OPTIMAL LOCATION AND SIZING OF RENEWABLE ENERGY BASED DISTRIBUTED GENERATION UNITS IN A RADIAL DISTRIBUTION POWER NETWORK USING ANT LION OPTIMIZATION ALGORITHM

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Abstract - The capability of Photovoltaic (PV) system and Wind turbine (WT) in providing electrical power with clean and environment-friendly makes it ideal for distributed generation (DG) resource in distribution networks to meet power demand with lesser environmental effects. The distribution networks power losses are largely influenced by the location and size of the DG unit. This paper introduces an ant lion optimization algorithm (ALOA) for identifying suitable location and capacity of renewable energy based DG units for different distribution network systems. Loss sensitivity factor (LSF) is used to determine candidate buses for DG placement and voltage sensitivity factor (VSF) is used to select a suitable bus location from candidate buses for DG unit installation. The proposed ALOA is developed to deduce the optimal size of different types of DG units at the selected bus locations. The performance of ALOA is validated for IEEE 33 bus and 69 bus radial distribution systems. To highlight the superiority of the proposed algorithm, the results are compared with other algorithms in terms of power loss reduction and voltage profile. The proposed algorithm has given improved performance over other algorithms in terms of power loss reduction and voltage profile enhancement. Also, the response of ALOA under varying loading condition is presented to outline its effectiveness towards voltage profile enhancement and power loss minimization at different load levels.

Keywords— Photovoltaic system, Wind turbine, Distributed generation, Ant lion optimization algorithm, Loss sensitivity factor, Voltage sensitivity factor

Nomenclature

i	Sending end bus
$i+1$	Receiving end bus
$LSF_{i,i+1}$	Loss Sensitivity Factor for the line connected between buses i and i+1
$R_{i,i+1}$	Resistance of distribution line connected between buses i and i+1
$X_{i,i+1}$	Reactance of distribution line connected between buses i and i+1
V_i	Voltage magnitude at bus i
V_{i+1}	Voltage magnitude at bus i+1
n	Number of ants
M_{Ant}	A matrix representing the location of ants
M_{OA}	A matrix representing the fitness value of ants
$M_{Antlion}$	A matrix representing the location of ant lions
M_{OAL}	A matrix representing the fitness value of ant lions
a_i	The minimum of random walk of i^{th} variable
d_i	The maximum of random walk in i^{th} variable
c_i^t	The minimum of i^{th} variable at t^{th} iteration
d_i^t	The maximum of i^{th} variable at t^{th} iteration.
$Antlion_j^t$	j^{th} ant lion position at t^{th} iteration
Ant_i^t	i^{th} ant position at t^{th} iteration
c^t	The minimum of all variables at t^{th} iteration
d^t	The maximum of all variables at t^{th} iteration
I	This is a ratio and is equals to $10^{w\frac{t}{T}}$
w	A constant defined according to the current iteration
t	Current iteration
T	Number of iteration count
R_A^t	Random walk of ant around the ant lion chosen by roulette wheel at t^{th} iteration
R_E^t	Random walk of ant around the elite at t^{th} iteration,
F_t	The total objective function
$\delta_1, \delta_2, \delta_3$	The weighting factors

f_1	Part of F_t which indicates minimization of active power losses
f_2	Part of F_t which refers to minimization of voltage deviation index
f_3	Part of F_t which illustrates the enhancement of voltage stability index
$P_{DG,Tloss}$	Total active power losses with DG units
P_{Tloss}	Total active power losses without DG units
V_i	The voltage magnitude at bus i
VSI (i+1)	Voltage stability index of bus i+1
P_{i+1}	Total effective real power beyond bus i+1
Q_{i+1}	Total effective reactive power beyond bus i+1
P_{Swing}	The active power of swing bus
P_{DG}	Total installed active power capacity of DG units
N_{DG}	Number of DG units
L	Total of number of transmission line in a distribution network
$P_{Lineloss}$	Total active power loss in distribution network
P_d (q)	The real power demand at bus q
Q_d(q)	The reactive power demand at bus q
Q_{Swing}	The reactive power of swing bus
Q_{DG}	Total reactive power capacity of installed DG units
$Q_{Lineloss}$	Total reactive power loss in distribution network
V_{min} ,V_{max}	The minimum and maximum voltage at bus i
P_{DG}^{min}, P_{DG}^{max}	The lower and upper limit of DG units active power capacity
Q_{DG}^{min}, Q_{DG}^{max}	The lower and upper limit of DG units reactive power capacity
NR	Not Reported

1. Introduction

The electrical power demand of the entire globe is majorly supplied from fossil fuel-based power station. They produce electricity by burning fossil fuels like coal, petroleum or natural gas and convert heat energy into rotational energy, which drives an electrical generator. There are two major concerns needs to be addressed in the existing power generating station. Firstly, conventional power station releases an enormous amount of flue gases containing carbon dioxide and greenhouse gas into the environment. This imposes a major impact on earth climate condition by contributing to global warming [1-5]. Secondly, higher power losses occur in the transmission and distribution power network while supplying electrical loads. These scenarios will become even worse when the electrical demand rises. Moreover, increased power demand causes more power loss and voltage deviation which accounts for voltage stability problem. Hence, in order to meet increased electrical demand with reduced power losses and flue gas emission, renewable energy based generation technologies are introduced in the existing power networks. These types of power resources are called as distributed generation as they are installed closer to the electrical load on the distribution network to minimize power losses. Mostly, Wind turbine (WT) and Photovoltaic (PV) system based technologies are incorporated as distributed generation units in distribution power network due to its ability to meet power demand with lesser emission of carbon dioxide when related to natural gas and coal [6-8]. Proper installation of DG unit offers numerous advantages such as reduction of power losses, power quality improvement and enhanced reliability at reduced fuel, operating and maintenance costs [9-10]. On the other hand, inadequate choice of location and size of DG results in increased power losses, costs and voltage stability problem [11].

Several optimization algorithms have been implemented to obtain an optimal solution on siting and sizing of DG unit in distribution systems. In [12] Genetic algorithm (GA) was utilized to determine the suitable location and capacity of DG units in order to avail power loss reduction and voltage improvement. In [13] Particle swarm optimization (PSO) and Differential evolution (DE) have been presented for identifying suitable bus location and size of the DG unit for improving voltage profile and reducing real power loss. Optimal capacity of multi-type distributed generators has been evaluated using Backtracking search optimization algorithm (BSOA) [14] to minimize real power loss with enhanced voltage profile. Artificial bee colony (ABC) algorithm was implemented in [15] to obtain optimal bus location, size and power factor of DG units to minimize total real power loss of distribution network. In [16] Cuckoo search algorithm (CSA) was employed for optimal DG allocation to reduce total system real power losses. Suitable bus location and size of the DG unit was determined via Modified teaching learning-based optimization (MTLBO) in [17]. Majority of researchers excluding [18-20] have not considered the effect of variable load and only considered the constant power load. Moreover, due to the complexity of the problem, the above-mentioned algorithms may not assure the desired solution towards optimal location and size of DG as they often get trapped in local minimum solution.

Ant lion optimization algorithm (ALOA) is a recently developed optimization technique by Mirjalili [21] which imitate the hunting mechanism of ant lions. The capability of ALOA in providing the solution to numerous optimization problems makes it adequate for solving economic power dispatch [22], load forecasting [23] and load frequency control [24] problems. This paper proposes LSF and VSF approach based ALOA to determine optimal site and size for different types of renewable DG units in radial distribution networks. In order to outline the superiority of the proposed algorithm towards power loss reduction and voltage profile enhancement, obtained results are related with numerous algorithms. The effectiveness of ALOA in reducing real power losses and enhancing the voltage magnitudes under different loading conditions is also presented in this paper.

The remaining part of the paper is organized as follows: Section 2 presents LSF and VSF methodology for selecting optimal DG locations. Overview of ALOA is highlighted in Section 3. Objective function formation is presented in Section 4. The simulation results are discussed in Section 5. Finally, the conclusion is presented in Section 6.

2. LSF and VSF based Optimal DG Location

The candidate bus locations for DG unit placement are found using LSF [25]. LSF determine the candidate buses to be consider for DG installation. Whereas, VSF used to select the most critical bus location for DG placement from candidate buses. Computation of LSFs helps to minimize the search area and time of the optimization process.

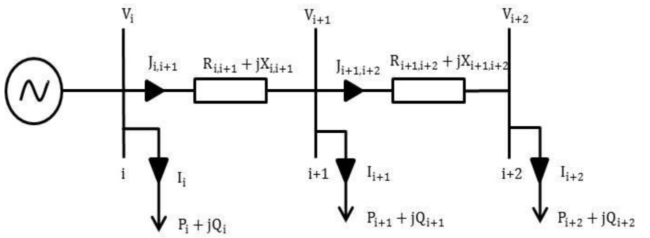

Fig.1. Sample Distribution Power Network

LSF for a distribution line connected between buses i and i+1 as illustrated in Fig.1 is evaluated using the following equation:

$$LSF_{i,i+1} = \frac{\partial P_{loss}}{\partial Q_{i+1,eff}} = \frac{2Q_{i+1}R_{i,i+1}}{|V_{i+1}|^2} \tag{1}$$

VSF is obtained by dividing the base case bus voltage by 0.95 [26]. Buses having VSF value less than 1.01 are considered for identifying critical bus locations for DG placement.

3. Overview of Ant Lion Optimization Algorithm

Mirjalili [21] developed a novel nature-inspired ant lion optimization algorithm which imitates the hunting behavior of ant lions in nature. Initially, ant lion larva creates a trap in the form of a cone-shaped pit in the sand with the help its massive jaw by moving along a circular path. Then, the larva waits under the bottom of the pit by hiding itself to catch the prey falling into the pit. The ant lion begins to shoot out the sand outwards once it senses a prey in the trap. As the trap is formed with sharp edges, the trapped prey slides into the bottom of the pit and gets caught by ant lion. Now, the ant lion will consume the trapped prey and prepare the pit for the next hunt.

3.1 Operators of ALO algorithm

The hunting mechanism between ant lions and ants is illustrated in ALO algorithm. In order to model such a mechanism, ants are allowed to move in the given search space and ant lions are permitted to hunt them using traps. In search of food, ants move stochastically in nature. Therefore, the movement of ants over the given search space is represented as a random walk using following equation:

$$X(t) = \begin{bmatrix} 0, cums(2r(t_1)-1), cums(2r(t_2)-1), \\ \text{..........................}, cums(2r(t_n)-1) \end{bmatrix} \tag{2}$$

Where, r(t) is a stochastic function and it can be represented using following equation:

$$r(t) = \begin{Bmatrix} 1\, if\ rand > 0.5 \\ 0\, if\ rand \le 0.5 \end{Bmatrix} \tag{3}$$

The positions of ants are saved and utilized during the optimization process using the following matrix:

$$M_{Ant} = \begin{bmatrix} A_{1,1} & A_{1,2} & .... & A_{1,d} \\ A_{2,1} & A_{2,2} & .... & A_{2,d} \\ : & : & : & : \\ A_{n,1} & A_{n,2} & .... & A_{n,d} \end{bmatrix} \tag{4}$$

The position of each ant in a matrix, M_{Ant} denotes the parameter for each solution. The fitness value of an objective function for each ant during the optimization process is saved using the following matrix:

$$M_{OA} = \begin{bmatrix} F_t([A_{1,1}, A_{1,2}, ..., A_{1,d}]) \\ F_t([A_{2,1}, A_{2,2}, ..., A_{2,d}]) \\ : \\ F_t([A_{n,1}, A_{n,2}, ..., A_{n,d}]) \end{bmatrix} \tag{5}$$

Also, the positions and fitness value of ant lions hiding in the search space are saved using the following matrices:

$$M_{Antlion} = \begin{bmatrix} AL_{1,1} & AL_{1,2} & \dots & AL_{1,d} \\ AL_{2,1} & AL_{2,2} & \dots & AL_{2,d} \\ \vdots & \vdots & \vdots & \vdots \\ AL_{n,1} & AL_{n,2} & \dots & AL_{n,d} \end{bmatrix} \quad (6)$$

$$M_{OAL} = \begin{bmatrix} F_t([AL_{1,1}, AL_{1,2}, \dots, AL_{1,d}]) \\ F_t([AL_{2,1}, AL_{2,2}, \dots, AL_{2,d}]) \\ \vdots \\ F_t([AL_{n,1}, AL_{n,2}, \dots, AL_{n,d}]) \end{bmatrix} \quad (7)$$

3.1.1 Random walks of ants

The position of ants alters according to (2). The position of ants is normalized using (8), in order to keep the random walk within the search space.

$$X_i^t = \frac{(X_i^t - a_i) \times (d_i^t - c_i^t)}{(d_i - a_i)} + c_i^t \quad (8)$$

3.1.2 Trapping in ant lion's pits

The ant lion traps affects the random walk of ants in the search space and it can be mathematically expressed using the following equations:

$$c_i^t = Antlion_j^t + c^t \quad (9)$$

$$d_i^t = Antlion_j^t + d^t \quad (10)$$

From (9) and (10), the vectors c and d makes ants walk randomly in a hyper sphere around a particular ant lion.

3.1.3 Building a trap

The hunting ability of ant lion is modeled using a roulette wheel. During the iteration process of ALOA, the ant lions are selected based on the fitness values with the help of roulette operator. This gives higher possibilities for fitter ant lions for trapping ants into the pits.

3.1.4 Sliding ants towards ant lion

With the help of the aforementioned mechanisms, the ant lion forms a trap according to their fitness value and ants are allowed to move randomly over search space. Whenever the ant falls into the trap, ant lion starts to shoot out sand from centre of the pit. This makes trapped ant to slides down towards ant lion which is trying to escape. In order to model this behavior mathematically, random walk of ants hyper sphere radius is minimized accordingly. This behavior can be represented using the following equations:

$$c^t = \frac{c^t}{I} \quad (11)$$

$$d^t = \frac{d^t}{I} \quad (12)$$

3.1.5 Catching prey and rebuilding the pit

This phase of the algorithm involves the calculation of objective function. If the objective function of ant is better than chosen ant lion then the position of ant lion is updated to the latest position of hunted ant. This increases the possibilities of trapping new ants. This phase of action can be represented using following:

$$Antlion_j^t = Ant_i^t \ \ if \ \ f(Ant_i^t) > f(Antlion_j^t) \quad (13)$$

3.1.6 Elitism

For each iteration of optimization process, the best ant lion solution attained so far is elected as elite. As elite is considered as the best solution, it should possess the ability to affect the ant's motion during all iterations. Hence, it is assumed that each ant in the search space randomly walks around chosen ant lion via roulette operator and elite concurrently as follows:

$$Ant_i^t = \frac{R_A^t + R_E^t}{2} \quad (14)$$

The pseudo code for the ALO algorithm is summarized in the following steps:

Step 1: Initialize the number of iterations, population size, and size of DG units. Set number of iterations = 500 and population = 30.

Step 2: Perform load flow analysis and compute LSF, VSF and fitness values of ant lions and ants.

Step 3: Assign the best ant lion solution as elite.

Step 4: With the help of roulette wheel, select an ant lion for every ant.

4.1 Make random walk and normalize it using (8).

4.2 Using (9) and (10) update the location of ant.

Step 5: Determine the fitness values of all ants by performing load flow analysis.

Step 6: If the fitness value of ant is more than ant lion, update the position of ant lion using (13).

Step 7: Update elite solution, if ant lion is fitter than elite.

Step 8: Stop the execution if stopping criteria is attained or go to step 4.

4. Objective Function Formation

A multi-objective function focuses on minimization of real power losses and improvement of voltage profile and voltage stability of distribution power network is presented in this paper. The optimal bus location and capacity for different DG units are obtained by solving the following equation [27]:

$$F_t = \min(\delta_1 f_1 + \delta_2 f_2 + \delta_3 f_3) \tag{15}$$

Where, δ_1, δ_2, and δ_3 are weighting factors and are taken as 0.5, 0.25 and 0.25 respectively. The absolute sum of weighting factors must add up to unity.

The term f_1 from objective function denotes minimization of active power losses and it is expressed using the following equation:

$$f_1 = \left(\frac{P_{DG,Tloss}}{P_{Tloss}} \right) \tag{16}$$

f_2 points to voltage deviation index (IVD) of each bus in the distribution system and it is expressed using following equation:

$$f_2 = \max\left(\frac{V_1 - V_i}{V_i} \right) \tag{17}$$

The DG size which yields higher voltage deviation index is eliminated with the help of IVD. In the course of DG placement, if the system experiences a voltage limit violations, this proposed technique helps to reduce voltage deviation near to zero and thus enhance voltage and voltage stability of the distribution system.

f_3 illustrates enhancement of voltage stability index (VSI) of the distribution network and it can be expressed as

$$f_3 = \left(\frac{1}{VSI(i+1)} \right) \tag{18}$$

Where, the mathematical expression of VSI is given in the following equation [27]:

$$\begin{aligned} VSI(i+1) &= |V_i|^4 - 4(P_{i+1} * X_{i,i+1} - Q_{i+1} * R_{i,i+1})^2 \\ &- 4(P_{i+1} * R_{i,i+1} - Q_{i+1} * X_{i,i+1}) * |V_i|^2 \end{aligned} \tag{19}$$

4.1 Equality and inequality constraints

The proposed objective function is minimized by considering the following equality and inequality constraints.

4.1.1 Equality constraint

Power conservation constraint

For all distribution network systems, the arithmetic sum of all incoming power must be equal to the sum of outgoing power [12,13].

$$P_{swing} + \sum_{i=1}^{N_{DG}} P_{DG}(i) = \sum_{i=1}^{L} P_{Lineloss}(i) + \sum_{q=1}^{N} P_d(q) \tag{20}$$

$$Q_{swing} + \sum_{i=1}^{N_{DG}} Q_{DG}(i) = \sum_{i=1}^{L} Q_{Lineloss}(i) + \sum_{q=1}^{N} Q_d(q) \tag{21}$$

4.1.2 Inequality constraints

Voltage constraint

The voltage profile of all buses of the distribution system must be kept within the following limit:

$$V_{\min} \le |V_i| \le V_{\max} \tag{22}$$

Where, V_{min} and V_{max} are considered as 0.95 p.u and 1.05 p.u respectively [12-13].

4.1.3 DG unit capacity limit constraint

In order to avoid reverse power flow in the distribution network, the installed capacity of DG units should not be greater than substation capacity [12].

$$\sum_{i=1}^{N_{DG}} P_{DG}(i) \le \frac{3}{4} \times \left[\sum_{i=1}^{L} P_{Lineloss}(i) + \sum_{q=1}^{N} P_d(q) \right] \tag{23}$$

$$\sum_{i=1}^{N_{DG}} Q_{DG}(i) \le \frac{3}{4} \times \left[\sum_{i=1}^{L} Q_{Lineloss}(i) + \sum_{q=1}^{N} Q_d(q) \right] \tag{24}$$

Where,

$$P_{DG}^{\min} \le P_{DG}(i) \le P_{DG}^{\max} \tag{25}$$

$$Q_{DG}^{\min} \le Q_{DG}(i) \le Q_{DG}^{\max} \tag{26}$$

5. Simulation Results and Discussion

The proposed ALOA has been implemented using MATLAB software and its performance is evaluated for IEEE 33 and IEEE 69 radial distribution system. Also, the effectiveness of ALOA is examined against different loading conditions.

5.1 IEEE 33 Bus test system

The performance of the proposed ALOA is initially tested on IEEE 33 bus radial distribution system. The test system has a total real power load of 3720 kW and reactive power load of 2300 kVAr at 12.66 kV. The test system data are inferred from [28]. The LSF and VSF for all buses are computed for base case condition and are illustrated in Fig.2. The optimal location for the DG unit is obtained via LSF and VSF. The ability of ALOA to determine the optimal site and size of different DG units is investigated and the results are related with other algorithms to outline its superiority.

5.1.1 Single DG Placement

Initially, the optimal bus location and capacity for different types of single DG unit is determined via ALOA and are given in Table 1. Based on LSF and VSF values, bus number 6 is selected as a suitable location for single DG placement. For a PV type, DG with a capacity of 2475 kW, minimize the total power losses of the system from 210.98 kW to 104.72 kW with a percentage loss reduction of 50.36. Also, total cost of annual energy saving of 55847.43$ is achieved via ALOA if the cost of energy loss is considered as 0.06$. Inclusion of DG unit increases the minimum bus voltage from 0.9038 p.u to 0.9501 p.u. Consequently, total VSI of the system is enhanced from 26.4657 to 28.6905. In order to outline the effectiveness of ALOA, the test results are compared with other algorithms [12-14] and are given in Table 2. Compared with other algorithms, ALOA gives superior results towards power loss minimization with a higher percentage of power loss reduction at acceptable voltage profile.

For a WT type DG unit, 65.25 % power loss reduction is achieved with a total power loss of 73.31 kW. Total cost of annual energy saving of 72359.36$ is obtained using ALOA. Also, the minimum bus voltage of the network is enhanced to 0.9516 p.u and total VSI is improved to 29.5326. Referring to Table 2, ALOA provides maximum power loss reduction when related to GA and BSOA. Furthermore, DG with WT type provides a superior outcome than PV type in terms of power loss reduction, voltage profile and VSI enhancement due to its reactive power support. The impact of installing a single DG unit over voltage profile and VSI of the distribution system is illustrated in Fig.3 and 4 respectively.

5.1.2 Two DG Placement

The effectiveness of ALOA towards providing an optimal solution is now validated by installing two DG units on IEEE 33 bus system. Bus numbers 13 and 30 are determined as a suitable location for PV type DG installation with a capacity of 846.3 kW and 1206.16 kW respectively. Addition of DG units in distribution power network decreases the total power losses to 81.1 kW with a power loss reduction of 61.56 % and increases the minimum bus voltage of the network from 0.9038 p.u to 0.9701 p.u as given in Table 1. Also, the total cost of annual energy saving of 67213.74$ is achieved. Compared to other algorithms [12-14], ALOA gives better outcome towards power loss reduction and voltage profile enhancement and is highlighted in Table 3.

For WT type, DG capacity of 920.20 kVA and 1590.21 kVA are obtained for optimal bus locations 13 and 30 respectively via ALOA. Power loss reduction of 86.45 % is obtained with total power losses of 28.57 kW at a total cost of annual energy saving 93769.68$. The minimum bus voltage and total VSI of the system is increased to 0.9806 p.u and 32.3301 respectively. From Table 3, it is clearly highlighted that ALOA outclasses BSOA in terms of power loss minimization and voltage profile enhancement. Fig.5 and 6 illustrate the effect of installing two DG units on voltage profile and VSI of the system respectively. Also, it is evident that WT type DG units have provided better results than PV type towards power loss reduction and voltage profile and VSI enhancement.

5.2 IEEE 69 Bus test system

The second system to be tested using ALOA is IEEE 69 bus radial distribution system which consists of 3800 kW of real power and 2690 kVAr of reactive power loads at 12.66 kV. The necessary line and bus data for test system are referred from [29]. The performance of the proposed algorithm is investigated with different types of single and two DG units. The performance results are related with various algorithms [12,15-17] to verify the superiority of ALOA.

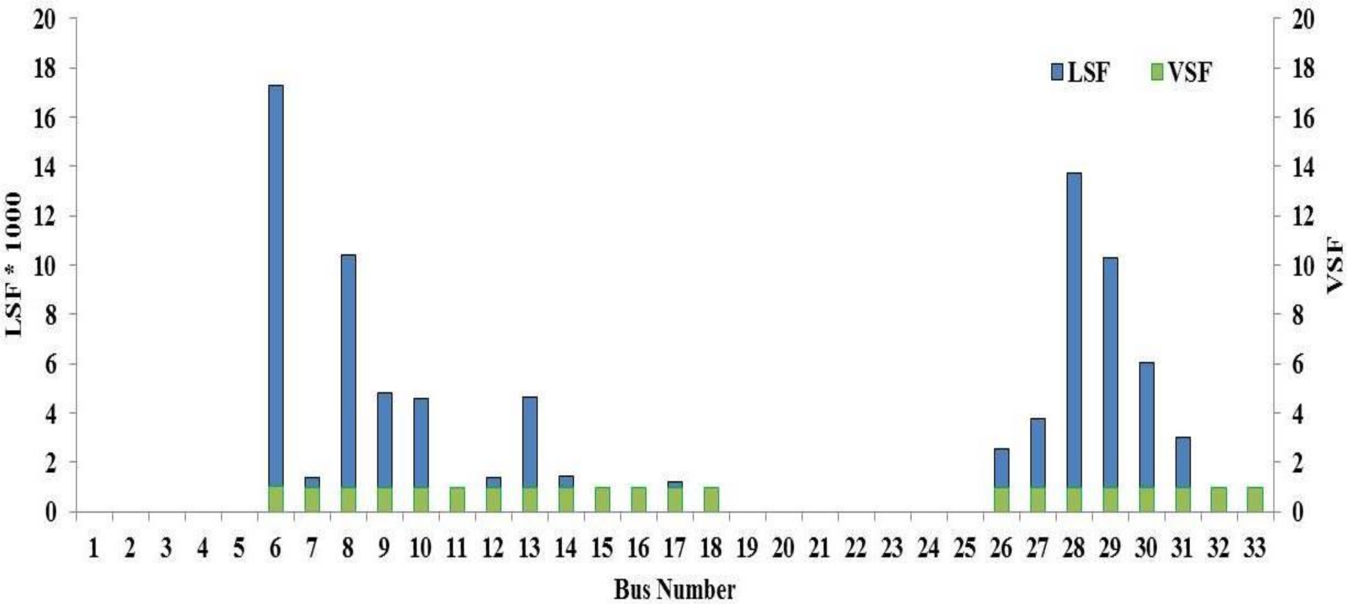

Fig. 2. VSF and LSF for IEEE 33 Bus System

Table 1. IEEE 33 Bus System Test Results with Different DG Units

No. DG units and type	Total losses (kW)	Loss reduction (%)	V_{mini} (p.u)	V_{max} (p.u)	Total DG Size at bus (kVA/p.f)	Total VSI	Cost of losses ($)	Savings ($/year)
Without DG	210.98	-	0.9038	0.9970	-	26.4657	110891.1	-
One – PV	104.72	50.36	0.9501	0.9981	2475/1@ 6	28.6905	55043.67	55847.43
One – WT	73.31	65.25	0.9516	0.9985	2194/0.866@ 6	29.5326	38531.74	72359.36
Two – PV	81.1	61.56	0.9701	0.9983	1206.16/1@13 846.3/1@ 30	30.4495	43677.36	67213.74
Two – WT	28.57	86.45	0.9806	1.0000	1590.21/0.8615 @ 13 920.20/0.8621 @ 30	32.3301	17121.42	93769.68

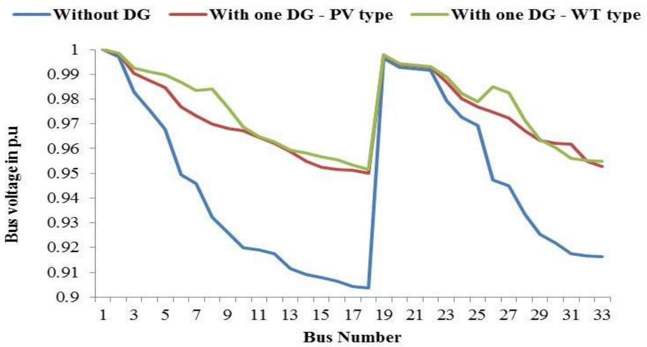

Fig.3. Voltage profile of IEEE 33 bus system with single DG unit

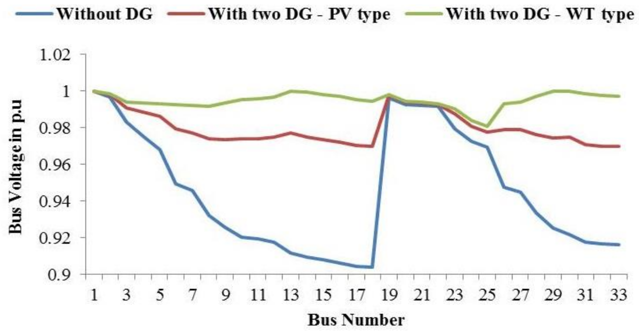

Fig.5. Voltage profile of IEEE 33 bus system with two DG units

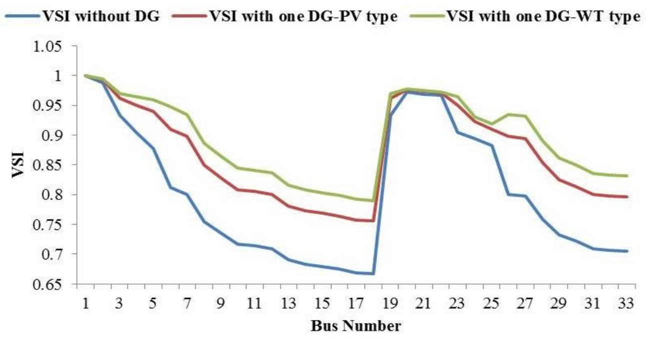

Fig.4. VSI of IEEE 33 bus system with single DG unit

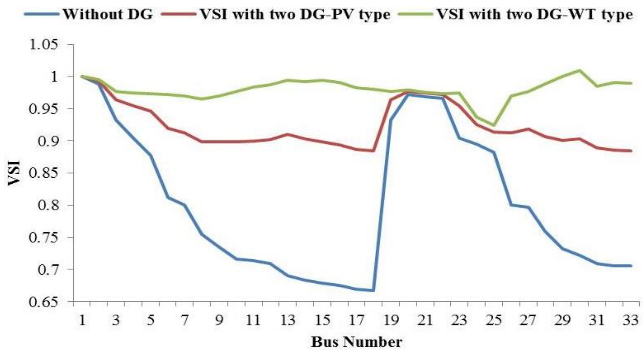

Fig.6. VSI of IEEE 33 bus system with two DG units

Table 2. Comparative Result of IEEE 33 Bus System with One DG Unit

Technique	DG Type	Optimal size of DG unit (kVA/p.f)	Optimal location of DG unit	Power loss with DG unit (kW)	Power loss reduction (%)	Bus voltage (p.u)	
						Minimum	*Maximum*
Without DG	-	-	-	210.98	-	0.9038	0.9970
GA [12]	PV	2580/1	6	105.48	48.21	NR	NR
EVPSO [13]		763/1	11	140.19	33.55	0.9284	0.9604
PSOPC [13]		1000/1	15	136.75	35.18	0.9318	0.9679
ADPSO [13]		1212/1	13	129.53	38.60	0.9348	0.9712
BSOA [14]		1857/1	8	118.12	44.01	0.9441	0.9982
ALOA		**2475/1**	**6**	**104.72**	**50.36**	**0.9501**	**0.9981**
GA [12]	WT	2980/0.95	6	72.68	64.32	NR	NR
BSOA [13]		2265/0.82	8	82.78	60.76	0.9549	1.0060
ALOA		**2194/0.866**	**6**	**73.31**	**65.25**	**0.9516**	**0.9985**

5.2.1 Single DG placement

The suitable bus location for installing a single DG unit is determined based on the LSF and VSF of buses as illustrated in Fig. 7. For PV type, bus number 27 is obtained as a candidate location for installing DG unit with a capacity of 1882.2 kW. The inclusion of the DG unit reduces the total real power losses to 80.23 kW with 64.34 % power loss reduction which results in a total annual energy cost saving of 74517$. With the addition of DG unit, the minimum bus voltage of the network is increased from 0.9092 p.u to 0.9684 p.u and total VSI from 65.5781 to 65.5976. The test results of single DG placement are summarized in Table 4. Also, the comparative analysis of ALOA with other algorithms [12,15-17] is presented in Table 5 and it is evident that when compared to other algorithms ALOA produces superior results towards power loss minimization.

Similarly, the total power losses are limited to 21.71 kW with 90.59 % power loss reduction for a WT type DG unit with a capacity of 2343.47 kVA at bus number 27. The net annual energy cost saving of 106326.14$ is achieved through ALOA. Also, the inclusion of the DG unit enhances the minimum bus voltage to 0.9727 p.u and total VSI to 66.7503. To outline the effectiveness of ALOA, its performances are compared with other algorithms as presented in Table 5. Table 5 clearly shows that ALOA outperforms all the other algorithms in terms of power loss reduction and thus contributing to maximum energy saving. Fig. 8 and 9 shows the impact of installing a single DG unit on voltage profile and VSI respectively.

Table 3. Comparative Results of IEEE 33 Bus System with Two DG Units

Technique	DG Type	Optimal size of DG unit (kVA/p.f)	Optimal location of DG unit	Power loss with DG unit (kW)	Power loss reduction (%)	Bus voltage (p.u) Minimum	Bus voltage (p.u) Maximum
Without DG	-	-	-	210.98	-	0.9038	0.9970
GA [12]	PV	837.5 / 1 1212.2 / 1	13 29	82.70	60.80	0.9684	NR
PSOPC 13]		916 / 1 767 / 1	8 12	111.45	47.17	0.9418	0.9738
EVPSO [13]		540 / 1 569 / 1	14 31	108.05	48.78	0.9457	0.9661
ADPSO [13]		550 / 1 621 / 1	15 30	106.24	49.64	0.9467	0.9667
BSOA [14]		880 / 1 924 / 1	13 31	89.34	57.65	0.9665	0.9981
ALOA	WT	**846.3 / 1** **1206.16 / 1**	**30** **13**	**81.10**	**61.56**	**0.9701**	**0.9983**
BSOA [14]		777 / 0.89 1032 / 0.70	13 29	31.98	84.84	0.9796	0.9986
ALOA		**920.20 / 0.8621** **1590.21 / 0.8615**	**30** **13**	**28.58**	**86.45**	**0.9806**	**1.0000**

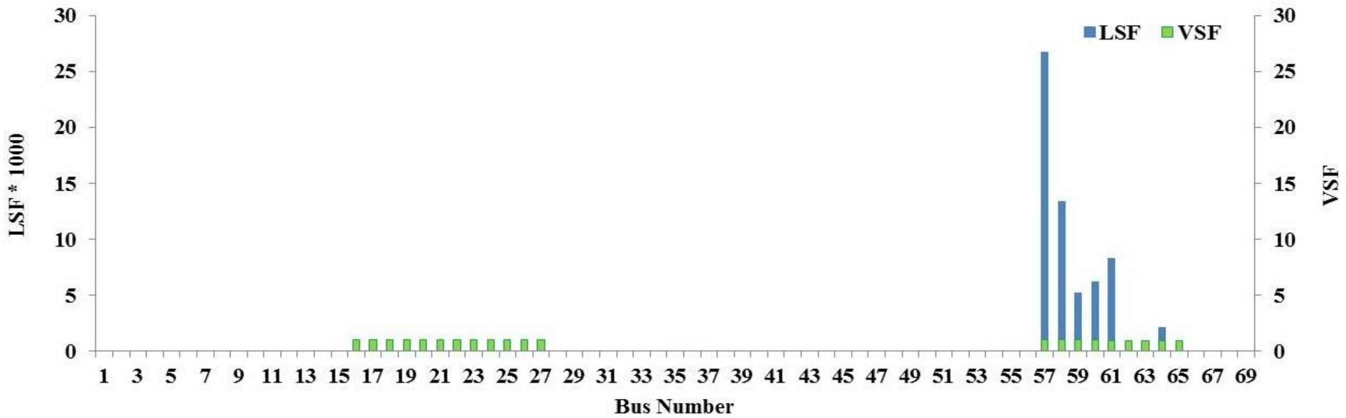

Fig.7. VSF and LSF for IEEE 69 Bus System

5.2.2 Two DG placement

The performance of ALOA on IEEE 69 bus system is now evaluated by installing two DG units. Candidate buses for DG placement are determined using LSF and VSF. For PV type DGs, bus numbers 17 and 61 are obtained as candidate buses for DG placement with the capacity of 836.8 kW and 1531.7 kW respectively. Incorporation of DG units reduces the total power losses to 65.78 kW with 70.76 % power loss reduction which yields annual energy cost saving of 80531.48$. Also, the minimum bus voltage of the network is increased from 0.9092 p.u to 0.9808 p.u and total VSI increased from 65.5781 to 67.1237. Moreover, the proposed algorithm offers better outcome towards power loss minimization than other algorithms [12,16,17] as highlighted in Table 6.

Similarly, for WT type, DGs with a capacity of 869.79 kVA and 1408.9 kVA are installed at bus numbers 17 and 61 respectively. The inclusion of DG units reduces the total power losses to 18.84 kW with 91.62 % power loss reduction which contributes to annual energy cost saving of 108357.38$. Also, the minimum bus voltage and total VSI of the network is enhanced to 0.9943 p.u and 68.5540 respectively. Comparative results of ALOA with various algorithms are presented in Table 6 and it is clearly highlighted that ALOA outperforms CSA towards power loss reduction. Furthermore, WT type DG units provide better outcomes than PV type in terms of power loss reduction, voltage profile and total VSI enhancement. The impact of providing two DG units on the voltage profile and VSI is illustrated in Fig. 10 and 11 respectively.

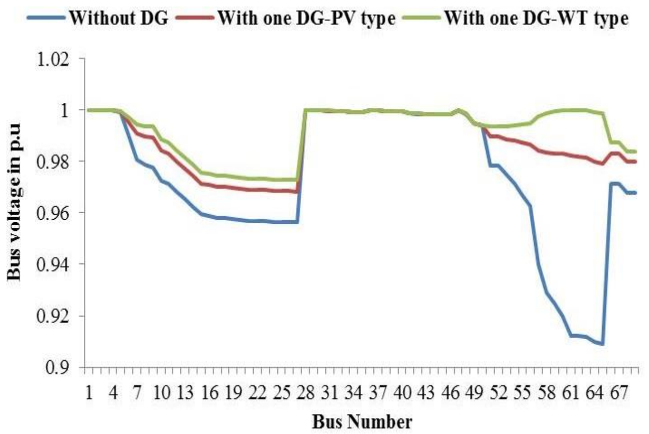

Fig. 8. Voltage Profile of IEEE 69 Bus System with Single DG Unit

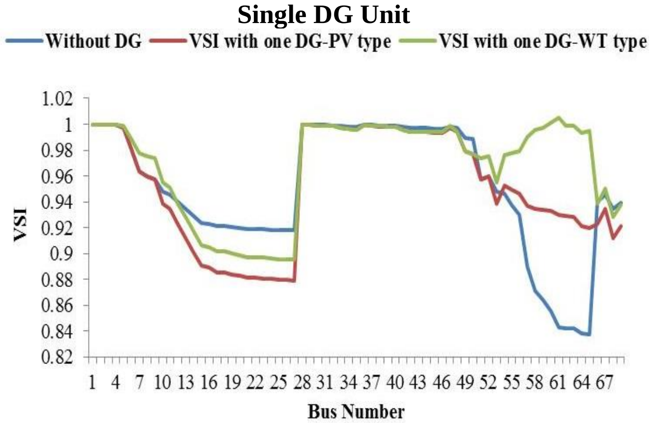

Fig. 9. VSI of IEEE 69 Bus System with Single DG Unit

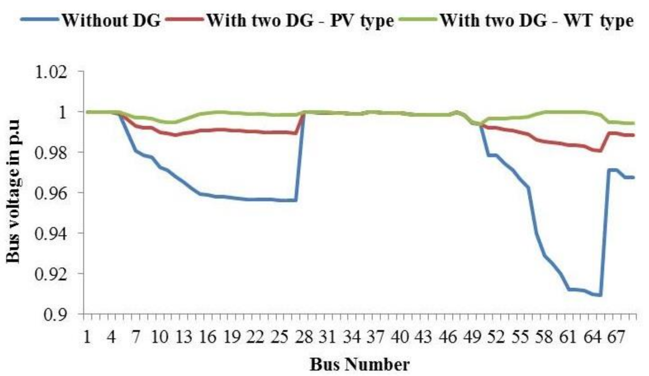

Fig. 10. Voltage Profile of IEEE 69 Bus System with Two DG Units

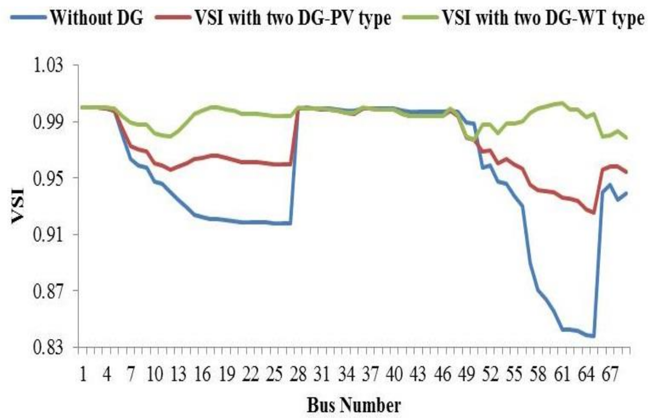

Fig. 11. VSI of IEEE 69 Bus System with Two DG Units

5.3 Effect of variable load

The power demand on a power system network is not always constant throughout the year. Therefore, the proposed ALOA should also be able to produce the desired solution for varying loading conditions. In order to investigate the performance of ALOA under variable load conditions, the power demand of the entire year has been divided into three groups as given in Table 7.

The optimal bus number and capacity of DG units, real power losses, and minimum and maximum bus voltages for IEEE 33 and 69 bus systems under different loading conditions is given in Table 8 and 9 respectively. In both test system, it is evident that total power losses of system are minimized for all loading conditions. Furthermore, under all these conditions bus voltages are kept within the specified limit.

Table 7. Different Load Levels

Load levels	Half load (L1)	Full load (L2)	Peak load (L3)
Level factor	0.5	1.0	1.6

Table 4. IEEE 69 Bus System Test Results with Different DG Units

No. of DG units and type	Total power loss (kW)	Power loss reduction (%)	V_{mini} (p.u)	V_{max} (p.u)	Total DG Size at bus (kVA/p.f)	Total VSI	Cost of losses ($)	Savings ($/year)
Without DG	225.00	-	0.9092	1.00	-	65.5781	118261.47	-
One – PV	80.23	64.34	0.9684	1.00	1882.2 / 1@ 27	65.5976	43744.48	74517.00
One – WT	21.71	90.59	0.9727	1.00	2343.47 / 0.835@ 27	66.7503	11935.32	106326.14
Two – PV	65.78	70.76	0.9808	1.00	1531.7 / 1@ 17 836.8 / 1@ 61	67.1237	37729.98	80531.48
Two – WT	18.84	91.62	0.9943	1.00	1408.90 / 0.823@ 17 869.79 / 0.831@ 61	68.5540	9904.091	108357.38

Table 5. Comparative Results of IEEE 69 Bus System with One DG Unit

Technique	DG Type	Optimal size of DG unit (kVA / p.f)	Optimal location of DG unit	Power loss with DG unit (kW)	Power loss reduction (%)
Without DG	-	-	-	225.00	-
ABC [15]	PV	1900 / 1	61	83.31	62.96
GA [12]		1872 / 1	61	83.18	63.02
CSA [16]		2000 / 1	61	83.80	62.74
MTLBO [17]		1819.69 / 1	61	83.32	62.95
ALOA		**1882.2 / 1**	**27**	**80.23**	**64.34**
GA [12]	WT	2155.6 / NR	61	38.46	82.90
CSA [16]		2300 / NR	61	52.60	76.60
ALOA		**2343.47 / 0.835**	**27**	**21.71**	**90.59**

Table 6. Comparative Results of IEEE 69 Bus System with Two DG units

Technique	DG Type	Optimal size of DG unit (kVA/p.f)	Optimal location of DG unit	Power loss with DG unit (kW)	Power loss reduction (%)
Without DG	-	-	-	225.00	-
GA [12]	PV	1777 / 1 555 / 1	61 11	71.79	68.08
CSA [16]		600 / 1 2100 /1	22 61	76.40	66.00
MTLBO [17]		519.70 / 1 1732.00 / 1	17 61	71.78	68.09
ALOA		**836.8 / 1** **1531.7 / 1**	**61** **17**	**65.78**	**70.76**
CSA [16]	WT	800 / NR 2000 / NR	18 61	39.90	82.26
ALOA		**869.79 / 0.831** **1408.90 / 0.823**	**61** **17**	**18.84**	**91.62**

Table 8. IEEE 33 Bus System Test Results for Different Loading Conditions

No. of DG units	Load levels	Size of DG units (kVA) at bus	Total power loss (kW)		% of loss reduction	V_{mini} (p.u)		V_{max} (p.u)	
			Without DG units	*With DG units*		*Without DG units*	*With DG units*	*Without DG units*	*With DG units*
One PV unit	L1	1368.10 @ 6	48.78	26.58	45.50	0.9540	0.9718	0.9986	0.9992
	L2	2475.00 @ 6	210.98	104.72	50.36	0.9038	0.9501	0.9970	0.9981
	L3	3126.36 @ 6	603.43	249.75	58.61	0.8360	0.9504	0.9950	0.9985
Two PV units	L1	579.47 @ 30 425.20 @ 13	48.78	21.07	56.81	0.9540	0.9847	0.9986	0.9991
	L2	846.30 @ 30 1206.16 @ 13	210.98	81.10	61.56	0.9038	0.9701	0.9970	0.9983
	L3	1884.00 @ 30 1413.70 @ 13	603.43	213.10	64.68	0.8360	0.9503	0.9986	0.9972

6. Conclusion

In this paper, ALOA has been proposed for determining the optimal bus location and capacity of renewable energy based units for IEEE 33 and 69 bus radial distribution systems. PV and WT type DG units have been considered as renewable resources for placement. The candidate bus locations for DG unit placement are obtained using LSF and VSF. For IEEE 33 bus system, bus number 6 has been considered for single DG placement and bus numbers 13 and 30 are selected for two DG installation. Similarly, for IEEE 69 bus system, bus number 27 is selected for single DG placement whereas bus numbers 17 and 61 are considered for two DG unit installation. The optimal size of different types of DG units has been computed via ALOA by minimizing the multi-objective function. The superiority of proposed ALOA was verified by comparing its performance with other algorithms in terms of total power losses, voltage profile and percentage of power loss reduction. For IEEE 33 bus system, total power losses are minimized from 210.98 kW to 104.72 kW with 50.36 % power loss reduction for single PV type DG unit. For single WT type DG unit, total power losses are further reduced to 73.31 kW with 65.25% power loss reduction.

Table 9. IEEE 69 Bus System Test Results for Different Loading Conditions

No. of DG units	Load levels	Size of DG units (kVA) at bus	Total Power loss (kW)		% loss reduction	V_{mini} (p.u)		V_{max} (p.u)	
			Without DG units	*With DG units*		*Without DG units*	*With DG units*	*Without DG units*	*With DG units*
One PV unit	L1	924.90@ 61	51.60	20.30	60.66	0.9567	0.9843	0.9999	1.0000
	L2	1882.20@ 61	225.00	80.23	64.34	0.9092	0.9684	0.9999	1.0000
	L3	2109.24@ 61	652.53	186.69	71.39	0.8445	0.9614	0.9998	1.0000
Two PV units	L1	890.87@ 61 262.74 @ 17	51.60	17.57	65.95	0.9567	0.9897	0.9999	1.0000
	L2	836.80 @ 61 531.70 @ 17	225.00	65.78	70.76	0.9092	0.9808	0.9999	1.0000
	L3	1985.50@ 61 1028.40@ 17	652.53	166.33	74.51	0.8445	0.9648	0.9998	1.0000

With two DG units placement, power loss reduction of 61.56 % is achieved with total power losses of 81.10 kW for PV type and 86.45 % power loss reduction is attained with a total power loss of 28.58 kW for WT type. Similarly, for IEEE 69 bus system, installation of single DG unit of PV and WT type reduce the total power losses of the network from 225.00 kW to 80.23 kW and 21.71 kW with 64.34 % and 90.59 % power loss reduction respectively. Also, power loss reduction of 70.76 % and 91.62 % are achieved with total power losses of 65.78 kW and 18.84 kW for two PV and WT type DG units respectively. VSI of the distribution network has been significantly improved for all DG unit placements. The comparative results have clearly highlighted the effectiveness of ALOA towards maximum power loss reduction with acceptable voltage profile. Also, the effectiveness of ALOA under different load levels has been successfully validated with single and two DG unit placement for both test systems and ALOA have significantly reduced the total power losses under all loading conditions. The proposed work can also be implemented on large distribution networks and unbalanced loads as future work.

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