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PSO Based Multi Objective Approach for Optimal Sizing and Placement of Distributed Generation

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Abstract: This study presents a multi-objective formulation using Particle Swarm Optimization (PSO) approach, for optimal placement and sizing of distributed generation (DG) resources in the power distribution systems in order to minimize the cost of power losses and improve the voltage profile and energy not supplied. The proposed method considers the options of the DGs installation and takes more number of significant parameters into account compare to the previous studies which consider only a few parameters for their optimization algorithms. Some of the so-called cost parameters considered in the proposed approach are: loss reduction, voltage profile improvement, environmental effects, fuel price and installation / exploitation / maintenance expenses and costs of load prediction of each bus. Using an optimal PSO Algorithm, in the proposed optimization method, a destination function that includes all of the above-mentioned cost parameters has been optimized. This method is also capable of changing the weights of each cost parameter in the destination function of the PSO Algorithm as well as the matrix of coefficients in the DIGSILENT environment. The proposed method has been applied and simulated on a sample IEEE 13-bus network. The obtained results show that any change in the weight of each parameter in the destination function of the PSO Algorithm and in the matrix of coefficients leads to a meaningful change in the location and capacity of the prospective DG.

Keywords: Cost optimization, distributed generation, DG placement, PSO algorithm

INTRODUCTION

Distributed generation is any electricity generation technology installed by a customer or independent electricity producer that is connected at the distribution systems level of the electric grid (Ackermann *et al.*, 2001). DG applications are growing due to environmental and economic issues, technological improvements and privatization of power systems. DG application, however, has positive and negative side effects for public industries and consumers (Fotuhi-Firuzabad and Rajabi-Ghahnavie, 2005). Generally, DG effects in distribution network depend on several factors such as the DG place, technology issues, capacity and the way it operates in the network. DG can significantly increase reliability, reduce losses and save energy while is cost effective, though it suffers from some disadvantages because of the isolated power quality functioning and voltage control problems. Generally, planners assess DG functioning in two respects: costs and benefits. Cost is one of the most important factors that should be considered regarding DG application (El-Khattam and Salama, 2004; Brown *et al*., 2001).

There are so many DG placement methods in hand though each of these methods only focuses on some parameters. The optimal DG placement defined in (Barker and De Mello, 2000) takes reliability, loss reduction and load prediction into account while it fails to account for other parameters such as productivity, cost effectiveness and type of DG. The optimal DG placement defined in (Hadisaid *et al.*, 1999) takes productivity, cost effectiveness, loss reduction and reliability and DG type into account and fails to consider other parameters. In (Kashem and Ledwich, 2002) only focuses on three parameters: DG cost, loss reduction and reliability. Also in (Dai and Baghzouz, 2003) defines its optimal DG placement method taking

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DG capacity, cost effectiveness and loss reduction into account. In addition, in Girgis and Brahma (2001) defines its optimal placement method taking stability, loss reduction and productivity into account. In Robert and Market (2006) optimal DG placement method takes loss reduction and load prediction into account. These fail to consider all aspects and parameters involving optimal DG placement. The present study is an attempt to define optimal DG placement by taking all pertinent parameters (loss reduction, voltage profile improvement, effects on environment, fuel price and installation and exploitation and maintenance expenses and load prediction cost) into account and since DG type is selected based on DG location based on its installation capacity, parameters specific to the location must be determined.

The main objective of this study is to show that each of the effective parameters appeared in the multi-objective target function of the proposed method, which optimizes the DG installation location and strength of variables, has direct impact on the optimized DG placement. This study shows that the DG placement optimization can be carried out with the purpose of voltage profile improvement and loss reduction which possibly cause the capacity of the DG to be floating.

DG PLACEMENT PROBLEM

Since the use of distributed sources is highly dependent on climatic and regional conditions, various DG technologies have been developed. These technologies are divided into three general categories (Von-Jouanne and Banergee, 2001; Teng *et al*., 2007):

- Technologies working on fossil fuels such as combustion engines, micro turbines and fuel batteries.
- Technologies working on new sources of energy such as wind turbines, solar cells, wave energy, geothermal and biomass.
- Technologies working on saving energy such as batteries, fly wheels, Superconducting Magnetic Energy Storage (SCMES), capacitors, Condensed Air Energy Storage (CAES) and Hydro Pumps.

Because of the traditional structure of power networks and lack of an active source of generation in the distribution system, as the installed capacity of generating sources increase, it becomes important to study the effects of these sources when they are working in tandem with electrical networks. The major effects of the distributed generation sources at the time of installment and exploitation include:

- Voltage profile changes along the network based on production capacity of the units and based on consumption load. This can specially be observed in radial feeders.
- Network losses change as a function of consumed load and production.
- Transit currents and voltages appear in the network as the instant distributed generation sources connect or disconnect.
- Quality of power and capability of the network protection system change.

Nowadays, because of the changes made in the power system structures for optimization purposes as well as the modernization of these structures, distributed generation sources are inevitably becomes important that in some countries they are considered as supplementary power supply systems. On the other hand, to satisfy the increasing power demand, huge power plants have to be constructed. There are, however, some obstacles such as finding a proper place for establishment, costs incurred due to the transfer of the electricity to places far away from the power plants and the long interval between decision-making and actual exploitation. Hence, distributed generation is now of great importance to development planners because they can be connected to the network easily and close to the load. Distributed generation is obviously a new attraction for power industry, commercial and regulating systems (Singh and Goswami, 2010).

In examining and identifying the technologies of DG sources and their effects on the distribution network, one should bear in mind that the technology being applied must be capable of producing the required power in order to enjoy the benefits of DG sources in the distribution network. Also, optimal DG placement should be selected taking the conditions and status of each bus in the network (Huang *et al*., 1996).

THE PROPOSED METHOD

In the present study, for the above-mentioned purpose, a destination function should be defined that includes all of the proposed parameters. The destination function, which is going to be minimized in this study and includes loss, voltage profile, environmental costs, fuel price, installation and exploitation and maintenance expenses and cost of load prediction for each bus, is as follows:

$$\begin{bmatrix} F(x) = K_1.C_{Loss} + K_2.C_{VPI} + \\ K_3.C_A + K_4.C_F + K_5.C_{DG} + K_6.C_L \end{bmatrix} (\$/KW) \quad (1)$$

where,

Table 1: Data on the lines

Sen.bus	Res.bus	R(ohm)	X(ohm)
1	2	0.176	0.138
2	3	0.176	0.138
3	4	0.045	0.035
4	5	0.089	0.069
5	6	0.045	0.035
5	7	0.116	0.091
7	8	0.073	0.073
8	9	0.074	0.058
8	10	0.093	0.093
7	11	0.063	0.050
11	12	0.068	0.053
7	13	0.062	0.053

Table 2: Data on the buses

No.bus	P (kw)	Q (kvar)
1	0	0
2	890	468
3	628	470
4	1112	764
5	636	378
6	474	344
7	1342	1078
8	920	292
9	766	498
10	662	480
11	690	186
12	1292	554
13	1124	480

C_{LOSS} = The cost of loss in all lines
C_{VPI} = The cost voltage profile improvement
C_A = The cost incurred due to effects on environment
C_F = The cost of the fuel used by DG sources
C_{DG} = The cost of installation, exploitation and maintenance
C_L = The cost of load prediction for each bus and for the buses in which the load amount is not predictable

DGs must save energy and this requirement incurs costs which have been taken into account in the above function. To define the destination function in (1), we have to make all parameters per unit to make them

Table 3: Coefficients applied to the parameters under the first (1) condition

Coefficient	Parameter	Coefficients applied to each parameter in destination function (%)
K_1	Loss reduction	30
K_2	Voltage profile	20
K_3	Effects on environment	10
K_4	DG fuel cost	15
K_5	DG cost	15
K_6	Load prediction cost	10

additive, this was accomplished by applying "*K*" coefficients (K_1-K_6). To calculate the cost of loss, first load flow is carried out in DIGSILENT software and then the results are used to calculate the losses and ultimately they are multiplied by the loss price. To calculate the cost of voltage profile improvement for each bus, the voltage difference for each bus is calculated before and after DG installment and the difference figure is multiplied by the cost of voltage profile improvement. To calculate pollution reduction cost using DG sources, the present study takes into account the variability of these coefficients for each bus depending on the type of the DG technology and the cost incurred due to pollution which is calculated (Kaplan, 1984).

DG cost includes primary cost and exploitation and maintenance costs, which is defined as follows (Teng *et al*., 2007):

$$C_{DG} = a + bP\left(\$ / KW\right) \tag{2}$$

where, *P* is the nominal active power of the DG. Also, *a* and *b* are calculated using the following formula:

$$a = \frac{Capital\ \ Cost\ (\$/KW\ ) \times Capacity(KW) \times Gr}{Life\ \ Time(Year) \times 365 \times 24 \times LF}\left(\$/KW\right) \tag{3}$$

$$b = Fuel\ \ Cost(\$/KW) + O\&MCost\ \ (\$/KW) \tag{4}$$

where,
Gr = The annual rate of interest
LF = The load coefficient of DG

Table 4: An example of the weights of each parameter

Bus no	Coefficients applied in each bus to effect on environment (%)	Coefficients applied in each bus to fuel price (%)	Coefficients applied in each bus to DG cost (%)	Coefficients applied in each bus to load prediction cost (%)
1	15	10	5	10
2	5	10	10	10
3	5	5	5	10
4	10	15	20	5
5	5	10	10	10
6	5	5	5	5
7	10	10	10	5
8	5	10	10	25
9	5	5	5	10
10	5	10	10	5
11	20	10	15	5

Table 5: The algorithm outputs

DG name	Location	Capacity (KW)
DG	BUS 8	911
Loss before DG	Loss after DG	LII
0.121466	0.118474	0.975367
VPI without DG	VPI with DG	VPII
0.086923	0.096581	1.111098

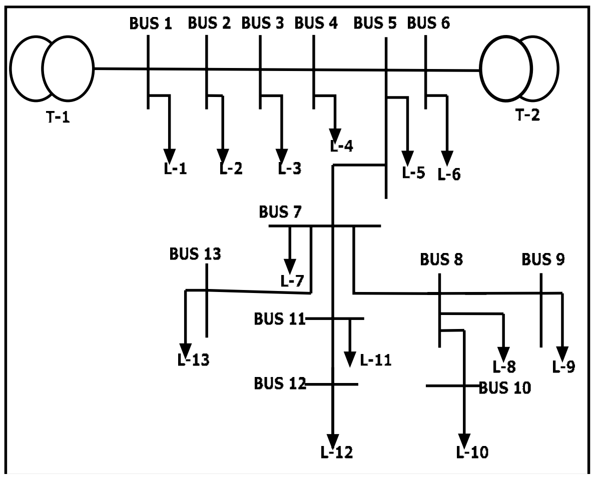

Fig. 1: Single line diagram for IEEE 13-bus distribution network

In this study, these values are considered equal to unity. It is noteworthy that each of the coefficients of the environmental pollutions effects, fuel price, installation and exploitation and maintenance expenses and load prediction have been defined in DIGSILENT environment in the form of a matrix where these parameters are variable of each bus. Such values are shown in Tables 1-12. This study has two major goals:

- Improvement of voltage profile
- Loss reduction. There are also some limitations based on which the destination function should be defined (Baghzouz, 2005):

$$V_{bus}^{\min} \leq V_{bus} \leq V_{bus}^{\max}$$

$$(Loss\ \ with\ \ DG) < (Loss\ \ without\ \ DG)$$

According to the first limitation the loss reduces when DG exists. Also, second limitation states that the authorized voltage of a certain bus depends on the minimum and maximum voltages of the bus.

SIMULATION NETWORK

In the proposed study, in order to observe and compare the results with those of the specified destination function, an IEEE 13-bus distribution network has been selected as a sample. It should be noted that the specified destination function could be generalized to be used for all distribution networks with any number of buses.

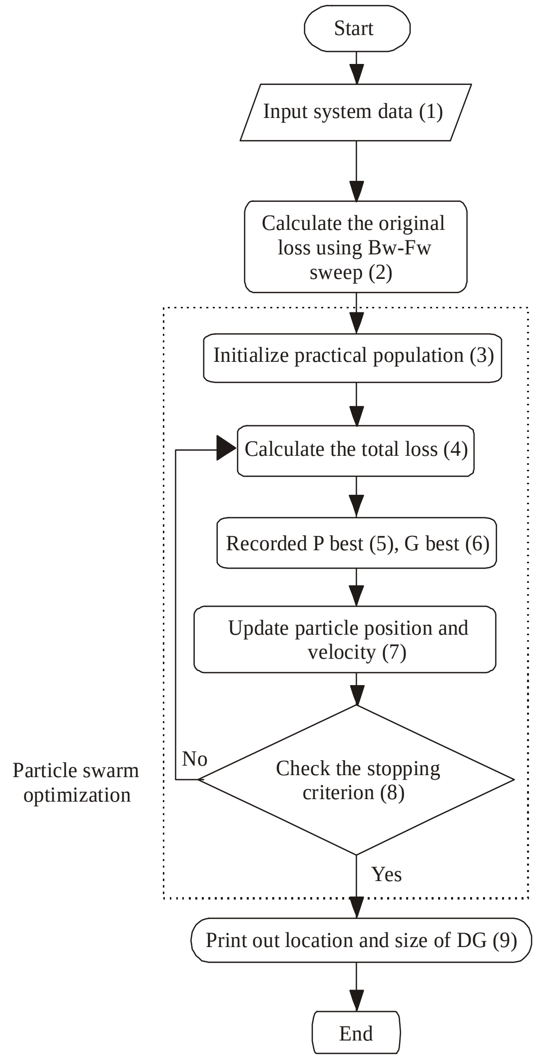

Fig. 2: PSO computational procedure

Moreover, the optimization algorithm of the destination function is a PSO Algorithm. The single line diagram of the network is illustrated in Fig. 1.

According to Fig. 1, 13-bus network contains two feeding sources in buses 1 and 6. Table 1 and 2 show the data on the lines and buses (Chiang and Wang, 1995).

THE PSO ALGORITHM IMPLEMENTATION

The Particle Swarm Optimizer (PSO) algorithm is first present by Dr. Kennedy and Dr. Eberhart and is a random evolution method based on intelligent search of the group birds. It has quick convergence speed and optimal searching ability for solving large-scale optimization problems (Kennedy and Eberhart, 1995).

The PSO-based approach for solving OPDG problem to minimize the loss takes the following steps (Fig. 2):

Step 1: Input line and bus data, and bus voltage limits.
Step 2: Calculate the loss using distribution load flow based on backward-forward sweep.
Step 3: 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 4: For each particle if the bus voltage is within the limits, calculate the total 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.
Step 8: If the iteration number reaches the maximum limit, go to Step 9. Otherwise, set teration 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 and the corresponding fitness value representing the minimum total real power loss.

In this study the optimization algorithm of the destination function is a PSO Algorithm whose population size = 200, Maximum generation k_{max} = 100.

SIMULATION PROCEDURE

This study aims to optimize the placement of DG and assess DG capacity using weight coefficients for various parameters independently taking cost into account. The coefficients of the first case shown in Table 3 include loss-reduction parameters like voltage profiles, environmental factors, fuel price, installation and exploitation and maintenance expenses and load prediction in the destination function of the PSO Algorithm shown by $(k_1 - k_6)$ in the destination function. However, other coefficients shown in Table 4 are related to the weight of parameters for the effects of environmental factors, fuel price, installation and exploitation and maintenance expenses and load prediction which are defined in an input matrix for the simulation software. In this case, since parameters related to loss reduction and voltage profile are calculated automatically, the coefficients of these parameters are not considered in the input matrix for the software. Thus, generally, parameters for any network have two conditions of weight coefficients with any number of buses. This has been achieved using PSO algorithm optimization in DIGSILENT environment. The parameter changes are illustrated because they are variable in each bus. Optimization is carried out with PSO Algorithm using a cost function. For this purpose, changes in the coefficients of the parameters are specified due to their variability in each bus. Optimization of the destination function has been carried out using a PSO Algorithm.

To assess the effect of loss reduction, voltage profile coefficient, environmental coefficient, fuel price, installation and exploitation and maintenance expenses and load prediction cost on the program, the program output was examined under two conditions (1), (2). For this purpose, different coefficients were applied to destination function parameters. Table 3 presents coefficients applied to parameters under the first condition, where parameters may vary depending on the place of the bus.

In addition, Table 4 presents an example of the weight of each parameter such as environmental pollution, fuel price, installation and exploitation and maintenance expenses and load prediction under the first condition. Table 5 presents program outputs regarding to the optimal capacity and placement of the prospective DG.

SIMULATION RESULT

The proposed method has been developed in DIGSILEN and MATLAB environments. The optimization algorithm in the present study is a PSO Algorithm. Table 5 presents the candidate position for DG installation in a 13-bus network as well as the capacity of optimal DG in terms of (KW) using LII and VPII indexes.

Also, in the above outlet, line loss reduction index is defined by (Kim and Kim, 2001):

$$LII = \frac{LL_{WDG}}{LL_{WODG}} \tag{5}$$

VPII=1: DG is not effective
VPII>1: DG has a positive effect on network voltage

To observe the effect of each parameter including environmental pollution, fuel price, installation and exploitation and maintenance expenses and load prediction cost, we changed the coefficients applied to

Table 6: An example of the weights of each parameter

Bus No	Coefficients applied in each bus to effect on environment (%)	Coefficients applied in each bus to fuel price (%)	Coefficients applied in each bus to DG cost (%)	Coefficients applied in each bus to load prediction cost (%)
1	10	5	5	10
2	5	10	10	10
3	10	10	10	5
4	10	5	5	20
5	5	10	10	10
6	25	5	5	5
7	10	5	5	10
8	5	25	25	10
9	5	10	10	5
10	5	5	5	10
11	10	10	10	5

Table 7: The algorithm outputs

DG name	Location	Capacity (KW)
DG	BUS 7	1236
Lost before DG	Lost after DG	LII
0.121266	0.117581	0.969612
VPI without DG	VPI with DG	VPII
0.079923	0.080131	1.002602

Table 8: Coefficients applied to the parameters under the second (2) condition

Coefficient	Parameter	Coefficient applied to each parameter in destination function (%)
K_1	Loss reduction	20
K_2	Voltage profile	10
K_3	Effects on environment	15
K_4	DG fuel cost	15
K_5	DG cost	15
K_6	Load prediction cost	25

each parameter in each bus in the form of a matrix. Table 6 presents the weight of another example of parameters such as environmental pollution, fuel price, installation and exploitation and maintenance expenses and load prediction, under condition of Table 3. In addition, Table 7 presents program outputs regarding to optimal capacity and placement of DG.

To test the program results under a different condition, we change all coefficients applied to the parameters of the destination function. Table 8 presents coefficients applied to parameters under different condition of Table 3. In addition, Table 9 presents the weight of parameters such as environmental pollution, fuel price, installation and exploitation and maintenance expenses and load prediction, under the same condition of Table 8. Also, Table 10 presents program output with regard to the optimal capacity and placement of DG.

To observe the effect of each parameter including environmental pollution, fuel price, installation and exploitation and maintenance expenses and load prediction cost, we changed again the coefficients applied to each parameter in each bus. Table 11 presents the weight of another example of parameters such as environmental pollution, fuel price, installation and exploitation and maintenance expenses and load prediction under the same conditions of Table 8. Finally, Table 12 presents program outputs with regard to the optimal capacity and placement of DG.

Table 9: An example of the weights of each parameter

Bus no	Coefficients applied in each bus to effect on environment (%)	Coefficients applied in each bus to fuel price (%)	Coefficients applied in each bus to DG cost (%)	Coefficients applied in each bus to load prediction cost (%)
1	5	10	20	5
2	5	5	10	20
3	10	5	5	5
4	5	5	5	5
5	10	10	5	10
6	10	5	20	5
7	5	5	5	20
8	10	25	5	5
9	5	10	10	5
10	15	5	5	5
11	20	15	10	15

Table 10: The program outputs

DG name	Location	Capacity (KW)
DG	BUS 11	723
Lost before DG	Lost after DG	LII
0.121266	0.115848	0.955321
VPI without DG	VPI with DG	VPII
0.096923	0.143230	1.477771

Table 11: An example of the weights of each parameter

Bus No	Coefficients applied in each bus to effect on environment (%)	Coefficients applied in each bus to fuel price (%)	Coefficients applied in each bus to DG cost (%)	Coefficients applied in each bus to load prediction cost (%)
1	10	15	20	5
2	5	10	10	5
3	10	5	5	10
4	20	5	5	5
5	5	10	5	10
6	5	5	20	10
7	5	5	5	5
8	10	25	5	10
9	15	10	10	5
10	10	5	5	15
11	5	5	10	20

Table 12: The program outputs

DG name	Location	Capacity (KW)
DG	BUS 11	635
Lost before DG	Lost after DG	LII
0.131266	0.122448	0.932823
VPI without DG	VPI with DG	VPII
0.089923	0.098982	1.100741

CONCLUSION

A PSO Algorithm based method has been developed in the DIGSILENT environment to apply to a sample IEEE 13-bus network to show the cost parameter optimization. In this study, we studied the effects of the significant parameters to optimally enhance the cost parameters (such as loss reduction, voltage profile improvement, environmental effects, fuel price, installation/ exploitation/ maintenance expenses and costs of predicting load of each bus). The cost parameters are variables, which are dependent on the status and position of each power network bus. The selection of distributed generation technology for specific and optimal placement purposes should be based on the types of the DG technology, while it should be condition-based and purpose-based as well.

It has been shown that any changes made in the weight of parameters such as loss reduction, voltage profile coefficient, coefficient of environmental pollution, fuel price, installation and exploitation and maintenance expenses and load prediction cost in the destination function of PSO Algorithm directly affect the optimal DG capacity and placement. In the end, the DG placement will be carried out with the purpose of improving voltage profile and loss reduction which cause the distributed generation capacity to be floating.

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