OPTIMAL DG PLACEMENT FOR MINIMUM REAL POWER LOSS IN RADIAL DISTRIBUTION SYSTEMS USING PSO

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ABSTRACT

This paper presents a new methodology using Particle Swarm Optimization(PSO) for the placement of Distributed Generators(DG) in the radial distribution systems to reduce the real power losses and to improve the voltage profile. A two-stage methodology is used for the optimal DG placement . In the first stage, single DG placement method is used to find the optimal DG locations and in the second stage, PSO is used to find the size of the DGs corresponding to maximum loss reduction. The proposed method is tested on standard IEEE 33 bus test system and the results are presented and compared with an existing method.

KEYWORDS: *DG placement, fuzzy approach, PSO, loss reduction, radial distribution system.*

1. INTRODUCTION

Distributed or dispersed generation (DG) or embedded generation (EG) is small-scale power generation that is usually connected to or embedded in the distribution system. The term DG also implies the use of any modular technology that is sited throughout a utility's service area (interconnected to the distribution or sub-transmission system) to lower the cost of service [1]. The benefits of DG are numerous [2, 3] and the reasons for implementing DGs are an energy efficiency or rational use of energy, deregulation or competition policy, diversification of energy sources, availability of modular generating plant, ease of finding sites for smaller generators, shorter construction times and lower capital costs of smaller plants and proximity of the generation plant to heavy loads, which reduces transmission costs. Also it is accepted by many countries that the reduction in gaseous emissions (mainly CO_2) offered by DGs is major legal driver for DG implementation [4].

The distribution planning problem is to identify a combination of expansion projects that satisfy load growth constraints without violating any system constraints such as equipment overloading [5]. Distribution network planning is to identify the least cost network investment that satisfies load growth requirements without violating any system and operational constraints. Due to their high efficiency, small size, low investment cost, modularity and ability to exploit renewable energy sources, are increasingly becoming an attractive alternative to network reinforcement and expansion. Numerous studies used different approaches to evaluate the benefits from DGs to a network in the form of loss reduction, loading level reduction [6-8].

Naresh Acharya *et al* suggested a heuristic method in [9] to select appropriate location and to calculate DG size for minimum real power losses. Though the method is effective in selecting location, it requires more computational efforts. The optimal value of DG for minimum system losses is calculated at each bus. Placing the calculated DG size for the buses one by one, corresponding system losses are calculated and compared to decide the appropriate location. More over the heuristic search requires exhaustive search for all possible locations which may not be applicable to more than one DG. This method is used to calculate DG size based on approximate loss formula may lead to an inappropriate solution.

In the literature, genetic algorithm and PSO have been applied to DG placement [10-13].In all these works both sizing and location of DGs are determined by GA. In this paper, the optimal locations of distributed generators are identified based on the single DG placement method and a PSO based technique which takes the number and location of DGs as input has been developed to determine the optimal size(s) of DG to minimize real power losses in distribution systems. The advantages of relieving PSO from determination of locations of DGs are improved convergence characteristics and less computation time. Voltage and thermal constraints are considered. The effectiveness of the proposed algorithm was validated using 33-Bus Distribution System [14].To test the effectiveness of proposed method, results are compared with the results of an analytical method reported in [15]. It is observed that the proposed method yield more savings as compared to analytical method.

2. TOTAL REAL POWER LOSS IN A DISTRIBUTION SYSTEM

The total I^2R loss (P_L) in a distribution system having *n* number of branches is given by:

$$P_{Lt} = \sum_{i=1}^{n} I_i^2 Ri \qquad (1)$$

Here I_i is the magnitude of the branch current and R_i is the resistance of the i^{th} branch respectively. The branch current can be obtained from the load flow solution. The branch current has two components, active component (I_a) and reactive component (I_r). The loss associated with the active and reactive components of branch currents can be written as:

$$P_{La} = \sum_{i=1}^{n} I_{ai}^2 Ri \qquad (2)$$

$$P_{Lr} = \sum_{i=1}^{n} I_{ri}^2 Ri \qquad (3)$$

Note that for a given configuration of a single-source radial network, the loss P_{La} associated with the active component of branch currents cannot be minimized because all active power must be supplied by the source at the root bus. However by placing DGs, the active component of branch currents are compensated and losses due to active component of branch current is reduced. This paper presents a method that minimizes the loss due to the active component of the branch current by optimally placing the DGs and thereby reduces the total loss in the distribution system. A two stage methodology is applied here. In the first stage optimum location of the DGs are determined by using fuzzy approach and in the second stage an analytical method is used to determine sizes of the DGs for maximum real loss reduction.

3. IDENTIFICATION OF OPTIMAL DG LOCATIONS BY SINGLE DG PLACEMENT ALGORITHM

This algorithm determines the optimal size and location of DG units that should be placed in the system where maximum loss saving occurs. First optimum sizes of DG units for all nodes are determined for base case and best one is chosen based on the maximum loss saving. If single DG placement is required this process is stopped here. This process is repeated if multiple DG locations are required by modifying the base system by inserting a DG unit into the system one-by-one.

3.1. Methodology

Assume that a single-source radial distribution system with *n* branches and a DG is to be placed at bus *m* and α be a set of branches connected between the source and bus m. The DG produces active current I_{DG}, and for a radial network it changes only the active component of current of branch set α. The current of other branches (∉=α) are unaffected by the DG. Thus the new active current I_{ai}^{new} of the i^{th} branch is given by

$$I_{ai}^{new} = I_{ai} + D_i I_{DG} \qquad (4)$$

where $D_i = 1$; if branch $i \in \alpha$

= 0; otherwise

The loss P_{La}^{com} associated with the active component of branch currents in the compensated currents in the compensated system (when the DG is connected) can be written as

$$P_{La}^{com} = \sum_{i=1}^{n} (I_{ai} + D_i I_{DG})^2 R_i \qquad (5)$$

The loss saving S is the difference between equation 3 and 5 and is given by

$$S = P_{La} - P_{La}^{com} = -\sum_{i=1}^{n} (2D_i I_{ai} I_{DG} + D_{DG} I_c^2) R_i \qquad (6)$$

The DG current I_{DG} that provides the maximum loss saving can be obtained from

$$\frac{\partial S}{\partial I_{DG}} = -2\sum_{i=1}^{n}(D_i I_{ai} + D_i I_{DG})R_i = 0 \quad (7)$$

Thus the DG current for the maximum loss saving is

$$I_{DG} = -\frac{\sum_{i=1}^{n} D_i I_{ai} R_i}{\sum_{i=1}^{n} D_i R_i} = -\frac{\sum_{i\in\alpha} I_{ai} R_i}{\sum_{i\in\alpha} R_i} \quad (8)$$

The corresponding DG size is

$$P_{DG} = V_m I_{DG} \quad (9)$$

V_m is the voltage magnitude of the bus *m*. The optimum size of DG for each bus is determined using eqn (9). Then possible loss saving for each DG is determined by using eqn (6).The DG with highest loss saving is identified as candidate location for single DG placement. When the candidate bus is identified and DG is placed, the above technique can also be used to identify the next and subsequent bus to be compensated for loss reduction.

3.2. Algorithm for Single DG Placement

Step 1: Conduct load flow analysis for the original system .

Step 2: Calculate the DG currents (I_{DG}) and DG size using equations 8 & 9 from *i*=2 for all buses except source bus.

Step 3: Determine loss saving (S) using equation 6, from *i*=2 for all buses except source bus.

Step 4: Identify the maximum saving and the corresponding DG size.

Step5: The corresponding bus is a candidate bus where DG can be placed. Modify the active load at this bus and conduct the load flow again.

Step 6: Check whether the saving obtain is more than 1kW. If yes, go to step 2. Otherwise, go to next step.

Step 7: print all the candidate locations to place DG sources and the sizes.

Here the effect of DG placement on real power loss only is considered. The effect of DG on Reactive power loss, voltage profile and system capacity rise is neglected.

Since the DGs are added to the system one by one, the sizes obtained using single DG placement algorithm are local optima not global optimum solution. The global optimal solution is obtained if multiple DGs are simultaneously placed in the system by using PSO algorithm. This method is explained in next section.

4. PARTICLE SWARM OPTIMIZATION

4.1. Introduction

Particle swarm optimization (PSO) is a population-based optimization method first proposed by Kennedy and Eberhart in 1995, inspired by social behavior of bird flocking or fish schooling [17]. The PSO as an optimization tool provides a population-based search procedure in which individuals called particles change their position (state) with time. In a PSO system, particles fly around in a multidimensional search space. During flight, each particle adjusts its position according to its own experience (This value is called Pbest), and according to the experience of a neighboring particle (This value is called Gbest),made use of the best position encountered by itself and its neighbor (Figure 1).

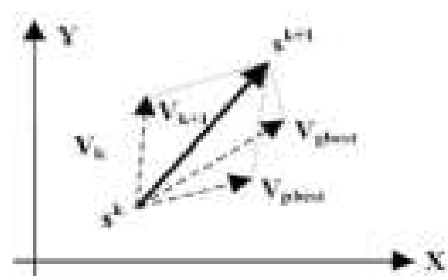

Figure 1: Concept of a searching point by PSO

This modification can be represented by the concept of velocity. Velocity of each agent can be modified by the following equation:

$$v_{id}^{k+1} = \omega v_{id}^{k} + c_1 rand \times \left(pbest_{id} - s_{id}^{k}\right) + c_2 rand \times \left(gbest_{d} - s_{id}^{k}\right)$$

…..(10)

Using the above equation, a certain velocity, which gradually gets close to pbest and gbest can be calculated. The current position (searching point in the solution space) can be modified by the following equation:

$$S_{id}^{k+1} = S_{id}^{k} + v_{id}^{k+1} \quad ....(11)$$

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*, v_{pbest} is velocity based on pbest, , v_{gbest} is velocity based on gbest, *n* is number of particles in a group, *m* is number of members in a particle, $pbest_i$ is pbest of agent *i*, $gbest_i$ is gbest of the group, ω_i is weight function for velocity of agent *i*, C_i is weight coefficients for each term.

The following weight function is used:

$$\omega_i = \omega_{max} - \frac{\omega_{max} - \omega_{min}}{k_{max}} .k \quad ....(12)$$

where, ω_{min} and ω_{max} are the minimum and maximum weights respectively. *k* and k_{max} are the current and maximum iteration. Appropriate value ranges for C_1 and C_2 are 1 to 2, but 2 is the most appropriate in many cases. Appropriate values for ω_{min} and ω_{max} are 0.4 and 0.9 [18] respectively.

4.2. Problem Formulation

$$Min \left\{ P_{Lt} = \sum_{i=1}^{n} |I_i|^2 R_i \right\} ...(13)$$

Subject to voltage constraints:

$$|V_{i\,min}| \le |V_i| \le |V_{i\,max}| \quad ...(14)$$

current constraints:

$$|I_{ij}| \le |I_{ij\,max}| \quad ...(15)$$

Where I_i is the current flowing through the i^{th} branch which is dependent on the locations and sizes of the DGs. Locations determined by fuzzy method are given as input.so the objective function is now only dependent on the sizes of the DGs at these locations.

R_i is the resistance of the i^{th} branch.

V_{imax} and V_{imin} are the upper and lower limits on i^{th} bus voltage.

I_{ijmax} is the maximum loading on branch ij.

The important operational constraints on the system are addressed by equations 14 and 15.

4.3. Algorithm to find the DG sizes at desired locations using PSO Algorithm

The PSO-based approach for finding sizes of DGs at selected locations to minimize the real power loss is as follows:

Step 1: Randomly generates an initial population (array) of particles with random positions and velocities on dimensions in the solution space. Set the iteration counter *k* = 0.

Step 2: For each particle if the bus voltage and line loading are within the limits, calculate the total real power loss. Otherwise, that particle is infeasible.

Step 3: For each particle, compare its objective value with *the individual best.* If the objective value is lower than *Pbest,* set this value as the current *Pbest,* and record the corresponding particle position.

Step 4: Choose the particle associated with the minimum *individual best Pbest* of all particles, and set the value of this *Pbest* as the current *overall best Gbest.*

Step 5: Maximum fitness and average fitness values are calculated. Error is calculated using The equation 16.

Error = (maximum fitness - average fitness) … (16)

If this error is less than a specified tolerance then go to step 9.

Step 6: Update the velocity and position of particle using equations (10) and (11) respectively.

Step 7: New fitness values are calculated for the new positions of all the particles. If the new fitness value for any particle is better than previous pbest value then pbest value for that particle is set to present fitness value. Similarly gbest value is identified from the latest pbest values.

Step 8:The iteration count is incremented and if iteration count is not reached maximum then go to step 2.

Step 9:gbest particle gives the optimal DG sizes in *n* candidate locations and the results are printed.

5. RESULTS AND DISCUSSION

First load flow is conducted for IEEE 33 bus test system[7]. The power loss due to active component of current is 136.9836 kW and power loss due to reactive component of the current is 66.9252 kW. A program is written in "MATLAB" to calculate the loss saving, DG size and location for maximum loss saving . For the first iteration the maximum loss saving is occurring at bus 6. The candidate location for DG is bus 6 with a loss saving of 92.1751 kW. The optimum size of DG at bus 6 is 2.4886 MW. By assuming 2.4886 MW DG is connected at bus 6 of base system and is considered as base case. Now the candidate location is bus 15with 0.4406 MW size and the loss saving is 11.4385 KW. This process is repeated till the loss saving is insignificant. The results are shown in Table I.

Table I: Single DG placement results

iteration No.	Bus No.	DG Size (MW)	Saving (KW)
1	6	2.4886	92.1751
2	15	0.4406	11.4385
3	25	0.6473	7.6936
4	32	0.4345	8.1415

The solution obtained above is local optimum solution but not global optimum solution. The DG sizes corresponding to global optimum solution are determined using PSO method. The candidate locations for DG placement are taken from single DG placement algorithm i.e. 6,15,25,32.With these locations, sizes of DGs are determined by using Particle swarm optimization Algorithm described in section 4. The sizes of DGs are dependent on the number of DG locations. Generally it is not possible to install many DGs in a given radial system. Here 4 cases are considered . In case I only one DG installation is assumed. In case II two DGs , in case III three DGS and in the last case four DGs are assumed to be installed. DG sizes in the four optimal locations, total real power losses before and after DG installation for four cases are given in Table II.

The last column in Table II represents the saving in Kw for 1 MW DG installation. The case with greater ratio is desirable. As the number of DGs installed is increasing the saving is also increasing. In case4 maximum saving is achieved but the number of DGs are four . Though the ratio of saving to DG size is maximum of all cases which represent optimum solution but the number of DGs involved is four so it is not economical by considering the cost of installation of 4 DGs. But in view of reliability, quality and future expansion of the system it is the best solution.

Table III shows the minimum voltage and % improvement in minimum voltage compared to base case for all the four cases. In all the cases voltage profile is improved and the improvement is significant. The voltage profile for all cases is shown in Fig.2.

Table III: Voltage improvement with DG placement

case No.	Bus No.	Min Voltage	% change
Base case	18	0.9118	
case1	18	0.9498	4.16
case2	33	0.9543	4.66
case3	33	0.9544	4.67
case4	30	0.9716	6.56

Table II: Results of IEEE 33 bus system.

Case	bus locations	DG sizes(Mw)	Total Size(MW)	losses before DG installation (Kw)	loss after DG installation (Kw)	saving(Kw)	saving/ DG size
I	6	2.5775	2.5775	203.9088	105.0231	98.8857	39.9
II	6	1.9707	2.5464		89.9619	113.9469	44.75
	15	0.5757					
III	6	1.7569	3.1152		79.2526	124.6562	40.015
	15	0.5757					
	25	0.7826					
IV	6	1.0765	3.0884		66.5892	137.3196	44.86
	15	0.5757					
	25	0.7824					
	32	0.6538					

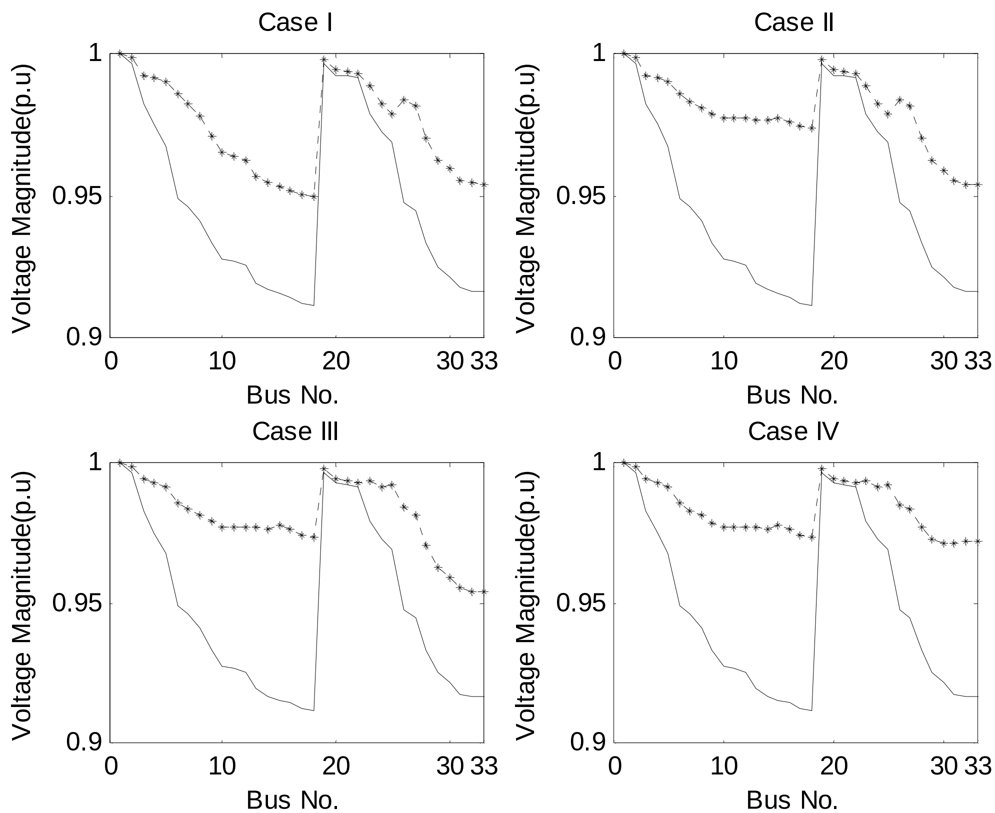

Fig.2:Voltage profile with and without DG placement for all Cases

Table IV :Loss reduction by DG placement

case No.	P_{La} **(kW)**	**% Saving**	P_{Lr} **(kW)**	**% Saving**	P_{Lt} **(kW)**	**% Saving**
Base case	136.98	----	66.92	----	203.909	----
Case1	43.159	68.49	61.86	7.56	105.023	48.49
Case2	28.523	79.18	61.44	8.2	89.9619	55.88
Case3	18.086	86.8	61.16	8.6	79.2515	61.134
Case4	5.5676	95.94	61.02	8.82	66.5892	67.34

Table IV shows % improvements in power loss due to active component of branch current, reactive component of branch current and total active power loss of the system in the four cases considered. The loss due to active component of branch current is reduced by more than 68% in least and nearly 96% at best. Though the aim is reducing the P_{La} loss, the P_{Lr} loss is also reducing due to improvement in voltage profile. From Table IV it is observed that the total real power loss is reduced by 48.5% in case 1 and 67% in case 4.

The convergence characteristics of the solution of PSO for all the four cases are shown in figure 3.

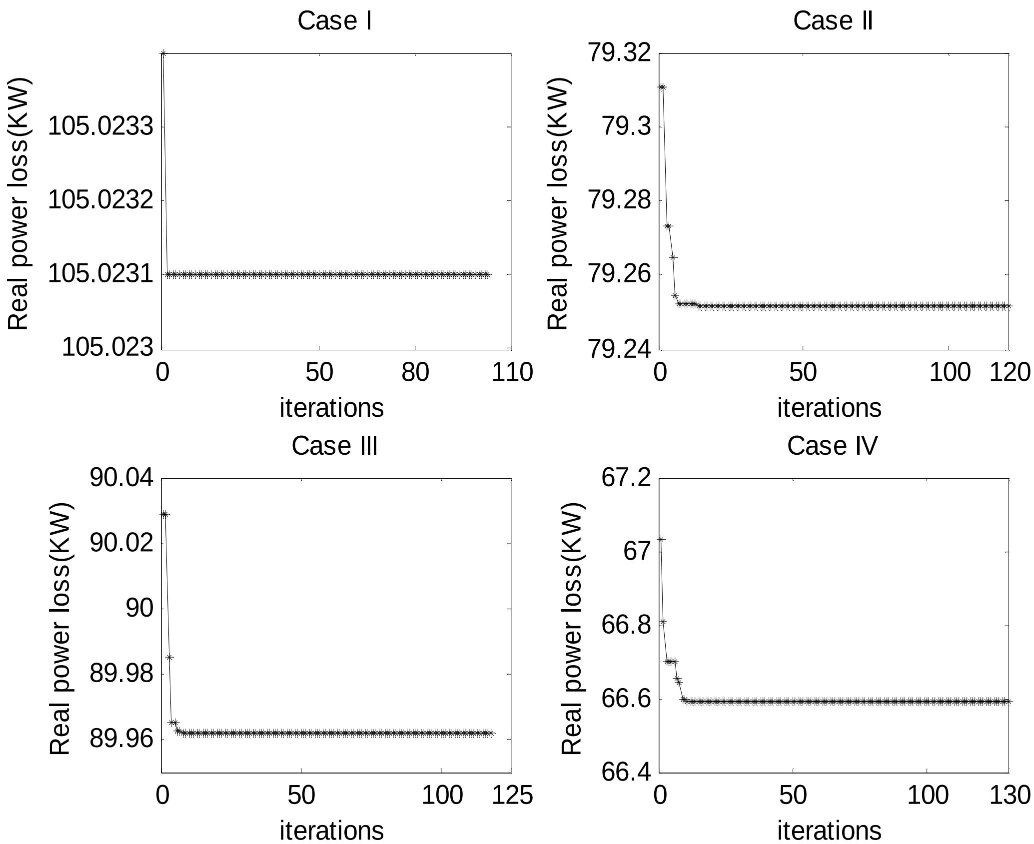

Figure 3: Convergence characteristic of the 33 bus test system.

Table V shows the minimum, average and maximum values of total real power loss from 100 trials of PSO-OPDG. The average number of iterations and average CPU time are also shown.

Table V: Performance of PSO algorithm for IEEE 33 Bus System

Total real power loss (kW)	Case I	Case II	Case III	Case IV
Min	105.023	89.9619	79.2515	66.5892
Average	105.023	89.9619	79.2515	66.5892
Max	105.023	89.9619	79.2515	66.5892
Avg. No. of iterations	102.56	118.23	122.07	129.98
Average Time (Min.)	0.667	89.9619	0.9823	1.063

5.1.Comparison Performance

A comparison of results by proposedmethod with an existing analytical method[15] is shown in Table VI.

Table VI: Comparison of results of IEEE 33-bus system by proposed method and other existing method.

Case	Bus No	sizes(Mw)		Total Size(Mw)		saving(Kw)	
		PM	AM	PM	AM	PM	AM
1	6	2.5775	2.4886	2.5775	2.4886	98.8857	92.1751
2	6	1.9707	1.8981	2.5464	2.4676	113.9469	113.859
	15	0.5757	0.5695				
3	6	1.7569	1.6923	3.1152	3.034	124.6562	124.579
	15	0.5757	0.5695				
	25	0.7826	0.7722				
4	6	1.0765	1.0188	3.0884	3.0107	137.3196	137.247
	15	0.5757	0.5695				
	25	0.7824	0.7722				
	32	0.6538	0.6502				

Savings by PSO algorithm are a little higher than the existing analytical method. The reason for this is in analytical method approximate loss formula is used. Table VII shows comparison of voltage profile improvement by the two methods. The minimum voltage and % improvement in minimum voltage compared to base case for all the four cases, for the two methods discussed, are shown in this Table.

From the above tables it is clear that beyond producing the results that matches with those of existing method, proposed method has the added advantage of easy implementation of real time constraints on the system like time varying loads, different types of DG units etc., to effectively apply it to real time operation of a system.

Table VII: Comparison of Voltage improvement

case No.	Min Voltage		% improvement	
	PM	AM	PM	AM
Base case	0.9118		---	
case1	0.9498	0.9486	2.149	1.985
case2	0.9543	0.9596	2.533	2.358
case3	0.9544	0.9621	2.533	2.358
case4	0.9716	0.98	6.153	5.933

6. CONCLUSIONS

In this paper, a two-stage methodology of finding the optimal locations and sizes of DGs for maximum loss reduction of radial distribution systems is presented. Single DG placement method is proposed to find the optimal DG locations and a PSO algorithm is proposed to find the optimal DG sizes. Voltage and line loading constraints are included in the algorithm.

This methodology is tested on IEEE 33 bus system. By installing DGs at all the potential locations, the total power loss of the system has been reduced drastically and the voltage profile of the system is also improved. Inclusion of the real time constrains such as time varying loads and different types of DG units and discrete DG unit sizes into the proposed algorithm is the future scope of this work.

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