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Optimal location and sizing determination of Distributed Generation and DSTATCOM using Particle Swarm Optimization algorithm

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ABSTRACT

A Particle Swarm Optimization algorithm for finding the optimal location and sizing of Distributed Generation and Distribution STATicCOMpensator (DSTATCOM) with the aim of reducing the total power loss along with voltage profile improvement of Radial Distribution System is proposed in this paper. The new-fangled formulation projected is inspired by the idea that the optimum placement of the DG and DSTATCOM can facilitate in minimization of the line loss and voltage dips in Radial Distribution Systems. A complete performance analysis is carried out on 12, 34 and 69 bus radial distribution test systems and each test system has five different cases. The results analyzed using Loss Sensitivity Factor shows the optimal placement and sizing of DG and DSTATCOM in Radial Distribution System effectively improves the voltage profile and reduces the total power losses of the system.

Introduction

The term DG is frequently used to represent small-scale electricity generation. DG is becoming more popular because the usage of electrical energy increases with demand. If the DG system runs technically efficient and is priced reasonably, it reduces the greenhouse gas emissions, improves the energy security, increases the power quality and reliability [1]. Distribution system loss mainly depends on the placement and sizing of DG. The minimization of power losses can be achieved with better voltage regulation and improvement of voltage stability in RDS [2,3]. But the main purpose of DG is to act as a source of active electric power and not reactive power [4].

The reactive power also accounts for a portion of total losses. The reactive power loss can be reduced by connecting shunt capacitors in parallel on primary distribution feeders. Therefore, optimal allotment of capacitor in radial distribution networks is the main issue of electric power utilities. The optimal allotment of capacitor deals with determination of location, sizing, category and number of capacitors such that maximum profitable benefits are achieved without violating the constraints [5]. Recently many literatures [6–10] have dealt with the same objective function of reducing both power loss and capacitor cost with proper capacitor allocation.

STATCOMs have been applied in distribution and transmission systems to regulate the bus voltage so as to provide reactive power and power factor control [11]. Using shunt connected voltage source converter known as DSTATCOM, power quality problems such as unbalanced load, voltage sag, voltage fluctuations and voltage unbalance are compensated [12]. The concept of replacing the shunt capacitor using DSTATCOM in RDS in order to reduce the power losses stated in [13]. The DSTATCOM is a power electronic-based Synchronous Voltage Generator (SVG) capable of providing rapid and uninterrupted capacitive and inductive reactive power supply.

The balance between the global and local search throughout the run makes PSO a successful optimization algorithm. In past several years, PSO has been successfully applied in many research and applications areas [14]. It is demonstrated that PSO gets better results faster when compared with other methods. Also in order to minimize the computational burden, this work has been solved using PSO instead of classic method mentioned in [12,15].

From this literature review it is understood that, placement and sizing of DG and DSTATCOM in RDS, reduce the total power loss with voltage improvement. In this work, real power loss is reduced using DG and reactive power compensation is done using DSTATCOM, thereby the total power loss of the RDS is reduced with voltage improvement. Here DG and DSTATCOM placement is analyzed

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in five different cases. PSO algorithm is used for implementation and the final results are analyzed with the help of LSF.

Distribution Static Compensator (DSTATCOM)

Fig. 1 shows the model of DSTATCOM, which shows that it is capable of injecting active power in addition to reactive power. Figs. 2 and 3 show the single line diagram of two buses of a distribution system and its phasor diagram respectively.

From Fig. 2, the relationships between voltage and current can be written as

$$V_{oj}\angle\alpha_0 = V_{oi}\angle\delta_0 - (R + jX)I_{oL}\angle\theta_o \tag{1}$$

where V_{oj} is the voltage of bus *j* before compensation; α_o is the angle of voltage V_{oj}; V_{oi} is the voltage of bus *i* before compensation; δ_0 is the angle of voltage V_{oi}; $Z = R + jX$ is the impedance between buses '*i*' and '*j*'; I_{oL} is the current flow in line before compensation; θ_0 is the angle of current I_{oL}.

In the steady state condition, the changes occur in all node voltages, especially the neighbouring nodes of DSTATCOM location and the branch current of the network is changed by installing the DSTATCOM in RDS [12]. The schematic diagram of buses '*i*' and '*j*' of the Distribution System, when DSTATCOM is installed for voltage regulation in bus '*j*', is shown in Fig. 4. The phasor diagram of these buses with DSTATCOM is shown in Fig. 5. Voltage of bus *j* changes from V_j to V_{jnew} when DSTATCOM is used.

$$\angle I_{D\text{-}STATCOM} = (\pi/2) + \alpha_{new}, \quad \alpha_{new} < 0 \tag{2}$$

$$V_{jnew}\angle\alpha_{new} = Vi\angle\delta - (R + jX)I_L\angle\theta - (R + jX)I_{D\text{-}STATCOM}\angle((\pi/2) + \alpha_{new}) \tag{3}$$

where $I_{D\text{-}STATCOM}\angle((\pi/2) + \alpha_{new})$ is the injected current by DSTATCOM; α_{new} is the angle of corrected voltage; $V_{jnew}\angle\alpha_{new}$ is the angle voltage of bus '*j*' after compensation; *Vi* is the angle voltage of bus '*i*' before compensation; δ is the angle of voltage *Vi*; I_L is the current flow in line after DSTATCOM installation; θ is the angle of current I_L.

Injected power by DSTATCOM can be written as

$$jQ_{D\text{-}STATCOM} = V_{jnem}(I_{D\text{-}STATCOM})^* \tag{4}$$

where

$$V_{jnew} = V_{jnew}\angle\alpha_{new} \tag{5}$$

$$I_{D\text{-}STATCOM} = I_{D\text{-}STATCOM}\angle((\pi/2) + \alpha_{new}) \tag{6}$$

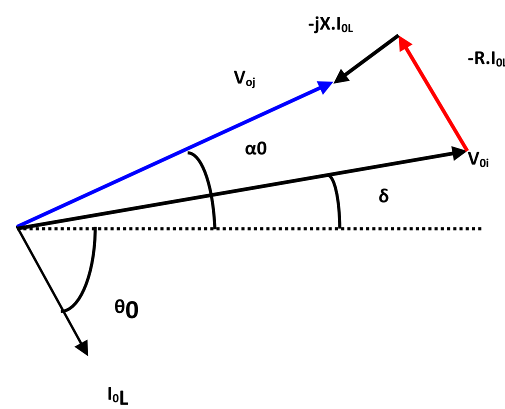

Fig. 3. Phasor diagram of voltages and current of the system shown in Fig. 2.

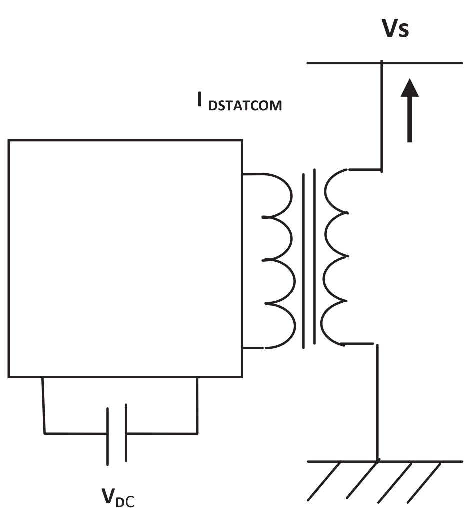

Fig. 1. A model of STATCOM.

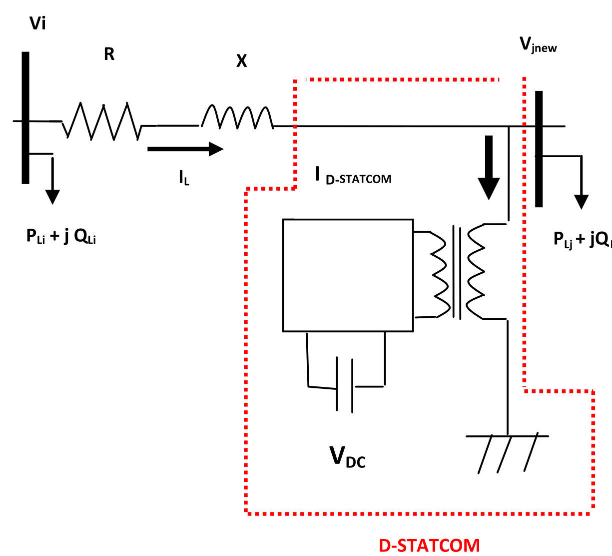

Fig. 4. Single line diagram of two buses of a distribution system with consideration of DSTATCOM.

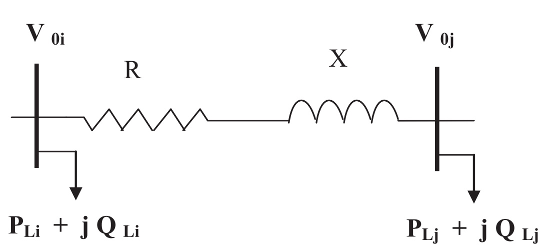

Fig. 2. Single line diagram of two buses of a distribution system.

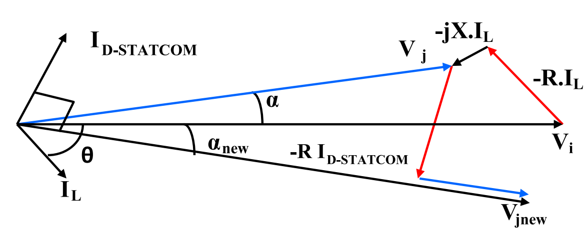

Fig. 5. Phasor diagram of voltages and currents of the system shown in Fig. 4.

Problem formulation

The objective of DG and DSTATCOM placement in the distribution system is to minimize the power loss of the system, subjected to certain working constraints given in Eq. (7). Mathematically, the objective function of the problem is described as:

$$\min f = \min(P_{Loss}) \tag{7}$$

where P_{Loss} is the total power loss of the RDS.

Constraints:

Equality Constraint:

Angle difference between V_{jnew} and $I_{D\text{-}STATCOM}$ = 90°.

To improve the power factor $I_{D\text{-}STATCOM}$must be kept in quadrature with V_{jnew}.

Inequality Constraints:

Power constraints:

The bus real power is limited to:

$$P_{LOSS} + \sum P_{Dj} = \sum P_{DGj} \tag{8}$$

The real power generation at node '*j*' by the installation of DG must be equal to the sum of the real power loss at that node to the actual real power demand at that node.

The bus reactive compensation power is limited to:

$$Q_j^c \leqslant \sum_{j=1}^{n} Q_{Lj} \tag{9}$$

where Q_j^c and Q_{Lj} are the compensated reactive power at bus '*j*' and the reactive load power at bus '*j*', respectively. To maintain the power quality, Q_j^c must be less than or equal to Q_{Lj} also voltage magnitude of each node and current through each branch must lie within the permissible range.

Voltage constraints:

$$V_{j\min} \geqslant Vj \geqslant |V_{j\max}|, \quad j = 1, 2, \ldots, N \tag{10}$$

Current constraints:

$$|Ij| \leqslant |Ij\max|, \quad j = 1, 2, \ldots, N \tag{11}$$

where V_{jnew} is the voltage of bus '*j*' after placement of DSTATCOM and $I_{D\text{-}STATCOM}$ is the current through the DSTATCOM. P_{LOSS} is the real power loss. P_{DGj} is the real power generation using DG at bus '*j*', P_{Dj} is the power demand at bus '*j*'. V_{jmin} and V_{jmax} are the minimum and maximum voltages of the *j*th bus respectively. Similarly I_{jmax} is the maximum value of the branch current.

Load flow analysis

The traditional load flow methods used in transmission systems, such as the Gauss–Seidel, Newton–Raphson and fast decoupled methods cannot be used to find the voltages and line flows in distribution systems because of high R/X ratio. For distribution systems, many specially designed load flow algorithms have been proposed in the literature [15–21]. In this paper A Direct Approach for Distribution System Load Flow Solution [22] has been used.

Direct load Flow (DLF) analysis

For distribution networks, the complex load S_i of bus '*i*' is expressed as,

$$S_i = P_i + Q_i, \quad i = 1, 2, \ldots, N \tag{12}$$

where N is the total no of buses, P_i is the real power at *i*th bus and Q_i is the reactive power at the *i*th bus. Current injection at bus '*i*' is given as,

$$I_i = (S_i/V_i)^* \tag{13}$$

where V_i is the voltage at bus '*i*'. To develop the two relationship matrix, a simple Radial Distribution System shown in Fig. 1 is used as an example. Using Eq. (13), the power injections can be converted into equivalent current injection matrix. By applying Kirchhoff's Current Law (KCL) to the distribution network the relationship between the bus current injections and branch currents is obtained. Some of the examples of branch current are,

$$B1 = I1 + I2 + I3 + I4 + I5 + I6 + I7 + I8$$
$$B3 = I3 + I4 + I5 + I6 + I7 + I8$$
$$B4 = I4 + I5 + I6$$
$$B6 = I6$$
$$B7 = I7 + I8$$
$$B8 = I8$$

Therefore, the relationship between the bus current injections and branch currents can be expressed as,

$$\begin{bmatrix} B1 \\ B2 \\ B3 \\ B4 \\ B5 \\ B6 \\ B7 \\ B8 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 1 & 1 & 1 & 1 & 1 & 1 \\ 0 & 0 & 0 & 1 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I1 \\ I2 \\ I3 \\ I4 \\ I5 \\ I6 \\ I7 \\ I8 \end{bmatrix} \tag{14}$$

The general form of Eq. (14) is,

$$[B] = [BIBC][I] \tag{15}$$

where BIBC is the bus-injections to branch-currents matrix. The voltage of buses 3, 4, and 5 are written as

$$V3 = V2 - (B3 * Z23) \tag{16a}$$
$$V4 = V3 - (B4 * Z34) \tag{16b}$$
$$V5 = V4 - (B5 * Z45) \tag{16c}$$

Substituting (16a) and (16b) into (16c), (16c) can be rewritten as

$$V5 = V2 - (B3 * Z23) - (B4 * Z34) - (B5 * Z45) \tag{17}$$

Similarly the voltage of all the buses is determined. Therefore, the relationship between branch currents and bus voltages can be expressed as

$$\begin{bmatrix} V1 \\ V1 \\ V1 \\ V1 \\ V1 \\ V1 \\ V1 \\ V1 \end{bmatrix} \begin{bmatrix} V2 \\ V3 \\ V4 \\ V5 \\ V6 \\ V7 \\ V8 \\ V9 \end{bmatrix} = \begin{bmatrix} Z12 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ Z12 & Z23 & 0 & 0 & 0 & 0 & 0 & 0 \\ Z12 & Z23 & Z34 & 0 & 0 & 0 & 0 & 0 \\ Z12 & Z23 & Z34 & Z45 & 0 & 0 & 0 & 0 \\ Z12 & Z23 & Z34 & Z45 & Z56 & 0 & 0 & 0 \\ Z12 & Z23 & Z34 & Z45 & Z56 & Z67 & 0 & 0 \\ Z12 & Z23 & Z34 & 0 & 0 & 0 & Z78 & 0 \\ Z12 & Z23 & Z34 & 0 & 0 & 0 & Z78 & Z89 \end{bmatrix} \begin{bmatrix} B1 \\ B2 \\ B3 \\ B4 \\ B5 \\ B6 \\ B7 \\ B8 \end{bmatrix} \tag{18}$$

Eq. (18) can be expressed as

$$[\Delta V] = [BCBV][B] \tag{19}$$

where BCBV is the branch-current to bus-voltage matrix.

From Eqs. (15) and (19), the relationship between bus current injections and bus voltages are expressed as

$$\begin{aligned}[\Delta V] &= [BCBV][BIBC][I] \quad (20)\\ &= [DLF][I] \quad (21)\end{aligned}$$

The solution for radial distribution load flow can be obtained by solving the Eqs. (22)–(24) iteratively.

$$Ii^k = (Si/Vi^k)^* \tag{22}$$

$$[\Delta V^{k+1}] = [DLF]\ [I^k] \tag{23}$$

$$[V^{k+1}] = [Vo]\ [\Delta V^{k+1}] \tag{24}$$

where 'k' is the iteration count and V_o is the initial voltage.

Power flow calculation

The power flows are computed by the following set of simplified recursive equations derived from the single-line diagram depicted in Fig. 6.

$$P_{i+1} = P_i - P_{Li+1} - R_{Li+1} * \frac{(Pi^2 + Qi^2)}{|Vi^2|} \tag{25}$$

$$Q_{i+1} = Q_i - Q_{Li+1} - X_{Li+1} * \frac{(Pi^2 + Qi^2)}{|Vi^2|} \tag{26}$$

where P_i and Q_i are the real and reactive powers flowing out of bus 'i', and P_{Li} and Q_{Li} are the real and reactive load powers at bus 'i'. The resistance and reactance of the line section between buses 'i' and '$i+1$' are denoted by $R_{i,i+1}$, and $X_{i,i+1}$, respectively. The power loss of the line section connecting buses 'i' and '$i+1$' may be computed as:

$$P_{Loss}(i, i+1) = R_{Li+1} * \frac{(Pi^2 + Qi^2)}{|Vi^2|} \tag{27}$$

$$Q_{Loss}(i, i+1) = X_{Li+1} * \frac{(Pi^2 + Qi^2)}{|Vi^2|} \tag{28}$$

The real, reactive and total power loss of the feeder, $P_{T,Loss}$, may then be determined by summing up the losses of all line sections of the feeder, which is given as:

$$P_{T,LOSS} = \sum_{i=0}^{n-1} P_{LOSS}(i, i+1) \tag{29}$$

$$Q_{T,LOSS} = \sum_{i=0}^{n-1} Q_{LOSS}(i, i+1) \tag{30}$$

$$P_{LOSS} = \sqrt{P_{T,LOSS}^2 + Q_{T,LOSS}^2} \tag{31}$$

Loss Sensitivity Factor (LSF)

The best possible nodes for the placement of DG and DSTATCOM are determined using the LSF. This reduces the search space for the optimization process [23] and in this paper LSF is used with slight modification in the calculation part as given below. According to that, active and reactive power loss given in Eqs. (32) and (33) are rewritten for kth line between buses p and q as,

$$P_{lineloss}(q) = \frac{(P_{eq}^2(q) + Q_{eq}^2(q)) * R(k)}{(V(q))^2} \tag{32}$$

$$Q_{lineloss}(q) = \frac{(P_{eq}^2(q) + Q_{eq}^2(q)) * X(k)}{(V(q))^2} \tag{33}$$

where $P_{eq}(q)$ and $Q_{eq}(q)$ are the total active and reactive power supplied ahead of the node 'q' respectively. In this paper it is suggested to use BIBC matrix for the calculation of $P_{eq}(q)$ and $Q_{eq}(q)$ as shown in Eq. (34) and (35).

$$P_{eq}(q) = BIBC * P_{RLPM} \tag{34}$$

$$Q_{eq}(q) = BIBC * Q_{REPM} \tag{35}$$

where P_{RLPM} and Q_{REPM} are the real and reactive power matrix of the total power system. This makes the calculation fast and easy. In this work, it is taken as the real power is supplied by the DG and the reactive power is compensated by DSTATCOM. Now, both the LSF can be obtained as shown below:

LSF for DG placement is,

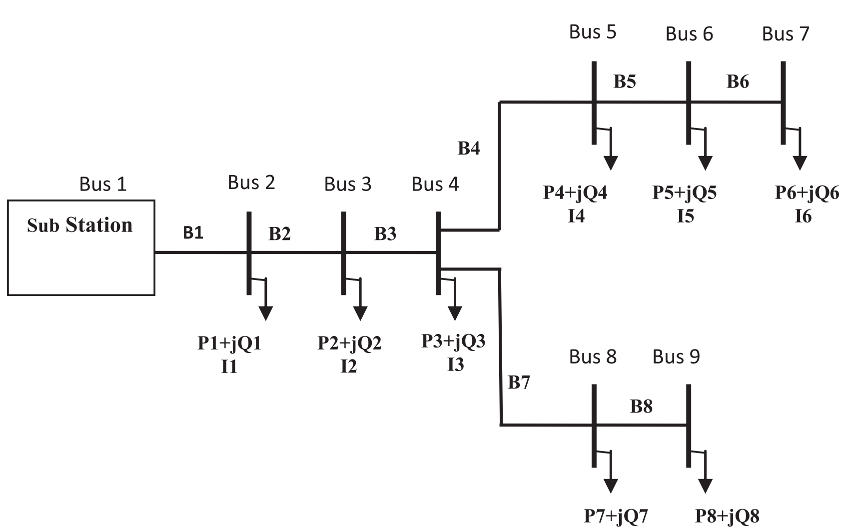

Fig. 6. Simple radial distribution system.

$$\frac{\partial P_{lineloss}}{\partial P_{eq}} = \frac{2 * P_{eq}(q) * R(k)}{(V(q))^2} \quad (36)$$

$$\frac{\partial P_{lineloss}}{\partial Q_{eq}} = \frac{2 * Q_{eq}(q) * R(k)}{(V(q))^2} \quad (37)$$

After calculating the LSF, the buses are arranged in descending order according to LSF values. This sequence is stored in a separate matrix $B(i)$. Now the buses having the voltage less than 0.95 is ordered in a sequence and it is stored in $V(i)$. This $V(i)$ decides whether that particular bus listed in $B(i)$ needs DG or DSTATCOM. From this optimal DG and STATCOM location is identified and the sizing can be done by any of the evolutionary algorithms. In this paper, PSO is suggested to find the optimum size of DG and STATCOM.

Particle Swarm Optimization (PSO)

PSO algorithm is that a population called a swarm is randomly generated and the swarm consists of individuals called particles. Each particle in the swarm denotes a probable explanation of the optimization problem. With a random velocity, each particle moves through a D-dimensional search space [24]. Each particle's velocity and position is updated using the following equations:

$$V_i^{k+1} = \omega V_i^k + C_1 rand1 * (Pbest - S_i^k) + C_2 rand2 * (Gbest - S_i^k) \quad (38)$$

$$S_i^{k+1} = S_i^k + V_i^{k+1} \quad (39)$$

$$\omega = \omega_{\max} - \frac{[(\omega_{\max} - \omega_{\min}) * current\ generation\ number]}{Maximum\ generation\ number} \quad (40)$$

where $\omega_{\max}$ is the initial value of the inertia weight and $\omega_{\min}$ is the final value of the inertia weight.

A certain velocity, which progressively gets close to P_{best} and G_{best} can be calculated using Eq. (38). The current position can be modified by using Eq. (39), where S^k is current searching point, S^{k+1} is modified searching point, V^k is current velocity, V^{k+1} is modified velocity of agent i, ω is weight function for velocity of the agent, C_1 and C_2 are weight coefficients for each term and rand1, rand2 are the random value generated between [0, 1].

Improved Particle Swarm Optimization (IPSO)

A particle search in the region of its neighbours in order to discover the one with the finest result so far, and uses information from that source to change its search in a promising direction. There is no assumption, however, that the best neighbour at time actually found a better region than the second or third best neighbours. Important information about the search space may be neglected through overemphasis on the single best neighbour [25]. So the Velocity equation is improved as

$$V_i^{k+1} = c * [\omega V_i^k + C_1 rand1 * (Pbest - S_i^k) + C_2 rand2 * (Gbest - S_i^k)] \quad (41)$$

where

$$c = \frac{2}{(2 - \phi - \phi 1)} \quad (42)$$

$$\phi 1 = \sqrt{\phi^2 - 4\phi} \quad (43)$$

When constriction is executed as in the second version above, improving the right-hand side of the velocity formula, the constriction coefficient 'c' is calculated from the values of the acceleration coefficient limits ϕ and ϕ_1. Here ϕ is varied between $\phi_{\min}$ and $\phi_{\max}$.

Implementation of proposed work

The PSO-based approach for solving the optimal placement and sizing of DG and DSTATCOM to minimize the total power loss and improvement of voltage profile takes the following steps:

Step 1: Get the Input. The input data are line impedance and bus data (Load Power i.e., Real Power and Reactive Power).
Step 2: Calculate the total power loss and each node voltage using distribution load flow based on Direct Load Flow Method.
Step 3: Set the bus count $C = 2$.
Step 4: Set the generation counter $j = 0$.
Step 5: With random positions and velocities, randomly generate an initial population.
Step 6: For each particle, calculate the total power loss using Eq. (31).
Step 7: Check the bus voltage if it lies within the limits or not. If it is not, then the particle is infeasible.
Step 8: Compare its objective value with the individual best for each particle. If the objective function is lower than 'Pbest', set this value as the recent 'Pbest' and record the equivalent particle position.
Step 9: Select the particle associated with the lowest individual best 'Pbest' of the entire particles, and set the value of this 'Pbest' as the present overall best 'Gbest'.
Step 10: Update the velocity and position of particle using Eqs. (41) and (39) respectively.
Step 11: If the generation number reaches the maximum limit, go to Step 12. Otherwise, set generation index to $j = j + 1$, and go back to Step 5.
Step 12: If the bus count attains the maximum limit, go to step13. Otherwise, set bus count to $C = C + 1$ and go back to step 4.
Step 13: Print out the optimal solutions.

The above step by step procedure is done for cases 2, 3, 4 and 5 that are mentioned in this paper. The optimal solutions include the optimal location, optimal size of DG and DSTATCOM in RDS. The corresponding fitness values to these solutions indicate the minimum total power loss. Using LSF the placement of DG and DSTATCOM is analyzed to discuss the proficiency of this work.

Simulation results and analysis

Table 1 show the parameters used in different algorithms selected for this work. In order to evaluate the proposed work the 12 bus, 34 bus and 69 bus test systems [26] are considered. The rated line voltage of all the test system is 12.6 kV. The total power loss for the 12 bus, 34 bus and 69 bus test systems obtained from the DLF are 0.0247 MW, 0.1638 MW and 0.24479 MW respectively. All the test systems are analyzed with five different cases.

Table 1
Selection of parameters for PSO algorithm.

Parameter	Population	Generation	C_1, C_2	ω_{max}	ω_{min}	Φmax	Φmin
12 Bus	20	150	1.2	0.8	0.1	0.42	0.41
34 Bus	20	150	1.2	0.8	0.1	042	0.41
69 Bus	20	150	0.9	0.8	0.1	0.42	0.41

Table 2
Before the placement of DG and DSTATCOM.

Test system	Total losses (MW)	Voltage (p.u)
12 Bus	0.0207	0.9672
34 Bus	0.2217	0.9663
69 Bus	0.2249	0.9196

Table 3
After the placement of DG or DSTATCOM.

Test system	Bus number	Only DG		Only DSTATCOM	
		Total losses (MW)	Size of DG (MW)	Total losses (MW)	Size of DSTATCOM (MVAr)
12 Bus	9	0.0078	0.0378	0.0100	0.0321
34 Bus	21	0.0729	0.1996	0.1336	0.1606
69 Bus	61	0.0830	1.8761	0.1679	0.9011

Table 4
After the placement of DG and DSTATCOM in 12 bus test system.

	Same place	Different place
Bus number for DG placement	9	9
Bus number for DSTATCOM placement	9	8
Size of DG (MW)	0.0390	0.0475
Size of DSTATCOM (MVAr)	0.0320	0.0378
Total loss (MW)	0.0025	0.0025
Voltage (p.u)	0.9995	0.9838

Table 5
After the placement of DG and DSTATCOM in 34 bus test system.

	Same place	Different place
Bus number for DG placement	21	21
Bus number for DSTATCOM placement	21	20
Size of DG (MW)	0.1371	0.2000
Size of DSTATCOM (MVAr)	0.1634	0.1612
Total loss (MW)	0.0404	0.0378
Voltage (p.u)	1.0041	0.9839

- case 1: Without DG and DSTATCOM. (i.e., DLF analysis results). Test results are tabulated in Table 2.
- case 2: With only DG (active power). Test results are tabulated in Table 3.
- case 3: With only DSTATCOM (reactive power). Test results are tabulated in Table 3.
- case 4: With DG and DSTATCOM (active power and reactive power) at same location. Test results are tabulated in Tables 4–6.
- case 5: With DG and DSTATCOM (active power and reactive power) at different locations. Test results are tabulated in Tables 4–6.

Test system 1: 12-bus system

- case 1: The total power loss is 0.0247 MW and the voltage at the 9th bus is 0.9672 p.u.
- case 2: The total loss after placement of DG is 0.0078 MW. The optimal location and the size of the DG are 9th bus and 0.0378 MW respectively.
- case 3: The total loss after placement of DSTATCOM is 0.0100 MW. The optimal place and the size of the DSTATCOM are 9th bus and 0.0321 MVAr respectively.
- case 4: The DG and DSTATCOM placement is at 9th bus. The total power loss is 0.0025 MW. The size of the DG and DSTATCOM are 0.039 MW and 0.0320 MVAr respectively. The voltage of bus 9 has been improved to 0.9995 p.u and it is 0.9672 p.u before the placement of DG and DSTATCOM.
- case 5: Here the optimal placement of DG is at 9th bus and DSTATCOM is at 8th bus. The total power loss is 0.0025 MW. The size of the DG and DSTATCOM are 0.0475 MW and 0.0378 MVAr respectively. The voltage of bus 9 has been improved to 0.9838 p.u and it is 0.9672 p.u before the placement of DG and DSTATCOM.

Table 6
After the placement of DG and DSTATCOM in 69 bus test system.

	Same place	Different place
Bus number for DG placement	61	62
Bus number for DSTATCOM placement	61	61
Size of DG (MW)	0.1223	0.1080
Size of DSTATCOM (MVAr)	0.9045	0.9039
Total loss (MW)	0.0337	0.0386
Voltage (p.u)	1.0231	0.9562

Fig. 7 shows the voltage profile improvement and the loss comparative analysis of cases 2, 3 and 4 are demonstrated in Fig. 10.

Analysis using LSF

Using the sensitivity analysis, the location of DG and DSTATCOM are ordered as bus 8, 9, 6 and 10. Top four buses are selected for analysis. Therefore, while placing the DG and DSTATCOM in same location, it chooses the bus 9 and for different location it chooses buses 9 and 8 for DG and DSTATCOM respectively.

Also it is concluded that, placement of DG and STATCOM reduces the total loss of the test system.

Test system 2: 34-bus system

- case 1: The total power loss is 0.2217 MW and the voltage at the 21st bus is 0.9663 p.u.
- case 2: The total loss after placement of DG is 0.0729 MW. The optimal place and the size of the DG are 21st bus and 0.1996 MW respectively.
- case 3: The total loss after placement of DSTATCOM is 0.1336 MW. The optimal place and the size of the DSTATCOM are 21st bus and 0.1606 MVAr respectively.
- case 4: The DG and DSTATCOM placement is at 21st bus. The total power loss is 0.0404 MW. The size of the DG and DSTATCOM are 0.1371 MW and 0.1634 MVAr respectively. The voltage of bus 21 has been improved to 1.0041 p.u and it is 0.9663 p.u before the placement of DG and DSTATCOM.
- case 5: Here the optimal placement of DG is at 21st bus and DSTATCOM is at 21st bus. The total power loss is 0.0378 MW. The size of the DG and DSTATCOM are 0.2000 MW and 0.1612 MVAr respectively. The voltage of bus 9 has been improved to 0.9839 p.u and it is 0.9663 p.u before the placement of DG and DSTATCOM.

Figs. 8 and 11 show, the voltage profile improvement and the loss comparative analysis of cases 2, 3 and 4.

Analysis using LSF

From sensitivity analysis, the location of DG and DSTATCOM are ordered as bus 20, 21, 22 and 23. Top four buses are selected for analysis. Therefore while placing the DG and DSTATCOM in the same location, it chooses bus 21 and for different location it chooses buses 21 and 20 for DG and DSTATCOM respectively.

Here also the total loss of the test system is reduced more when both DG and DSTATCOM are placed.

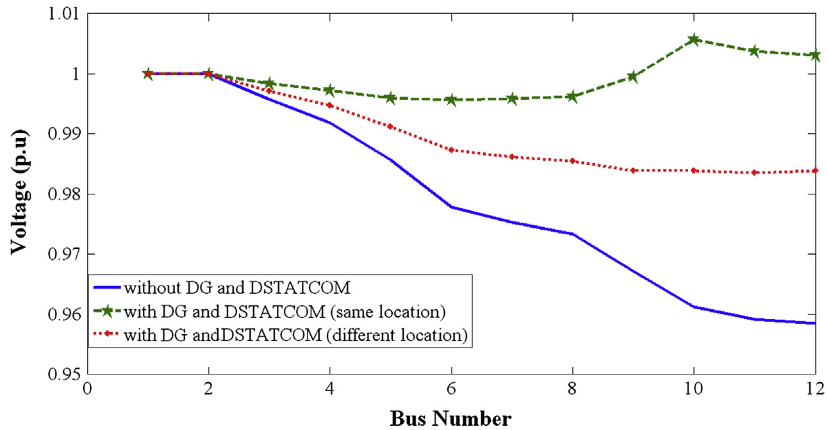

Fig. 7. Voltage profile improvement for 12 bus system.

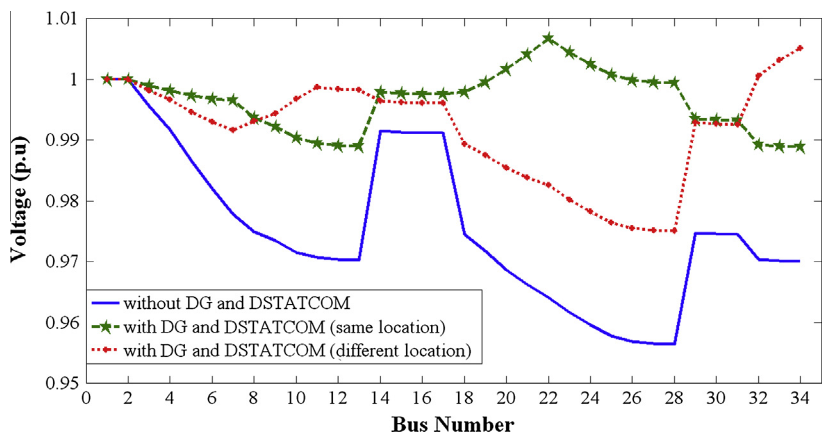

Fig. 8. Voltage profile improvement for 34 bus system.

Test system 3: 69-bus system

case 1: The total power loss is 0.2249 MW and the voltage at the 61th bus is 0.9196 p.u.

case 2: The total loss after placement of DG is 0.0830 MW. The optimal place and the size of the DG are 61th bus and 1.8761 MW respectively.

case 3: The total loss after placement of DSTATCOM is 0.1679 MW. The optimal place and the size of the DSTATCOM are 61th bus and 0.9011 MVAr respectively.

case 4: DG and DSTATCOM placement is at 61th bus. The total power loss is 0.0337 MW. The size of the DG and DSTATCOM are 0.1223 MW and 0.9045 MVAr respectively. The voltage of bus 61 has been improved to 1.0231 p.u and it is 0.9196 p.u before the placement of DG and DSTATCOM.

case 5: Here the optimal placement of DG is at 62th bus and DSTATCOM is at 61th bus. The total power loss is 0.0386 MW. The size of the DG and DSTATCOM are 0.1080 MW and 0.9039 MVAr respectively. The voltage

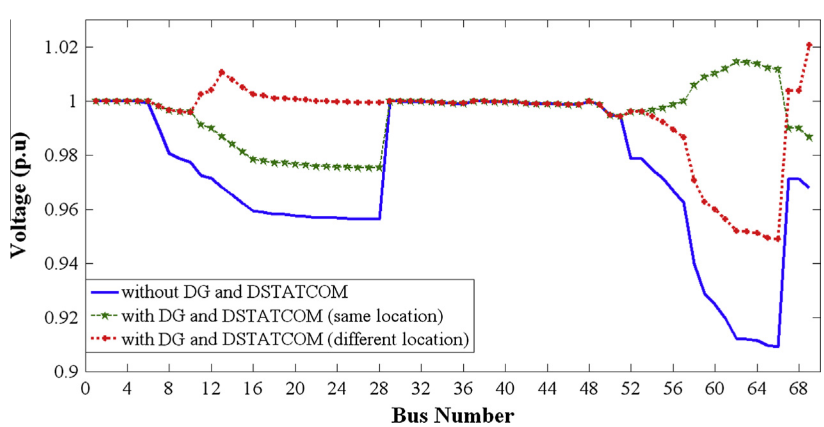

Fig. 9. Voltage profile improvement for 69 bus system.

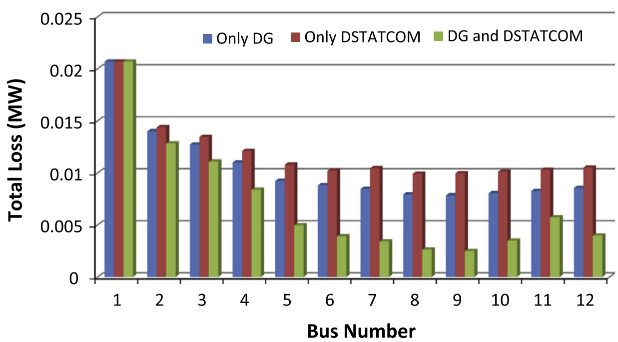

Fig. 10. Comparative analysis of total loss of 12 bus system.

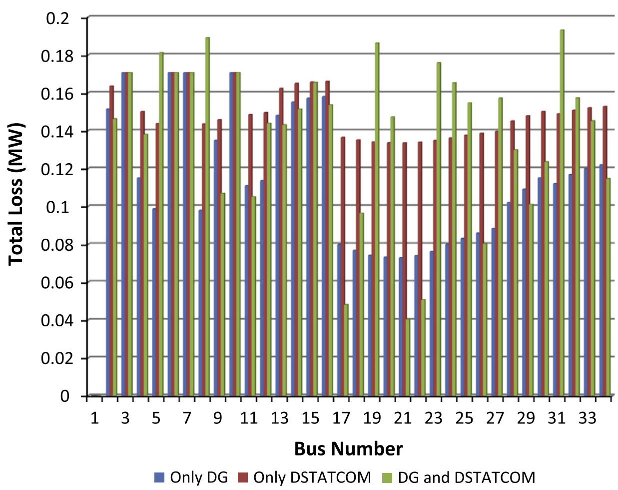

Fig. 11. Comparative analysis of total loss of 34 bus system.

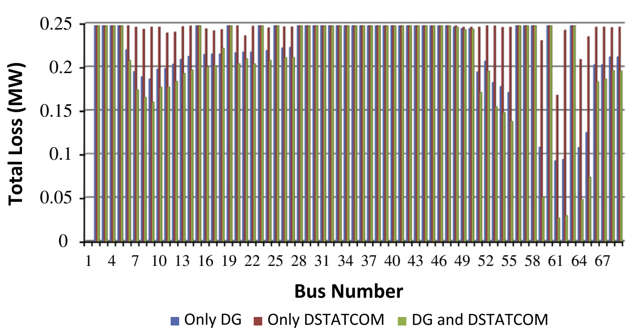

Fig. 12. Comparative analysis of total loss of 69 bus system.

of bus 61 has been improved to 0.9562 p.u and it is 0.9196 p.u before the placement of DG and DSTATCOM.

Figs. 9 and 12 show, the voltage profile improvement and the loss comparative analysis of the last four cases respectively.

Analysis using LSF

From sensitivity analysis, the location of DG and DSTATCOM are ordered as bus 61, 60, 62 and 59. Top four buses are selected for analysis. Therefore while placing the DG and DSTATCOM in same location, it chooses bus 21 and for different places it choose buses 62 and 61 for DG and DSTATCOM respectively.

DG and DSTATCOM placement reduces the total loss of the test system compared to the other cases.

Overall analysis

From the above analysis, it is concluded that placement of both DG and DSTATCOM reduces the total loss equally irrespective of whether they are placed at the same bus or at different buses in the three test systems. Also the results show good improvement in voltage at the chosen optimal locations, when they are placed at the same bus compared with the placement of DG and DSTATCOM in different buses.

Conclusion

In this paper, PSO based DG and DSTATCOM placement and sizing in Radial Distribution System for three different test systems are carried out. The study is done with five different cases. The results are compared and tabulated. Also the results are analyzed using LSF method. The results show that, DG and DSTATCOM placement (cases 4 and 5) reduces the total loss of the test system compared to the other cases (cases 1, 2 and 3). Also DG and DSTATCOM can be placed in a same bus or it can be placed in different buses. In both the cases the results obtained are same. Also the placement of DG and DSTATCOM is proved using LSF in this work. For the future work the DG and DSTATCOM placement can be done by using LSF and the sizing can be done with PSO, because LSF reduces the processing time. From this research it is concluded that optimizing DG and DSTATCOM location and sizing the total power loss of the Radial Distribution System is reduced with voltage improvement using PSO. Also it is suggested that both DG and DSTATCOM placement in same bus has provided the improved voltage profile, compared with the placement at different buses.

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