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Ant Lion Optimization Algorithm for optimal location and sizing of renewable distributed generations

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ABSTRACT

Renewable sources can supply a clean and smart solution to the increased demands. Thus, Photovoltaic (PV) and Wind Turbine (WT) are taken here as resources of Distributed Generation (DG). Location and sizing of DG have affected largely on the system losses. In this paper, Ant Lion Optimization Algorithm (ALOA) is proposed for optimal location and sizing of DG based renewable sources for various distribution systems. First the most candidate buses for installing DG are introduced using Loss Sensitivity Factors (LSFs). Then the proposed ALOA is used to deduce the locations and sizing of DG from the elected buses. The proposed algorithm is tested on two IEEE radial distribution systems. The obtained results via the proposed algorithm are compared with other algorithms to highlight its benefits in decreasing total power losses and consequently increasing the net saving. Moreover, the results are presented to confirm the effectiveness of ALOA in enhancing the voltage profiles for different distribution systems and loading conditions. Also, the Wilcoxon test is performed to verify the superiority of ALOA.

1. Introduction

DG is an electric power source connected to the distribution system directly or on the customer site [1–4]. It presents a cleaner power production, since various DG use renewable sources like WT and PV systems [4]. The major features of DG are decreasing line losses, increasing efficiency, improving power quality, enhancing system reliability and reducing fuel, operating and maintenance costs [4,5]. However, inappropriate selection of location and size of DG lead to greater losses and costs than without DG [6].

The problem of DG placement and sizing was solved using various techniques. An adaptive protection scheme has been developed in Ref. [7] via neural networks for distribution systems with high penetration of DG units. The optimal size of renewable energy sources in DG is discussed in Refs. [8,9], where the objective function and constraints are modeled with fuzzy sets. A systematic simple approach to allocate multiple DG units in distribution network is presented in Ref. [10]. The concept of equivalent load is extended to identify the load centroid precisely. In Ref. [11] load shedding is considered as a way to achieve a trade-off between the reliability enhancement and the size of DG to be installed.

Recently, many optimization algorithms have been addressed in literature to deal with the problem of locations and sizing of DG in distribution systems. The application of the tabu search for the optimal sizing of small isolated hybrid power systems has been illustrated in Ref. [12]. The application of GA and Simulated Annealing to the optimal allocation of DG in distribution network is discussed in Ref. [13]. The methodology in Ref. [14] aims to handle the problem using GA in order to minimize the electrical losses in primary distribution network and to guarantee acceptable reliability levels and voltage profile. A combined algorithm is suggested in Ref. [15] to evaluate the DG site and size in distribution network. The site of DG is searched by GA and its size is optimized by PSO. In Ref. [16], PSO is used to find the optimum location of DG units. PSO has been presented in Ref. [17] to determine the best locations for DG and capacitor in the distribution network with various economic factors, which results in maximizing profit. The problem of optimal planning of DG in distribution networks is treated in Ref. [18] via ant colony algorithm. A MINLP is suggested in Ref. [19] to solve this problem. Harmony search algorithm is introduced in Ref. [20] as the optimization technique to deal with this problem to minimize losses. ABC algorithm is employed in

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Nomenclature

P_k, Q_k	The total effective active and reactive power supplied behind the bus '*k*'
V_k	The magnitude of voltage at bus *k*
R_{ik}, X_{ik}	The resistance and reactance of transmission line between bus'*i*' and '*k*'
V_i	The magnitude of voltage at bus *i*
K_P	The cost per kW-Hours
n	The maximum number of ants
$r(t)$	A stochastic function
t	The step of random walk
M_{ant}	The matrix for saving the position of each ant
$ant_{i,j}$	The value of the j-th variable of i-th ant
d	The number of variables
M_{oa}	The matrix for saving the fitness of each ant
$M_{antlion}$	The matrix for saving the position of each ant lion
$antlion_{i,j}$	The value of the j-th variable of i-th ant lion
M_{oal}	The matrix for saving the fitness of each ant lion
A_i	The minimum of random walk of i-th variable
C_i^t	The minimum of i-th variable at t-th iteration
C^t	The minimum of all variables at t-th iteration
C_j^t	The minimum of all variables for i-th ant
D_i^t	The maximum of i-th variable at t-th iteration
D^t	The vector including the maximum of all variables at t-th iteration
D_j^t	The maximum of all variables for i-th ant
$Ant\ lion_j^t$	The position of the selected j-th ant lion at t-th iteration
I	This ratio equals to $10^{w}\frac{t}{T}$
T	The maximum number of iterations
w	To adjust the accuracy level of exploitation
r_a^t	The random walk around the ant lion selected by the roulette wheel at t-th iteration
r_e^t	The random walk around the elite at t-th iteration
Ant_i^t	The position of i-th ant at t-th iteration
P_{Loss}	The total power losses after compensation
F_t	The total objective function
f_1	The part of F_t that express the minimization of power losses
f_2	The part of F_t that express the enhancement of voltage profiles
f_3	The part of F_t that express the improvement of VSI
w_1, w_2, w_3	The weighting factors
P_{Swing}	The active power of swing bus
Q_{Swing}	The reactive power of swing bus
L	The number of transmission line in a distribution system
$Pd(q)$	The demand of active power at bus *q*
$Qd(q)$	The demand of reactive power at bus *q*
N	The number of total buses
$V_{\min}$	The minimum voltage at bus *i*
$V_{\max}$	The maximum voltage at bus *i*
P_{DG}	The installed active power of the DG
Q_{DG}	The installed reactive power of the DG
N_{DG}	The number of installed unit of the DG
$P_{DG}^{\min}, P_{DG}^{max}$	The minimum and maximum real outputs of the DG unit
$Q_{DG}^{\min}, Q_{DG}^{max}$	The minimum and maximum reactive outputs of the DG unit
S_{Li}	The actual complex power in line i
$S_{Li(rated)}$	The rated complex power in that line i

List of abbreviations

ALOA	Ant Lion Optimization Algorithm
DG	Distributed Generation
LSFs	Loss Sensitivity Factors
PV	Photovoltaic system
WT	Wind Turbine
GA	Genetic Algorithm
PSO	Particle Swarm Optimization
PGSA	Plant Growth Simulation Algorithm
DSA	Direct Search Algorithm
MTLBO	Modified Teaching Learning-Based Optimization
CSA	Cuckoo Search Algorithm
ABC	Artificial Bee Colony
MINLP	Mixed Integer Non Linear Programming
BSOA	Backtracking Search Optimization Algorithm
VSI	Voltage Stability Index
BB-BC	Big Bang–Big Crunch
SGA	Standard Genetic Algorithm
NR	Not Reported

Ref. [21] to determine the optimal DG-unit's size, power factor and location to minimize the total system real power loss. Differential evolution is employed in Ref. [22] to determine optimal DG capacity for minimum power losses, but economic aspects are not considered. Bacteria foraging is used in Ref. [23] for optimal planning of DG units in the distribution system. Imperialist competitive algorithm is used in Ref. [24] to minimize the power loss in the system. PGSA is employed in Ref. [25] to determine the sizing of the DG unit and loss sensitivity factor is used in selection of the optimal location of DG. Power system reconfiguration in a radial distribution network for reducing losses and improving voltage profile via PGSA with DG is introduced in Ref. [26]. Firefly algorithm is developed in Ref. [27] for determining the optimal location and capacity of DG. CSA is discussed in Ref. [28] to minimize losses. However, the previous algorithms may not guarantee finding the optimum locations of DG due to complexity of the problem.

A new optimization algorithm known as Ant Lion Optimization Algorithm (ALOA) has been presented by Mirjalili [29]. It is one of the most recently nature-inspired algorithms that emulate the hunting mechanism of ant lions in nature. It proves its superiority in many fields which are shown in Refs. [30–33]. ALOA optimizes DG in distribution system has not been considered yet. This encourages us to develop ALOA to deal with this problem. It is introduced to determine the optimal locations and sizing of DG in radial distribution systems. The results of ALOA are compared with various techniques to detect its superiority in solving the problem of optimal locations and sizing of DG and thus reducing the active power losses and mitigating the voltage profiles for various loading conditions. Also, the statistical assessment of the proposed algorithm is verified.

2. Loss Sensitivity Factors

LSFs are employed here to assign the candidate buses for DG installation [34]. The area of search is greatly reduced and consequently the time consumed in optimization process by using LSFs.

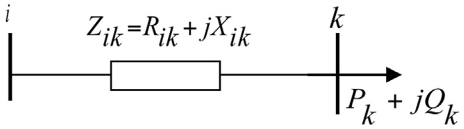

Fig. 1. Radial distribution system equivalent circuit.

For a transmission line '*l*' connected between '*i*' and '*k*' buses, as given in Fig. 1:

The active power loss in this line is specified by $I_l^2 R_{ik}$, which can be given by,

$$P_{ik-loss} = \frac{\left(P_k^2 + Q_k^2\right) R_{ik}}{(V_k)^2} \tag{1}$$

The LSFs can be computed from the following equation:

$$\frac{\partial P_{ik-loss}}{\partial Q_k} = \frac{2Q_k{*}R_{ik}}{(V_k)^2} \tag{2}$$

The normalized voltages are obtained by dividing the base case voltages by 0.95 [35]. If the values of these voltages are less than 1.01 they can be considered as candidate buses for installing DG. It is worth note that the LSFs decide the sequence in which buses are to be considered for installing DG.

3. Overview of Ant Lion Optimization Algorithm

Ant Lion Optimizer (ALO) is a novel nature-inspired algorithm presented by Mirjalili in 2015 [29]. The ALO mimics the hunting mechanism of ant lions in nature. An ant lion larva digs a cone-shaped pit in sand by moving along a circular path and throwing out sands with its massive jaw [36–38]. After digging the trap, the larva hides underneath the bottom of the cone and waits for insects to be trapped in the pit [39,40]. The edge of the cone is sharp enough for insects to fall to the bottom of the trap easily. Once the ant lion realizes that a prey is in the trap, it tries to catch it. Then, it is pulled under the soil and consumed. After consuming the prey, ant lions throw the leftovers outside the pit and prepare the pit for the next hunt [30]. The pseudo code of the ALO algorithm is shown in appendix A.

3.1. Operators of the ALO algorithm

The ALO algorithm mimics the interaction between ant lions and ants in the trap. To model such interactions, ants are required to move over the search space and ant lions are allowed to hunt them and become fitter using traps. Since ants move stochastically in nature when searching for food, a random walk is chosen for modeling ants' movement as follows:

$$\begin{aligned} X(t) = [0, cums(2r(t_1) - 1), cums(2r(t_2) - 1, ..\\ ...., cums(2r(t_n) - 1)] \end{aligned} \tag{3}$$

where *cums* calculates the cumulative sum and $r(t)$ is defined as follows:

$$r(t) = \left\{ \begin{array}{ll} 1 & if \;\; r\,and > 0.5 \\ 0 & if \;\; r\,and \le 0.5 \end{array} \right\} \tag{4}$$

The location of ants are stored and used during optimization process in the following matrix:

$$M_{ant} = \begin{bmatrix} ant_{1,1} & ant_{1,2} & ..... & ant_{1,d} \\ ant_{2,1} & ant_{2,2} & .... & ant_{2,d} \\ : & : & : & : \\ ant_{n,1} & ant_{n,2} & .... & ant_{n,d} \end{bmatrix} \tag{5}$$

The location of an ant refers the parameter for each solution. MatrixM_{ant} is considered to save the position of each ant. The objective function is employed during optimization and the following matrix saves the fitness value for each ant:

$$M_{oa} = \begin{bmatrix} F_t\left([ant_{1,1}, ant_{1,2}, ...ant_{1,d}]\right) \\ F_t\left([ant_{2,1}, ant_{2,2}, ...ant_{2,d}]\right) \\ : \\ F_t\left([ant_{n,1}, ant_{n,2}, ...ant_{n,d}]\right) \end{bmatrix} \tag{6}$$

Also, the ant lions are hiding in the search space. The followings matrices are used to save their locations.

$$M_{antlion} = \begin{bmatrix} antlion_{1,1} & antlion_{1,2} & ..... & antlion_{1,d} \\ antlion_{2,1} & antlion_{2,2} & .... & antlion_{2,d} \\ : & : & : & : \\ antlion_{n,1} & antlion_{n,2} & .... & antlion_{n,d} \end{bmatrix} \tag{7}$$

$$M_{oal} = \begin{bmatrix} F_t\left([antlion_{1,1}, antlion_{1,2}, ...antlion_{1,d}]\right) \\ F_t\left([antlion_{2,1}, antlion_{2,2}, ...antlion_{2,d}]\right) \\ : \\ F_t\left([antlion_{n,1}, antlion_{n,2}, ...antlion_{n,d}]\right) \end{bmatrix} \tag{8}$$

3.1.1. Random walks of ants

Ants change their positions randomly based on the equation (3). To keep the random walks inside the search space, they are normalized using the following equation:

$$X_i^t = \frac{(X_i^t - A_i) \times \left(D_i - C_i^t\right)}{(D_i^t - A_i)} + C_i \tag{9}$$

3.1.2. Trapping in ant lion's pits

Random walks of ants are affected by ant lions' traps. To model this supposition, the following equations are introduced:

$$C_i^t = Ant\ lion_j^t + C^t \tag{10}$$

$$D_i^t = Ant\ lion_j^t + D^t \tag{11}$$

Equation (10 -11) give that ants walk randomly in a hyper-sphere defined by the vectors *C* and *D* around a selected ant lion.

3.1.3. Building trap

A roulette wheel is used to model the ant lion's hunting ability. The ALO algorithm is required to employ a roulette wheel operator for selecting ant lions based of their fitness during iterations. This mechanism shows high chances to the best ant lions for catching ants.

3.1.4. Sliding ants towards ant lion

With the previous mechanisms, ant lions can build traps relative to their fitness and ants are required to move randomly. However, ant lions shoot sands outwards the center of the pit once they sense that an ant is in the trap. This behavior slides down the trapped ant that is trying to escape. To model this behavior, the radius of ant's random walk hyper-sphere is decreased adaptively. The following equations are presented in this regard:

$$c^t = \frac{c^t}{I} \tag{12}$$

$$d^t = \frac{d^t}{I} \tag{13}$$

3.1.5. Catching prey and re-building the pit

In this step, the objective function is calculated. If the ant has a better objective function than the selected ant-lion then it changes its position to the latest position of the hunted ant to improve its chance of catching new one. The following equation is illustrated in this regard:

$$Ant\ lion_j^t = Ant\ lion_i^t \quad if\ f\left(Ant_i^t\right) > f\left(Ant\ lion_j^t\right) \tag{14}$$

3.1.6. Elitism

It is important to maintain the best solution acquired at each step of optimization task. The best ant lion achieved so far in each iteration is saved as the elite. Since the elite is the best ant lion, it should be capable to affect the motions of all ants during iterations. Thus, it is assumed that every ant randomly walks around a selected ant lion by the roulette wheel and the elite simultaneously as follows:

$$Ant_i^t = \frac{r_a^t + r_e^t}{2} \tag{15}$$

4. Objective function

The proposed objective function is used to reduce the power losses and to improve the voltage profiles and VSI. The DG locations and their sizing can be obtained optimally by solving the following objective function [15,41]:

$$F_t = w_1 f_1 + w_2 f_2 + w_3 f_3 \tag{16}$$

where f_1 presents the reduction in active losses and it can be expressed as shown in the following equation:

$$f_1 = \frac{\sum_{i=1}^{L}\left(P_{Lineloss}(i)\right)_{after\ DG}}{\sum_{i=1}^{L}\left(P_{Lineloss}(i)\right)_{before\ DG}} \tag{17}$$

f_2 displays the improvement of voltage profiles and it can be defined as the following equation:

$$f_2 = \frac{\sum_{i=1}^{N}\left|V_i - V_{i,ref}\right|_{after\ DG}}{\sum_{i=1}^{N}\left|V_i - V_{i,ref}\right|_{before\ DG}} \tag{18}$$

f_3 offers the enhancement of VSI. Then f_3 can be defined as:

$$f_3 = \frac{1}{VSI(k)_{after\ DG}} \tag{19}$$

where VSI is formulated as the following equation [15,42]:

$$\begin{aligned} VSI(k) = {} & |V_i|^4 - 4(P_k \,.\, X_{ik} - Q_k \,.\, R_{ik})^2 \\ & - 4(P_k \,.\, R_{ik} + Q_k \,.\, X_{ik}) \cdot |V_i|^2 \end{aligned} \tag{20}$$

w_1, w_2 *and* w_3 are weighting factors. The sum of the absolute values of the weights assigned to all impacts should add up to one as shown in the following equation:

$$|w_1| + |w_2| + |w_3| = 1 \tag{21}$$

In this paper, w_1 is taken as 0.5 while w_2 *and* w_3 are taken as 0.25.

4.1. Equality and inequality constraints

Equation (16) is minimized whilst satisfying the following constraints.

4.1.1. Equality constraint

- **Power conservation constraint**

The algebraic sum of all incoming and outgoing power flow over the distribution system should be equal [43,44]; thus,

$$P_{Swing} + \sum_{i=1}^{N_{DG}} P_{DG}(i) = \sum_{i=1}^{L} P_{Lineloss}(i) + \sum_{q=1}^{N} Pd(q) \tag{22}$$

$$Q_{Swing} + \sum_{i=1}^{N_{DG}} Q_{DG}(i) = \sum_{i=1}^{L} Q_{Lineloss}(i) + \sum_{q=1}^{N} Qd(q) \tag{23}$$

4.1.2. Inequality constraints

- **Voltage constraint**

The magnitude of voltage at each bus must be limited by the following equation:

$$V_{\min} \le |V_i| \le V_{\max} \tag{24}$$

where $V_{\min}, V_{\max}$ are taken as 0.95 and 1.05 p.u respectively as given in Refs. [43,44].

- **DG limits constraint**

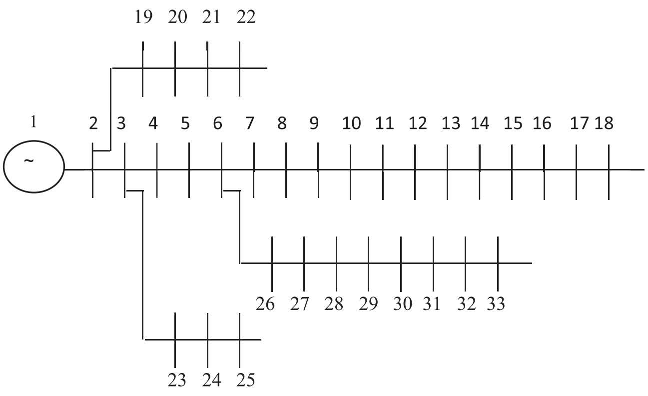

Fig. 2. The line diagram of the 33 bus system.

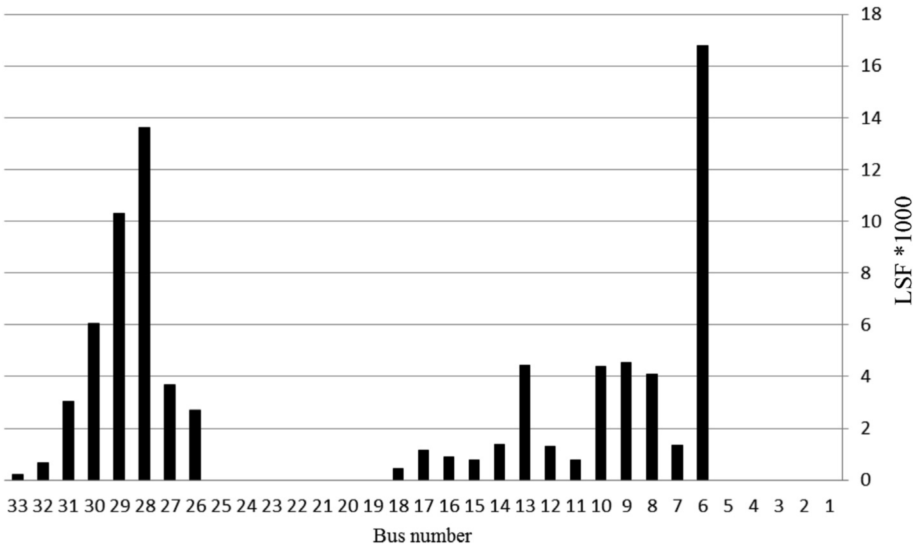

Fig. 3. The values of LSFs for 33 bus system.

Table 1
Results for 33 bus system.

Items	Without -DG	With DG (kVA/P.F)			
		One DG		Two DG	
		PV	WT	PV	WT
Total losses (kW)	210.98	103.053	71.75	82.6	30.9251
Loss reduction (%)	–	51.15	65.99	60.85	85.34
Minimum voltage	0.9040	0.9503 @bus 18	0.9528 @bus 18	0.9732 @bus 33	0.9806 @bus 25
Maximum voltage	0.9970	0.9986 @bus 2	0.9986 @bus 2	0.9986 @bus 2	1.0061 @bus 13
Total DG	–	2450/1 @bus 6	2238.8/0.87@bus 6	850/1 @bus 13 1191.1/1 @bus 30	1039.5/0.862@bus 13 1463/0.837 @bus 30
VSI	25.8867	28.6881	28.8427	29.4794	31.0190
Cost of losses ($)	110891.1	54164.65	37711.8	43414.56	16254.23
Saving ($/year)	–	56726.45	73179.3	67476.54	94636.86

Table 2
Results for installing one DG in 33 bus system.

DG type	Technique	DG installation		Power loss		Bus voltage	
		Size (kVA/P.F)	Bus	Value (kW)	Percentage	Minimum	Maximum
_	Without	–	–	210.98	–	0.9038	0.9453
PV	GA [43]	2580/1	6	105.481	48.21	NR	NR
	EVPSO [44]	763/1	11	140.19	33.55	0.9284	0.9604
	PSOPC [44]	1000/1	15	136.75	35.18	0.9318	0.9679
	AEPSO [44]	1200/1	14	131.43	37.7	0.9347	0.9715
	ADPSO [44]	1210/1	13	129.53	38.60	0.9348	0.9712
	DAPSO [44]	1212/1	8	127.17	39.7	0.9349	0.9635
	Analytical [45]	2490/1	6	111.24	47.27	NR	NR
	GA [46]	2380/1	6	132.64	37.13	NR	NR
	[47]	1000/1	18	142.34	33.29	0.9311	NR
	BSOA [48]	1857.5/1	8	118.12	44.01	0.9441	0.9982
	Proposed	**2450/1**	**6**	**103.053**	**51.15**	**0.9503**	**0.9986**
WT	GA [43]	2980/0.95	6	72.68	64.32	NR	NR
	BSOA [48]	2265.24/0.82	8	82.78	60.76	0.9549	1.006
	Proposed	**2238.8/0.87**	**6**	**71.75**	**65.99**	**0.9528**	**0.9986**

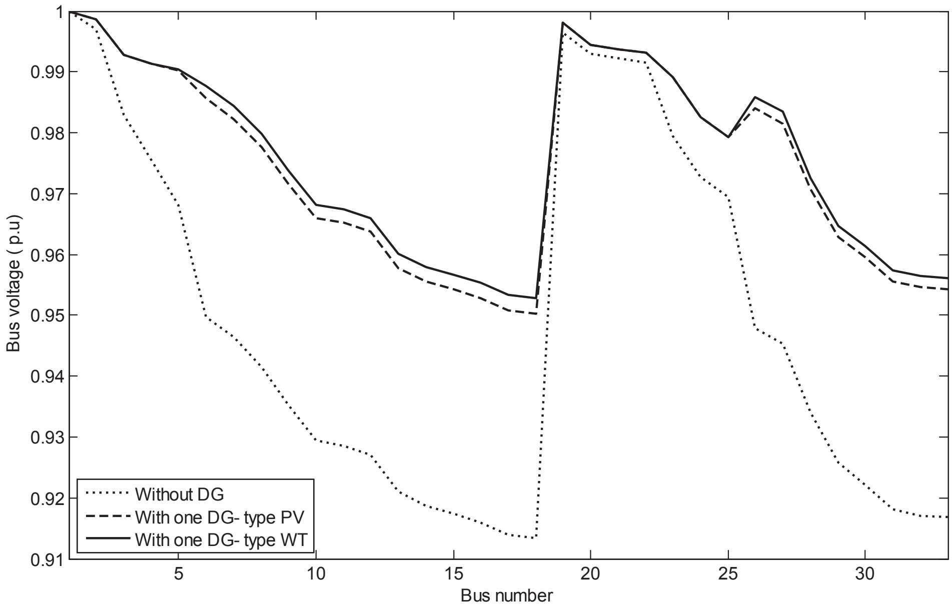

Fig. 4. The effect of installing one DG on voltages of 33 bus system.

To prevent reverse power flow, the installed capacity of DG in the network has been limited so as not to exceed the power supplied by the substation [43].

$$\sum_{i=1}^{N_{DG}} P_{DG}(i) \le \frac{3}{4} \times \left[\sum_{i=1}^{L} P_{Lineloss}(i) + \sum_{q=1}^{N} Pd(q) \right] \tag{25}$$

$$\sum_{i=1}^{N_{DG}} Q_{DG}(i) \le \frac{3}{4} \times \left[\sum_{i=1}^{L} Q_{Lineloss}(i) + \sum_{q=1}^{N} Qd(q) \right] \tag{26}$$

$$P_{DG}^{\min} \le P_{DG}(i) \le P_{DG}^{\max} \tag{27}$$

$$Q_{DG}^{\min} \le Q_{DG}(i) \le Q_{DG}^{\max} \tag{28}$$

The DG models are mentioned in appendix B.

- **Line Capacity Constraint**

The complex power through any line must be less than its rating value as given by the following equation.

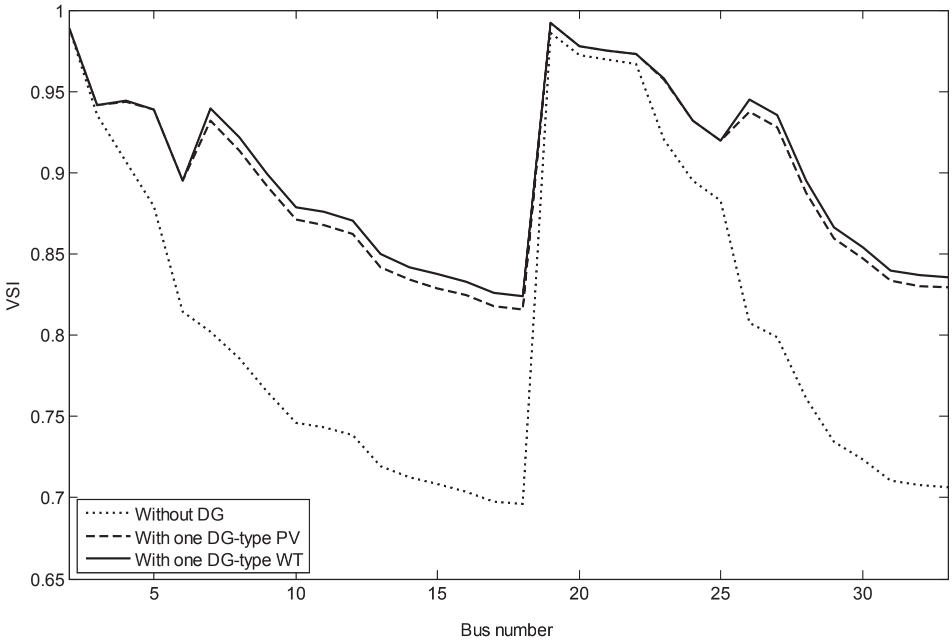

Fig. 5. The effect of installing one DG on VSI of 33 bus system.

Table 3
Results for installing two DG in 33 bus system.

DG type	Technique	DG installation		Power loss		Bus voltage	
		Size (kVA/P.F)	Bus	Value (kW)	Percentage	Minimum	Maximum
–	Without	–	–	210.98	–	0.9038	0.9453
PV	GA [43]	837.5/1	13	82.7	60.8	0.96846	NR
		1212.2/1	29				
	PSOPC [44]	916/1	8	111.45	47.17	0.9418	0.9738
		767/1	12				
	EVPSO [44]	540/1	14	108.05	48.78	0.9457	0.9661
		569/1	31				
	AEPSO [44]	600/1	14	106.38	49.57	0.9447	0.9671
		600/1	29				
	ADPSO [44]	550/1	15	106.24	49.64	0.9467	0.9667
		621/1	30				
	DAPSO [44]	1227/1	13	95.93	54.53	0.9651	0.9819
		738/1	32				
	GA [46]	1718/1	6	96.580	54.22	NR	NR
		840/1	8				
	BSOA [48]	880/1	13	89.34	57.65	0.9665	0.9981
		924/1	31				
	Proposed	**850/1**	**13**	**82.6**	**60.85**	**0.9732**	**0.9984**
		1191.1/1	**30**				
WT	BSOA [48]	777/0.89	13	31.98	84.84	0.9796	0.9986
		1032/0.7	29				
	Proposed	**1039.5/0.862**	**13**	**30.9251**	**85.34**	**0.9806**	**1.0061**
		1463/0.837	**30**				

$$S_{Li} \le S_{Li(rated)} \tag{29}$$

5. Results and discussion

The superiority of the proposed ALOA with LSFs is examined for various distribution systems. The results of 33 and 69 bus radial distribution systems are given below in details. The proposed algorithm has been performed via Matlab.

5.1. 33 bus test system

The first tested case via the suggested LSFs and ALOA is the 33 bus system. Fig. 2 shows the system diagram which consists of main feeders and three laterals. This system has a total load of 3720 kW and 2300 kVAr at a voltage level of 12.66 kV. The system data are

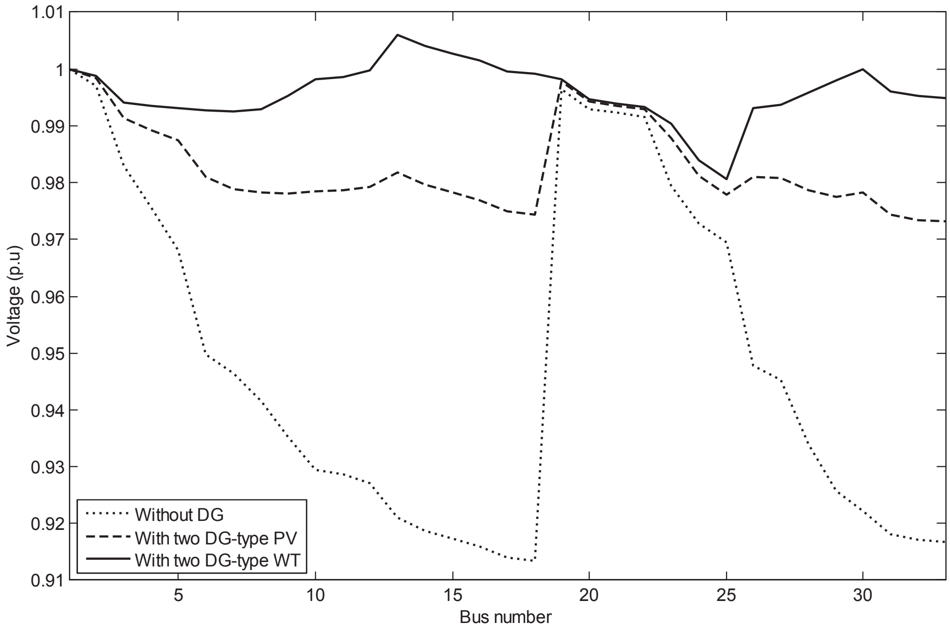

Fig. 6. The effect of installing two DG on voltages of 33 bus system.

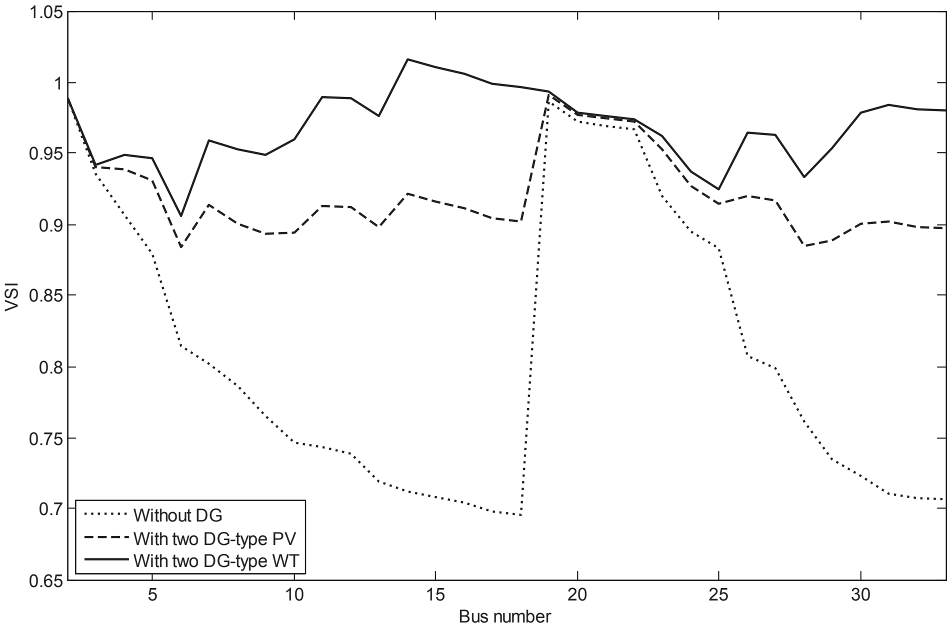

Fig. 7. The effect of installing two DG on VSI of 33 bus system.

presented in Ref. [42]. The values of LSFs for all buses are given in Fig. 3. The notability of the proposed ALOA to select the optimal locations and sizing of DG is verified compared with those obtained in Refs. [43,44,45,46,47 and 48]. Table 1 demonstrates the effects of installing different types and numbers of DG on system performances.

5.1.1. *Single DG location*

For single DG installation, the optimal location and size are found using ALOA as given in Table 1. Bus number 6 is the best location for DG installation with a size of 2450 kW for PV type. The power losses are decreased to 103.053 kW with percentage reduction of 51.15. If the energy loss cost of 0.06$ has been taken in consideration. The annual energy saving is 56726.45$ via the proposed ALOA. The minimum voltage is increased from 0.9040 p.u to 0.9503 p.u. Also, compared with [43,44,45,46,47 and 48] the proposed algorithm shows better results in terms of power loss, percentage reduction of power and minimum voltage as introduced in Table 2. Moreover, the effects of DG installation on voltage profiles and VSI are presented in Figs. 4 and 5 respectively. With WT type, the power losses are reduced to 71.75 kW which is the lowest one compared with GA and BSOA. Also, the percentage reduction of losses is 65.99 which is the highest one. The annual energy saving is 73179.3$ via the proposed ALOA. The minimum voltage is enhanced to 0.9528p.u which is in the specified limits. In addition, the designed WT type gives better results than PV type in terms of voltage profiles and VSI as displayed in Figs. 4 and 5. Moreover, the total power loss is mostly

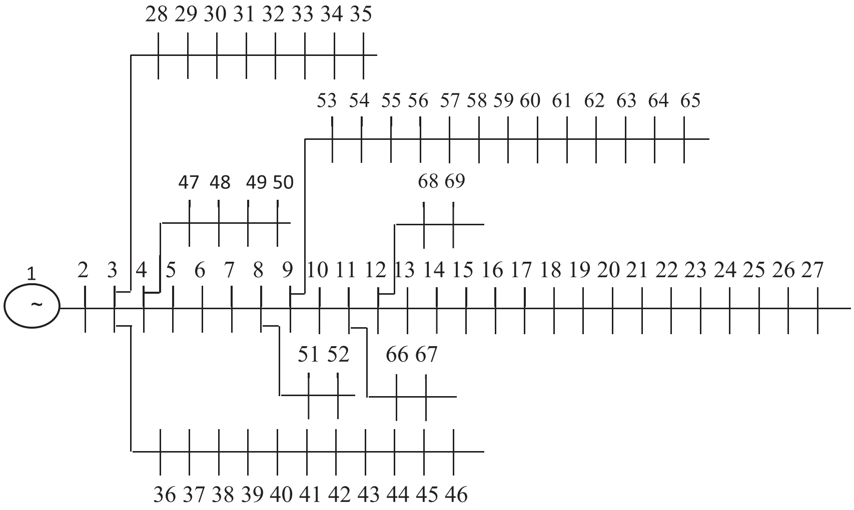

Fig. 8. The line diagram of the 69 bus system.

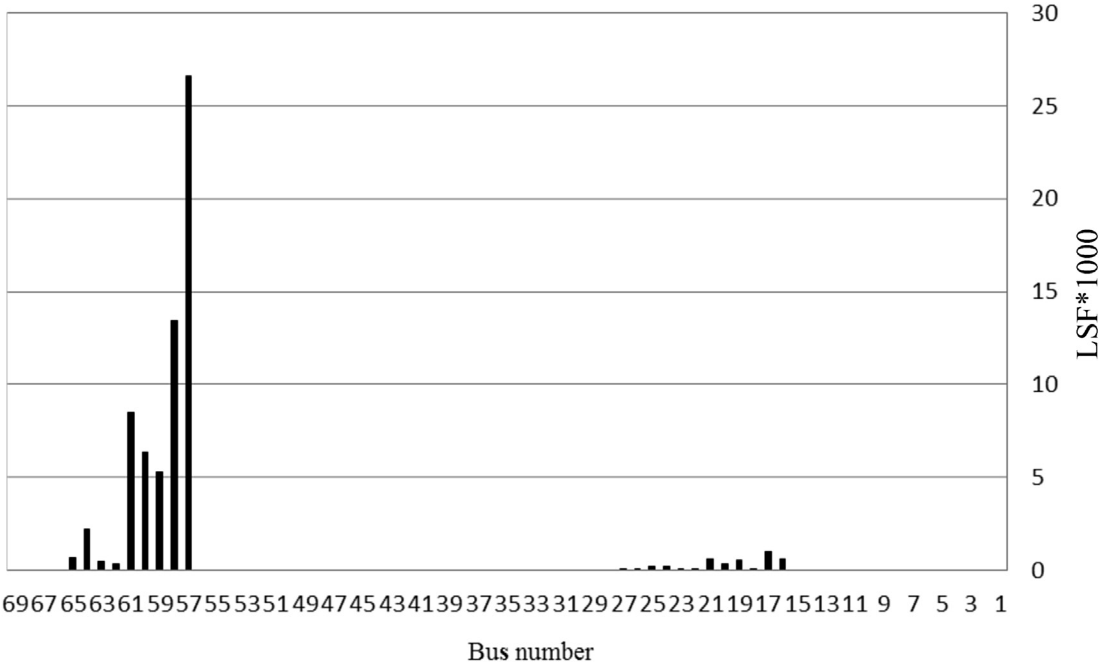

Fig. 9. The values of LSFs for 69 bus system.

reduced in the case of WT due to the availability of reactive power generation.

5.1.2. Two DG locations

To validate the effectiveness of the proposed ALOA for finding the optimal location and size of DG, it is applied for two DG locations. For PV type, bus number 13 and 30 are the best locations for DG installation with size of 850 kW and 1191.1 kW respectively. The power losses are minified to 82.6 kW with percentage reduction of 60.85. The annual energy saving is 67476.54$ via the proposed ALOA. The minimum voltage is enlarged from 0.9040 p.u to 0.9732 p.u as reported in Table 1. Also compared with [43,44,46,48], the proposed algorithm shows supreme results in terms of power loss, percentage reduction of power and minimum voltage as shown in Table 3. Moreover, the effects of DG installation on voltage profiles and VSI are seen in Figs. 6 and 7 respectively. With WT type, the power losses are minimized to 30.9251 kW with percentage reduction of 85.34. The annual energy saving is 94636.86$ via the proposed ALOA. The minimum voltage is improved to 0.9806 p.u. Thus, the proposed algorithm outperforms BSOA in minimizing losses and enhancing voltage profiles. In addition, the designed WT type gives better results than PV type in terms of voltage profiles and VSI as visualized in Figs. 6 and 7. Moreover, the reduction in total power losses in WT type is greater than PV type due to the injected reactive power generation.

5.2. 69 bus test system

The second tested case via the suggested algorithm is the 69 bus system. Fig. 8 shows the system diagram which consists of main feeders and seven branches. This system has a total load of 3800 kW and 2690 kVAr at 12.6 kV. The system data are given in Ref. [49]. The order of candidate buses for this system according to their LSF values is 57, 58, 61, 60, 59, 64, 17, 65, 16, 21, 19, 63, 20, 62,

Table 4
Results for 69 bus system.

Items	Without -DG	With DG (kVA/P.F)			
		One DG		Two DG	
		PV	WT	PV	WT
Total losses (kW)	224.94	81.776	23.1622	70.750	20.9342
Loss reduction (%)	–	63.645	89.703	68.547	90.69
Minimum voltage	0.9102	0.9679 @bus 27	0.9716 @bus 27	0.9801 @bus 65	0.9742 @bus 65
Maximum voltage	1.00	1.0 @bus 2	1.0 @bus 2	1.0000 @ bus 2	1.0001 @bus 17
Total DG	–	1800/1 @bus 61	2227.9/0.82 @bus 61	538.777/1 @bus 17 1700/1 @bus 61	726.627/0.83 @bus 17 1500/0.8 @bus 61
VSI	61.2379	64.4323	65.3523	65.8042	66.2031
Cost of losses ($)	118228.46	42981.46	12174.05	37186.2	11003.02
Saving ($/year)	–	75247	106054.41	81042.26	107225.44

Table 5
Results for installing one DG in 69 bus system.

DG type	Technique	DG installation		Power loss	
		Size (kVA/P.F)	Bus	Value (kW)	Percentage
–	Without	–	–	224.94	–
PV	ABC [21]	1900/1	61	83.31	62.96
	GA [43]	1872/1	61	83.18	63.02
	Analytical [45]	1810/1	61	81.44	63.79
	Analytical [50]	1807.8/1	61	92	59.1
	Grid Search [50]	1876.1/1	61	83	63.1
	GA [51]	1794/1	61	83.4252	62.91
	PSO [52]	1337.8/1	61	83.206	63.01
	CSA [53]	2000/1	61	83.8	62.74
	SGA [53]	2300/1	61	89.4	60.3
	PSO [53]	2000/1	61	83.8	62.75
	MTLBO [54]	1819.691/1	61	83.323	62.95
	BB-BC [55]	1872.5	61	83.2246	63
	Proposed	**1800/1**	**61**	**81.776**	**63.645**
WT	GA [43]	2155.6/NR	61	38.458	82.9
	CSA [53]	2300/NR	61	52.6	76.6
	SGA [53]	2600/NR	61	64.4	71.37
	PSO [53]	2300/NR	61	52.6	76.6
	BB-BC [55]	2223/0.81	61	23.1737	89.697
	Proposed	**2227.9/0.82**	**61**	**23.1622**	**89.703**

25, 24, 23, 26, 27, 18 and 22 as appeared in Fig. 9. The superiority of the proposed technique to solve the problem of optimal location and sizing of DG compared with those obtained in Refs. [21,43,45,46,50,51,52,53,54 and 55] is confirmed.

5.2.1. *Single DG location*

For single DG installation, the optimal location and size are obtained via ALOA. Table 4 summarizes the developed results for installing single and two DGs. Bus number 61 is the best location for DG installation with a size of 1800 kW for PV type. A reduction in the total active power losses to 81.776 kW is resulted which illustrates a 63.645% reduction. The annual energy saving is 75247$ via the proposed ALOA. The minimum voltage is grown from 0.9102 p.u to 0.9679 p.u. Also, compared with [21,43,45,50,51,52,53,54 and 55] the proposed algorithm introduces better results in terms of power losses and percentage reduction of power as displayed in Table 5. Moreover, the effects of DG installation on voltage profiles and VSI are given in Figs. 10 and 11 respectively. With WT type, the power losses are constringed to 23.1622 kW with percentage reduction of 89.703. The annual energy saving is 106054.41$ via the proposed ALOA. The minimum voltage is increased to 0.9716 p.u. Thus, the proposed algorithm outlasts GA, CSA, SGA, PSO and BB-BC in minimizing losses and consequently improving saving. In addition, the designed WT type shows better results than PV type in terms of voltage profiles and VSI as clarified in Figs 10 and 11.

5.2.2. *Two DG locations*

For two DG installation, the optimal location and size are gained using ALOA as given in Table 4. For PV type, bus numbers 17 and 61 are the best locations for DG installation with size of 538.777 kW and 1700 kW respectively. The power losses are decreased to 70.75 kW with percentage reduction of 68.547. The annual energy saving is 81042.26$ via the proposed algorithm. The minimum voltage is modified from 0.9102 p.u to 0.9801 p.u. Also, compared with [46,51,53 and 54] the proposed algorithm gives better results in terms of power losses and percentage reduction of power as reported in Table 6. Moreover, the effects of DG installation on voltage profiles and VSI are displayed in Figs. 12 and 13 respectively. With WT type, the power losses are lowered to 20.9342 kW providing a 90.69% reduction in total power losses. The annual energy saving is 107225.44$ via the proposed ALOA. Thus, the proposed algorithm outperforms CSA, SGA and PSO in diminishing losses and enhancing saving. The minimum voltage is grown to 0.9742 p.u. In addition, the designed WT type gives superior results than PV type in terms of voltage profiles and VSI as mentioned in Figures 12 and 13. Also, the reactive power capability of WT has a considerable effect on reducing power losses and improving voltage profiles.

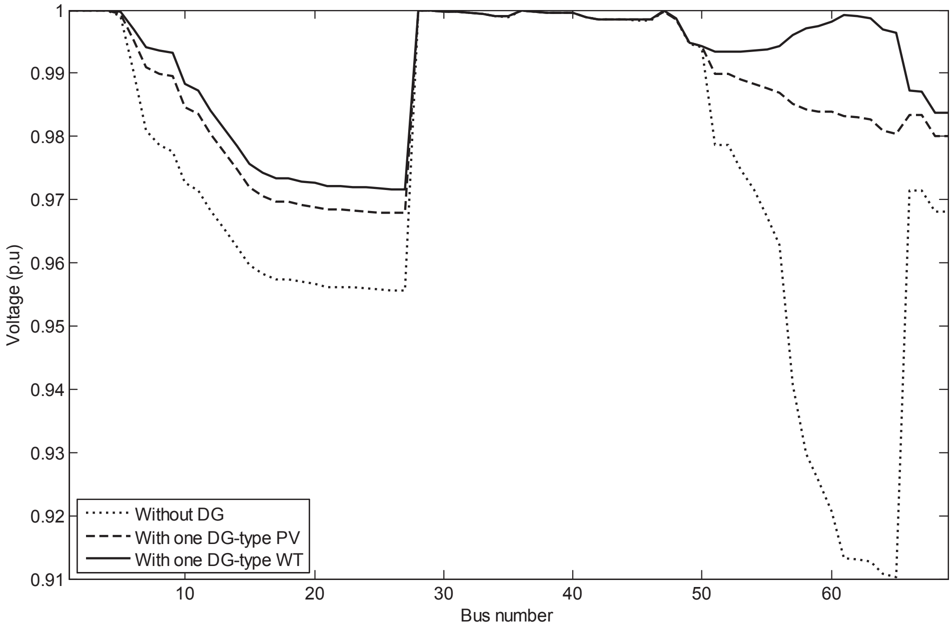

Fig. 10. The effect of installing one DG on voltages of 69 bus system.

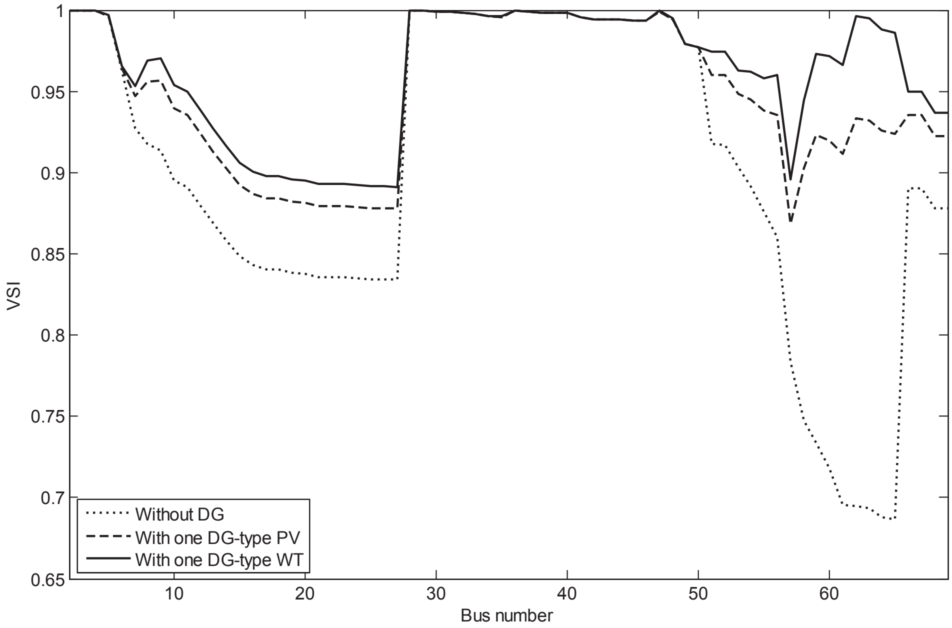

Fig. 11. The effect of installing one DG on VSI of 69 bus system.

5.3. *Effect of variable load*

A constant load over the year is a hypothetical case as the load profile has the impact of seasonal and time variations. In order to mimic this effect, the load of the entire year has been considered as combination of three load levels of different durations as given in Table 7. ALOA finds the optimal sizes of DG for different load levels. The values of losses, installed DG and minimum and maximum voltage profiles are displayed for 33 and 69 bus systems in Tables 8 and 9 with variable loads. It can be seen that, the losses are reduced at different loads as the number of locations is grown. Moreover, the voltages are within the specific borders. This is achieved for both systems.

Table 6
Results for installing two DG in 69 bus system.

DG type	Technique	DG installation		Power loss	
		Size (kVA/P.F)	Bus	Value (kW)	Percentage
-	Without	–	–	224.94	–
PV	GA [46]	1777/1 555/1	61 11	71.7912	68.08
	GA [51]	6/1 1794/1	1 62	84.233	62.55
	CSA [53]	600/1 2100/1	22 61	76.4	66
	SGA [53]	1000/1 2400/1	17 61	82.9	63.1
	PSO [53]	700/1 2100/1	14 62	78.8	64.97
	MTLBO [54]	519.705/1 1732.004/1	17 61	71.776	68.09
	Proposed	**538.777/1** **1700/1**	**17** **61**	**70.750**	**68.547**
WT	CSA [53]	800/NR 2000/NR	18 61	39.9	82.26
	SGA [53]	600/NR 2300/NR	18 62	44	80.4
	PSO [53]	900/NR 1900/NR	18 62	42.4	81.15
	Proposed	**726.627/0.83** **1500/0.8**	**17** **61**	**20.9342**	**90.69**

5.4. *Wilcoxon test*

The Wilcoxon signed rank sum test is a non-parametric statistical hypothesis test [56]. It is used to test the null hypothesis that two samples come from the same population against an alternative hypothesis, especially that a particular population tends to have larger values than the other [57].

Let the null hypothesis: $H_0 : \mu_o = \mu_a$

Let the alternative hypothesis: $H_1 : \mu_o \neq \mu_a$

Where

$\mu_o$is the mean value of bus voltages for the original system before installing DG,

$\mu_a$is the mean value of bus voltages after installing DG due to ALOA and it is repeated for other algorithms,

The significance level $\alpha = 0.05$ is established.

Table 10 shows the probability (p) of the statistical Wilcoxon rank sum test for the 33 bus system with one installed DG type PV. This gives a p-value = 4.5229e-4, which is less than 0.05, so the null hypothesis is rejected. This is strong evidence that the voltages of the system after installing DG using ALOA are improved compared with the original system. Moreover, the probability of ALOA is the smallest one compared with other algorithms. Consequently, it has the greatest change than others even with different parameters.

6. Conclusions

In this paper, ALOA has been successfully implemented with LSFs for optimal location and sizing of DG based renewable sources in various distribution systems. The designed problem has been formulated as an optimization task with computing power losses, voltage profiles and VSI. The effectiveness of the suggested approach is clarified by using different test systems. The results have been compared with those obtained using other algorithms. It is obvious from the comparison that the proposed approach provides a notable performance in terms of power

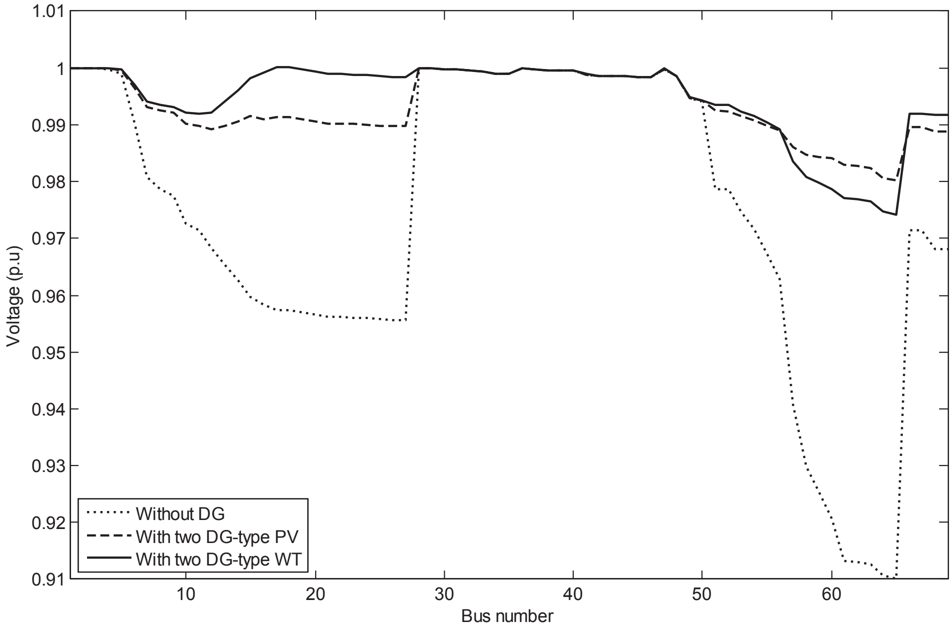

Fig. 12. The effect of installing two DG on voltages of 69 bus system.

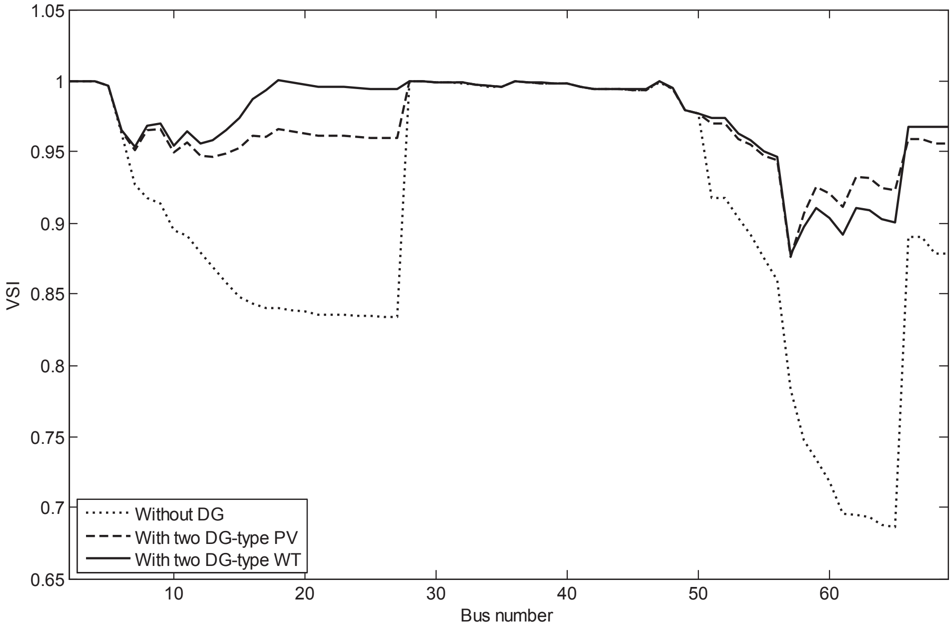

Fig. 13. The effect of installing two DG on VSI of 69 bus system.

Table 7
Duration of different load levels.

Load levels	L_1	L_2 (Base case)	L_3
Level	0.625	1.0	1.25
Duration time (hours)	1000	6760	1000

losses and saving. Moreover, the proposed ALOA is robust and it can be applied for variable loads demand. Also, the superiority of the proposed ALOA is confirmed via statistical Wilcoxon test. Applications of the proposed algorithm to large scale distribution power systems and unbalanced one are the future scope of this work.

Table 8
Optimal located PV units at different loadings for 33 bus system.

No of PV units	Load levels	Size of DG (Kw) at bus			Losses (kW)	Minimum voltage	Maximum voltage
		6	13	30			
One	L_1	1600	–	–	43.8253	0.9641	0.9988
	L_2	2450	–	–	103.053	0.9503	0.9986
	L_3	3160.8305	–	–	169.2436	0.9505	0.9987
Two	L_1	–	600	900	34.7122	0.9737	0.9988
	L_2	–	850	1191.1	82.6	0.9732	0.9986
	L_3	–	855.3	1209.4	130.2715	0.9681	0.9980

Table 9
Optimal located PV units at different loadings for 69 bus system.

No of PV units	Load levels	Size of DG (Kw) at bus		Losses (kW)	Minimum voltage	Maximum voltage
		61	17			
One	L_1	1600	–	32.47	0.9792	1.0
	L_2	1800	–	81.776	0.9679	1.0
	L_3	2129.5835	–	130.6164	0.9624	1.0
Two	L_1	1500	500	28.3599	0.9823	1.0
	L_2	1700	538.777	70.75	0.9801	1.0
	L_3	1935.5929	654.5052	112.549	0.9878	1.0

Table 10
The Wilcoxon test probability for various algorithms.

Algorithm	ALOA	BSOA [48]	[47]	EVPSO [44]	PSOPC [44]	ADPSO [44]	DAPSO [44]	ALOA other parameters
p	4.5229e-4	0.0035	0.0036	0.0248	0.005	0.0015	0.0154	4.5229e-4

Appendix A

The pseudo code of the ALO algorithm is defined as follows:

```
Step 1 Initialize the first population of ants, ant lions randomly,
       LSFs and DG. Run load flow and calculate the fitness of ants
       and ant lions.
Step 2 Find the best ant lions and assume it as the elite.
Step 3 For each ant, select an ant lion using Roulette wheel
       3.1 Create a random walk and normalize it to keep it inside
           the search space,
       3.2 Update the position of ant,
       3.3 Update the values of c and d,

   End for

Step 4 Run load flow and calculate the fitness of all ants,
Step 5 Replace an ant lion with its corresponding ant if it becomes
       fitter,
Step 6 Update elite if an ant lion becomes fitter than the elite,
Step 7 Repeat from step 3 until a stopping criteria is satisfied.
```

ALOA parameters: Number of ant lions = 30, maximum number of iterations = 500.

Appendix B

The model of PV and WT are described below:

i) PV model

The output power of PV system is subject to the temperature and the solar radiation of the location under consideration. The relationship between PV output power and radiation can be established as:

$$P_{PV} = \left\{ \begin{array}{ll} P_{PVr} \times \left(\dfrac{W}{W_r} \right), & 0 \le W \le W_r \\ P_{PVr}, & W_r \le W \end{array} \right\}$$

Where W and W_r are the solar radiation (W/m^2) for the selected location and the rated radiation at the earth's surface $(1000W/m^2)$ respectively. P_{PVr} is the rated PV output power at solar radiation of $(1000W/m^2)$ and temperature of 25° C.

ii) WT model

The relationship between the output power of a WT and wind speed can be formulated as:

$$P_W = \left\{ \begin{array}{ll} 0, & 0 \le V \le V_{ci}, \quad or \quad V \ge V_{co} \\ P_{Wr} \times \left(\dfrac{V - V_{ci}}{V_r - V_{ci}} \right), & V_{ci} \le V \le V_r \\ P_{Wr}, & V_r \le V \le V_{co} \end{array} \right\}$$

whereP_{Wr} is the rated wind output power at the rated speed. V, V_r,V_{ci} and V_{co} are the wind speed at the selected location, the rated wind speed, the cut in speed and the cut out speed respectively.

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