

Voltage Profile improvement by optimal DG allocation using atom search optimisation in radial and mesh distribution system

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Abstract

Recent years have seen a considerable increase in the generation of power using renewable energy sources. This paper deals with the allocation of distributed generations (DG) in radial as well as mesh distribution network (RDSm&MDSm, respectively). The allocation of DG is been done through a meta-heuristic technique known as Atom Search Optimisation. In the paper, the power loss is reduced, along with simultaneous improvement of voltage profile of the system. The proposed algorithm has been tested on IEEE 33 & 69 radial and weakly meshed system with 5 tie lines is considered for power loss minimisation using single and multiple DGs. Two power factors are considered for the simulation 0.8 lag and 0.9 pf lag. The simulation results are carried out in MATLAB.

Keywords: Distributed Generation, Distribution System, Atom Search Optimization (ASO), Meta-Heuristic, Loss Minimization, Weakly Meshed Network.

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1. Introduction

The power flow in a distribution system (DSm) is unidirectional flow with a radial structure of the system. It is evident from the pace of increase in population, there is continuous escalation in power demand, and so due to this, power system is subjected to many problem mainly, in the distribution component. Nearly 70% losses, of transmission and distribution (t&d), occur at the distribution level and about 30% at the transmission level(Prasad et al., 2019b) . This motivates researches to do analysis mainly in the distribution component of the power system. With opening of decentralized production of energy generation the scope of on-site generations is increasing to deal with loss problems on distribution side (Ang et al., 2018a). The addition of decentralized technologies is known as Distributed Generation (DG) which can generate on-site power and hence manage the load demand (El-Saadany et al., 2007). However, DGs are defined in various ways like, as defined in (Murthy & Kumar, 2013) and according to

IEEE it is defined as ‘utilities that generate electricity and are smaller than central station, designed in such way to be connected at any purpose directly within the system’.

In DGs feeders are not needed, because it is near to the consumer end and renewable sources can be used for generation, so that carbon emission can also reduce. In DS_m, placement of DG must be optimized to enhance reliability, power quality, voltage profile and to reduce power loss and if not optimally allocated then it may distort the voltage profile and as a result may increase the system power losses. DG can be classified as renewable or non-renewable energy sources. By using renewable DG, greenhouse gases emission can also control, so it will help to protect the environment. DG can be grid-connected or islanded mode. In grid-connected DG, distribution generation is connected to grid, if grid required power, it supplies to the grid. In Island mode, DG works as an individual unit with no relation with grid.

Owing to several advantages, the main challenge that DGs faces is its optimal sizing and optimal location. If the DGs are not appropriately allocated then, it would lead to an increase in active power loss in DS_m instead of reducing the same (Balu & Mukherjee, 2021). Hence it becomes an important aspect of allocation of DG/s in DS_m. With the advent of technology since 1970s, many optimization techniques and algorithms have been developed, mainly inspired from the nature, and put into use in the real world problems (Mithulanathan et al., 2004). Some of the techniques includes Genetic Algorithm (GA) (Mithulanathan et al., 2004), Analytical Method (Acharya et al., 2006), Elephant Herding Algorithm (Prasad et al., 2019a), Particle Swarm Optimization (PSO) (Prakash, 2021), Sine-Cosine Algorithm (Ang et al., 2018b; Karimulla & Ravi, 2021).

In (Acharya et al., 2006) the author has proposed analytical method for allocation and sizing though being fast but linear system has been assumed. In (Mithulanathan et al., 2004) the author has used GA as an optimization and in (Prakash, 2021) author has proposed PSO and technique though being very reliable but takes much time and space in computation and also not suitable for large bus systems due to time consumption. The proposed method of allocation of DG using ASO algorithm is robust and saves computation resources making the operation more efficient. Test results demonstrates the feasibility and validity of the same. In the paper ASO is used for global location for decreasing the power loss, and improving the voltage profile. Direct load flow method used for load flow calculation (Teng, 2003).

The paper is structured as follows, section 2 describes formulation of problem. Section 3 sets up the algorithm to solve the optimization problem using ASO. Findings and discussions are mentioned in section 4. Finally, in section 5, conclusions are added.

2. Problem Formulation

The section deals with the Direct Load Flow (DLF) for RDS_m and MDS_m, mathematical objective function formulation, constraints, annual energy savings for standard IEEE 33 and 69 RDS_m and MDS_m

2.1 DLF Analysis:

For load flow analysis of RDS_m and MDS_m, authors have used the methodology proposed by J.H.Teng (Teng, 2003). DLF method is employed in analysis is due to the convergence problem posed by traditional load flow, due to high R/X ratio of DS_m. The analysis is developed with the help of BIBC and BCBV matrices. These matrices provide the relation between branch current, bus voltages and bus current injections. The algorithm for the same can be expressed as follows.

1. Read: line data, bus data, base kV, base MVA.

2. Calculate: injected powers, i.e.,

$$P_{inj}^i = P_{gen}^i - P_{load}^i$$

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3. Set: iteration k=1.

4. Initialize: tolerance (ϵ) 0.0001, $V^{\max} = 0.0$.

5. Calculate: nodal current injections.

6. Compute: currents, in branches, in backward direction using Backward Sweep $[B] = [BIBC][I]$.

7. Compute: modal voltages in forward direction using Forward Sweep $[\Delta V] = [BCBV][B]$, where $[\Delta V] = [V^0] - [V]$.

8. Compute: mismatches ΔV using $\Delta V^{k+1} = V^0 - \Delta V^{k+1}$

9. Check: $\Delta V_i^k > \Delta V^{\max}$ then set $\Delta V^{\max} = \Delta V_i^k$.
10. If $\Delta V^{\max} \leq \varepsilon$ go to 12, else set $k=k+1$, and go to 4.
11. Stop

2.2 Objective Formulation:

The main intent of the study is to enhance voltage profile which is achieved using minimizing the total active power losses (TAPL).

$$O_f = \text{minimize (TAPL)} \quad (1)$$

RDSm

$$P_{\text{loss}} = Br_l^2 * r \quad (2)$$

$$Q_{\text{loss}} = Br_l^2 * x \quad (3)$$

$$\text{TAPL} = \sum_1^n P_{\text{loss}} \quad (4)$$

MDSm

$$P_{\text{lossTie}} = Br_{l,\text{new}}^2 * r_t \quad (5)$$

$$Q_{\text{lossTie}} = Br_{l,\text{new}}^2 * x_t \quad (6)$$

$$\text{TAPL} = \sum_1^n (P_{\text{loss}} + P_{\text{lossTie}}) \quad (7)$$

2.3 Constraints:

2.3.1 *Voltage Constraints:* During the optimization procedure the voltage V_i should not be exceeding the prescribed limits.

$$V_i^{\min} \leq V_i \leq V_i^{\max} \quad (8)$$

2.3.2 *Current Constraint:* The current constraints are so initialized such that maximum current does not exceed the rated current I_i^k . Maximum current $I_i^{k,\max}$ is taken as 10 times the rated current

$$I_i^k \leq I_i^{k,\max} \quad (9)$$

2.3.4 *DG Constraints:* The size of DG/s (P_{DG}) cannot exceed the total load in the system.

$$P_{DG}^{\min} \leq P_{DG} \leq P_{DG}^{\max} \quad (10)$$

2.4 Annual Energy Savings (ESA):

It is defined as total annual savings of energy in an annum due to addition of external DG or any other devices.

$$ESA = [(TAPL_{before_{DG}}) - (TAPL_{after_{DG}})] * 8760 \quad (11)$$

3. Atom Search Optimization and Methodology

The ASO technique is a meta-heuristic optimization technique that stimulates the interactions of atoms as taking place in real world which is inspired from Newton's II Law of Motion. In general, the interaction between atoms is either attractive or repulsive depending upon the relation between relative distance between 2 atoms and length scale, that represents the average distance of each atom, and the common position of its neighbors K as described in (Zhao et al., 2019).

Thus in simulation studies for faster convergence within side first degree of recurrence, each atom interacts with as many as possible atoms with highest fitness value in its K neighbours. Moreover, to increase utilization in ending of iteration count, atoms are forced to associate with as low as possible atoms, with high fitness in K neighbour atoms (Kamel et al., 2019).

The detailed study and methodology and parameters is referred from (Abdel-Rahim et al., 2019; Kamel et al., 2019; Zhao et al., 2019). This algorithm can be incorporated in optimal allocation of DG/s in DSM. The pseudo code for the same is as follows.

1. Read: line data and load data.
2. Run: DLF analysis to compute TAPL.
3. Initialize: limits of DG.
4. Initialize: random number of atoms(X) (solutions), their velocities (size of DG) and positions (within the limits of number of buses in the system).
5. Assign the fitness value, i.e., TAPL of system as Fit_best=INF. For each atom X at each bus do,
 - a. If Fit_i < Fit_best, then
 - i. Fit_best = Fit_i.
 - ii. End if.
 - b. Calculate the mass of the atom.
 - c. Determine the neighbors K.
 - d. Calculate forces of interaction and constraint as in (Kamel et al., 2019; Zhao et al., 2019).
 - e. Calculate the acceleration of atom.
 - f. Update the velocities and positions of atom.
 - g. End, for.
6. End, While.
7. Find: best solution X_best i.e., size and location of the DG.
8. Find: best fitness value Fit_best i.e., minimum TAPL.
9. End

Table 1. ASO Parameter

ASO Parameters	Range
Population Size	50
Iterations Count	1000
Depth –Weight	50
Multiplier – Weight	0.2
Voltage Limit	$0.95 p.u. \leq V_i \leq 1.05 p.u.$
DG's Size Limit	$100kVA \leq P_{DG} \leq 3700kVA$

3. Results & Discussions

The paper, the ASO is applied for optimally allocating DG in standard IEEE 33 and 69 bus RDSm and MDSm. The line data for RDSm and MDSm has been referred from (D. B. Prakash & Lakshminarayana, 2018; Sharma & Murty, 2014; Sivanagaraju et al., 2005). The constraints for optimization are considered from Table 1(IEEE, 2003; Zhao et al., 2019).The following cases for DG implementation has been considered for studies of both IEEE 33 and 69 bus RDSm and MDSm.

- Case 1: Base Case: W/o DG.
- Case 2: With 1 DG at 0.8 pf.
- Case 3: With 2 DGs at 0.8 pf.
- Case 4: With 1 DG at 0.9 pf.
- Case 5: With 2 DG at 0.9pf.

3.1 Radial Distribution System (RDSm):

3.1.1. 33 Bus RDSm: The total load drawn from substation is 3715 kW and 2300 kVAr. The voltage profile for different cases consisting of IEEE 33 Bus RDSm is depicted in Figure 2. Table 2 shows the impact of increasing DG with change in pf from 0.9 pf lag to 0.8 pf lag. In Figure 1, the dotted line represents the minimum voltage limit (0.95 p.u.). The authors observed that in Case I, more than half of buses had voltage below permissible limit but with optimal allocation of DG with considering different cases voltage profile of all the buses are enhanced and becomes more desirable with more number of DGs and with pf that is more lagging.

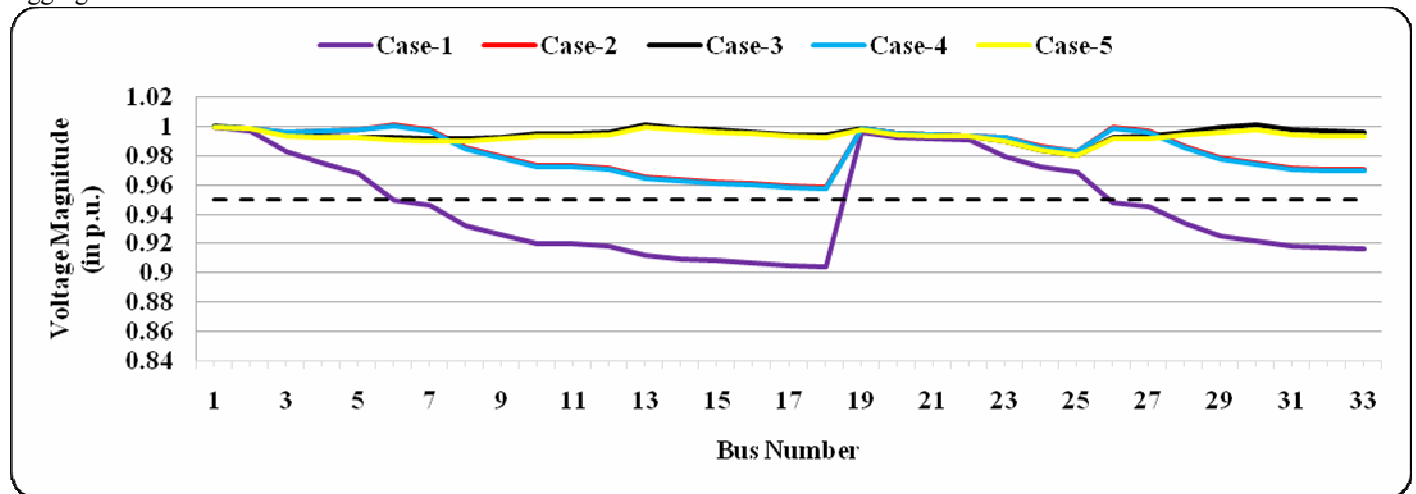


Figure 1. Impact of DG/s on voltage profile of IEEE-33 bus RDSm

3.1.2. 69 Bus RDSm: The total load drawn from substation is 3802.6 kW and 2694.6 kVAr. The voltage profile for different cases consisting of IEEE 69 Bus RDSm is depicted in Figure 3. Table 2 shows the impact of increasing DG with change in pf from 0.9 pf lag to 0.8 pf lag.

From Figure 2, the dotted line represents the minimum voltage limit (0.95 p.u.). The authors observed that in Case I, more than half of buses had voltage below permissible limit but with optimal allocation of DG with considering different cases taken. Voltage profile of all the buses is enhanced and becomes more desirable with more number of DGs and with pf that is more lagging.

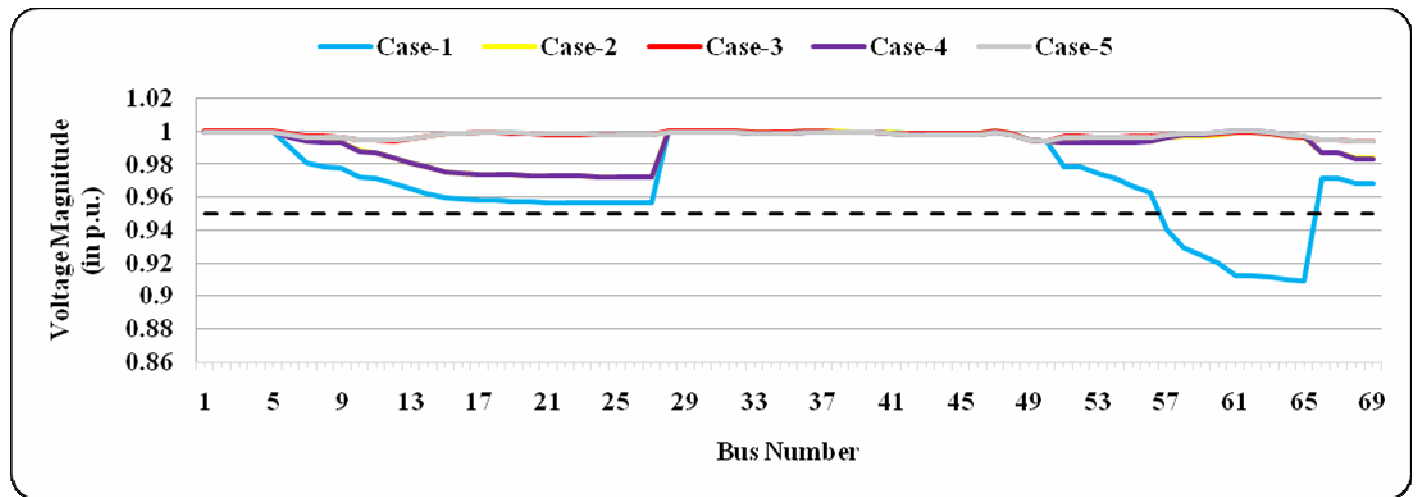


Figure 2. Impact of DG/s on voltage profile of IEEE-69 bus RDSm

Authors observed that with pf becoming more lagging, there is minimal improvement in voltage profile, as observed in figure 2. However, it was also observed that with increasing number of DGs in system TAPL and TQPL are reduced significantly and %savings also increases, which can be observed from table 2.

Table 2. Impact of DG/s on IEEE 33 & 69 Bus RDSm.

Bus System		TPL (kW)	TQL (kVAr)	Size (kVA)	Location (@ Bus)	ESA (kWhr)	% Energy Savings
IEEE 33 Bus System	Case 1	210.07	143.03	-	-	-	-
	Case 2	68.08	54.93	3103.60	6	1,243,832.40	67.59
	Case 3	30.48	21.93	1028.66 1503.22	12 30	1,573,208.40	85.49
	Case 4	71.07	56.98	3079.01	6	1,217,640.00	66.16
	Case 5	35.56	25.36	936.98 1494.97	13 30	1,528,707.62	83.07
IEEE 69 Bus System	Case 1	224.99	102.16	-	-	-	-
	Case 2	23.28	14.43	2243.09	61	1,766,979.60	89.65
	Case 3	7.89	8.43	574.28 1494.97	20 61	1,901,976.00	96.50
	Case 4	27.96	16.46	2216.00	61	1,725,928.80	87.57
	Case 5	13.31	10.12	714.00 2200.00	17 61	1,854,316.80	94.08

3.2 Mesh Distribution System (MDSm):

3.2.1. 33 Bus MDSm with 5 loops: The TAPL without any DG is obtained to be 241.71 kW and TRPL to be 171.25 kVAr. The influence of DG/s, on voltage profile of the system is illustrated in figure 3. The table 3 shows the impact of allocation of DG/s on TAPL and % energy savings. From the figure 3 it is observed that all buses had voltage under prescribed limit and with maximum enhancement is achieved with 2 DG/s at different pf.

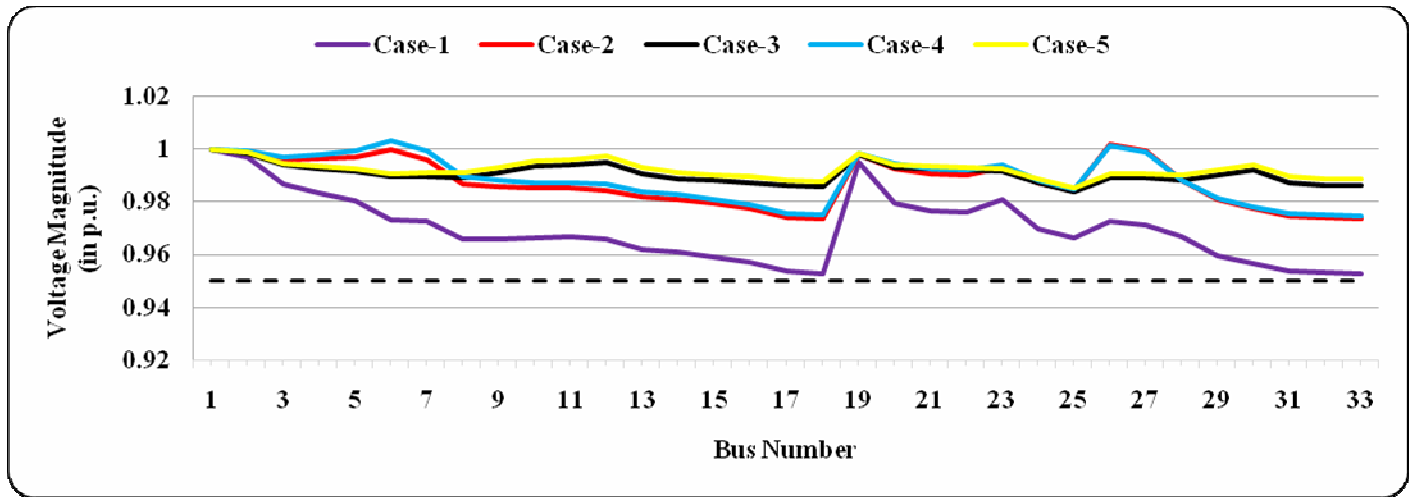


Figure 3. Impact of DG/s on voltage profile of IEEE-33 bus MDSm

3.2.2. 69 Bus MDSm with 5 loops: The TAPL and TRPL without DG, is obtained to be 205.96 kW and 110.34 kVAr, respectively. The impact of DG/s on voltage profile of the system, is depicted in figure 4. Table 3 shows the impact of DG/s on TAPL and TRPL with % savings in energy annually.

Authors observed that though voltage being under prescribed limit there are certain buses such as 27, 61 that cause voltage to deviate from flat profile. But, with optimal allocation and increase in number of DG/s there is enhancement in the voltage profile and pf changing from 0.8 pf lag to 0.9 pf lag, with number of DG/s being constant, there is only little improvement in voltage profile. With maximum enhancement being observed with 2 DG/s at different pf.

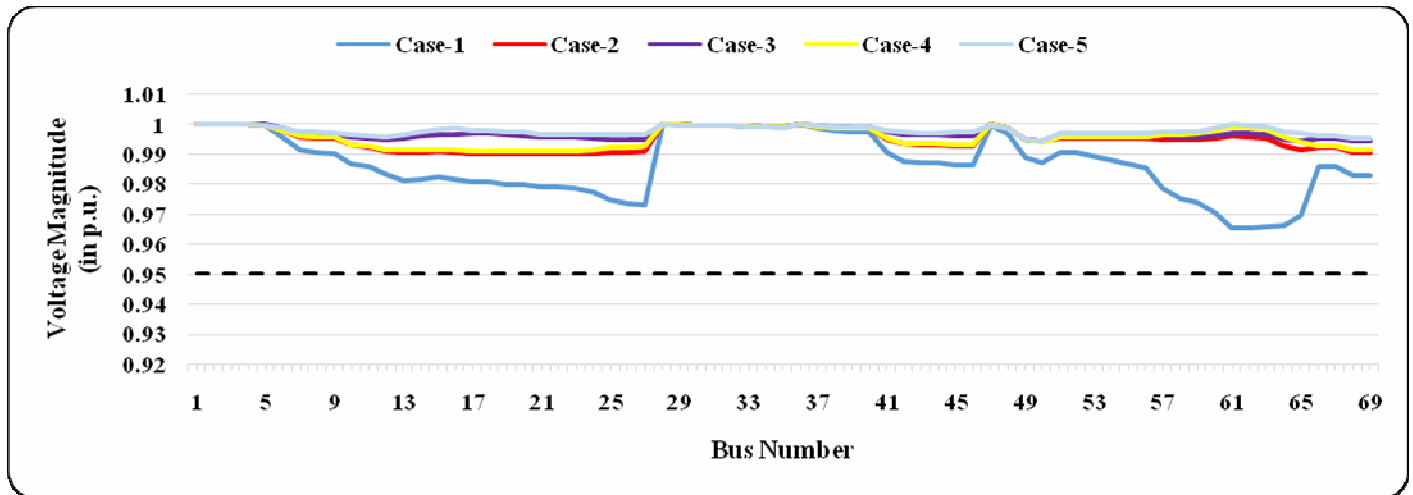


Figure 4. Impact of DG/s on voltage profile of IEEE-69 bus MDSm

Table 3. Impact of DG/s on IEEE 33& 69 Bus MDSm.

Bus System		TPL (kW)	TQL (kVAr)	Size (kVA)	Location (@ Bus)	ESA (kWhr)	% Energy Savings
IEEE 33 Bus System	Case 1	241.71	171.25	-	-	-	-
	Case 2	71.85	57.72	3302.96	6	1,487,973.60	70.27
	Case 3	30.79	21.88	1124.80 1659.66	11 30	1,847,659.20	87.26
	Case 4	74.67	61.25	3300.00	6	1,463,271.40	69.10
	Case 5	31.95	23.63	1034.00 1774.00	10 30	1,837,497.60	86.78

Table 3 (cont'd). Impact of DG/s on IEEE 33& 69 Bus MDSm.

Bus System		TPL (kW)	TQL (kVAr)	Size (kVA)	Location (@ Bus)	ESA (kWhr)	% Energy Savings
IEEE 69 bus System	Case 1	205.96	110.34	-	-	-	-
	Case 2	24.77	15.77	2404.29	61	1,587,244.40	87.97
	Case 3	10.76	9.13	558.13 2273.90	22 61	1,709,952.00	94.77
	Case 4	25.22	15.87	2435.00	61	1,583,282.40	87.75
	Case 5	11.31	9.13	803.00 2176.00	17 61	1,705,134.00	94.50

The ASO optimization is compared with other methods on basis of %time savings, which is shown in table 4. It is inferred that compared to GA, ASO saves 77.8% time (in secs). However, it observed that compared to Gravitational Search Algorithm (GSA) the time savings are 25.3%. All the optimizations were simulated with iteration count of 1000. The total average time of all cases are taken for comparison.

Table 4. Comparison of various algorithm with proposed method.

Algorithm	Total average time taken (sec) (1000 iteration)	% Time Savings by ASO algorithm
GA(Mithulananthan et al., 2004)	50.9	77.8
PSO(Prakash, 2021)	16.1	30.4
CSA(Uniyal & Kumar, 2016)	36.4	69.2
GSA(Uniyal & Kumar, 2016)	15.0	25.3
Proposed: ASO	11.2	-

5. Conclusions

In the paper with ASO algorithm, proper allocation of DG/s is obtained that improves the voltage profile along with loss minimization. The table 3 shows % average time saved in DG allocation in RDSm and MDSm. It is concluded that there is more enhancement in voltage profile when number of DG/s are increased but remains almost unchanged with change in the power factor. Also, with increase in number of DG/s there is an increase in ESA, but the rate of savings is decreased. Moreover, in the weakly MDSm there is relative significant improvement in voltage profile and less voltage fluctuations than RDSm. However the network complexity and cost of feeders increases, so there is simply tradeoff between simplicity and voltage improvement. Present analysis may help DNO for developing better future plans for RDSm and MDSm.

Nomenclature

P_{inj}^i	Injected Power at i^{th} branch
P_{gen}^i	Generated Power at i^{th} branch
P_{load}^i	Load Power at i^{th} branch
B	Branch Current Vector
I	Bus Current Vector
$BIBC$	Bus Injection to Branch Current Matrix
$BCBV$	Branch Current to Bus Voltage Matrix
ΔV	Mismatch Voltage
k	Iteration Count
r	Resistance of Branch
x	Reactance of Branch

n	Number of Nodes
r_t	Resistance of Tie-Line
x_t	Reactance of Tie-Line
P_{loss}	Active Loss in RDSm
Q_{loss}	Reactive Loss in RDSm
$P_{loss_{tie}}$	Active Tie-Line Loss in MDSm
$Q_{loss_{tie}}$	Reactive Tie-Line Loss in MDSm
V_i^{\min}	Minimum limit of Voltage at i^{th} Branch
V_i^{\max}	Maximum limit of Voltage at i^{th} Branch
I_i^k	Rated Current at k^{th} iteration in i^{th} Branch
$I_i^{k,\max}$	Maximum Current at k^{th} iteration in i^{th} Branch
P_{DG}^{\min}	Minimum DG Size
P_{DG}^{\max}	Maximum DG Size
$TAPL$	Total Active Power Loss
$TAPL_{\text{before}_{DG}}$	Total Active Power Loss before DG Allocation
$TAPL_{\text{after}_{DG}}$	Total Active Power Loss after DG Allocation

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Biographical notes

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