Optimal Placement and Sizing of Multiple Distributed Generation using Combined Differential Evaluation - HPSO Method

V. Veera Nagireddy, D. V. Ashok Kumar, K. Venkata Reddy

***Abstract-* Integration of renewable energy based Distributed Generation (DG) units in modern days of conventional radial distribution systems provides potential benefits in terms service continuity and makes more reliable. The power injections from renewable sources are located close to the load centers which provide system voltage support, reduction in system losses and performance improvement. This paper presents an enhanced approach for DG placement in radial distribution feeders to reduce the real power loss and to improve the voltage profile. The DG placement approach involves the identification of location for DG placement and the size of the DG to be installed at the identified location. The location of the nodes where the DG should be placed is decided by a hybrid Particle Swam Optimization and Differential Evaluation method. A case study with an IEEE 34 bus distribution feeder is presented. A comparison is made between the proposed HPSO approach and the classical Particle Swarm Optimization (PSO). The proposed hybrid Differential Evaluation Particle Swarm Optimization (DEPSO) method is proven to give better results in terms of loss reduction and better voltage profile.**

***Index Terms* — particle swarm optimization, PSO, Differential evolution, DEPSO, distributed generation, voltage profile improvement, loss reduction, Load flows.**

I. INTRODUCTION

Distributed generation (DG) refers to small-scale (1 kW – 50 MW) electric power generators that produce electricity at a site close to customers or that are tied to an electric distribution system. There are many reasons a customer may choose to install a distributed generator [2]. DG can be used to generate a customer's entire electricity supply, for peak shaving (generating a portion of a customer's electricity onsite to reduce the amount of electricity purchased during peak price periods). The distributed generation systems are operated in parallel with utility power systems, especially with reverse power flow, the power quality problems become significant. Power quality problems include frequency deviation, voltage fluctuation, harmonics and reliability of the system [7]. As the modern days of human need of electric energy demand is ever increasing. Due to limitation on fossil fuel resources, alternative solutions to traditional large power stations are under high priority in recent years to meet growing energy demand of the future [14]. Also large power stations are discouraged due to many environmental concerns.

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But the power system today over 21% of the total electrical energy generated in India as a loss in Transmission (5-7%) and Distribution (15-18%). The production of electrical energy is deficit in the country is currently about 35% yearly but in season of summer more than 50% now a day [6]. Clearly it is identified that the reduction in losses can reduces this deficit significantly. It is possible to bring down the distribution losses to 6-8% level in India with the modern technological options (including information technology) in the Electrical Power Distribution Sector which will enhance better controlling and monitoring [1]. The way of utilizing the Renewable sources can significantly improve the performance of distribution system. Generally, the term Distributed Generation (DG) refers to electric power generation technology which is integrated within distribution systems, nearer to the consumers. Distributed generators are connected to the medium or low voltage grid. DG improves the operation value of the distribution network. It can reduce the cost of electricity, and lower emissions of air pollutants. They are not centrally planned and usually are smaller than 30 MW [4]. The integration of distributed generation resources to the grid is the exploitation of the renewable resources such as hydro, wind, solar, geothermal, biomass and ocean energy, fuel cells which are naturally available around the country and also are smaller in size. Accordingly, these resources can only be tapped through integration to the distribution system by means of distributed generation [5]. Even there is no consensus on the exact definition of distributed generation (DG). Particle Swarm Optimization (PSO) and Differential Evolution Particle Swarm Optimization (DEPSO) are the popular methods in all the engineering fields. In this paper, DEPSO method has been used to find the size and location of the DGs. The DG sizing is designed with the objective function, which minimizes the power loss. Particle Swarm Optimization is an optimization system in which each agent called particle flies in M-dimensional space S as per hysterical experiences of its own and its colleagues. The velocity of k^{th} particle is represented as $u_k = (u_{i1}, u_{i2}, \dots\dots, u_{im}, \dots\dots u_{iM})$ and the location of the particle is $y_k = (y_{i1}, y_{i2}, \dots\dots, y_{im}, \dots\dots y_{iM})$. The best previous position is represented as $p_i = (p_{i1}, p_{i2}, \dots\dots, p_{im}, \dots\dots p_{iM})$, called p_{best}. The index of the best p_{best} is represented by the symbol g, called g_{best}. The particles are calculated at each step by following equations [8]:

$$u_{in} = u_{in} + d_1.rand().(p_{im} - y_{im}) + d_2.rand().(p_{gm} - y_{im}) \quad (1)$$

$$y_{im} = y_{im} + u_{im} \quad (2)$$

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Where u is velocity, d_1 and d_2 are acceleration Constants $rand()$ are random values ranges from 0 to 1. In certain stage of evaluation, the inactive particles may present because of too closeness of p_{best} and g_{best}. The lost of diversity for $|p_{im} - p_{gm}|$ is typically occurred in the later stage of evolution process. The DPSO version [9] introduces random mutations on the y_{im} of particles with small probability d_n, which is difficult to be determined along with the evolution, at least not be too large to avoid disorganization of the swarm. This can be improved by a Gaussian distribution [10], but a function of consensus on the step-size along with the search process is preferable. A bare bones version [11] for satisfying such requirements is to replace the equations (1) by a Gaussian mutation with the mean $(p_{im} + p_{gm})/2$and the standard deviation$|p_{im} - p_{gm}|$, which may be also be inefficient when $|p_{im} - p_{gm}|$ is very small.

II. MATHEMATICAL FORMULATION FOR DG MODEL

The DGs can be modeled as a negative load delivering real and reactive power to the Radial distribution system [15]. The objective function for loss minimization is given by

$$minimize\ f = \sum_{ij=1}^{n} P_{lossij} \quad (3)$$

The above equation is subject to following constraints:

i. Voltage magnitude at each node must be within permissible ranges to maintain power quality.

$$v_j^{min} \le v_j \le v_j^{max} \quad (4)$$

ii. Magnitude of Current in each branch (feeder, laterals, and switches) must be within their permissible ranges.

$$\mathrm{I}_{ij} \le \mathrm{I}_{ij}^{max} \quad (5)$$

The total loads of any partial network should not exceed the capacity limit of that total power source.

$$P_{ij} \le P_{ij}^{max} \quad (6)$$

$$Q_{ij} \le Q_{ij}^{max} \quad (7)$$

iii. The total active power line losses of the network are always greater than or equal to the distributed generator active losses of the network.

$$\sum_{ij} \mathrm{P_{lossG}} \le \sum_{ij} \mathrm{P_{loss}} \quad (8)$$

In addition to that the total power generated by DG can be limited subject to a penetration level 10%. i.e. the power generated by DG must be less than or equal to 10% of total feeder load [3].

$$\sum_j \mathrm{P_{Gj}} \le 0.1 \sum_j \mathrm{P_{Lj}} \quad (9)$$

$$\sum_j \mathrm{Q_{Gj}} \le 0.1 \sum_j \mathrm{Q_{Lj}} \quad (10)$$

III. DIFFERENTIAL EVOLUTION PARTICLE SWARM OPTIMIZATION (DEPSO)

A. Particle Swarm Optimization (PSO):

Particle swarm optimization (PSO) is a population based stochastic search technique, which optimizes a problem iteratively to improve a candidate solution. It is inspired by social behavior of bird flocking and fish schooling [13]. Particle velocity is very important parameter in PSO, because it is the step size of the swarm. All particles proceed by adjusting the velocity that each particle moves in every dimension of the search space in each step. Exploration and exploitation are the two important characteristics. The ability to explore different area of the search space for locating a good optimum is exploration. While exploitation is the ability to concentrate the search around a searching area for refining a good solution. When the velocity increases to large values, then particle's positions update quickly. As a result, particles leave the boundaries of the search space and diverge. Therefore, to control this divergence, particles' velocities are reduced in order to stay within boundary constraints. The sequence of fitness evaluation for each PSO candidate solution is shown in Fig. 1. During the process of optimization, high speed of convergence sometimes generates a quick loss of diversity which leads to undesirable premature convergence.

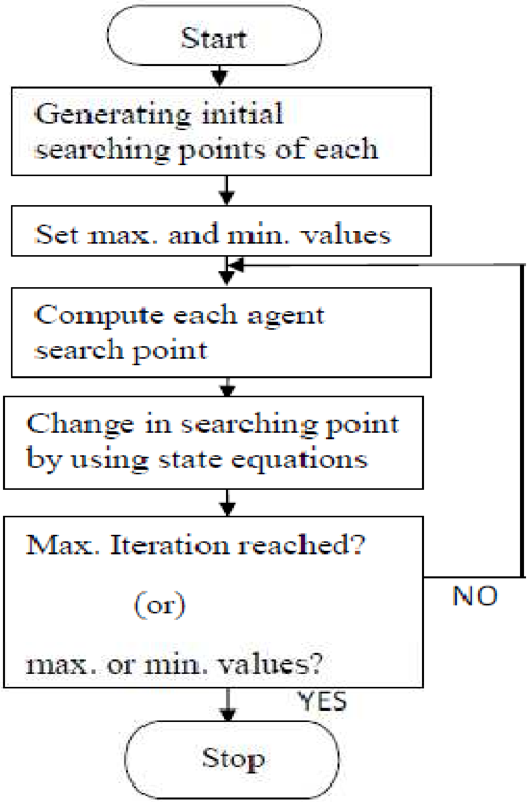

Fig. 1 Flow Chart of PSO

So algorithm suffers from the partial optimism, which degrades the regulation of its speed and direction and also decreases accuracy. These disadvantages can be overcome by differential evolution combining with particle swarm optimization to improve the accuracy.

B. Proposed DEPSO Algorithm:

The application of DEPSO algorithm for finding the optimal DG penetration level is shown in Fig. 2. In the proposed DEPSO scheme, differential evolution operator provides mutations [12] on the p_m, with a trail point, $T_m = p_m$for m^{th} dimension. Each candidate solution from PSO is passed to the conventional power flow followed by the differential evaluation. While searching the optimal location for DG, the DEPSO algorithm uses the three vectors as simple rules for each agent viz. i) to go away from the nearest agent; ii) to step toward the destination; iii) to go to the center of the

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swarm. Each agent tries to modify its position such that using the distance between them p_{best} and current position and g_{best}. The velocity of each agent can be modified from equation (1) to the following equation:

$$u_i^{k+1} = .u_i^k + d_1.rand(1).(p_{best} - y_i^k) + d_2.rand(2).(g_{best} - y_i^k) \quad (11)$$

where u_i^k is velocity of agent at iteration k, v is weighting function, c_i is weighting factor, $rand$ *is* random number between 0 and 1, y_i^k is current position of agent i iteration at k, p_{best} is best position of agent I, and $g_{best}$is best of the group. The inertia weight is to reduce the velocities over time (or iterations), and to converge the swarm more accurately and efficiently compared to the equation (1) with (11). The particles can hardly change their direction to move towards optimum, and the swarm diverges with increase velocities over time.

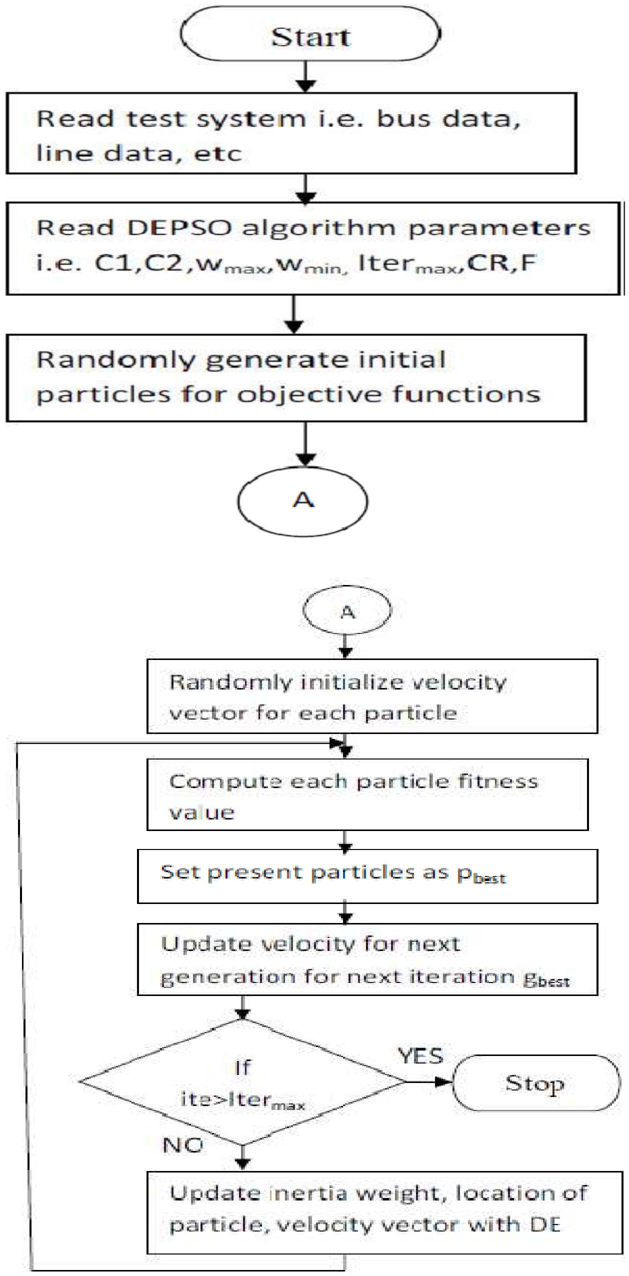

Fig. 2 Flow Diagram of Proposed Approach

The inertia weight is either a fixed value or dynamically changing values. The fixed value can be used at initial implementations for whole process of particles, but to control the exploration and exploitation of the search space, dynamically changing inertia values is used. The large inertia value allows all particles to move freely in the search space at the initial steps and decreases over time. Thus the process is shifting from the exploratory mode to the exploitative mode, which produces good results in optimization problems [16]. The inertia weight value decreases linearly with the iteration number, to control global and local exploration balance, to reach quick optimum with quick convergence. The weighting function according to inertia weight approach is:

$$v = v_{max} - \frac{(v_{max} - v_{min})}{iter_{max}} * iter \quad (12)$$

$$IF\ rand() \leq CR\ then\ y_i = F(b_i - c_i) \quad (13)$$

Otherwise

$$x_{im} = y_{im} \quad (14)$$

Where $a_i, b_i\ and\ c_i$ are the three agents within the population of the m^{th} dimension, $CR(0,1)$ is cross over, F is differential weight and x_{im} is new position.

The overall step-by-step procedure of DEPSO algorithm is as follows.

- Step 1. Read test system data i.e. bus data, line data, DEPSO parameters etc.
- Step 2. Randomly initializes population of individuals and the velocity vector.
- Step 3. Run conventional power flow for each individual to solve real and reactive power balance equations taking into account of DG sources at system frequency.
- Step 4. Evaluate objective function of each individual particle (fitness value)
- Step 5. Set present particles as P*best*.
- Step 6. Update state variables using equations (1) to (10).
- Step 7. Set new particles as g*best* with new positions towards best point.
- Step 8. If the termination criterion is satisfied, go to step 9.
- Step 9. Update the velocity and location of particle with DEPSO method using equations (11) to (14).
- Step 10. Output the optimal configuration of DG units (size and location) and Stop.

DEPSO will provide a consensus mutation on p_m along with diversity of swarm by performing Particle Swarm Optimization (PSO) operator and the Differential Evaluation (DE) operator [12] alternately, i.e. PSO operator using equations (1) and (2) will be performed at the odd generations, and DE operator using equations (11) to (14) will be performed at the even generations, which emerges from the nature of the search itself, keeping the diversity of p_{best} and $g_{best}$by changing p_m.

IV. RESULTS AND DISCUSSIONS

The system under study is an IEEE-34 bus network having system voltage of 11 kV and the total real and reactive power demand of 4.636 MW and 2.873 MVAr respectively.

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The single line diagram of IEEE 34 bus distribution system is shown in Fig. 3.

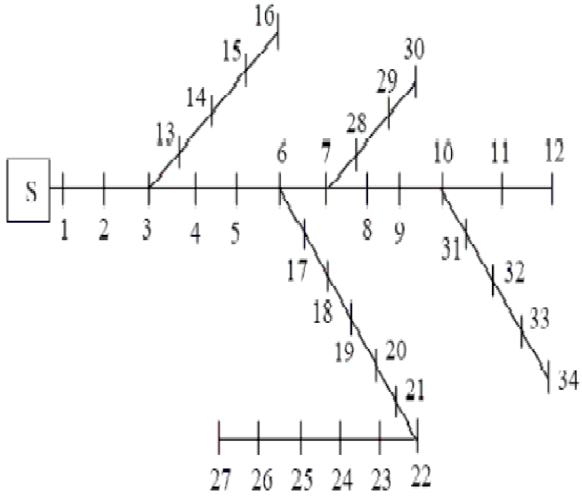

Fig. 3 Single Line Diagram of IEEE 34 Distribution System

First base case load flow (without DG) analysis is done to calculate the bus voltage magnitudes are shown in the below Fig. 4 and total network real power loss, reactive power loss and total losses are 223.77kW, 170.6989kVAR, in the conventional radial distribution system (CRDS). From Fig 4 it is identified that the voltages at buses 19, 22, 20, 21, 23, 24, 25, 26, 27 are below the voltage constraint limits. Hence it is required to improve the voltage profiles with the help of DG placement. The proposed DEPSO-based method and the conventional PSO based methods are applied to IEEE 34 distribution model system as shown in fig 1. The effectiveness of DEPSO compared with the conventional PSO and without DG integration and it is investigated. The inertia weights ω_{min} and ω_{max} is 0.4 and 0.9 respectively which do not depend on problems. According to observations the DEPSO parameters are as C1 = C2= 2.05, rand1 =0.1, rand2 = 0.2, Si=0.729, CR = 0.9 and F = 0.8. The bus voltage comparison for three cases i.e. for without DGs compensation, with multiple DG compensation based on PSO method and with multiple DG compensation based on DEPSO method as shown in figure 4 and figure 5.

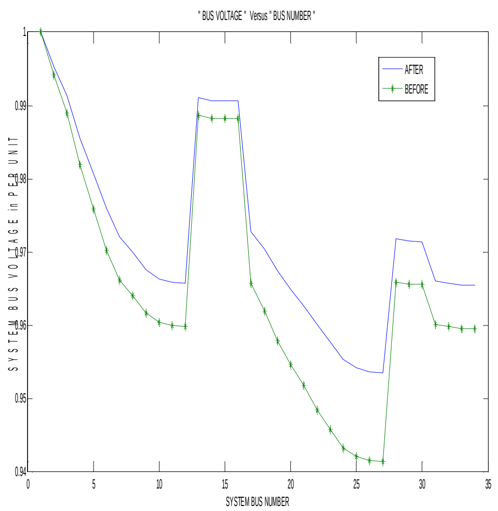

Fig. 4 System Bus Voltage before and after Gs Compensation based on DEPSO Method

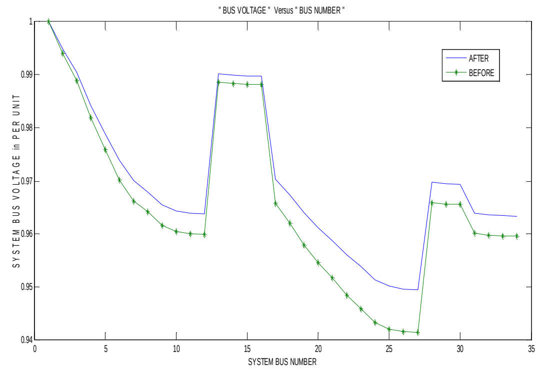

Fig. 5 System Bus Voltage before and after DG Compensation based on PSO Method

Further, load flow with DG capacity of 10% of the total feeder loading capacity is carried out to find optimal placement and size. In this approach system is investigated purely active power & reactive power changes with candidate bus based on Distributed Generation. In this model DG delivers power irrespective of the node voltage. Such source is modeled as a negative load delivering real power and performance of the voltage profiles is in three cases i.e. without DGs, with DGs using PSO based method and with DEPSO based method among this DEPSO method provides best voltage profile. Figure 6 and figure 7 shows the comparison of bus voltages and real power loss of PSO and DEPSO. It is clear from the figures that voltage profile has improved and the real power loss has decreased.

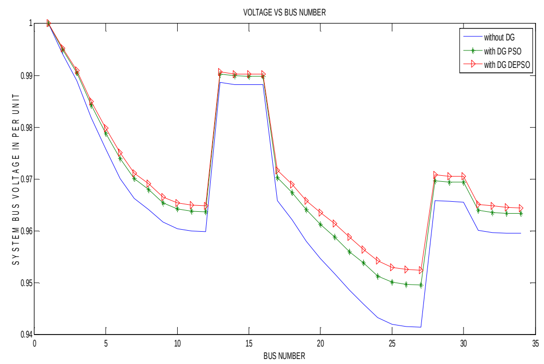

Fig. 6 System Bus Voltage before and after DG Compensation based on PSO Method and DEPSO Method

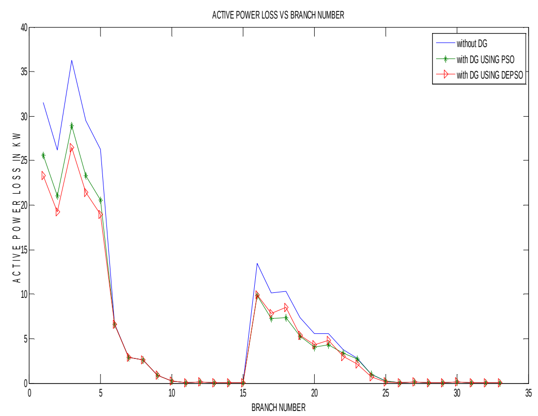

Fig. 7 Active Power Loss before and after DGs Compensation based on PSO Method and DEPSO Method

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The proposed method, DEPSO based method gives best location and size by which best voltage profile can be obtained. The voltage profile throughout distributed system as shown in fig.6 indicates the proposed method can improve voltage profile. Table.1 shows results comparisons of minimum voltage and location and size of DGs, PSO method suggested that two DGs of ratings of 1.186 MVA at node 23 and 0.672 MVA at node 19, in which active losses are 178.779 KW. The proposed DEPSO method suggested that two DGs of ratings of 1.1069 MVA at node 22, 0.6035 MVA at node 19, in which real losses are 169.92 KW. The minimum voltage is 0.9415 p.u with conventional radial distribution system. It can be improved to the voltage is 0.9496 p.u with PSO based method and to the voltage is 0.952 p.u with proposed DEPSO method. Table 1 and Table 2 shows the analysis of results obtained from load flow program before and after placing DGs. It is evident that the voltage profile has improved and the real power loss has decreased due to DGs placement. Comparing the performance of PSO and DEPSO there is an extra loss minimization and voltage profile improvement in DEPSO over PSO. In both the PSO and DEPSO algorithms, the simulation was performed and compared. It is found that in the proposed work, the percentage of reduction in loss is 24.06%, the percentage of increase in voltage profile is 1.147%. But the PSO based method has 20.10% and 0.86% respectively. Hence, the proposed DEPSO approach is proved to provide a better performance.

Table.1 Results of DGs Location & Sizing

Bus No.	19	22	23	27	Total KVAR
PSO	672	----	1186	----	1858
DEPSO	603.5	1106.9	----	----	1710.4

Table.2 Total Power Loss (KW) and Minimum Bus Voltage

Total real power loss (KW)			Minimum voltage (p.u)		
Before DGs placement	After DGs placement		Before DGs placement	After DGs placement	
	With PSO	With DEPSO		With PSO	With DEPSO
223.77	178.779	169.92	0.9415	0.9496	0.9523
% decrease	20.10	24.06	% Increase	0.86	1.147

V. CONCLUSION

This paper presents a hybrid particle swarm with differential evolution operator called DEPSO, to determine the optimum allocation of multiple DGs in radial distribution system to reduce losses and voltage improvement based on Differential Evaluation Particle Swarm Optimization method. The multiple DGs having real and reactive power generation at optimal allocation causes to improve voltage profiles and reduces the system losses. DGs can provide a portion of the real and reactive power to the load locally hence the voltage profiles of all the buses are improved, thus current through a section of the distribution line, in turn, results in a boost in the voltage magnitude at the consumer side. The significance of DEPSO based DGs allocation in distribution system are explored. This work presents a comparative analysis for PSO and DEPSO. The simulation results shows that DEPSO based method is robust and competitive to PSO based method for placement and sizing of DGs. From the result it has been observed that there is an improvement in voltage profile and reduction in real power loss with help of DEPSO method.

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