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Particle Swarm Optimization Based Method for Optimal Placement and Estimation of DG Capacity in Distribution Networks

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ABSTRACT

This paper presents optimal placement and estimation of distributed generation (DG) capacity using Particle Swarm Optimization (PSO) approach in the radial distribution systems to reduce the real power losses and to gain voltage profile improvement. Furthermore, the proposed method focuses on the installation of the DGs 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 is loss reduction, voltage profile improvement, fuel price and costs of load prediction for each bus. Using an optimal PSO Algorithm, the proposed optimization method, a destination function that includes all of the 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 and the matrix of coefficients in the DIGSILENT environment. The cost parameters are variables dependent on the status and position of each bus in the network, putting forth an optimal DG placement. 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 in the distribution network.

Keywords: *Distributed Generation (DG), Distribution Network, Optimization, PSO Algorithm.*

I. INTRODUCTION

With the increasing expanding of network construction in the modern power system and the rapid development of renewable energy resource, distributed generation (DG) has become an important form of electrical source. More and more DGs are connected into the power distribution system. It is predicted that DG would have a share of about 20% of new generating units being on lined [1]. 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 [2]. 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 [3], [4].

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 [5] 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 [6] takes productivity, cost effectiveness, loss reduction, and reliability and DG type into account and fails to consider other parameters. In [7] only focuses on three parameters: DG cost, loss reduction and reliability. Also in [8] defines its optimal DG placement method taking DG capacity, cost effectiveness and loss reduction into account. In addition, in [9] defines its optimal placement method taking stability, loss reduction and productivity into account. In [10] 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, fuel price 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 organization of the remainder of this paper is as follows. Section II describes the implementation of the proposed method on a sample IEEE 13-bus distribution system. Section III describes simulation network and the finally the PSO algorithm Procedure and simulation results are shown in Section IV, V, VI and VII respectively followed by conclusions.

II. 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, fuel price and cost of load prediction for each bus, is as follows:

$$\left[F(x) = K_1.C_{Loss} + K_2.C_{VPI} + K_3.C_F + K_4.C_L\right](\$/KW)\ (1)$$

where C_{LOSS} is the cost of loss in all lines, C_{VPI} is the cost voltage profile improvement, C_F is the cost of the fuel used by DG sources and C_L is 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 additive, this was accomplished by applying "K" coefficients (K_1-K_4). 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. [11].

It is noteworthy that each of the coefficients of the fuel price 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 paper has two major goals: 1) Improvement of voltage profile, 2) Loss reduction. There are also some limitations based on which the destination function should be defined [12]:

1) $(Loss\ \ with\ \ DG) < (Loss\ \ without\ \ DG)$
2) $V_{bus}^{\min} \le V_{bus} \le V_{bus}^{\max}$

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.

III. SIMULATION NETWORK

In the proposed work, 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 can be generalized to be used for all distribution networks with any number of buses. Moreover, the optimization algorithm of the destination function is a PSO Algorithm. The single line diagram of the network is illustrated in Fig. 1.

Fig. 1: Single line Diagram for IEEE 13-bus Distribution Network

According to Fig. 1, 13-bus network contains two feeding sources in buses 1 and 6. Tables 1 and Table 2 show the data on the lines and buses [13].

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

IV. THE PSO ALGORITHM PROCEDURE

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 [14].

The PSO-based approach for solving OPDG problem to minimize the loss takes the following steps:

Step 1: Input line and bus data, and bus voltage limits.
Step 2: 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 Pbest, set this value as the current Pbest, and record the corresponding particle position.
Step 6: 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 7: Update the velocity and position of particle.
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, and the corresponding fitness value representing the minimum total real power loss.

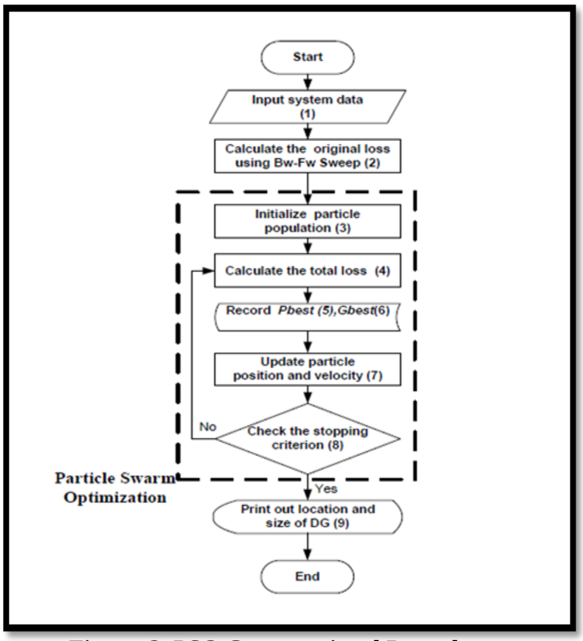

Figure. 2. PSO Computational Procedure

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

V. SIMULATION

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, fuel price and load prediction in the destination function of the PSO Algorithm shown by (k_1 - k_4) in the destination function. However, other coefficients shown in Table 4 are related to the weight of parameters for the effects of fuel price 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, fuel price 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.

Table 3: Coefficients Applied to the Parameters under the First (1) Condition

Coefficien t	Parameter	Coefficients applied to each parameter in destination function
K_1	Loss reduction	45%
K_2	Voltage profile	30%
K_3	DG fuel cost	15%
K_4	Load prediction cost	10%

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

Table 4: An example of the Weights of Each Parameter

Bus No	Coefficient applied in each bus to fuel price	Coefficients applied in each bus to load prediction cost
1	5%	10%
2	15%	10%
3	5%	10%
4	15%	5%
5	10%	10%
6	5%	5%
7	15%	5%
8	10%	20%
9	5%	10%
10	10%	5%
11	5%	10%

VI. 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.

Table 5: The Algorithm Outputs

DG name	Location	Capacity (kW)
DG	BUS 9	784
Loss before DG	Loss after DG	LII
0.121466	0.109454	0.901108
VPI without DG	VPI with DG	VPII
0.896743	0.954583	1.064500

Also, in the above outlet, line loss reduction index is defined by [15-16]:

$$LII = \frac{LL_{WDG}}{LL_{WODG}} \qquad (2)$$

Where LL_{WDG} and LL_{WODG} are the losses incurred with and without DG presence, respectively. This indicator can have the following implications under the following three conditions:

- LII<1: DG reduces loss
- LII=1: DG is not effective
- LII>1: DG increases loss

Furthermore in Table 5, VPII indicates voltage profile improvement and shows the effect of DG placement on the voltage profile which is defined as follows [17]:

$$VPII = \frac{VP_{WDG}}{VP_{WODG}} \qquad (3)$$

Where VP_{WDG} and VP_{WODG} are the voltage profiles with and without DG presence, respectively, and can be interpreted as follows under the following conditions:

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

To observe the effect of each parameter including fuel price and load prediction cost, we changed the coefficients applied to each parameter in each bus in the form of a matrix. Table 6 presents the weight of another example of parameters such as fuel price and load prediction, under condition of Table 3.

In addition, Table 7 presents program outputs regarding to optimal capacity and placement of DG.

Table 6: An Example of the Weights of Each Parameter

Bus No	Coefficient applied in each bus to fuel price	Coefficients applied in each bus to load prediction cost
1	10%	5%
2	5%	10%
3	10%	5%
4	5%	20%
5	10%	10%
6	5%	10%
7	5%	10%
8	25%	10%
9	10%	5%
10	5%	10%
11	10%	5%

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Table 7: The Algorithm Outputs

DG name	Location	Capacity (kW)
DG	BUS 11	556
LOST BEFOR DG	LOST AFTER DG	LII
0.131266	0.122448	0.932823
VPI WITHOUT DG	VPI WITH DG	VPII
0.913423	0.958982	1.049873

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 fuel price 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.

Table 8: Coefficients Applied to the Parameters under the First (2) Condition

Coefficient	Parameter	Coefficient applied to each parameter in destination function
K_1	Loss reduction	30%
K_2	Voltage profile	40%
K_3	DG fuel cost	10%
K_4	Load prediction cost	20%

Table 9: An Example of the Weights of Each Parameter

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

Table 10: The Algorithm Outputs

DG name	Location	Capacity (kW)
DG	BUS 10	680
LOST BEFOR DG	LOST AFTER DG	LII
0.121266	0.119888	0.988636
VPI WITHOUT DG	VPI WITH DG	VPII
0.909323	0.974523	1.071701

To observe the effect of each parameter including fuel price 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 fuel price 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 11: An Example of the Weights of Each Parameter

Bus No	Coefficient applied in each bus to fuel price	Coefficients applied in each bus to load prediction cost
1	5%	5%
2	15%	20%
3	5%	5%
4	5%	5%
5	10%	10%
6	5%	5%
7	5%	20%
8	20%	5%
9	10%	5%
10	5%	5%
11	15%	15%

Table 12: The Algorithm Outputs

DG name	Location	Capacity (kW)
DG	BUS 7	1180
LOST BEFOR DG	LOST AFTER DG	LII
0.121266	0.107581	0.887148
VPI WITHOUT DG	VPI WITH DG	VPII
0.884123	0.987634	1.117077

VII. CONCLUSIONS

In this paper, we studied the effects of the significant parameters to optimally enhance the cost parameters (such as loss reduction, voltage profile improvement, fuel price and costs of predicting load of each bus). The cost parameters are variables which are dependent on the status and position of each bus of the power network. Unlike the previous works on intelligent DG placement which all consider only a few parameters to be optimized; the proposed method uses many possible significant parameters into account to be formulized and optimized.

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. It has been shown that any changes made in the weight of parameters such as loss reduction, voltage profile coefficient, fuel price and load prediction cost in the destination function of PSO Algorithm directly affect the optimal DG capacity and placement.

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