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Optimal Placement of Capacitor Banks in order to Improvement of Voltage Profile and Loss Reduction based on PSO

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Abstract: This study develops an optimal placement method in order to sizing and sitting of capacitor banks in IEEE 33 bus test system. The proposed method in order to optimization in this article is Particle Swarm Optimization and the objective function is composed of two parts. The most part of proposed objective function considers improvement of voltage profile and other part is active power losses of the system in nominal load of mention system. In order to use of Particle Swarm Optimization algorithm, at first, placement problem is written as an optimization problem which includes the objective function and constraints, and then to achieve the most favorite results, Particle Swarm Optimization (PSO) method is applied to solve the problem. High performance of the proposed algorithm in mention system is verified by simulations in MATLAB software and in order to prove of feasibility of proposed method this optimization in three cases - one capacitor bank, two capacitor banks, and three capacitor banks- will accomplish.

Key words: Capacitor placement, loss reduction, optimization, particle swarm optimization

INTRODUCTION

The voltage stability problem in distribution networks is becoming more and more critical as utilities operate their systems at higher and higher loads. Increasing network loading results in increases in active and reactive power losses. In order to compensation of this losses in distribution systems, capacitor bank have been used originally. Reactive power compensation is necessary in order to voltage profile correction and reduction of active and reactive loss power (Chung-Fu, 2008). Therefore, the capacitor banks can have intricately effect on the power-flow, voltage profile, stability and quality of power supply for customers and electricity suppliers. The benefits of this composition depend extremely on location and sizing of this capacitor bank. If this sizing and sitting do not have the appropriate location and value, the profile of voltage and active and reactive losses may be will be increased (Haghifam and Malik, 2007).

The varying methods were proposed in order to detection of best size and optimum sites of capacitor banks. Grainger and Lee, (1981) considered the optimization problem as a nonlinear programming problem as continuous variables by treating the capacitor sizes and the site. Fuzzy logic (FL) has good results for capacitor bank allocation when combined with GAs under sinusoidal operating conditions in order to loss reduction (Ng *et al*., 2000). Duran (1968) considered of capacitor sizes as discrete variables and applying dynamic programming to find the optimal solution. the solution of this problem was formulated by the gradient method combined with a clustering algorithm that, may be fast, but does not guarantee to find the global optimized solution (Gallego *et al*., 2001).

An immune-based optimization technique is proposed for radial distribution system in order to reach to optimal point of capacitor banks allocation optimization problem (Huang, 2000). Nonlinear loads effect on best point sites of capacitor banks was analysis in radial system (Baghzouz, 1991). Combination of Evolutionary Programming (EP) algorithm with fuzzy logic (Venkatesh and Ranjan, 2006) was proposed to placement the optimal capacitor banks. Civanlar *et al*. (1988) conducted the early research on feeder reconfiguration for loss reduction.

Baran and Wu (1989) modeled the problem of loss reduction and load balancing as an integer programming problem. A harmonic power flow method is used with considers harmonic couplings caused by the nonlinear loads (Masoum *et al*., 2004). Chiang *et al*., (1990) used the optimization techniques based on Simulated Annealing (SA) to search the global optimum solution to the capacitor placement problem. Mendes *et al*., (2005) is used of the Genetic Algorithm (GA) to solve the optimization problem to select the optimal point of capacitor banks for radial distribution system.

In this study, Particle Swarm Optimization (PSO) which is capable of finding global or near global optimum solution is used for optimal size and site of capacitor bank in 33-bus of IEEE test system with tie line(Kashem *et al*., 2000). Objective functions are gathered to form a multi objective optimization problem. The objective function is composed of two parts. The most part of proposed objective function considers improvement of voltage profile and other part is active power losses of the system in nominal load of mention system. At first, placement problem is written as an optimization problem and then to achieve the best results, PSO technique is applied to solve the problem. The Results and power flow program is written in *MATLAB* software. The results explore the effectiveness of the proposed technique applied on simulation test system.

PROBLEM FORMULATION

This study discusses the capacitor placement problems of distribution systems. The objective is to minimize the system power loss and improvement of voltage profile, subject to operating constraints under a certain load pattern. The mathematical model of the Multi Objective Function (MOF) in this paper in order to achieve the performance calculation of distribution systems for capacitor size and location problem can be expressed as follows:

$$MOF = \sigma_1 VPI + \sigma_2 RPL \tag{1}$$

where, σ_1 and σ_2 consider in this study 0.7 and 0.3 respectively.

Objective functions formulation: As can be seen in Eq. (1), objective function combined from two components. One part is Real Power Loss (RPL) that is 30 percent of mention objective function and Voltage Profile Improvement (VPI) that combined 70% of objective function.

Real power loss formulation (RPL): Buses voltage, line currents and real power loss in system lines calculates from the output results of power-flow which is used of Newton-Raphson in this study.

If vi is ith bus voltage and vj is jth bus voltage that specify from power flow results, the line current between ith and jth buses is given by:

$$I_{ij} = \frac{V_i - V_j}{Z_{ij}} \tag{2}$$

where, Zij is the impedance between ith and jth buses, the transmission power between the ith and jth buses and vice versa calculated by:

$$S_{ij} = V_i I^*_{ij} \tag{3}$$

$$S_{ji} = V_j I^*_{ji} \tag{4}$$

The real active loss between ith and jth buses is defined as:

$$P^{i,j}_{loss} = real(S_{ij} + S_{ji}) \tag{5}$$

Total loss power in power system is defined by:

$$P^{Total}_{Loss} = \sum_{i=1}^{N} \sum_{j=i}^{N} P^{i,j}_{loss} \tag{6}$$

where, N is the number buses of power system and RPL is given by:

$$RPL = \frac{P^{Total}_{Loss}}{P^{no\min al}_{Loss}} \tag{7}$$

where, P is the real power loss in nominal condition of study system.

Voltage profile improvement (VPI): One of the components of optimizes location and size of the capacitor banks is the improvement in voltage profile. This index penalizes the size-location pair which gives higher voltage deviations from the nominal value (Vnom). In this way, closer the index to zero better is the network performance. The VPI can be defined as:

$$VPI = \max_{i=2}^{n} \left(\frac{|V_{nom}| - |V_i|}{|V_{nom}|} \right) \tag{8}$$

CONSTRAINS FORMULATION

The multi objective function (1) is minimized subjected to various operational constraints to satisfy the electrical requirements for distribution network. These constraints are the following.

- Power-Conservation Limits: The algebraic sum of all incoming and outgoing power including line losses over the whole distribution network should be equal to zero:

$$P_{Gen} - \sum_{i=1}^{n} P_D - P^{Loss}_{total} = 0 \tag{9}$$

- Distribution Line Capacity Limits: Power flow through any distribution line must not exceed the thermal capacity of the line:

$$S_{ij} < S_{ij}^{max} \tag{10}$$

- Voltage Limits: the voltage limits depend on the voltage regulation limits should be satisfied:

$$V_i^{\min} \le V_i \le V_i^{\max} \tag{11}$$

This study employs Particle Swarm Optimization technique to solve the above optimization problem and search for optimal or near optimal set of problem. Typical ranges of the optimized parameters are [0.01 100] MVAr for capacitor and [0.95-1.05] for voltage of buses

Particle swarm optimization algorithm: Particle swarm optimization has been used to solve many optimization problems since it was proposed by Kennedy and Eberhart (Eberhart and Kennedy, 1995). PSO is one of the most recent developments in the category of combinatorial met heuristic optimizations (Gaing, 2003). In PSO, each individual is referred to as a particle and represents a candidate solution to the optimization problem (Yoshida *et al*., 2000).

In first, a population of random solutions ‘‘particles’’ in a D-dimension space are composed. Each particle is a solution. The ith particle is represented by $X_i = (x_{i1}, x_{i2}, . . . , x_{iD})$. Situation of each particle will be change in next stage. The best situation of each particle will be determined by fitness function. If the fitness functions has minimum value so far it is called best situation and save in Pbesti. The global version of the PSO keeps track of the overall best value (gbest), and its location, obtained thus far by any particle in the population (Mandal *et al*., 2008). PSO consists of, at each step, changing the velocity of each particle toward its pbest and gbest according to Eq. (12). The velocity of particle i is represented as $V_i = (v_{i1}, v_{i2}...,v_{iD})$. Acceleration is weighted by a random term, with separate random numbers being generated for acceleration toward pbest and gbest. The position of the ith particle is then updated according to Eq. (13) (Binghui *et al*., 2007).

$$v_{id} = w \times v_{id} + c_1 \times rand(\,) \times (P_{id} - x_{id}) + c_2 \times rand(\,) \times (P_{gd} - x_{id}) \quad (12)$$

$$x_{id} = x_{id} + cv_{id} \quad (13)$$

where, Pid and Pgd are pbest and gbest, c_1 and c_2 are constant values, ω will be determined by this equation:

$$\omega = \omega_{\max} - \frac{\omega_{\max} - \omega_{\min}}{iter_{\max}} \times iter \quad (14)$$

ω max and ωmin are the maximum and minimum value of ω respectively. At first ω start with large value that in the end of problem the value of the ω will be minimum.

In this optimization problem, the number of particles and the number of iterations are selected 30 and 50, respectively. Dimension of the particles will vary for each condition

CASE STUDY AND PLACEMENT RESULTS

In the case study presented in this section, we attend how capacitor placement affects system power loss reduction and voltage profile enhancement. In this study, the placement of only a single capacitor, two capacitor and three capacitor banks are considered. To demonstrate the utility of the proposed placement algorithm, a 33-bus test system with tie lines (Kashem *et al*., 2000) and shown in Fig. 1 is considered and the system details are given in Table 1.

At First, we consider that one capacitor bank which its size is between 25KVAr-10MVAr will placements in mention network. The results of this study is shown in Table 2 and Fig. 2, Table 2 shows that the power loss of the network with capacitor bank and without capacitor. With comparing of power loss in two cases that is obvious the capacitor placement can be has effect in power loss in whole mention network. Figure 2 illustrate buses voltage in two cases. With attention to this Figure, the voltage profile with capacitor bank is better than without capacitor and almost capacitor bank can be affect to all of buses voltage.

Table 1: lines, active and reactive power details in study system

Branch	Sen.	Rec.	Active	Reactive	Resistance	Reactance
1	1	2	100	60	0.0922	0.0470
2	2	3	90	40	0.4930	0.251 1
3	3	4	120	80	0.3660	0.1 864
4	4	5	60	30	0.3811	0.1941
5	5	6	60	20	0.8190	0.7070
6	6	7	200	100	0.1872	0.6188
7	7	8	200	100	1.7114	1.2351
8	8	9	60	20	1.0300	0.7400
9	9	10	60	20	1.0440	0.7400
10	10	11	45	30	0.1966	0.0650
11	11	12	60	35	0.3744	0.1238
12	12	13	60	35	1.4680	1.1550
13	13	14	120	80	0.5416	0.7129
14	14	15	60	10	0.5910	0.5260
15	15	16	60	20	0.7463	0.5450
16	16	17	60	20	1.2890	1.7210
17	17	18	90	40	0.7320	0.5740
18	2	19	90	40	0.1640	0.1565
19	19	20	90	40	1.5042	1.3554
20	20	21	90	40	0.4095	0.4784
21	21	22	90	40	0.7089	0.9373
22	3	23	90	50	0.4512	0.3083
23	23	24	420	200	0.8980	0.7091
24	24	25	420	200	0.8960	0.7011
25	5	26	60	25	0.2030	0.1034
26	26	27	60	25	0.2842	0.1447
27	27	28	60	20	1.0590	0.9337
28	28	29	120	70	0.8042	0.7006
29	29	30	200	600	0.5075	0.2585
30	30	31	150	70	0.9744	0.9630
31	31	32	210	100	0.3105	0.3619
32	32	33	60	40	0.3410	0.5302
33*	21	8			2.0000	2.0000
34*	22	12			2.0000	2.0000
35*	9	15			2.0000	2.0000
36*	25	29			0.5000	0.5000
37*	33	18			0.5000	0.5000

Table 2: Results of sizing and sitting with a single capacitor bank

Number of	Capacitor size	Capacitor site	Network loss
Without capacitor			70.2 KW
One capacitor	1182	15	66.8 KW

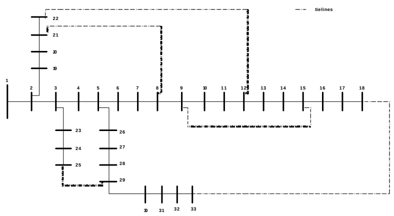

Fig. 1: IEEE 33 bus study system with tie lines

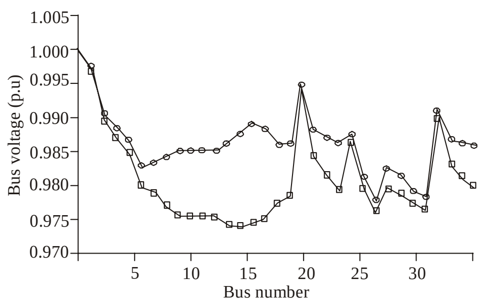

Fig. 2: Voltage profile of study system with a single capacitor bank and without capacitor

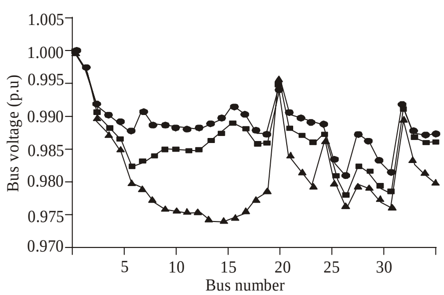

Fig. 3: voltage profile of study system with two capacitor banks - single capacitor and without capacitor

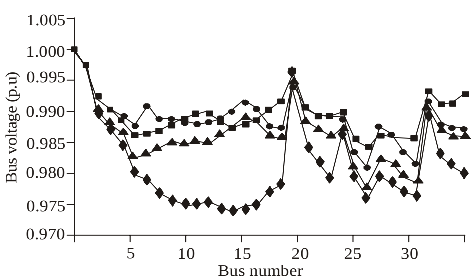

Fig. 4: voltage profile of study system with three capacitor banks- two capacitor banks - single capacitor and without capacitor

In the other scenario, two capacitor banks that size of them between 25KVAr-10MVAr too, considered in order to allocation in mentioned system. Results of this case present in Table 3 and Fig. 3. In this figure the voltage profile of three cases (without capacitor, one capacitor and two capacitor banks sizing and sitting) are presented. As can be seen, that is obvious the two capacitor placement results in line power losses and voltage profile is better than one capacitor bank and without capacitor in study system.

Table 3: Results of sizing and sitting with two capacitor banks-single capacitor and without capacitor

Number of Capacitor	Capacitor size (kvAr)		Capacitor site		Network loss
Without capacitor					70.2 KW
One capacitor	1182		15		66.8 KW
Two capacitor	1053.9	986.05	7	15	65.6 KW

Table 4: Results of sizing and sitting with three capacitor banks-two capacitor banks-single capacitor and without capacitor

Number of Capacitor	Capacitor size (kvAr)			Capacitor site			Network loss
Without Capacitor							70.2 KW
One capacitor	1182			15			66.8 KW
Two capacitor	1053.9	986.05		7	15		65.6 KW
Three capacitor	806.01	772.1	846.52	12	29	33	62.7 KW

In the final case, we assume that three capacitor banks in order to optimal placement are considered. The result of this study in represented power system. The results of line power loss that present in Table 4 depict in this case this power loss become less than other cases and in Fig. 4 the voltage profile is shows. The voltage profile in this case is better than previous cases.

CONCLUSION

In this study, a different approach based on Particle Swarm Optimization in order to Multiobjective optimization analysis, including one, two and three capacitor banks, for size-site planning of capacitor banks in distribution system was presented. In solving this problem, at first problem was written in the form of the optimization problem which its objective function was defined and written in time domain and then the problem has been solved using PSO. The proposed optimization algorithm was applied to the 33-bus test system with tie lines.

The results clarified the efficiency of this algorithm for improvement of voltage profile and reduction of power losses in study system

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