in the optimal scenario has been improved significantly as shown in Figure 12. As an outcome, the voltage profile has been improved by 5% with the inclusion of multiple DGs.

In Figure 13, it can be clearly seen that the suggested MOALO algorithm converges to an optimal solution more quickly.

7.4 Comparison of Proposed Work with GA Optimization Technique

The result of the proposed algorithm for DGs size and placement has been compared with that of GA in the IEEE 33 bus system. The results of this

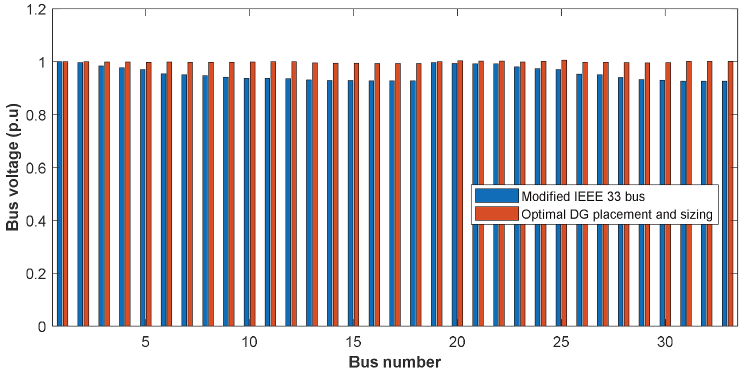

Figure 11 Voltage profile of IEEE 33 bus system.

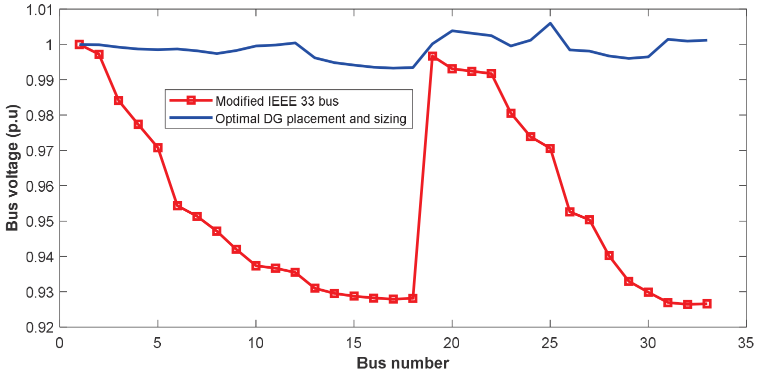

Figure 12 Voltage amplitude comparison between the base and optimal scenario.

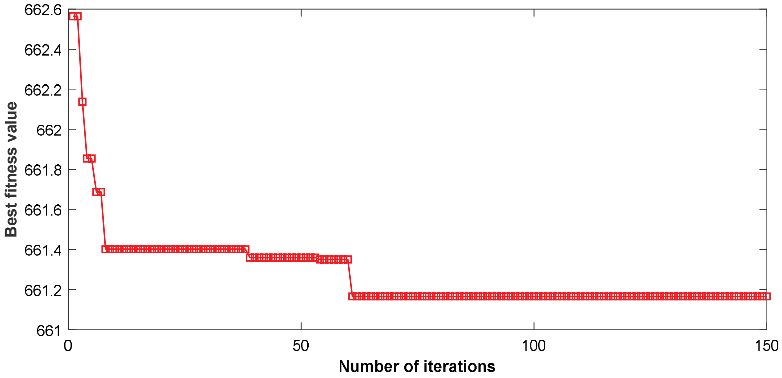

Figure 13 Objective function best fitness value with no. of iteration.

Table 7 Effects of DG placement on power loss minimization

Active Power Losses without DG (KW)	Active Power Losses with DG (KW)	Reactive Power Losses without DG (kVAR)	Reactive Power Losses with DG (kVAR)
164.6452	17.6652	108.7772	8.1593

Table 8 Comparison between proposed algorithm with GA

Optimization Technique	Test System	DGs Location	Optimal DG Size (kW)	LMP	Social Welfare Maximization
MOALO	33	25	910	20.0731	9.4%
		20	459	20.0187	
		31	736	20.0819	
		12	571	20.0363	
		6	546	20.0109	
GA [45]	33	14	673	22.322	5%
		18	1000	22.486	
		24	660	22.268	
		30	902	22.324	
		33	1000	22.469	

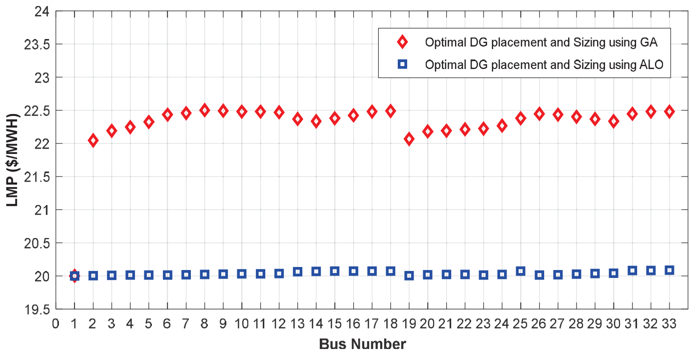

Figure 14 Comparison of LMP using GA and LMP.

comparison are shown in Table 8. The MOALO gives better results that is 9.4% improvement in social welfare in comparison to GA.

8 Conclusion and Future Scope

A novel MOALO technique has been applied and tested for IEEE 33 bus radial DN in order to get the OSL of multiple DGs to improve the social welfare, reduction of power losses with a better voltage profile. By employing MOALO, the best feasible DG location and size have been achieved. The real energy value of each node may be determined using LMP. According to the simulation results, more DGs will lead to a scenario where the loads are supplied by the native generators and minimized the losses. The employed strategy results in 6, 1, 14, 13, and 12% enhancement in social welfare at bus number 6, 12, 20, 25, 31, and 5% improvement in voltage profile as well as, active and reactive power losses are reduced by 146.98 kW and 100.6179 kVAR respectively. The SWM obtained in the case of MOALO technique was compared with GA for IEEE 33 bus system. It has been observed that MOALO gives 9.4% whereas GA gives only 5% which shows that MOALO is a better technique for SWM. The future scope of the proposed work may be to incorporate different types of DGs such as combined heat and power, wind, solar, etc. Additionally, MOALO may be expanded to consider the various factors in the electrical distribution system such as including peak demand, overloads, microgrid problems, etc.

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