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Research Article

Using Intelligent Algorithms to Find the Optimal Placement of Distributed Generation

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Abstract: This study used Hybrid Genetic-Particle Swarm Optimization (HGPSO) and Particle Swarm Optimization (PSO) for the allocation of Distributed Generation (DG) in order to minimize the total real loss and improve voltage profile in a primary distribution system. The mutation operation of the Genetic Algorithm (GA) is implemented into the Particle Swarm Optimization (PSO) approach. One aspect missing from existing approaches is the capability to efficiently site and size a predefined number of DGs. Here, Hybrid Genetic-Particle Swarm Optimization aims to overcome this shortcoming. The results obtained from the proposed algorithm applied to a 45-bus radial distribution system demonstrate its good performance and capability. Results show that the HGPSO is better than PSO in order to obtain the maximum loss reduction as well as maximum voltage profile improvement for each case of optically placed multi-DGs.

Keywords: Distributed generation, hybrid genetic-particle swarm optimization, particle swarm optimization, real power loss**,** sitting and sizing, voltage profile

INTRODUCTION

Distributed Generation can be defined as an electrical power source connected directly to the distribution network or on the consumer side of the meter. It may be understood in simple term as small-scale electricity market (Khanjanzadeh *et al*., 2011).

The effects of Distributed Generation (DG) on voltage profile, line losses, short circuit current, amount of injected harmonic and system reliability are to be evaluated separately before installing it in a distribution network. The planning of the electric system at the presence of DG requires defining of several factors including the best technology to be used, the number and the capacity of the units, the best location, the type of network connection, etc. The impact of DG on operating characteristics of the system such as electric losses, voltage profile, stability and reliability needs to be appropriately evaluated. The problem of DG allocation and sizing is of great importance. Installing DG units at non optimal places may result in an increase in system losses, implying an increase in costs and therefore, having an opposite effect to what is desired. As a result, using an optimization method capable of indicating the best solution for a given distribution network can be very useful for system planning engineers. Selecting the best places for installing DG units and their preferable sizes in large distribution systems is a complex combinatorial optimization problem.

The challenge of determining optimal locations of DGs is an interesting research area due to technical and economical reasons. The use of DG (such as micro-turbines, fuel cells, photovoltaic, combustion engines, wind turbines, etc.) can help to reduce the system loss and avoid investment on transmission and distribution expansion. Appropriate sizes and optimal locations of DGs are the main way to reach this goal (Rosehart and Nowicki, 2002; Wang and Nehrir, 2004).

Generally three types of DGs may be considered as bellow:

- DG is capable of supplying only real power.
- DG is capable of supplying only reactive power.
- DG is capable of supplying real power but consuming proportionately reactive power.

The optimal placement and sizing of generation units in distribution networks has been continuously studied in order to achieve different aims. The objective can be the minimization of active losses of the feeder (Nara *et al*., 2001; Rahman *et al*., 2004), the minimization of total network supply costs, which includes generators operation and losses compensation (Celli and Pilo, 2001; El-Khattam *et al*., 2004; El-Khattam *et al*., 2005; Gandomkar *et al*., 2005), the best utilization of available generation capacity (Keane and O'Malley, 2005), THD reduction (Khanjanzadeh *et al*., 2011) and improving voltage profile (Gandomkar *et al*., 2005).

In this study, as a contribution to the methodology of economical analyzing of DGs, an algorithm is developed for the allocation and sizing of generators in distribution networks in order to voltage profile

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improvement as well as loss reduction in distribution networks. The Hybrid Genetic-Particle Swarm Optimization (HGPSO) is used as the optimization technique. In Section an introduction to the Hybrid Genetic-Particle Swarm Optimization Algorithm (HGPSO) is presented.

PROPOSED ALGORITHM

Basic genetic algorithm: Genetic Algorithm is a general-purpose search techniques based on principles inspired from the genetic and evolution mechanisms observed in natural systems and populations of living beings. Their basic principle is the maintenance of a population of solutions to a problem (genotypes) as encoded information individuals that evolve in time (Gandomkar *et al*., 2005). Generally, GA comprises three different phases of search:

Phase 1: Creating an initial population
Phase 2: Evaluating a fitness function
Phase 3: Producing a new population

A genetic search starts with a randomly generated initial population within which each individual is evaluated by means of a fitness function. Individual in this and subsequent generations are duplicated or eliminated according to their fitness values. Further generations are created by applying GA operators. This eventually leads to a generation of high performing individuals. There are usually three operators in a typical genetic algorithm (Gandomkar *et al*., 2005): the first is the production operator (elitism) which makes one or more copies of any individual that posses a high fitness value; otherwise, the individual is eliminated from the solution pool; the second operator is the recombination (also known as the 'crossover') operator. This operator selects two individuals within the generation and a crossover site and carries out a swapping operation of the string bits to the right hand side of the crossover site of both individuals. Crossover operations synthesize bits of knowledge gained from both parents exhibiting better than average performance. Thus, the probability of a better offspring is greatly enhanced; the third operator is the 'mutation' operator. This operator acts as a background operator and is used to explore some of the invested points in the search space by randomly flipping a 'bit' in a population of strings. Since frequent application of this operator would lead to a completely random search, a very low probability is usually assigned to its activation.

Particle swarm optimization: PSO is one of the optimization techniques and belongs to EC techniques. The method has been developed through a simulation of simplified social models. The features of the method are as follows (Kennedy and Eberhart, 1995; Fukuyama *et al*., 1999):

- The method is based on researches on swarms such as fish schooling and bird flocking.
- It is based on a simple concept. Therefore, the computation time is short and it requires few memories.

According to the research results for bird flocking, birds are finding food by flocking (not by each individual). It leaded the assumption that information is owned jointly in flocking. According to observation of behavior of human groups, behavior pattern of each individual is based on several behavior patterns authorized by the groups such as customs and the experiences by each individual (agent). The assumptions are basic concepts of PSO. PSO is basically developed through simulation of bird flocking in two-dimension space. The position of each individual (agent) is represented by XY axis position and also the velocity is expressed by vx (the velocity of X axis) and vy (the velocity of Y axis). Modification of the agent position is realized by the position and velocity information.

An Optimization technique based on the above concept can be described as follows: namely, bird flocking optimizes a certain objective function. Each agent knows its best value so far (pbest) and its XY position. Moreover, each agent knows the best value so far in the group (gbest) among pbest. Each agent tries to modify its position using the following information:

- The current positions (x, y)
- The current velocities (vx, vy)
- The distance between the current position and pbest and gbest

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

$$v_i^{k+1} = wv_i^k + c_1 rand \times (pbest_i - s_i^k) + c_2 rand \times (gbest - s_i^k) \quad (1)$$

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:

$$s_i^{k+1} = s_i^k + v_i^{k+1} \quad (2)$$

Figure 1 shows a concept of modification of a searching point by PSO and Fig. 2 shows a searching concept with agents in a solution space.

The inertia weight is calculated using Eq. (3) for this research:

$$w_i = w_{max} - \frac{w_{max} - w_{min}}{k_{max}} \times k \quad (3)$$

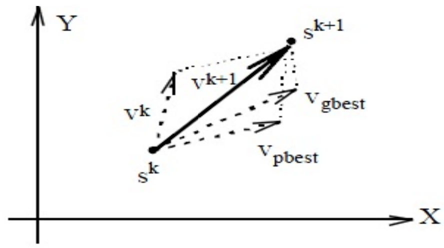

Fig. 1: Concept of modification of a searching point by PSO

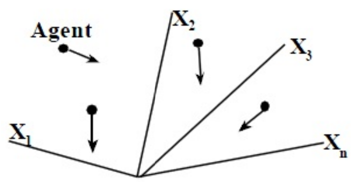

Fig. 2: Searching concept with agents in a solution space by PSO

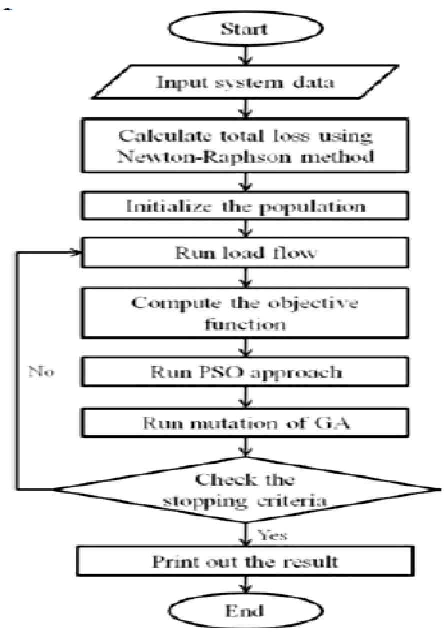

Fig. 3: The procedures of the HGPSO in DG allocation problem

where,

w_{max} and w_{min}	=	Maximum and minimum inertia weight, respectively
k and k_{max}	=	The current and maximum iteration, respectively

Hybrid genetic-particle swarm optimization: In basic PSO, the gbest value presents some effect related to the velocity update. Based on Eq. (1) if the particles' pbest is similar to the gbest, then the particle will only moves away from its current position if its inertia weight (w).

Table 1: Parameters setting for HGPSO

Parameters	Value
Number of Particles	30
C_1	2.0
C_2	2.0
w_{max}	0.9
W_{min}	0.4
p_m	0.5
Number of DG	1 and 2
DG Size	0.01MW to 2.5 MW
Maximum Iterations	100

and previous velocity is nonzero. If the particles' previous velocity is very close to zero, then all particles will stop moving if they get closer to the gbest, causing the stagnantation for the population. So the Hybrid Genetic-Particle Swarm Optimization (HGPSO) approach is introduced to solve this problem. The HGPSO method combines the mutation operation of the GA with PSO. This process avoids the particles to be trapped in the local minima. The mutation operation of the GA is implemented into PSO algorithm. The procedures of the algorithm are summarized in Fig. 3 (Wong *et al*., 2011).

The parameters setting for the proposed method is shown in Table 1.

PROBLEM FORMULATION

The total power loss in a distribution system with given operating conditions can be calculated by following equation is referred to as exact loss (Elgerd, 1971):

$$\sum_{i=1}^{n}\sum_{j=1}^{n} A_{ij}(P_iP_j + Q_iQ_j) + B_{ij}(Q_iP_j - P_iQ_j) \quad (4)$$

where,

$$A_{ij} = \frac{R_{ij}\cos(\delta_i - \delta_j)}{V_iV_j} \quad (5)$$

$$B_{ij} = \frac{R_{ij}\sin(\delta_i - \delta_j)}{V_iV_j} \quad (6)$$

The objective of this study is reducing the real power loss by finding the optimum place of DGs. This can be formulated as following objective function:

$$Minimize \quad P_L = \sum_{k=1}^{Nsc} Loss_k \quad (7)$$

The optimization must be done in such a way that following three constraints would be satisfied as below:

$$\sum_{i=1}^{N} P_{DGi} = \sum_{i=1}^{N} P_{Di} + P_L \quad (8)$$

$$|V_i|^{min} \le |V_i| \le |V_i|^{max} \tag{9}$$

$$|I_{ij}| \le |I_{ij}|^{max} \tag{10}$$

DG TYPES

DG type 1: Certain type of DGs like photovoltaic will produce only real power. In such a case, when the DG supplies only real power, to find the optimal DG size at bus i the necessary condition for minimum loss is:

$$P_i = P_{DGi} - P_{Di} = -\frac{1}{A_{ii}} \sum_{i,j=1}^{n} (A_{ij} P_j - B_{ij} Q_j) \tag{11}$$

Last equation can be rewritten as below:

$$P_{DGi} = P_{Di} - \frac{1}{A_{ii}} \sum_{i,j=1}^{n} (A_{ij} P_j - B_{ij} Q_j) \tag{12}$$

This equation represents the optimal DG size for each bus so that minimize the real power loss.

DG type 2: A DG such as synchronous condenser provides only reactive power to improve the voltage profile. In this case to determine optimal location of DG, we differentiate the loss equation on either side with respect to Q_i. The optimal size of this type of DG for every bus in the system is given by:

$$Q_{DGi} = Q_{Di} - \frac{1}{A_{ii}} \sum_{i,j=1}^{n} (A_{ij} Q_j + B_{ij} P_j) \tag{13}$$

DG type 3: This type of DG will supply real power and in turn will absorb reactive power. For example in case of the wind turbines, induction generator produces real power where the reactive power will be consumed in the process (Ermis *et al*., 1992). In this type of DGs the amount of reactive power they require is an ever increasing function of the active power output. The reactive power consumed by the DG (wind generation) can be given in simple form as in the case of (DTI, 2004) by following equation:

$$Q_{DG} = -(0.5 + P_{DG}^2) \tag{14}$$

This loss equation may be modified. After following the similar methodology of first two types, optimal DG size can be found by solving following equation:

$$0.0032 A_{ii} P^3_{DGi} [1.004 A_{ii} + 0.08 A_{ii} Q_{Di} - 0.08 Y_i] + (X_i - A_{ii} P_{Di}) = 0 \tag{15}$$

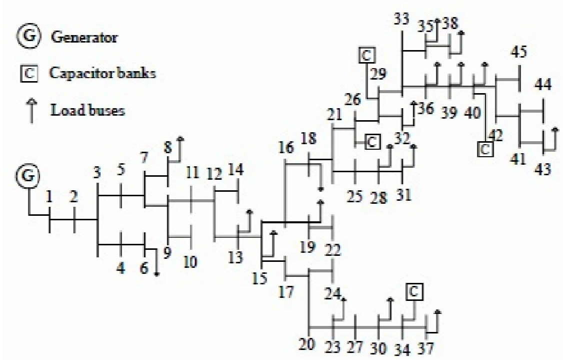

Fig. 4: The IEEE 45 bus radial distribution system

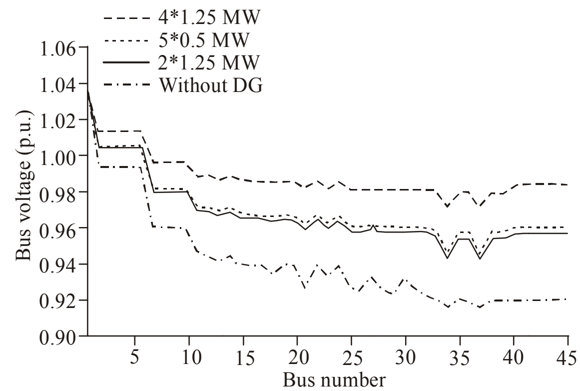

Fig. 5: Bus voltage before and after DG installation for DG type1 with HGPSO algorithm

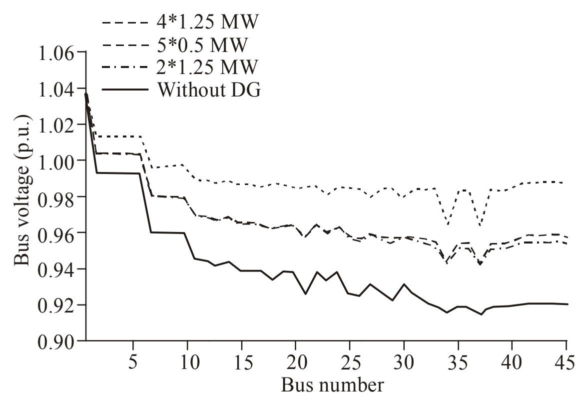

Fig. 6: Bus voltage before and after DG installation for DG type1 with PSO algorithm

Eq. (15) can be used to achieve the amount of real power that a DG should produce when located at bus i , so as to obtain the minimum system loss where the amount of receive power that it consumes can be calculated from Eq. (14).

SIMULATION RESULTS

The distribution test system used in this study is the IEEE 45-bus system is shown in Fig. 4. This 45-

Table 2: Optimal DG Placement for 2 DGs Type 1 with HGPSO and PSO

Method	DG size (MW)	Bus No	Losses without DG MW	Losses without DG MVAR	Losses with DG MW	Losses with DG MVAR	Losses reduction% Real	Losses reduction% Reactive
HGPSO	2*1.25	40 42	2.058	4.6219	1.3549	3.0374	34.16	34.28
PSO	2*1.25	41 45	2.058	4.6219	1.3792	3.0398	32.98	34.23

Table 3: Optimal DG Placement for 4 DGs Type 1 with HGPSO and PSO

Method	DG size (MW)	Bus No	Losses without DG MW	Losses without DG MVAR	Losses with DG MW	Losses with DG MVAR	Losses reduction% Real	Losses reduction% Reactive
HGPSO	4*1.25	37 40 41 42	2.058	4.6219	0.8725	1.9114	57.61	58.65
PSO	4*1.25	38 40 41 45	2.058	4.6219	0.8797	1.9189	57.25	58.48

Table 4: Optimal DG Placement for 5 DGs Type 1 with HGPSO and PSO

Method	DG size (MW)	Bus No	Losses without DG MW	Losses without DG MVAR	Losses with DG MW	Losses with DG MVAR	Losses reduction% Real	Losses reduction% Reactive
HGPSO	5*0.5	35 39 40 42 43	2.058	4.6219	1.3712	3.0481	33.38	34.05
PSO	5*0.5	30 39 40 43 44	2.058	4.6219	1.3944	3.1018	32.24	32.88

bus system has 44 sections with the total load 16.8343MW and 7.41894 MVAR.

The primary total real power loss and reactive power loss in the system are 2.04327MW and 4.4859MVAR, respectively.

The voltage profile before installation DGs and after optimally placing the DGs is shown in Fig. 5 and 6. As it can be seen from Fig. 5 and 6 the voltage profile has been improved after optimally installing of DG.

Table 2 and 3 show that the ratio of loss reduction percentage to the total capacity of DGs which is one of the DGs economical indicators where in the first case, this indicator is influenced more than the two other cases and as a result the first case is more economical.

Furthermore since fewer DGs are used in the first case, expenses and cost for installing and maintaining will significantly decrease in comparison with the two other cases.

Comparing Table 2 to 4, it is clear that by increasing the number of DGs with the same capacity, losses of the network will decrease and it is also clear that by increasing the number of DGs, voltage profile will improve and that the voltage profile for the third case is better than the other two cases. However considering the economical aspects, maintenance and protection and installation of DGs, the first case is preferred.

CONCLUSION

This study introduce a method based on HGPSO and PSO for finding the optimal placement of multi-DGs to improve voltage profile as well as reducing the real power loss in a distribution network.

Comparing the results obtained by applying each of two algorithms, it is clearly proven that the voltage profile and the loss reduction percentage of the system obtained by placement of DGs using HGPSO algorithm, is better than PSO algorithm. Also convergence of HGPSO algorithm is faster than PSO algorithm and this is because HGPSO algorithm provides the correct answers with high accuracy in the first few iterations which makes the responding time of this algorithm extremely fast. Finally it can be said that HGPSO algorithm is more effective than PSO algorithm.

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