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Simultaneous Placement of Capacitor and DG in Distribution Networks Using Particle Swarm Optimization Algorithm

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Abstract

Nowadays, using distributed generation (DG) resources, such as wind and solar, also improving the voltage profile in distribution companies has been considered. As optimal placement and sizing of shunt capacitors become more prevalent, utilities want to determine the impact of the various capacitors placement in distribution systems. Locating and determining the optimal capacity of shunt capacitors in order to reduce power losses and improving the voltage profile and using the maximum capacity of transmission lines, are one of the common problems in the design and control of power systems. Using the shunt capacitors, not only improve voltage profiles, but also reduce system losses. In this study, a genetic algorithm (GA) and particle swarm optimization (PSO) algorithm are proposed for simultaneous placement of capacitors and DG resources in order to reduce power losses and improve the voltage profile in a case study radial distribution network. Simulations applied on IEEE 70-bus and 86-bus test system, and finally solutions of the proposed algorithms are compared.

Keywords: Particle Swarm Optimization (PSO), Capacitor Placement, Radial distribution network, Power loss reduction, DG placement, Genetic Algorithm (GA).
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1. Introduction

Studies show that about 13% of the generated energy in the power system is dissipated in distribution networks. Since most system components, including electrical loads on the power system consuming reactive power, the reactive losses should be considered. By increasing the reactive load current, system losses also is increased. The most common methods for resolving this problem are to use shunt capacitors, DG resources and restructuring distribution network. Shunt capacitors improve the voltage profile and reduce system losses. In addition, the capacities of lines and active power transfer capability have been increased by compensation of consuming reactive current [1].

Determine the location and optimal sizing of capacitors can be obtained by solving an optimization problem. Nowadays, innovative and intelligent methods have been used in solving different optimization problems. Some examples of the optimization techniques which are used in solving problem of optimal capacitor placement in the distribution network are as below.

In [2], capacitor placement problem and optimal capacity determination in order to increase reliability in the distribution network and improve power quality are studied by the particle swarm algorithm. In [3], a fuzzy set theory is used for optimal placement of capacitors to reduce power losses in the radial distribution network. Reference [4], have suggested a simple strategy for the capacitor placement problem and improve power quality based on GA, the objective function comprises the cost of power losses and costs related to the capacitor banks.

In [5], self-adaptive harmony search algorithm for the optimal capacitor placement is provided to reduce power losses in the distribution network. Reference [6], an improved harmony search algorithm is used for optimal capacitor placement in the distribution network. In [7], the authors proposed a new adaptive modified firefly algorithm to solve the optimal capacitor placement problem; the objective function comprises the cost of power losses and the cost of installing capacitors. In [8], the authors proposed the particle swarm algorithm by considering the harmonic distortion for the capacitor placement. The objective function is a combination of the capacitor costs and active losses costs. In [9], the PSO algorithm has been used to solve this problem, the objective function is a combination of the capacitor costs and active losses costs in radial distribution systems. In [10], the particle swarm algorithm is expressed to determine the optimal size and location of DG in order to reduce active power losses and improve system reliability. In [11], the placement of DG sources is investigated in order to reduce losses and improve voltage profile. In [12], improving voltage profiles as the objective function is considered in the allocation of DG. In [13], the placement of distributed generation by considering a multi objective function in order to reduce losses and improve the voltage profile has been investigated. In [14], the placement of DG resources with the aim of improving the voltage profile and system reliability have been investigated, in some researches, DG and other devices placement have been simultaneously analyzed. In [15], the placement of DG, recloser and remote control switches with the aim of improving reliability and reducing losses have been investigated.

In this paper, a genetic algorithm (GA) and particle swarm optimization (PSO) algorithm are proposed. A new method of simultaneous capacitors placement and DG resources will be proposed to reduce power losses and improve voltage profile. The objective function of this optimization problem is the power losses. The proposed method is tested in 33-bus and 85-bus radial distribution systems. The other parts of the paper are organized as follows: In section II, direct load flow method which used in this paper is described. In section III and section IV, PSO and GA algorithms are introduced. In section V, the objective function of the proposed approach and the constraints have been investigated, In Section VI, after introducing tested network, simulation results of GA and PSO algorithms in the distribution 33-bus network are analyzed. In section VII, simulation results of GA and PSO algorithms in the 85-bus distribution network are analyzed.

2. Direct Load Flow

Since the wind output power is an erratic quality, it's difficult to be determined. Generally, in many studies analyzing wind output power through wind velocity and using linear definition of output power of wind turbine generator to model the actual wind power has been proposed [11].

$$[B]=[BIBC].[I] \tag{1}$$

$$[\Delta V]=[BCVB].[B] \tag{2}$$

And the corresponding equivalent current injection at the k-th iteration can be calculated from equation (3):

$$I_i^K = \frac{P_i + jQ_i}{V_i^K} \tag{3}$$

Equation (2) is expressed as follows:

$$[\Delta V]=[BCVB].[BIBC] . [I] = [DLF]. [I] \tag{4}$$

The solution for load flow can be obtained by solving (3) till (6) iteratively:

$$[\Delta v^{k+1}] = [DLF][I^k] \tag{5}$$

$$[V^{K+1}] = [V^0] - [\Delta V^{K+1}] \tag{6}$$

V^0 is the value of the refrence bus, Δv^{k+1} is the voltage drop on branches in new iteration and V^{K+1} is the claculated bus voltage.

According to the proposed method for solving load flow, Jacobian or admittance matrix is not required. The difference between this method and normal methods is in lack of calculation in the inverse impedance matrix, which is due to topological network, impedance matrix is singular and inversion is impossible [16].

3. Particle swarm optimization algorithm(PSO)

Particle swarm is one of the best methods for population-based evolutionary. PSO is inspired by the social behavior of some animals such as flocking behavior of birds and the schooling behavior of fish. The PSO algorithm is comprised of particles collection that moves around the search space influenced by their own best past location and the best location of the whole swarm or a close neighbor. This algorithm is applicable to almost all the problems in multiple-dimensional, complex constrained and nonlinear programming [17], particle swarm algorithm structure is as follows:

Population: It is a set of 'n' number of particles described as $X = \{X_1, X_2, .., X_n\}$.

Swarm: It is an apparently disorganized population of moving particles that tend to cluster together while each particle seems to be moving in random directions.

Particle Velocity (V): It is the velocity of the moving particle described as $V = \{V_1, V_2, \dots, V_n\}$.

Personal best (pbest): Best position achieved so far by particle.

Global Best (gbest): It is the best position among all the individual pbest of the particles achieved so far.

In each iteration, velocity and position of sample particle i-th by using equation (7,8) are updated.

$$v_i^{k+1} = \omega v_i^k + c_1 r_1 \left(pb_i^k - x_i^k\right) + c_2 r_2 (gb_i^k - x_i^k) \quad (7)$$

$$x_i^{k+1} = x_i^k + v_i^{k+1} \quad (8)$$

c_1 and c_2 are Acceleration factors and r_1, r_2 are normally distributed random values, and ω is inertia weight. Using inertia weight makes a compromise between the ability to explore global and local. A large inertia weight, driving for larger particle velocity vector across the answer space and it is employed to improve the global search capability for finding the global optimum. A little inertia weight is used to improve the neighbourhood scan ability for rapid convergence rate. Actually, the lower weight makes the search in areas that have been experienced in the past, will continue with greater precision. Often the inertia weight factor is set in the implementation of the algorithm and during learning. In this paper inertia weight is decreased from 1 to approximately zero [18].

$$w = w_{max} - \frac{W_{max} - W_{min}}{iter_{max}} . iter \quad (9)$$

iter is the current iteration number and $iter_{max}$ is the maximum iteration number. Amount of velocity Vi (Velocity vector) in each dimension between $[-v_{max} \; + v_{max}]$ is limited in order to reduce the possibility of leaving the search space by particle. In this paper, PSO algorithm is conducted for the simultaneous capacitor and DG placement in the following steps:

Step 1: Importing network data and algorithm parameters. Then an initial population is produced with initial velocity and position, that including location and capacity of the installed capacitor and DG in the network bus. The iteration index is set to zero (k=0)

Step 2: By calculating the objective function for the initial population, particle fitness is determined. The objective function for the optimal capacitor and DG placement is the total cost, according to equation (10) is in the formulation of the problem.

Step 3: The fitness value of the particle is compared with previous particle best (pbest) value in iteration. If the current fitness value is less than its pbest value, then assign the pbest value to the current value (This problem is minimization), and is updated at each iteration.

Step 4: determine the current global best (gbest) maximum value among the particles individual best (pbest) values, and is updated in iteration.

Step 5: Current position of particles is updated by using equation (7, 8).

Step 6: If the stop criteria are achieved (maximum iteration), the algorithm ends, otherwise the iteration index is set to k=k+1 and repeat steps from 2.

Finally, the optimum answer (best position particle) represents the optimal location and the optimal number of capacitor banks and DG resources; in addition, the corresponding fitness value is the lowest active losses.

A) Genetic algorithm(GA)

Genetic algorithm is a search algorithm based on the process of biological evolution [19]. GA algorithm provides solutions by producing a series of chromosomes as initial generation. The new generation is achieved through the generating, crossover and mutation operators form a powerful search mechanism [20]. The optimization process by GA works as follows:

B) Generate an initial population

At first, a randomly initial population is generated, including small components called chromosome.

C) Assess population by using evaluation function

At this point, each chromosome is evaluated according to its fitness. Evaluation function is calculated, by using the equation (10), for all chromosomes by considering objective function an individual fitness is computed in order to selection function for the next step.

D) Selection operator

The selection function determines which of the parents' chromosomes will survive and continue on to the next generation by considering the amount of their fitness.

E) Crossover and mutation operators

During genetic cycle parental, chromosomes combined to generate new child chromosome, then in mutation, the child chromosome randomly is selected And a gene on this chromosome is mutated or changed.

F) Termination criterion

Generally, the maximum number of generations is the termination Criterion. However, other criteria e.g., Improvement insufficiency of the best answer during several generations can be considered as a convergence criteria.

In this study to determine simultaneous placement of capacitors and DG resources in the distribution system, the genetic algorithm has been used as follows:

Step 1: Importing network data and algorithm parameters. Then an initial population is produced with initial velocity and position, that including location and capacity of the installed capacitor and DG in the network bus. The iteration index is set to zero (k=0)

Step 2: By calculating the objective function for the initial population, particle fitness is determined. The objective function for the optimal capacitor and DG placement is the total cost, according to equation (10) is in the formulation of the problem.

Step 3: At this step, the selection operator is applied; according to the evaluation function two parent chromosomes should be selected.

Step 4: The crossover operator is utilized for parent chromosome reproduction and creating a new generation.

Step 5: In this phase, the mutation operator is used in order to modify or mutate genes in the chromosomes for a new generation.

Step 6: If the stop criteria are achieved (maximum iteration), the algorithm ends, otherwise the iteration index is set to k=k+1 and repeat steps from 2.

Finally, the optimum answer (best position particle) represents the optimal location and the optimal number of capacitor banks and DG resources; in addition, the corresponding fitness value is the lowest active losses.

4. Objective Function

The objective function for simultaneous placement of capacitors and DG resources is calculated by equation (10):

$$P_{loss} = \sum R_K I_K^2 \qquad (10)$$

P_{loss} :active power losses ،R_k: k-th ohmic resistance of feeder branch I_k: k-th current flowing through feeder branch, Constraints of optimization problem is defined as follows:

Circuit constraints of the network for load flow calculations:

$$P_i = V_i \sum V_j Y_{ij} \cos(\delta_i - \delta_j - \gamma_{ij}) \qquad (11)$$

$$P_i = V_i \sum V_j Y_{ij} \cos(\delta_i - \delta_j - \gamma_{ij}) \qquad (12)$$

The bus voltage limitation and the rate of line loading

$$Vmin \leq Vj \leq Vmax \qquad j = 1:n \qquad (13)$$

$$Ii \leq Imax \qquad i = 1:n \qquad (14)$$

The amounts of installed capacity are constrained by the DG resources and capacitor penetration factor by the following equations:

$$\sum_{i=1}^{Ndg} P_{max}^{dg} \leq K_p^{dg} \sum P_{load} \qquad (15)$$

$$\sum_{i=1}^{Ncap} Q_{max}^{cap} \leq K_p^{cap} \sum Q_{load} \qquad (16)$$

- k_p^{dg}: DG resources penetration in the network
- k_p^{cap}: Capacitor penetration in the network

5. Results of Simulation in the 33-bus Distribution Network

A 33-bus network data about the study are as follows: rated voltage 12.66 KV, other information about the branches impedance and the load that connected to the branches are expressed in [21]. The total active and reactive power is 3715 KW and 2300 KVAR, respectively. Total active power losses are 202.71 kW. The parameters of the algorithms are as follows: Initial population for both algorithms is 300. Maximum iteration for PSO is 200 and maximum generation for GA is 200. In this section, 4 DGs with 500 kW capacity and 4 Capacitors with 300 Kvar capacities are used. The amount of generating active power of DG resources is limited between 100 and 500 kW. Additionally, the amount of capacitors reactive power is limited between 100 and 300 Kvar.

A) *Test result of GA algorithm*

By using GA, optimal capacitor and DG placement are implemented in the 33-bus network, and the results are as follows:

The convergence characteristic of GA is shown in Fig.1. In addition, Fig.2 indicates improvement in the voltage profile before and after installation of capacitors and DG resources.

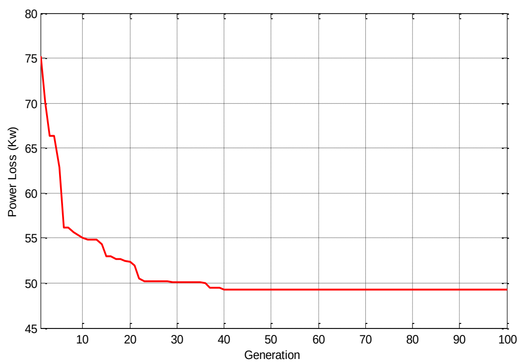

Fig. 1. The convergence characteristic of GA algorithm

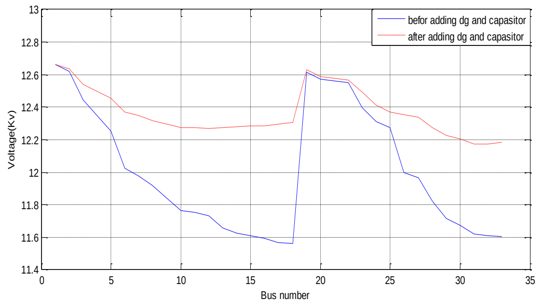

Fig. 2. Voltage profile before and after installation of Capacitors and DG resources

B) Test result of PSO algorithm

A conventional PSO algorithm for optimal capacitor and DG resource placement in the 33-bus network is performed. The convergence characteristic of the PSO algorithm is shown in Fig.3. Fig.4 indicates improvement in the voltage profile before and after installation of capacitors and DG resources. The results of capacitor installation and also DG placement by using GA and PSO Algorithm in the 33-bus network are listed in Table1 and Table 2.

Table.1.
The results of capacitor and DG installation by using GA algorithm in 33-bus network

Title	***GA algorithm***
Optimal place and capacity of Capacitor(Kvar)	Bus 31-300 Bus 30-300 Bus 8-110 Bus 7-300 Bus 14-300
Optimal place and capacity of DG resources(Kw)	Bus 28-500 Bus 30-100 Bus 4-100 Bus 29-200 Bus 6-500
Total power losses(Kw)	49.350

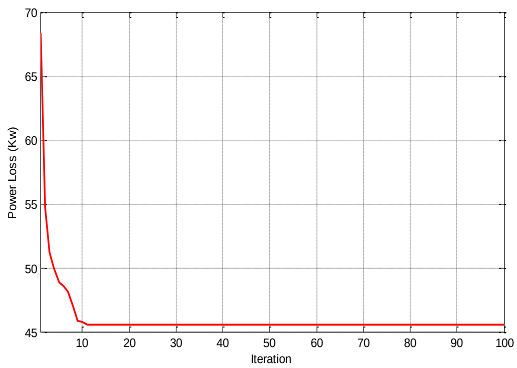

Fig. 3. The convergence characteristic of the PSO algorithm

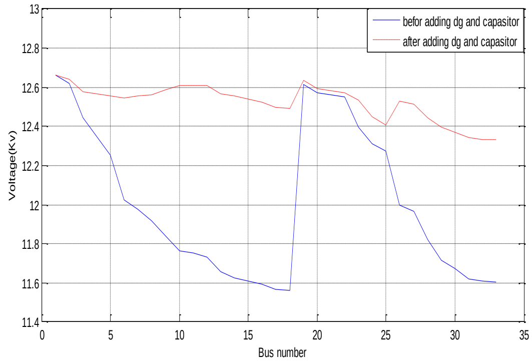

Fig. 4. Comparison between the voltage profile before and after installation of Capacitors and DG resources

Table.2.
The results of capacitor and DG installation by PSO algorithm in 33-bus network

Title	***PSO algorithm***
Optimal place and capacity of Capacitor(Kvar)	Bus 12-100 Bus 28-240 Bus 16-160 Bus 33-150 Bus 26-220
Optimal place and capacity of DG resources(Kw)	Bus 6-300 Bus 28-200 Bus 16-400 Bus 33-400 Bus 29-300
Total power losses(Kw)	45.485

The simulation results demonstrate better performance of the PSO algorithm Compared with GA algorithm. The amount of active power losses after placement by GA algorithm is 46.650 Kw and by using the PSO algorithm reached to 43.685 Kw. According to compare the results of both algorithms in optimal capacitor and dg placement issues, can be found that PSO algorithm than GA algorithm yielded better results (reduce the active power losses of 49.350 Kw to 45.485 Kw). The amount of active power losses in the network before installing capacitors and DG is 202.71 kW. According to the Fig. 2 and Fig 4 after installing capacitors and DG, the voltage profile is improved. Voltage profile improvement in PSO is more significant.

6. Simulation Results in 85-Bus Distribution Network

An 86-bus network data about the study are as follows: rated voltage 11.4 KV, other information about the branches impedance and the load that connected to the branches are expressed in [22]. The total active and reactive power is 28350 KW and 20700 KVAR, respectively. Total active power losses are 315.714 kW. In this section, 4 DGs with 500 kW capacity and 4 Capacitors with 300 Kvar capacities are used. The amount of generating active power of DGs is limited between 100 and 500 kW. The amount of capacitors reactive power is limited between 100 and 300 Kvar.

A) Test Result of GA algorithm

By using GA, optimal capacitor and DG placement are implemented in the 85-bus network, and the results are as follows: The convergence characteristic of GA is shown in Fig.5. Fig.6 indicates improvement in the voltage profile before and after installation of capacitors and DG resources.

B) Test Result of PSO algorithm

A conventional PSO algorithm for optimal capacitor and DG resource placement in the 85-bus network is performed. The convergence characteristic of the PSO algorithm is shown in Fig.7. Fig.8 indicates improvement in the voltage profile before and after installation of capacitors and DG resources.

The results of capacitor installation and also DG placement by using GA and PSO Algorithms in the 85-bus network are listed in Table3.the results show better performance of the PSO algorithm compared with GA algorithm. The amount of active power losses after placement by GA and PSO algorithm is 290.608 kW and 286.989 kW, respectively. It can be found that, subject to the both algorithms results, in optimal capacitor and (DG) placement problems, PSO algorithm gives better result than GA algorithm (by reducing the active power losses from 290.608 Kw to 286.989 Kw). The amount of active power losses in the network before installing capacitors and DG is 315.714 kW

Both GA and PSO algorithms have good performance in capacitor and DG placement. However, according to the results of both algorithms in optimizing the objective function can be found that the particle swarm (PSO) has better results compared with Genetic algorithm (GA).

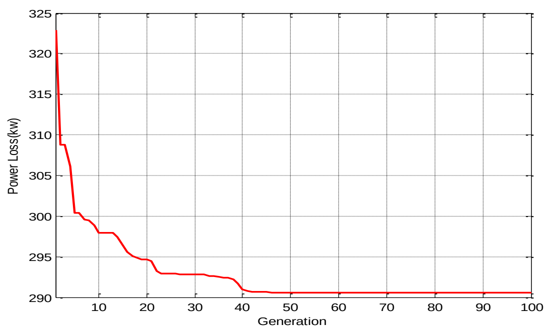

Fig. 5. The convergence characteristic of the GA algorithm

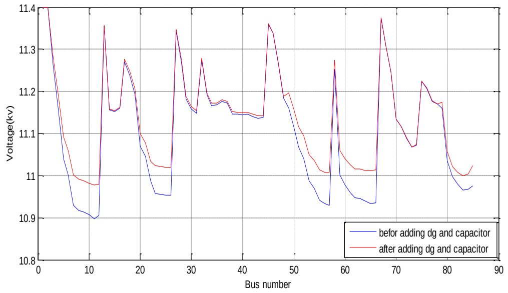

Fig. 6. Comparison between the voltage profile before and after installation of Capacitors and DG resources

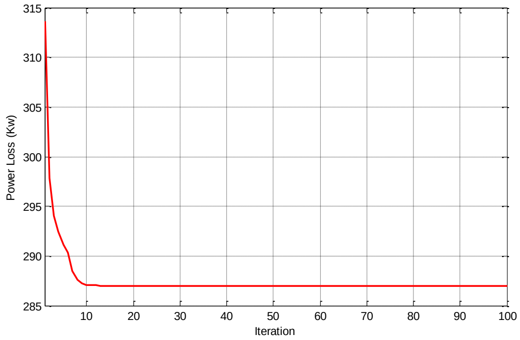

Fig. 7. The convergence characteristic of the PSO algorithm

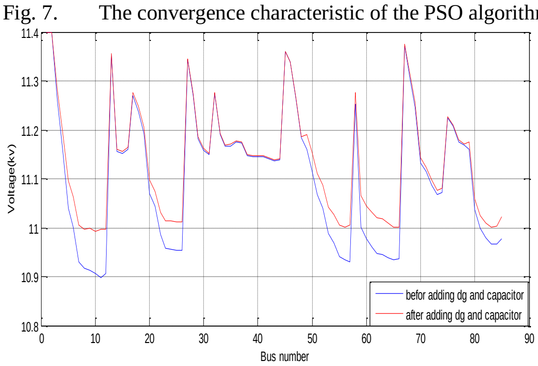

Fig. 8. Comparison between the voltage profile before and after installation of Capacitors and DG resources

Table.3.
The results of capacitor and DG installation by using GA and PSO algorithms in the 85-bus network

Title	***GA algorithm***	***PSO algorithm***
Optimal place and capacity of Capacitor(Kvar)	Bus 73-300 Bus 23-300 Bus 84-300 Bus 57-300 Bus 65-300	Bus 23-300 Bus 85-300 Bus 11-300 Bus 57-300 Bus 65-300
Optimal place and capacity of DG resources(Kw)	Bus 66-200 Bus 65-100 Bus 82-100 Bus 3-100 Bus 57-500	Bus 67-100 Bus 84-100 Bus 3-200 Bus 85-100 Bus 8-500
Total power losses(Kw)	290.608	286.989

7. Conclusion

Using DG resources can be profoundly effective in the electrical network, including the reduction of losses, improve voltage profile distribution networks. Due to the improvement in voltage profile, distribution companies pay more attention to DG resources and capacitor banks. Moreover, in this study simultaneous placement is performed in the 33-bus and 85-bus networks in order to reduce losses and improvement in voltage profile. The applied approach led to the distribution of DG units and capacitors in effective parts. The presented algorithms in this study are GA and PSO algorithms.

Results of both algorithms show that in addition to reducing active losses also voltage profile is improved. Both algorithms try to minimize the active losses in the distribution network. However, Particle swarm optimization (PSO) has better results compared with Genetic algorithm (GA)

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