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Optimal Allocation of DG Units for Power Loss Reduction and Voltage Profile Improvement of Distribution Networks using PSO Algorithm

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***Abstract*—**This paper proposes a Particle Swarm Optimization (PSO) based technique for the optimal allocation of Distributed Generation (DG) units in the power systems. In this paper our aim is to decide optimal number, type, size and location of DG units for voltage profile improvement and power loss reduction in distribution network. Two types of DGs are considered and the distribution load flow is used to calculate exact loss. Load flow algorithm is combined appropriately with PSO till access to acceptable results of this operation. The suggested method is programmed under MATLAB software. Test results indicate that PSO method can obtain better results than the simple heuristic search method on the 30-bus and 33-bus radial distribution systems. It can obtain maximum loss reduction for each of two types of optimally placed multi-DGs. Moreover, voltage profile improvement is achieved.

***Keywords*—**Distributed Generation (DG), Optimal Allocation, Particle Swarm Optimization (PSO), Power Loss Minimization, Voltage Profile Improvement.

I. INTRODUCTION

THE share of distributed generators (DGs) in power systems has been slowly increasing in the last few years. According to CIGRE report, the contribution of DG in Denmark and Netherlands has reached 37% and 40% respectively, as a result of liberalization of power market in Europe. Electric Power Research Institute's (EPRI) study forecasts that 25% of the new generation will be distributed by 2010 and a similar study by the National Gas Foundation believes that the share of DGs in new generation will be 30% by the year 2010. With the Kyoto protocol put in place where there will be a favorable market fo DG that are coming from "Green Technologies", the share of DGs will increase more than before. The planning of the power electric system with the presence of DG requires the definition of several factors such as: the best technology to be used, the number and the capacity of the units, the best location, the type of DG units and network connection, etc. The problem of DG allocation and sizing is of great importance. The installation of DG units at non-optimal places can results in an increase in system losses, implying in an increase in costs and, therefore, having an effect opposite to the desired. Figure 1 shows a plot of typical power loss versus size of DG at two different busses in a typical 30-bus distribution network. It is obvious that for a particular bus, as the size of DG is increased, the losses are reduced to a minimum value and increase beyond a size of DG at that location. If the size of DG is further increased, the losses start to increase. So given the characteristics of the distribution system, it is not advisable to construct sufficiently high DG in the network. So as mentioned before, optimal size and location of DG units play an important role in minimizing the system power loss.

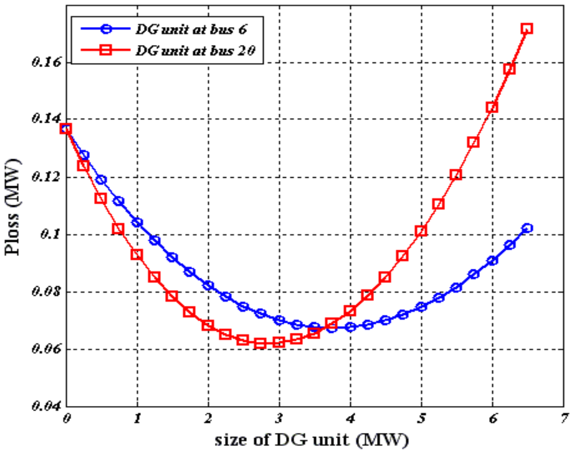

Fig. 1 System power loss Vs size of DG placed at two different bus bars in a typical 30-busbar distribution network

In this paper, two types of DG units are considered as follows:

Type 1: DG is capable of supplying only real power.

Type 2: DG is capable of supplying both real and reactive power.

The optimal placement of the DG units has been continuously studied in order to achieve different aims. The objective can be the minimization of the active losses of the distribution network, or the minimization of the total network supply costs, which includes generators operation and losses compensation. In this paper PSO algorithm is used as the optimization technique to allocate DG units optimally in order to improve voltage profile and reduce power loss of distribution network.
The organization of this paper is as follows; In section II, a brief discussion of distributed generation issues is presented. Section III addresses the problem formulation. Section IV is an introduction to the particle swarm optimization algorithm

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used in the methodology proposed in this paper. The proposed solution method is discussed in section V. In section VI, two test systems used for simulations, is introduced. Simulation results on the test systems are illustrated in section VII. Then, the conclusion is given in section VIII. [1]-[8].

II. DISTRIBUTED GENERATION

The definition of distributed generation takes different forms in different markets and countries and is defined differently by different agencies. International Energy Agency (IEA) defines distributed generation as generating plant serving a customer on-site or providing support to a distribution network, connected to the grid at distribution-level voltages. CIGRE defines DG as the generation, which has the following characteristics: It is not centrally planned; It is not centrally dispatched at present; It is usually connected to the distribution network; It is smaller than 50-100 MW. Other organizations like Electric Power Research Institute (EPRI) defines distributed generation as generation from a few kilowatts up to 50MW. In general, DG means small scale generation. The most general and simplest definition of DG is as follows: "Distributed Generation is an electric power source connected directly to the distribution network or on the customer site of the meter".

III. PROBLEM FORMULATION

In this paper, the number, location and size of DG units are decided in such way that minimum system power loss and desired voltage profile is obtained. So it is needed to define system power loss as a function of DG size and system bus voltages. So we have:

$$P_{loss} = \sum_{line(i,j)=1}^{m} P_{line(i,j)} \tag{1}$$

In this equation P_{loss} is the real power loss and m is the number of branches in the power system.

$$P_{line(i,j)} = P_i - P_j \tag{2}$$

$$P_i = P_{DGi} - P_{Di} = |V_i| \sum |V_k| [g_{ik}\cos(\theta_i - \theta_k) + b_{ik}\sin(\theta_i - \theta_k)] \tag{3}$$

$$Q_i = Q_{DGi} - Q_{Di} = |V_i| \sum |V_k| [g_{ik}\sin(\theta_i - \theta_k) + b_{ik}\cos(\theta_i - \theta_k)] \tag{4}$$

'i' is the location of DG unit (i=1, 2, 3…, n) and 'n' is the total number of bus bars in distribution network. Also for DG type one, we have: $Q_{DGi} = 0$.

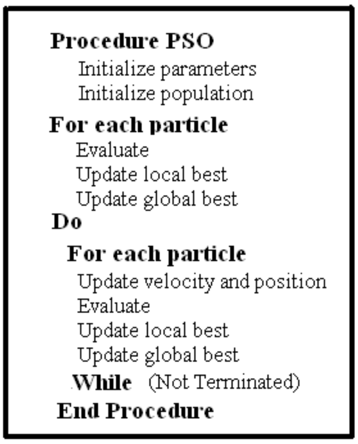
P_i and Q_i are net real and reactive power injection in bus ' i ' respectively. V_i and δ_i are the voltage magnitude and voltage angle at bus 'i' respectively. P_{DGi} and Q_{DGi} are the real and reactive power generations of DG at bus 'i'. P_{Di} and Q_{Di} are the real and reactive power demand at bus 'i'. So objective is to minimize P_{loss} considering following constraints:

$$\begin{cases} |V_{i_{min}}| \le |V_i| \le |V_{i_{max}}| \\ P_{line(i,j)} \le P_{line(i,j)_{max}} \end{cases}$$

Proper settings for $|V_{i_{min}}|$ and $|V_{i_{max}}|$, results in better voltage profile of system [1]-[13].

IV. PARTICLE SWARM OPTIMIZATION (PSO)

Particle Swarm Optimization (PSO) was first introduced by Kennedy and Eberhart as an optimization method for continuous nonlinear functions. It is a stochastic optimization technique based on individual improvement, social cooperation and competition in the population. PSO is inspired of the behaviors of social models like bird flocking or fish schooling. Since its introduction, PSO become an important tool for the optimization problems. It is famous for its fast convergence to a solution close to the optimal, by balancing the local search and global search i.e., exploitation and exploration, respectively. By its nature it is very suitable for continuous optimization problems but it can also be used for combinatorial problems. PSO is a population-based method in which a swarm includes several individuals called particles. Each particle has a position and a velocity. The position of a particle is a candidate solution and updated at each iteration by using the current velocity. The velocity of a particle, is reevaluated by using the particle's inertia as well as the social interaction (swarm's experience) and personal experience of the particle. The quality of a position is measured based on a fitness function. The experience of each particle is usually captured by its local best position. The experience of the swarm is captured by the global best position. In the course of the several iterations, particles make use of this experience and are supposed to move towards the optimum position.



```
Procedure PSO
    Initialize parameters
    Initialize population
For each particle
    Evaluate
    Update local best
    Update global best
Do
   For each particle
      Update velocity and position
      Evaluate
      Update local best
      Update global best
   While  (Not Terminated)
End Procedure
```

Fig. 2 Basic PSO algorithm used in the proposed methodology

First, the initial population is formed with respect to the PSO parameter setting. Individuals can be initialized randomly or to predetermined locations. After the initial phase, several iterations of update and evaluation steps are performed until a stopping condition is met. Generally, the stopping condition is the attainment of a maximum number of iterations or the maximum number of iterations between two improvements. During the update step, for each particle, the velocity and the position of the particle at iteration t+1 are calculated by using the Equations (5) and (6).

$$v^{t+1}=w.v^{t}+c_1.r_1.(p_{best}-p^{t})+c_2.r_2.(g_{best}-p^{t}) \tag{5}$$

$$p^{t+1}=p^{t}+v^{t+1} \tag{6}$$

In these equations, v^t and p^t are the velocity and the position of a particle at iteration t, respectively. The parameters c_1 and c_2 are coefficients of learning factors, which are the weights of contribution of personal experience and social experience. Appropriate values for c_1 and c_2 are 1 to 2 but 2 is the most appropriate in many cases. The stochastic behavior of PSO is achieved by r_1 and r_2 which are random numbers generally in (0-1). The parameter w is the inertia weight which is the balancing factor between exploration and exploitation. For faster convergence, inertia weight is usually selected to be high at the beginning (which lets PSO to explore) and decreased in course of optimization. The following weight function is usually used in most cases:

$$w=w_{max}-\frac{w_{max}-w_{min}}{iter_{max}}.iter \tag{7}$$

In this equation, w_{min} and w_{max} are the minimum and maximum weights respectively. Appropriate values for w_{min} and w_{max} are 0.4 and 0.9 respectively. Also $iter$ and $iter_{max}$ are current number of iteration and maximum number of iterations, respectively. After the update step, the fitness function value is calculated for each particle based on its position (candidate solution represented by the particle). The local best position p_{best} of each particle and the global best position g_{best} are updated using these fitness values [9].

V. PROPOSED METHODOLOGY

The proposed PSO-based technique for optimal allocation of DG units in the power systems, is as follows:

Step 1: Input the line and busbar data and busbar voltage limits.

Step 2: Calculate the system power loss using distribution load flow.

Step 3: Randomly generate an initial population (array) of particles with random positions and velocities on dimensions in the solution space. Set the iteration counter k=0. n is the number of DG units used in the system for DG type 1, each particle consist of 2n parts, n for sizes and another n for locations of DG units. But for DG type 2, each particle consist of 3n parts, 2n for real and reactive power size of DG units and n parts for locations of DG units.

In this paper, Simulations are done for n=1,2,3 separately. Maximum sizes of real and reactive power of DG units are considered to be 6.5 MW and 6.5 Mvar, respectively.

Step 4: For each particle, if the bus voltage is within limits, calculate the total system power loss. 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 associated with the minimum individual best p_{best} of all particles and set the value of this p_{best} as the current overall best (g_{best}).

Step 7: Update the velocity and position of particle using (5) and (6) respectively.

Step 8: If the iteration number reaches the maximum limit, go to step 9, otherwise set iteration index k=k+1 and go back to step 4.

Step 9: Print out the optimal solution to the target problem.

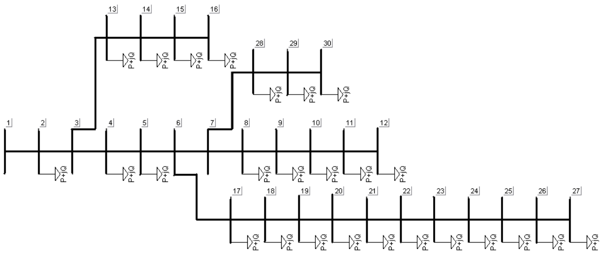
The best position includes the optimal locations and size of DG units and the corresponding fitness value representing the minimum total real power loss.

This procedure is for just one DG unit. For allocating of two DG units, this procedure is followed and then optimal size and location for first DG unit is decided. This DG unit with optimal size is put in the decided optimal location and again the solution method is used to decide optimal size and location for second DG unit. This algorithm is used for optimal allocating of multi-DGs in the power system.

Sometimes just one DG unit is placed in power system for achieving desired goals but after years it is needed to add another DG unit(s). Usually, because of economic issues, the place of first DG unit is kept unchanged. This is why we have used such a methodology in this paper [10]-[15].

VI. CASE STUDIES

In this paper simulations are carried out on 30-bus [16] and 33-bus [17] test distribution networks. First, a type 1 DG unit is put in the test system and the methodology mentioned in last section is applied in order to find optimal size and location of DG unit. Then a type 2 DG unit is used, applying proposed methodology, optimal size and location of DG unit is decided. This process is exactly repeated for 2 and 3, type 1 and type 2, DG units, separately. After the evaluating the results, optimal type, size, number and place of DG unit(s) is decided. Schematics of the two 30 and 33-bus test systems used in this paper are shown in Fig 3.



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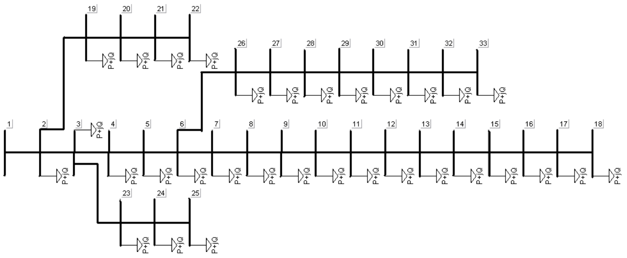

b

Fig. 3 (a) 30-bus and (b) 33-bus test systems used in this paper for simulations

VII. Simulation Results

As mentioned before, a distribution load flow is performed on the 30 and 33-bus test systems in order to calculate the P_{loss} and Q_{loss} in absence of DG unit(s) in the system. Obtained results are shown in table 1. Then during 3 steps, the number of DG units used in the test power system, varies from 1 to 3. In each step, the type of DG unit(s) is also changed from 1 to 2. Using the PSO algorithm, optimal size, location, type and number of DG units are decided. The results obtained from simulations for DG type 1 and type 2 for system power loss reduction, are shown in tables 2 and 3, respectively. It should be noted that, results obtained for system voltage profile improvement are shown in Figs 4, 5, 6 and 7.

TABLE I
System Power Losses in Absence of DG Units

System (# of busbars)	P_{loss} (kw)	Q_{loss} (kvar)
30	137	41
33	211	143

TABLE II
Optimal Sizes And Locations Of Type One Dg Units Used In 30 And 33-Bus Test Systems

System	Bus No.	DG Size (MW)	Bus No.	DG Size (MW)	Bus No.	DG Size (MW)	P_{Loss} (KW)	Q_{Loss} (Kvar)	Loss Reduction (%)	
									Real	Reactive
30	25	2.865					58	16	57.6	60.9
	17	1.138	25	2.865			50	13	63.5	68.29
	4	0.375	17	1.138	25	2.865	49.7	12.8	63.7	68.78
33	6	2.591					112	83	46.44	41.96
	15	0.473	6	2.591			96.2	69	54.4	51.75
	25	0.637	15	0.473	6	2.591	88.6	63	58	55.94

TABLE III
Optimal Sizes And Locations Of Type Two Dg Units Used In 30 And 33-Bus Test Systems

System	Bus No.	DG Size (MW)	DG Size (Mvar)	Bus No.	DG Size (MW)	DG Size (Mvar)	Bus No.	DG Size (MW)	DG Size (Mvar)	P_{Loss} (KW)	Q_{Loss} (Kvar)	Loss Reduction (%)	
												Real	Reactive
30	25	2.869	1.780							29	55	78.83	82.92
	17	1.092	0.730	25	2.865	1.780				19	4	86.13	90.24
	4	0.282	0.048	17	1.092	0.730	25	2.870	1.780	18	3	86.86	92.68
33	6	2.551	1.755							68	55	67.77	61.54
	15	0.463	0.272	6	2.551	1.755				52	40	75.35	72.03
	25	0.685	0.310	15	0.463	0.272	6	2.551	1.755	43	34	79.62	76.22

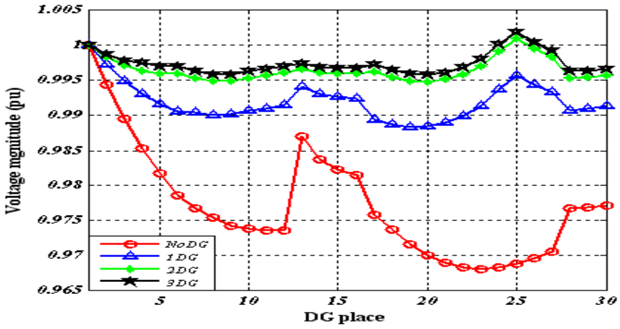

Fig. 4. Voltage profile of 30-bus test system, in presence of type 1 DG unit(s).

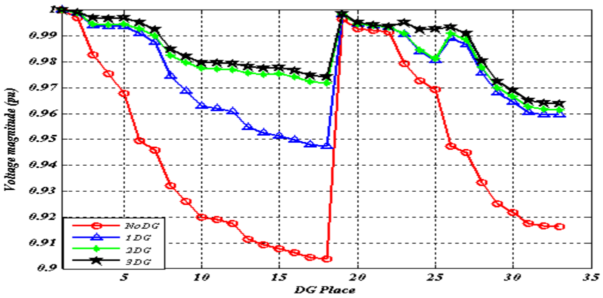

Fig. 5 Voltage profile of 33-bus test system in presence of type 1 DG unit(s)

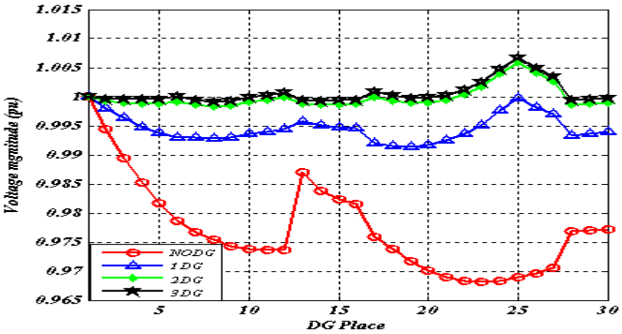

Fig. 6 Voltage profile of 30-bus test system in presence of type 2 DG unit(s)

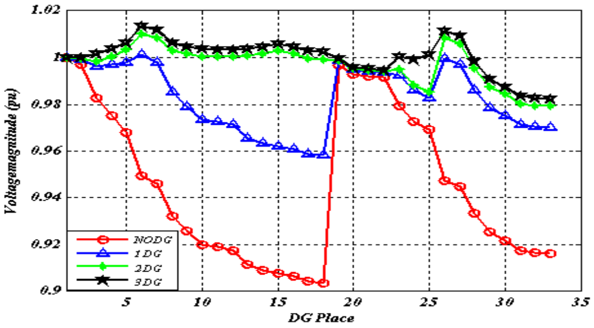

Fig. 7 Voltage profile of 33-bus test system in presence of type 2 DG unit(s)

Results obviously show that the more the number of DG units the less the system power loss and the better the system voltage profile. In practice, Due to economical issues, it is not advisable to use more than 3 DG units in power systems. Adding 4th DG unit to the system does not make a considerable change in system power loss reduction and voltage profile improvement. These results can be clearly obtained from tables I and II and Figs 4, 5, 6 and 7.

Table I and II show that, for 30-bus test system, maximum reduction in system real power loss (P_{loss}), for 3, type 1 and type 2, DG units are about 63.7% and 86.6%, respectively. These two tables also show that, for 33-bus test system, using 3 type 1 DG units, leads to 58% reduction in system real power loss. Similar value for 3 type 2 DG units, is about 79.62%. From results it can be figured out that, type 2 DG units, decreases system real power loss about 20% more than type 1 DG units. So optimal allocation of DG units in power systems, not only reduces power loss and improves voltage profile, but also increases the active power transfer capacity of transmission lines.

VIII. CONCLUSION

Increasing the number of DG units in power system can reduce system power loss and improve voltage profile. type of DG units is another important factor. Results prove that using type 2 DG units has better impact on system power loss reduction and system voltage profile improvement. Using type 2 DG units reduce system power loss about 20% more than type 1 DG units. Place and size of DG units are also other important factors that affect on system power loss and voltage profile. In this paper a PSO algorithm for optimal placement of multi-DG is proposed which efficiently minimizes the total real power loss, satisfying transmission line limits and constraints. The proposed methodology is so fast and efficient and at the same time so accurate in determining the size, type, number and location of DG unit(s).

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