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Optimum placement of multi type DG units for loss reduction in a radial distribution system considering the distributed generation suitability index using evolutionary algorithms

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Abstract. Due to the increasing need for electricity, insertion of distributed generation (DG) into a distribution system attracts the attention of the deregulated power market. Placing DG in the distribution system inherently reduces the power loss and improves the system voltage profile. The choice of DG, proper placement and sizing of DG all play a vital role. This paper presents an effective methodology to identify the optimum location of multi type DG in the distribution system. The particle swarm optimization (PSO) algorithm and differential evolution (DE) are applied to identify the proper location and size of DG using the distributed generation suitability index (DGSI). The optimum location of DG is identified through DGSI and optimum sizing is done by means of the power loss minimization technique using evolutionary algorithms. The effective power loss reduction and improved system voltage profile are evaluated using sixteen combinations of different types of DGs with the standard IEEE 33-bus test system. The results reveal that power loss reduction and voltage profile improvement are effectively addressed by the DE algorithm.

Key words: distributed generation, distributed generation suitability index, particle swarm optimization, differential evolution, voltage profile.

1. Introduction

Distributed generation (DG) is a small electricity generating source with power rating between 5 MW and 500 MW. It can be connected directly to the distribution network or customer premises. Recently, inserting capacitors and placing DGs in distribution systems have become the effective methodology applied to boost the distribution system performance in terms of power loss reduction, voltage profile improvement and stability [1, 2]. In practice, DGs are placed at the consumer end and are generally inserted at the distribution level. The rating of DG is relative to the distribution system capacity and structure. Subhodip Saha *et al.* have proposed the chaotic symbiotic organisms search algorithm to identify the optimum location and rating of DGs in a radial distribution system, considering objectives of power loss minimization and voltage stability enhancement [3]. Aashish Kumar Bohre *et al.* emphasized the task of reducing active and reactive power as a multi objective problem, by installing multiple DGs in the standard 33-bus and 69-bus radial distribution systems [4]. This work has considered the reliability and voltage deviation index, too.

Muhammad Mohsin Aman *et al.* have presented simultaneous optimum DG placement and tie-switch allocation using the discrete artificial bee colony algorithm [5]. Alireza Heidari *et al.* have addressed the problem of placing sectionalizing switches in the distribution network, by having multiple DGs and thereby minimizing the total cost without losing the acceptable level of system reliability [6]. Analytical equations for optimum location and size of DG in the radial distribution system have also been considered to reduce the active and reactive power losses [7]. The expression has been formulated on the basis of change in the active and reactive component of branch current in the presence of DG.

Combination of the fuzzy and ant colony optimization algorithm for simultaneous reconfiguration, placement and sizing of DGs and DFACTS devices in a distribution system has been introduced for the purpose of minimizing power loss [8]. There is also multi-DG placement discussion for power loss minimization in literature [9].

A new combination of analytical techniques and the genetic algorithm (GA) for optimum placement and sizing of the DGs has been recommended, in order to reduce the distribution losses [10]. Non-dominated sorting particle swarm optimization (PSO) has been applied to improve the distribution network performance, by optimally reconfiguring the distribution network along with the DG reactive power dispatch [11]. The harmonic search algorithm for simultaneous reconfiguration of the distribution system and optimum location of DG has been suggested to reduce the active power loss and voltage deviation at the nodes [12]. Alireza Heidari *et al.* have discussed the islanding operation of incorporating DG units into the dis-

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tribution system. In addition, mixed integer non-linear programming is proposed for the optimum placement of manual and automated sectionalizing switches as well as protective devices [13].

Wanxing Sheng has introduced an improved version of non-dominated sorting GA for the optimum placement of DGs in the distribution system to achieve minimum loss, better voltage profile and a maximum voltage stability margin [14]. Firas M.F. Flaih has proposed a modified PSO algorithm to improve the performance of the distribution system by reducing the real power loss using reconfiguration. This algorithm is used to identify the switches, which have to be opened to reduce the power loss [15]. PSO technique is also applied to find the optimum place for DG in the distribution network for achieving better voltage stability and to improve short-circuit-level of the system [16]. The analytical approach based on the power sensitivity index has been discussed for optimum placement of DG in the distribution system [17]. This method resulted in problem complexity as the number of DGs increased.

Muthubalaji *et al.* have presented a combinational approach of the multi objective ant colony and bacterial foraging algorithm to place the STATCOM in an electrical distribution network, in order to minimize the total cost and power loss [18]. They have also recommended a multi objective approach to solving the reconfiguration problem of the radial distribution network with DGs [19]. The focus of the approach is to reduce the power loss and to improve the voltage profile of the system. Moreover, the reliability index and energy not supplied are minimized to improve system reliability. Gondomar *et al.* have suggested a combinational approach of GA and simulated annealing method for optimum location of DGs [20].

DGs are classified into four different types based on their injecting and absorbing capability of real and reactive powers. Those are: i) Type 1: DGs capable of injecting real power (P) only; ii) Type 2: DGs capable of injecting reactive power (Q) only; iii) Type 3: DGs capable of injecting both real and reactive power; iv) Type 4: DGs capable of injecting real power but consuming reactive power. The literature review discussed above reveals that performance enhancement of the distribution system is examined by placing any one type of DG, type 1 of DG in particular, alone. But, this study alone does not bring out the enhancement of system voltage profile and loss reduction, as a combination of DGs is essential to observe improvement.

Hence, this paper has analyzed different combinations of DGs in relation to the system voltage profile improvement. This work has attempted to investigate the performance of the distribution system in the presence of sixteen combinations of four types of DGs and has brought out the suitable combination that reduces the power loss and enhances the system voltage profile. Unlike previous studies, here DGs are not combined simultaneously, whereas they are placed one after the other. Moreover, many researchers have used the loss sensitivity index (LSI) and voltage stability index (VSI) for identification of the optimum location of DG to reduce the losses. Yet in this paper the authors have used a novel index called the distributed generation suitability index (DGSI) to locate the DG.

2. Distributed generation suitability index

In this paper, the optimum location of DGs in the distribution system is identified by an index called DGSI. For finding the DGSI, the voltage stability index (VSI) before and after using DG are considered, in addition to power losses for getting to the optimum location [21]. The bus with the least DGSI is selected for the placement of DG. The DGSI can be calculated by means of the following formula:

$$\begin{aligned}\mathrm{DGSI} = \mathrm{w}_1 * \frac{\text{VSI without DG}}{\text{VSI with DG}} + \\ + \mathrm{w}_2 * \frac{\mathrm{P}_{\mathrm{loss}}\text{ without DG}}{\mathrm{P}_{\mathrm{loss}}\text{ with DG}} + \\ + \mathrm{w}_3 * \frac{\mathrm{Q}_{\mathrm{loss}}\text{ without DG}}{\mathrm{Q}_{\mathrm{loss}}\text{ with DG}}\end{aligned} \tag{1}$$

where w_1, w_2 and w_3 are the weighting factors, such that $\mathrm{w}_1 + \mathrm{w}_2 + \mathrm{w}_3 = 1$; ($\mathrm{w}_1 = 0.4$, $\mathrm{w}_2 = 0.3$ and $\mathrm{w}_3 = 0.3$).

Optimum location is found using the DGSI, and sizing is optimized using evolutionary algorithms such as differential evolution (DE) and particle swarm optimization (PSO). DGs are placed one after the other and not simultaneously. Standard IEEE 33-bus system is used as the test system. DGSI is calculated by placing 1 kW capacity DG at each bus, i.e., from 2$^{\text{nd}}$ bus to 33$^{\text{rd}}$ bus. The bus with the least DGSI is identified as optimum location for the DG. For that optimum location, sizing is obtained using DE and PSO with the objective of minimizingP_{loss}, P_{loss} and DGSI. Different types of DGs are optimally located in the system at different locations, without altering the position of the first DG, following the same procedure.

3. Problem Formulation

The objective of the work includes active power loss minimization, reactive power loss minimization and DGSI minimization [22].

i. Active power loss minimization

$$P_{loss} = \min\left(\sum_{i=1}^{n} I_i^2 * R_i\right); \tag{2}$$

ii. Reactive power loss minimization

$$Q_{loss} = \min\left(\sum_{i=1}^{n} I_i^2 * X_i\right)\mathrm{VSI}. \tag{3}$$

Equality constraints:

$$P_i = P_{DGi} - P_{Di} \tag{4}$$

$$Q_i = Q_{DGi} - Q_{Di}. \tag{5}$$

Inequality constraints:

$$\mathrm{V}_{\mathrm{imin}} \le \mathrm{V}_{\mathrm{i}} \le \mathrm{V}_{\mathrm{imax}} \tag{6}$$

$$\mathrm{P}_{\mathrm{GDimin}} \le \mathrm{P}_{\mathrm{GDi}} \le \mathrm{P}_{\mathrm{GDimax}} \tag{7}$$

$$\mathrm{Q}_{\mathrm{GDimin}} \le \mathrm{Q}_{\mathrm{GDi}} \le \mathrm{Q}_{\mathrm{GDimax}} \tag{8}$$

where I_i is the line current at bus i, in amps; R_i is line resistance, in ohms; X_i is the line reactance at bus i, in ohms; P_i and Q_i are the real and reactive power flows at bus i; P_{DGi} and Q_{DGi} are the real and reactive power generations from DG placed at bus i; P_{Di} and Q_{Di} are the real and reactive power demands at bus i; V_i is the voltage magnitude at bus i; V_{imin} and V_{imax} are the upper and lower limits of voltage; P_{DGimin} and P_{DGimax} are the minimum and maximum values of P_{DGi}; Q_{DGimin} and Q_{DGimax} are the minimum and maximum values of Q_{DGi}.

4. PSO algorithm for DG sizing

In the US, Russell Eberhart and James Kennedy invented the evolutionary algorithm called PSO in 1995. This idea is inspired by the social behaviour of birds, fishes, and insects. This algorithm combines self-experience with social behaviour. Each particle in the search space adjusts its flying, according to its own experience as well as the flying experience of the other particles, to obtain the best solution. Best position of the particle is denoted by P_{best} and best overall position found by the particle is denoted by G_{best}. Each particle updates its position and velocity during each of its iterations [23]. The parameter setting is given in Table 1.

Table 1
Parameters for PSO algorithm

Parameter	Value
No. of particles	20
No. of iterations	50
C1	1
C2	3
Initial inertia weight	0.9
Final inertia weight	0.4

Velocity of each particle can be modified by means of the following equation:

$$V_i^{k+1} = w \times v + C_1 \times rand_1 \times \left(P_{besti} - S_i^k\right) + \\ + C_2 \times rand_2 \times \left(G_{besti} - S_i^k\right) \tag{9}$$

where V_i^{k+1} – Velocity of particle t at iterations
w – weight function which is given by

$$w = w_{\max} - \frac{w_{\max} - w_{\min}}{iter_{\max}} iter$$

W_{max} – initial inertia weight;
W_{min} – final inertia weight;
$iter_{max}$ – maximum iteration number;
$iter$ – current iteration number;
C_1 and C_2 – weight coefficients;
$rand_1$ and $rand_2$ are random numbers between 0 and 5;
S_i^k – current position of particle i at iteration k.

Now the new position can be obtained using:

$$S_i^{k+1} = S_i^k + V_i^{K+1}. \tag{10}$$

The steps to finding the optimum size and location of DG through the PSO algorithm are presented below [24]:

Step 1: Input line and bus data.
Step 2: Calculate the base case loss using the backward-forward sweep algorithm.
Step 3: Generate an initial population of particles with random positions and velocities on dimensions (rating of DG and DGSI value) in the solution space. Initiate iteration as k = 0.
Step 4: For each particle, if the bus voltage is within the limits, calculate total loss by means of equations 3 and 4. Otherwise, that particle is infeasible.
Step 5: For each particle, compare its objective value with the individual best. If the objective value is lower than P_{best}, set this value as the current P_{best}, and record the corresponding particle position.
Step 6: Choose the particle related with the minimum P_{best} of all particles, and make this value G_{best}
Step 7: Update the velocity and position of particle.
Step 8: If iteration reaches the maximum, go to step 9. Otherwise, increment, i.e. k = k + 1, and go to Step 4.
Step 9: Save the optimum solution. The best position gives the optimum place and size of DG. Subsequently resulting fitness value represents minimum total real and reactive power losses.

5. DE algorithm for DG sizing

In 1996, Storn and Price introduced an evolutionary algorithm called DE [25] for finding the global optimum solution of a given problem. DE mainly involves four steps such as initialisation, mutation, recombination and selection. In the initialisation step, upper and lower bounds for each parameter are defined. The population size is denoted by N and each of the N parameter vectors undergoes mutation, recombination and selection. The search space gets swelled by mutation. Recombination allows reusing individuals which were previously successful. Selection is the process by which we can choose the best fit individuals. The parameter setting is given in Table 2.

Table 2
Parameters for DE algorithm

Parameter	Value
No. of particles	20
No. of iterations	50
Crossover probability	0.4
Lower bound of scaling factor	0.2
Upper bound of scaling factor	0.8
Lower bound of decision variables	0.5
Upper bound of decision variables	2

The algorithm for DG location and sizing are given as follows [25]:

Step 1: Run load flow for base case.
Step 2: Find the distributed generation suitability indices (DGSI) at each node using equation (1). Calculate DG value at individual buses and put DGSIs of all the nodes in rising order to form a list.
Step 3: Choose the bus with the lowest DGSI value.
Step 4: Input the chosen value into the DE algorithm and optimize DG capacity at all buses, using the objective function equations (3), (4) and (5).
Step 5: Adjust the capacity of DG in small steps and estimate power loss for each by means of load flow analysis.
Step 6: Note down the size of DG that gives minimum loss.
Step 7: Compare the loss with the previous solution. If loss is less than for the previous solution, store this new solution and discard the previous one.
Step 8: Repeat Steps 4 to 7 for all buses as per the priority list.
Step 9: Execute the load flow for the final values again.

6. Results and Discussion

The IEEE 33-bus system, considered for carrying out the simulation, is shown in Fig. 1. The test system has 5 ties and 32 sectionalizing switches, with a total load of 3.7 MW and 2.3 MVAR. Using the MATLAB software, a program has been formulated, based on the proposed methodology.

6.1. Base Case of IEEE 33-Bus Test System. The total active and reactive power loss of the base case, without allocating DG, is obtained as 210.0594 kW and 142.5320 KVAR, respectively. VSI for the same is obtained as 0.1723. For minimizing active and reactive power loss, DGs are allocated optimally. The optimum location of the first DG is found out by calculating the DGSI for all the buses. The bus with minimum DGSI is the optimum location for first DG. Then sizing of this DG is obtained by placing a 1 kW DG at each bus. For finding the optimum location and sizing of the second DG, the system with a single DG is taken as the base case. The optimum location is found by calculating DGSI at all buses and the bus with the minimum DGSI becomes the suitable location for second DG. The sizing of the second DG is also determined by placing 1 kW at each bus. This procedure is repeated for various types of DGs. The proposed methodology is evaluated using the PSO algorithm and DE algorithm and a comparison has been made between their results.

6.2. Determination of location and sizing of types of DGs using the PSO algorithm.

6.2.1. Case study with type 1 and type 2 DG. The combination of type 1 and type 2 DG is chosen for enhancing the distribution system performance. The PSO algorithm is applied for this case, and the optimum location is identified from the bus with the lowest DGSI value. The active power, reactive power loss and VSI are presented in Table 3.

Table 3
Location and sizing with type 1 and type 2 DG using the PSO algorithm

Sl. No	Type of DG	DG location	Rating (KW)	Ploss (KW)	Qloss (KVAR)	VSI
1	1	24	1.0212	178.7406	124.6652	0.1673
2	1 and 2	24,28	1.0212, 1.9937	56.9091	46.5972	0.0860

Type 1 DG alone is optimally placed at the 24^{th} bus, since it has the least DGSI value with an optimum rating of 1.0212 KW. Moreover, active and reactive power losses are reduced from 210.0594 KW and 142.5320 KVAR to 178.7406 KW and 124.6652 KVAR, respectively. For further investigation, type 2 DG is placed without altering the system with type 1 DG. Type 2 DG is optimally located at the 28^{th} bus, since it has the least DGSI value, with an optimum rating of 1.9937 kW. For this combination, active power loss and reactive power loss are fur-

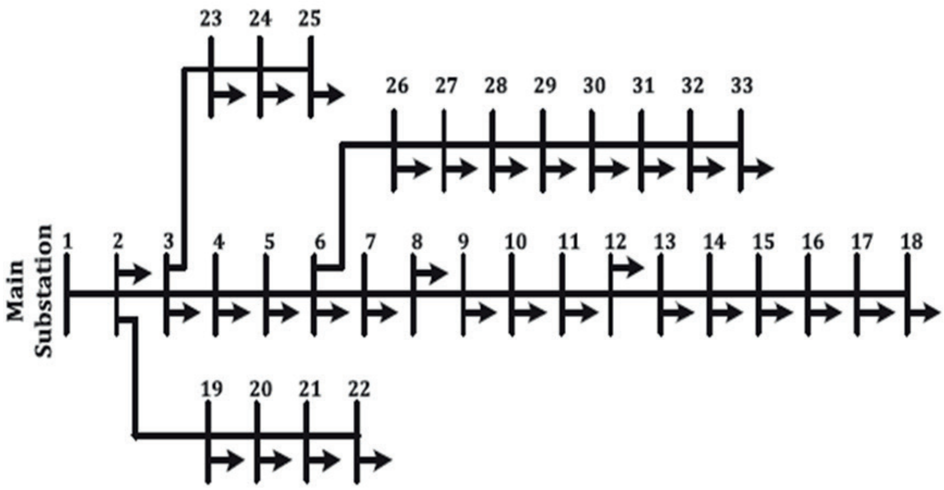

Fig. 1 IEEE 33-Bus Test System

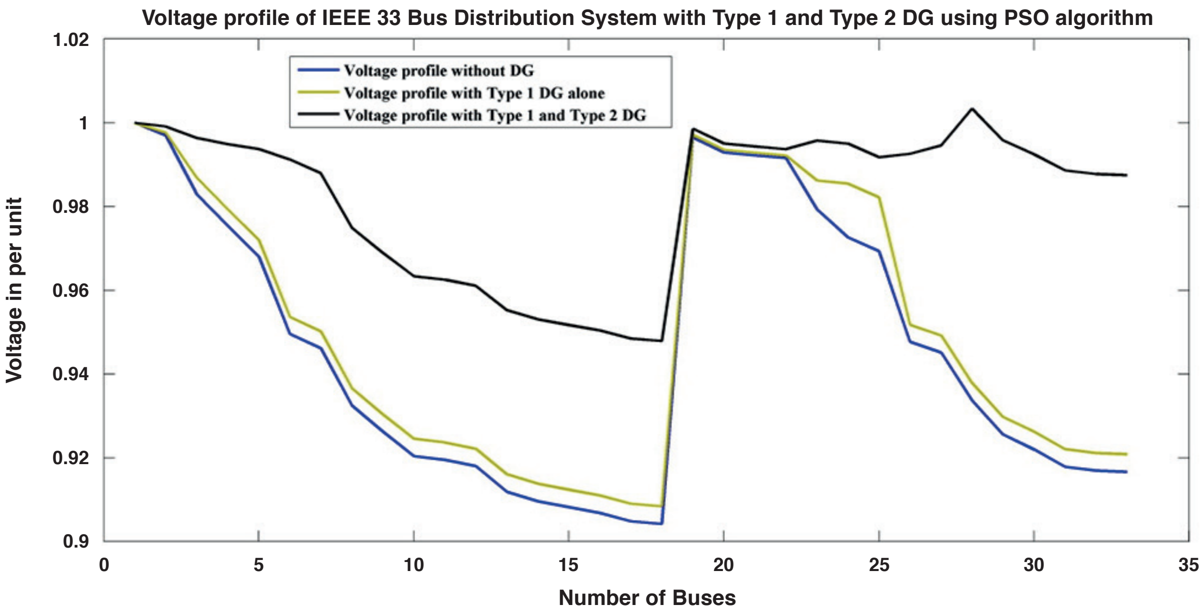

Fig. 2. Voltage profile of the system with type 1 and type 2 DG using the PSO algorithm

ther reduced to 56.9091 KW and 46.5972 KVAR, respectively. The voltage profile of the system without DG, with type 1 DG and with type 1 and 2 DG are shown in Fig. 2.

6.2.2. Case study with type 1 and type 3 DG. In this case, type 1 DG is kept in the same location, whereas type 2 DG is replaced by type 3, with the optimum location having been identified following the previous case procedure. It is evident from Table 4 that active and reactive power losses are reduced to 141.6849 KW and 100.8373 KVAR, respectively. The voltage profile of the system without DG, with type 1 DG and with type 1 and 3 DG is shown in Fig. 3.

Table 4
Location and sizing with type 1 and type 3 DG using the PSO algorithm

Sl. No	Type of DG	DG location	Rating (KW)	Ploss (KW)	Qloss (KVAR)	VSI
1	1	24	1.0213	178.7387	124.6643	0.1673
2	1 and 3	24,7	1.0220, 1.6443	141.6849	100.8373	0.1337

6.2.3. Case study with type 1 and type 4 DG. In this case, type 4 DG is optimally placed along with Type 1 DG, which is

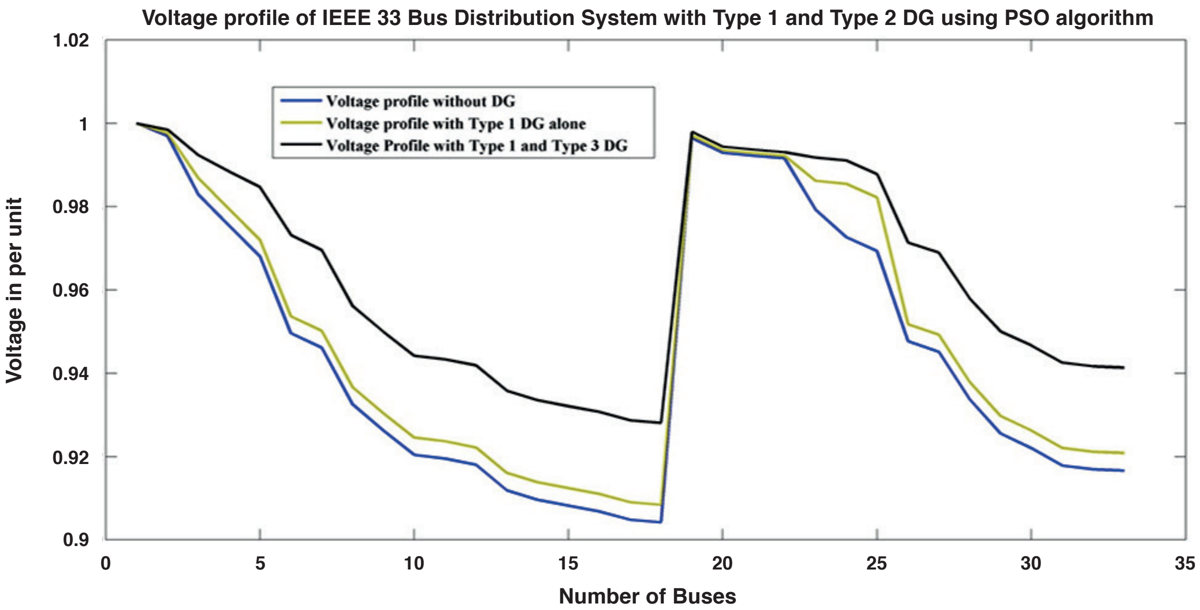

Fig. 3. Voltage profile of the system with type 1 and type 3 DG using the PSO algorithm

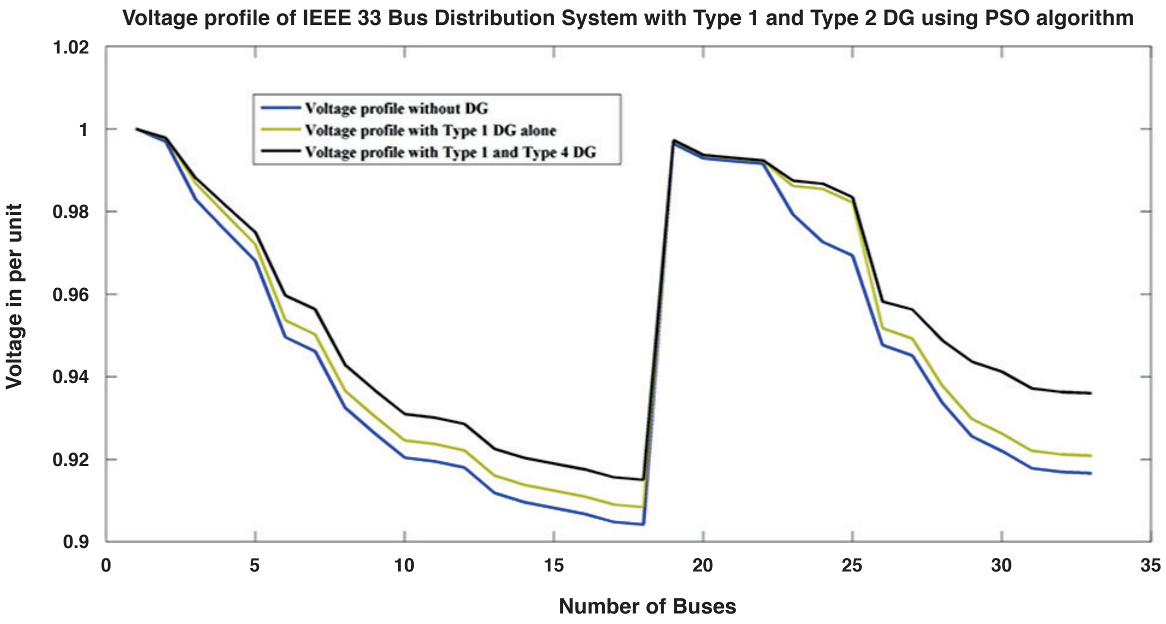

Fig. 4. Voltage profile of the system with type 1 and type 4 DG using the PSO algorithm

Table 5
Location and sizing with type 1 and type 4 DG using the PSO algorithm

Sl. No	Type of DG	DG location	Rating (KW)	Ploss (KW)	Qloss (KVAR)	VSI
1	1	24	1.0213	178.7387	124.6643	0.1673
2	1 and 4	24,30	1.0213, 1.2971	119.4895	85.7406	0.1629

already placed at the 24th bus. The results obtained are shown in Table 5.

The 30th bus having the least DGSI value is identified as the optimum location for type 4 DG. The optimum size of DG is found as 1.2971 KW. It is evident from Table 5 that active power loss and reactive power losses are decreased to 119.4895 KW and 85.7406 KVAR, respectively. The voltage profile of the system without DG, with type 1 DG and with type 1 and 4 DG are shown in Fig. 4.

6.3. Determination of location and sizing of types of DGs using the DE algorithm

6.3.1. Case study with type 1 and type 2 DG. Here, the combination of type 1 and type 2 DG is chosen for enhancing the performance of the distribution system. The optimum location, sizing, active power loss, reactive power loss and VSI, for type 1 alone and for a type 1 and 2 combination are determined using the DE algorithm. The results are shown in Table 7.

When type 1 DG alone is optimally placed at the 24th bus with optimum rating of 0.6463 KW, active and reactive power losses are reduced from 210.0594 KW and 142.5320 KVAR to 187.0739 KW and 129.0820 KVAR, respectively. The VSI is also reduced from 0.1723 to 0.1597. For further power loss minimization and VSI, another type of DG, type 2 in this case, has been installed in the system, after the successful installation of type 1 DG. For type 2, DG is optimally located at the 11th bus with optimum rating of 1.4836 KW, along with type 1 DG, wherein the active power loss, reactive power loss and VSI are further reduced to 79.1861 KW, 56.2335 KVAR and 0.1439, respectively. The voltage profile of the system without DG, with type 1 DG and with type 1 and 2 DG are shown in Fig. 5.

Table 7
Location and sizing with type 1 and type 2 DG using the DE algorithm

Sl. No	Type of DG	DG location	Rating (KW)	Ploss (KW)	Qloss (KVAR)	VSI
1	1	24	0.6463	187.0739	129.0820	0.1597
2	1 and 2	24,11	0.6463, 1.4836	79.1861	56.2335	0.1439

6.3.2. Case study with type 1 and type 3 DG. Here, the combination of type 1 and type 3 DG is chosen for enhancing the performance of the distribution system. The optimum location, sizing, active power loss, reactive power loss and VSI, for type 1 alone and for a type 1 and 3 combination are given in Table 8 for the DE algorithm.

Table 8
Location and sizing with type 1 and type 3 DG using the DE algorithm

Sl. No	Type DG	DG location	Rating (KW)	Ploss (KW)	Qloss (KVAR)	VSI
1	1	24	0.6463	187.0739	129.0820	0.1817
2	1 and 3	24,7	0.6463, 1.1381	156.4065	108.4446	0.1597

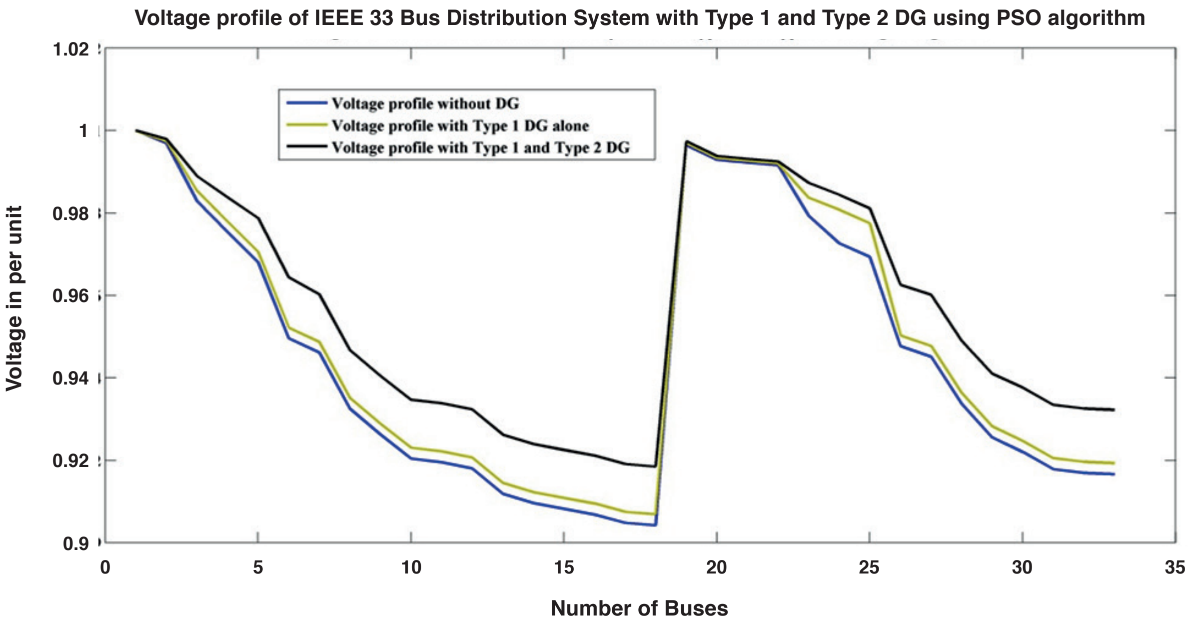

Fig. 5 Voltage profile of the system with type 1 and type 2 DG using DE algorithm

When type 1 DG alone is optimally placed at the 24th bus with optimum rating of 0.6463 KW, active and reactive power loss get reduced from 210.0594 KW and 142.5320 KVAR to 187.0739 KW and 129.0820 KVAR, respectively. The VSI is also reduced from 0.1723 to 0.1817. For further power loss minimization and VSI, another type of DG, type 3 in this case, is installed in the system after the successful installation of type 1 DG. For type 3, DG is optimally located at the 7th bus with optimum rating of 1.1381 KW, along with type 1 DG. The active power loss, reactive power loss and VSI are further reduced to 156.4065 KW, 108.4446 KVAR and 0.1597, respectively. The voltage profile of the system without DG, with type 1 DG and with type 1 and 3 DG is illustrated in Fig. 6.

6.3.3. Case study with type 1 and type 4 DG. Here, the combination of type 1 and type 4 DG is chosen for enhancing the performance of the distribution system. With the DE algorithm, the optimum location, sizing, active power loss, reactive power loss and VSI, for this combination of DG, i.e. for type 1 alone and for a type 1 and 4 combination, are all given in Table 9.

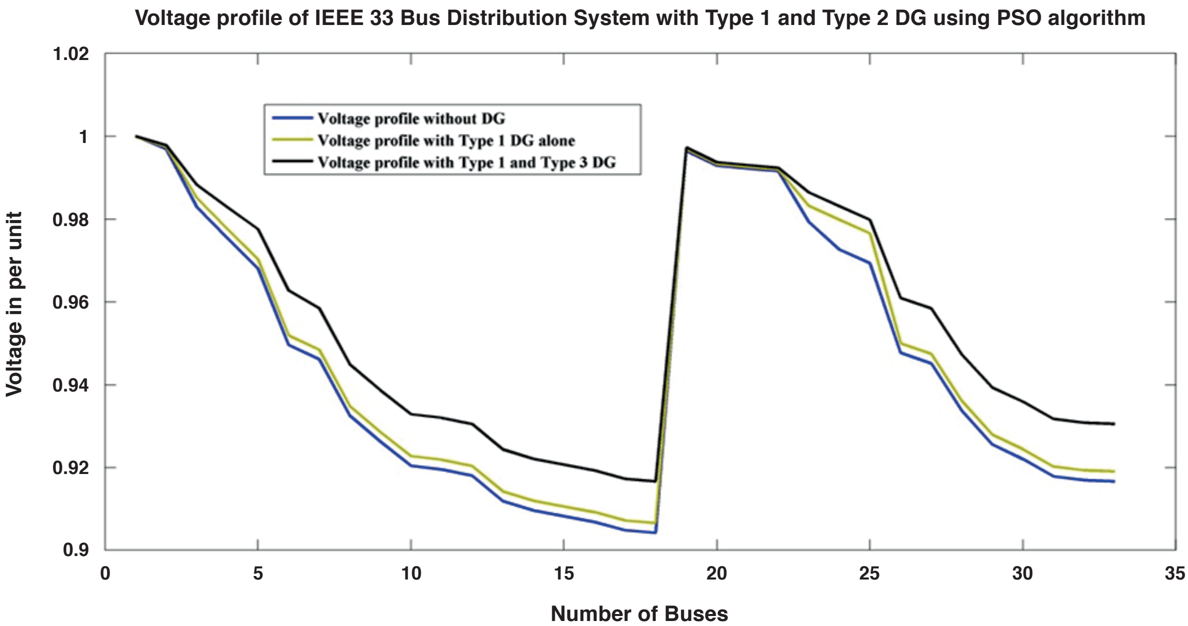

Fig. 6. Voltage profile of the system with type 1 and type 3 DG using the DE algorithm

Table 9
Location and sizing with type 1and type 4 DG using the DE algorithm

Sl. No	Type of DG	DG location	Rating (KW)	P_{loss} (KW)	Q_{loss} (KVAR)	VSI
1	1	24	0.5723	189.1465	130.2433	0.1573
2	1 and 4	24,11	0.5723, 0.9173	152.4911	106.7345	0.1509

When type 1 DG alone is optimally placed at the 24th bus with optimum rating of 0.5723 KW, active and reactive power losses are reduced from 210.0594 KW and 142.5320 KVAR to 189.1465 KW and 130.2433 KVAR, respectively. The VSI is also reduced from 0.1723 to 0.1573. For further power loss minimization and VSI, another type of DG, type 4 in this case, is installed in the system after the successful installation of type 1 DG. For type 4, DG is optimally located at the 11th bus with optimum rating of 0.9173 KW, along with type 1 DG. The active power loss, reactive power loss and VSI get further reduced to 152.4911 kW, 106.7345 KVAR and 0.1509, respectively. The voltage profile of the system without DG, with type 1 DG and with type 1 and 4 DG are shown in Fig. 7.

Similarly, performance of the distribution system using all the sixteen combinations of the four different types of DGs is evaluated using the DE algorithm while the optimum location and sizing of DG, active and reactive power loss, and VSI for each combination are tabulated in Table 10.

From Table 10, it is conferred that for the 6th combination, i.e. that of type 2 and type 2, DG is optimally allocated to the

Table 10
Comparison of different DG combinations for power loss reduction and voltage profile improvement

Sl. No	Type of DG	DG location	Rating (KW)	Ploss (KW)	Qloss (KVAR)	VSI
1	1 and 1	24,30	0.6235, 0.2452	108.803	78.284	0.1648
2	1 and 2	24,11	0.6463, 1.4836	79.186	56.233	0.1439
3	1 and 3	24,7	0.6463, 1.1381	156.406	108.446	0.1817
4	1 and 4	24,11	0.5723, 0.9173	152.491	106.734	0.1509
5	2 and 1	11,24	1.4833, 0.5315	81.077	57.346	0.1406
6	2 and 2	11,30	1.5021, 0.9585	42.934	31.378	0.0281
7	2 and 3	11,24	1.4752, 0.8862	88.505	62.356	0.1544
8	2 and 4	11,5	1.5873, 1.0100	88.7575	63.390	0.1486
9	3 and 1	24,30	0.8488, 1.3005	120.958	85.901	0.1764
10	3 and 2	24,11	0.8548, 1.4893	88.8226	62.611	0.1536

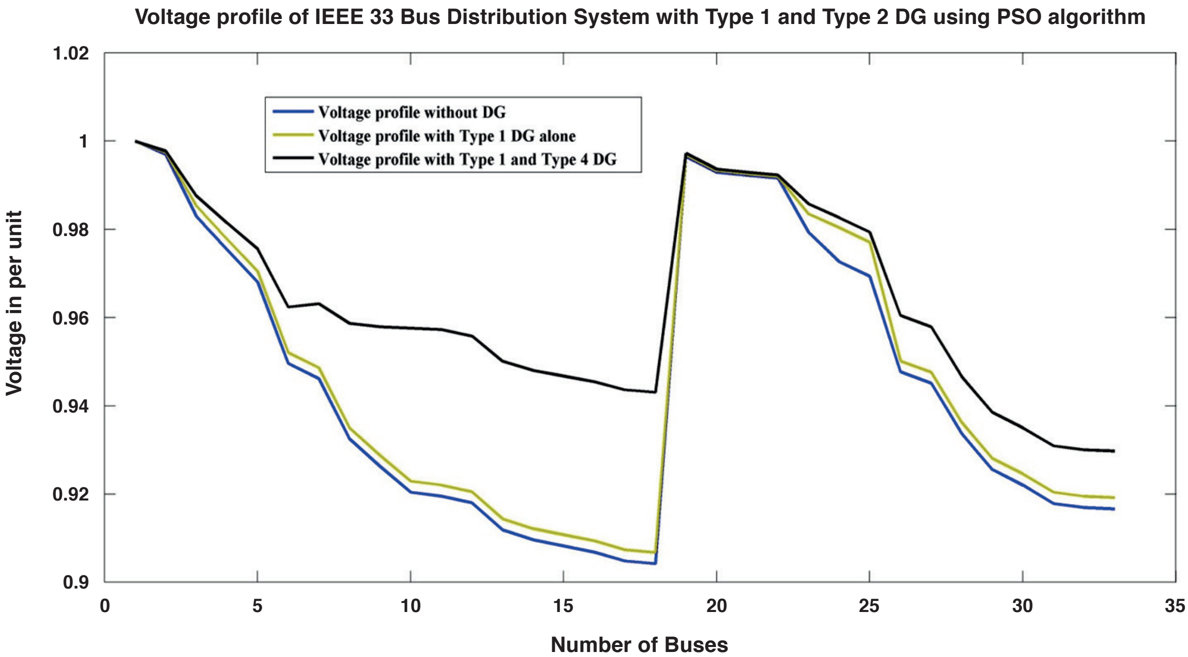

Fig. 7. Voltage profile of the system with type 1 and type 4 DG using the DE algorithm

Sl. No	Type of DG	DG location	Rating (KW)	Ploss (KW)	Qloss (KVAR)	VSI
11	3 and 3	24,7	0.8657, 1.1301	172.183	117.953	0.1913
12	3 and 4	24,11	0.8892, 0.9265	157.322	110.593	0.1639
13	4 and 1	11,24	0.962, 0.6504	150.468	105.821	0.1533
14	4 and 2	11,30	0.9361, 0.9398	85.0511	60.803	0.1657
15	4 and 3	11,24	0.9093, 0.9363	156.566	110.140	0.1652
16	4 and 4	11,26	0.9585, 0.9718	161.833	112.538	0.1601

11th and 30th bus with 1.5021 KW and 0.9585 KW, respectively, and this results in a reduction of active power loss, reactive power loss and VSI from 210.0594 KW, 142.5320 KVAR and 0.1732 to 42.9348 KW, 31.3782 KVAR and 0.0281. Thus the minimum VSI has enhanced voltage stability and yielded a better voltage profile.

The DE algorithm proves to be better than the PSO algorithm for all case studies. Table 11 depicts that the DE algorithm gives a better percentage reduction of P_{loss} and Q_{loss} as 79.56% and 77.99%, respectively, than the PSO, which gives only 71.26% and 68.14%, respectively.

Table 11
Comparison of PSO and DE with the base case for power loss reduction and voltage profile improvement

	P_{LOSS} (KW)	Q_{LOSS} (KVAR)	P_{LOSS} reduction (%)	Q_{LOSS} reduction (%)
Base case	210.0594	142.5320	–	–
PSO	60.3711	45.4063	71.26	68.14
DE	42.9348	31.3782	79.56	77.99

7. Conclusion

This paper has presented a methodology to be applied to effectively reduce the power loss in a radial distribution network (RDN) by optimally locating two different types of DGs with proper sizing. This method utilizes the DGSI for optimum placement of DG and evolutionary algorithms for its sizing. Four different types of DGs were considered. A combination of any two types of DG was placed at a time for evaluation. Performance evaluation of the proposed methodology was conducted using the DE algorithm. The best combination which yields minimum power loss with a better voltage profile was found using this very DE algorithm. Moreover, the algorithm's effectiveness was appraised by means of applying the PSO algorithm for the same network. The results show that the DE algorithm has outperformed PSO and achieves an active, reactive power loss reduction of 79.56% and 77.99%, respectively, with the combination of two type 2 DGs placed at the candidate bus 11 and 30. The voltage profile has also improved. As a result, performance of the distribution system is enhanced with power loss minimization and an improved voltage profile.

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