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Optimal Allocation of Distributed Generation and Capacitor Banks in Order to Loss Reduction in Reconfigured System

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Abstract: The concern about the limitation of fossil fuels and also rising consciousness of environmental protection, cause the installation of DGs increase annually. This study develops an optimal placement method in order to sizing and sitting of distributed generation and capacitor banks in IEEE 33 bus test system that reconfigured. The algorithm for optimization in this paper is simulated annealing. The proposed objective function considers active power losses of the system and the voltage profile in nominal load of system. High performance of the proposed algorithm in mention system is verified by simulations in MATLAB software and in order to illustrate of feasibility of proposed method this optimization will accomplish in two cases.

Key words: Capacitor placement, DG placement, loss reduction, optimization, simulated annealing

INTRODUCTION

Recently, the most part of countries energy consumption in the world supplied by fossil fuel resources. But, in this regard, they have faced with many problems which can include environmental pollution and terminable fossil resources. Growing of Distributed Generation can be has effect in voltage profile, stability, power loses at power system both in distribution and transmission side. In order to improvement of power system situation such as correction of voltage profile, addition of stability, decrease of loses power and etc, it is necessary that the installation of DGs in power system become systematically (Thong *et al*., 2007). Also, Reactive power compensation is necessary in order to voltage profile correction and reduction of active and reactive loss power for provide of reactive power compensate in distribution systems, capacitor bank have been used originally (Chung-Fu Chang, 2008).

The varying methods were proposed in order to detection of best size and optimum sites of capacitor banks and distributed generations. In Keane and O'Malley (2006), a mixed integer linear program was proposed to determine of optimum location. A TS search method to find the optimal solution of their problem was explained in (Katsigiannis and Georgilakis, 2008), but the TS is known to be time consuming algorithm also it is may be trapped in a local minimum.

In order to minimization of real power losses of power system in ref (Lalitha *et al*., 2010), a PSO algorithm was developed to specify the optimum size and location of a single DG unit. The problem was converted to an optimization program and the real power loss of the system was the only aspect considered in this study in order to determine of optimally location and size of only one DG unit.

The placement of one DG unit with specific size in (Ochoa *et al*., 2006) was explained. In this paper multi objective function such as power line losses, modify of voltage profile, line loading capacity and short circuit level were considered. P-V curves in ref (Singh and Goswami, 2010) have been used for analyzing voltage stability in electric power system to determine the optimum size and location of multiple DG units to minimize the system losses under limits of the voltage at each node of the system.

In the past decade, some evolutionary computational techniques such as Genetic Algorithms (GA) (Levitin *et al*., 2000), Simulated Annealing (SA) (Chiang *et al*., 1995) and Tabu Search (TS) (Huang *et al*., 1996) have been widely used to detection of best location and size of capacitor banks. These algorithms are in the form of probabilistic heuristics, with global search properties. Though GA methods have been employed successfully to solve complex optimization problems, recent research has identified deficiencies in GA performance. This degradation in efficiency is apparent in applications with highly epistatic objective functions (i.e., where the parameters being optimized are highly correlated) (the crossover and mutation operations can not ensure improved fitness of offspring because chromosomes in the population havesimilar structures and their average fitness is high toward the end of the evolutionary process) (Eberhart and Shi, 1998). Moreover, the premature convergence of GA degrades its performance and reduces its search capability, which leads to a higher probability for obtaining a local optimum (Evolutionary Computation, 2000).

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In Huang (2000) an immune-based optimization technique is proposed for radial distribution system in order to reach to optimal point of capacitor banks allocation optimization problem. Nonlinear loads effect on best point sites of capacitor banks in radial system was analysis in Baghzouz (1991) Combination of Evolutionary Programming (EP) algorithm with fuzzy logic in Venkatesh and Ranjan (2006) was proposed to placement the optimal capacitor banks.

In this study, Simulated Annealing (SA) is used for optimal size and site of Distributed Generation and capacitor banks in 33-bus of IEEE test system with tie line that present in Kashem *et al*. (2000). In this article the objective functions is reduction of power losses. But will be shown that the optimization will reduced the reactive power losses of system and will improve the voltage profile.

This study develops an optimal placement method in order to sizing and sitting of distributed generation and capacitor banks in IEEE 33 bus test system that reconfigured. The proposed objective function considers active power losses of the system and the voltage profile in nominal load of System. The simulation test systems were simulated in *MATLAB* software.

PROBLEM FORMULATION

This article discusses the capacitor banks and distributed generations placement problems of distribution systems simultaneously. The objective is to minimize the system power loss subject to operating constraints under a certain load pattern. The mathematical model of the Objective Function in this paper in order to achieve the performance calculation of distribution systems for capacitor and DGs size and location problem can be expressed as follows:

Objective functions formulation: 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 I_i is the ith bus current and v_i is ith bus voltage and v_j is jth bus voltage can be written:

$$I_i = V_i \sum_{j=0}^{N} y_{ij} - \sum_{j=1}^{N} y_{ij} V_j \quad j \neq i \tag{1}$$

The active and reactive power of ith Bus calculated by:

$$P_i + Q_i = V_i I^*_I \tag{2}$$

The Eq. (2) can be written such as:

$$I_i = \frac{P_i - jQ_i}{V_i^*} \tag{3}$$

by replacing of Eq. (3) in Eq. (1), the equation for voltage calculation gets result:

$$\frac{P_i - jQ_i}{V_i^*} = V_i \sum_{j=0}^{N} y_{ij} - \sum_{j=1}^{N} y_{ij} V_j \quad j \neq i \tag{4}$$

with applying of Newton method can be got the buses voltage. Specify from power flow results, the line current between ith and jth buses is given by:

$$I_{ij} = \frac{V_i - V_j}{Z_{ij}} \tag{5}$$

where, Z_{ij} is the impedance between *ith* and *jth* buses, the transmission power between the *ith* and *jth* buses and vice versa calculated by:

$$S_{ij} = V_i I_{ij}^* \tag{6}$$

$$S_{ji} = V_j I_{ji}^* \tag{7}$$

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

$$P_{loss}^{i,j} = real\left(S_{ij} + S_{ji}\right) \tag{8}$$

Total loss power in power system is defined by:

$$P_{Loss}^{Total} = \sum_{i=1}^{N} \sum_{j=1}^{N} P_{loss}^{i,j} \tag{9}$$

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

$$RPL = \frac{P_{Loss}^{Toyal}}{P_{loss}^{nominal}} \tag{10}$$

where, $P_{loss}^{nominal}$ is the real power loss in nominal condition of study system.

- **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:

$$P_{Gen} - \sum_{i=1}^{n} P_D - P_{total}^{Loss} = 0 \tag{11}$$

- **Distribution line capacity limits:** Power flow through any distribution line must not exceed the thermal capacity of the line:

$$S_{ij} < S_{ij}^{\max} \quad (12)$$

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

$$V_i^{\min} \le V_i \le V_i^{\max} \quad (13)$$

This study Simulated Annealing 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.

Simulated annealing algorithm: The SA algorithm performance like the other algorithms is based on search technique in the desired zone. First, several initial conditions are assumed to start the algorithm. In this process, determination is based on the particles energy, i.e., an action in this method is acceptable whenever a particle in the position X_0 having energy E_0 goes to the position X having energy E such that if the current position is better than the before one, it is selected, unless the current position is selected with the following probability:

$$P(x) = e^{\frac{E-E_0}{K_B T}} \quad (14)$$

which, KB and T are the Boltzmann coefficient and temperature, respectively. The possibility to accept the inferior position will be higher whenever the current position energy will be less than the previous one and the temperature is high. In T = 0, the inferior condition will be never accepted. During this process, the temperature is decreased based on annealing law from the initial temperature T_0 to the zero temperature, so that it means a search algorithm. Since this algorithm is strong, it could be better than the other ones to find the optimum point (Goffe *et al*., 1994; Ingber, 1993). One of the annealing laws in the algorithm is defined as follows:

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

Branch nom	Sen. node	Rec. node	Active power of Rec	Reactive power of Rec	Resistance ohms	Reactance ohms
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

$$T(i)=\frac{T_0}{\ln(i)} \tag{15}$$

i is the number of iterations.

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

The proposed SA algorithm is exerted to 33-bus test system with tie lines that shown in Fig. 1 (Kashem *et al*., 2000) to specify the optimal size and site of distributed generation units and capacitor banks such that the power losses reduction is minimized. The system line data and load data are given in Table 1. For this test system, 1 DG unit and 1 capacitor bank are optimally sized and placed. The size and location of DG unit and capacitor bank are given in Table 2.

The value of the OF and the influence of optimal placement and sizing of DG unit and capacitor bank on the active and reactive power losses of the system are given in Table 2.

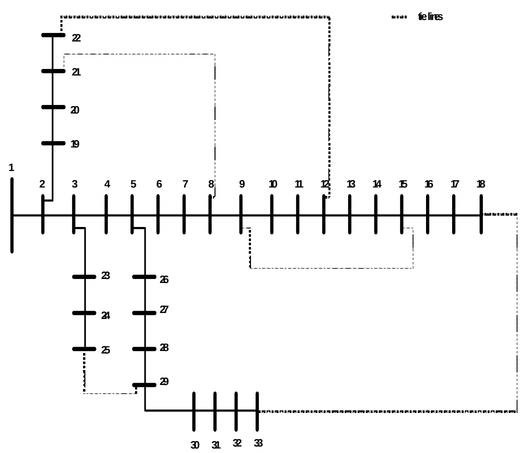

Fig. 1: IEEE 33 bus study system with tie lines

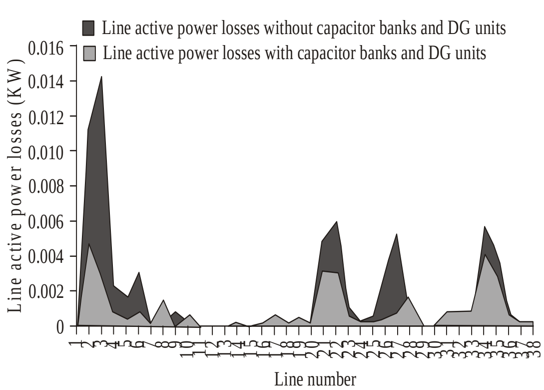

Fig. 2: Active power losses of system lines without and with

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

Capacitor site & size	DG site & size	Active power losses	Reactive power losses
Site	Site	Before placement	Before placement
Bus 15	Bus 25	70.2 KW	49.8 KVAr
Size	Size	After placement	After placement
687.0 KVAr	1467.3 KW	36.3 KW	28.8 KVAr

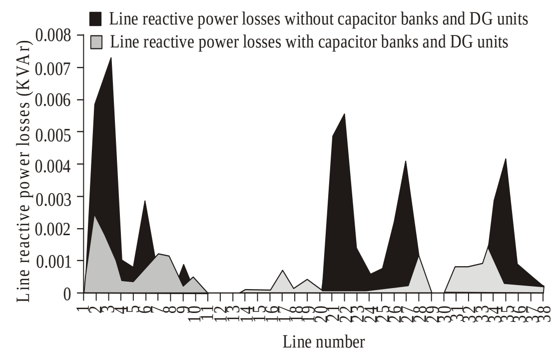

Fig. 3: Reactive power losses of system lines without and with DG and capacitor

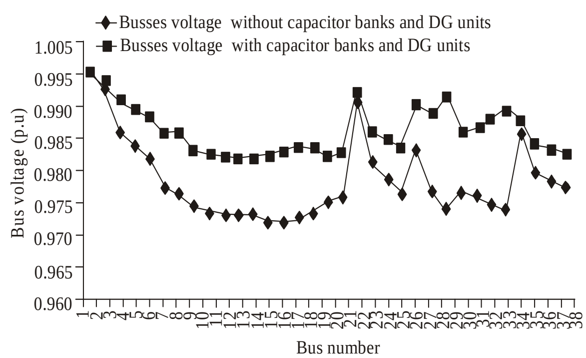

Fig. 4: Voltage amplitude of system buses without and with DG and capacitor

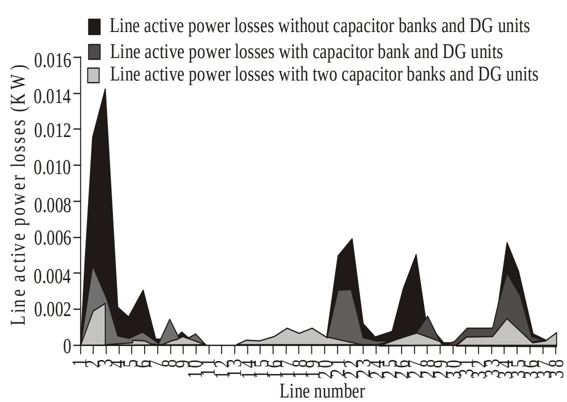

Fig. 5: Active power losses of system lines without and with one and two DG and capacitor

Table 3: Results of sizing and sitting with two DG units and capacitor banks

Capacitor site & size	DG site & size	Active power losses	Reactive power losses
Site	Site	Before placement	Before placement
Bus 21	Bus25	70.2 KW	49.8 KVAr
Bus 18	Bus15		
Size	Size	After placement	After placement
524.7 KVAr	1260.8 KW		
685.3 KVAr	1043.1 KW	19.4 KW	15.7 KVAr

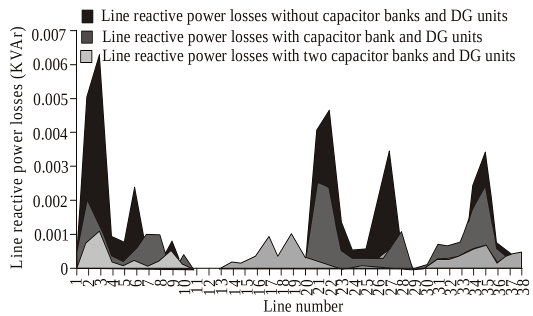

Fig. 6: Reactive power losses of system lines without and with one and two DG and capacitor

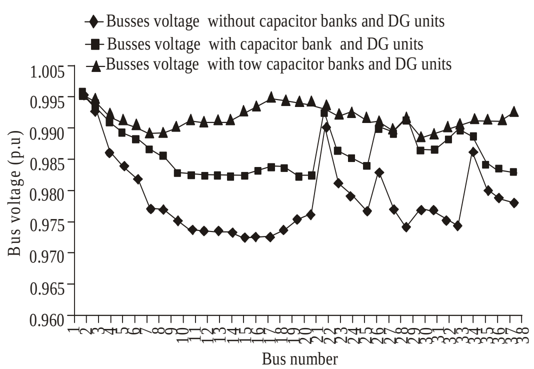

Fig. 7: Voltage amplitude of system buses without and with one and two DG and capacitor

It is shown that the optimal placement of DG unit and capacitor bank in the system caused a reduction in both active power losses and reactive power losses. The real power loss was 70.2 kW that after placement reduce to 36.3 kW. The reactive power loss was 49.8 KVAr so reduce to 28.8 KVAr. The effect of settling DG unit and capacitor bank in the mention system on the active power losses and reactive power losses and voltage profile is shown in Fig. 2, 3 and 4.

Figure 2 shows the line active losses of the system with and without DG and capacitor. It is clear that for most of the lines, active losses decreased. This is true for line reactive power losses that shown in Fig. 3. Figure 4 shows the improvement in voltage profile under nominal load condition. As shown in figure the voltage at most of buses before settling DG unit and capacitor bank to the system is worse than after fixing.

In the next study, the proposed algorithm used for sizing and sitting of two distributed generation units and two capacitor banks in mention 33-bus test system. The results of this location present in Table 3. The impact of optimal placement and sizing of DG units and capacitor banks on the active and reactive power losses of the system are given in Table 3 too.

In this case the active power losses of the system reduce from 70.2 to 19.4 kW and reactive power losses reduce from 49.8 to 15.7 kVAr.

Figure 5 and 6 illustrate active power losses and reactive power losses of system without DG units and capacitor banks, with one DG unit and one capacitor bank and with 2 DG units and 2 capacitor banks. With comparison of these results, that is obvious that the losses of the system reduce with increasing of number of DG units and capacitor banks.

Figure 7 shows the improvement in voltage profile under nominal load condition. As shown in figure the voltage at most of buses before inserting DG units and capacitor banks to the system is worse than after location.

CONCLUSION

In this study, a different approach based on Simulated Annealing in order to reduction of active power losses including one and two DG units and capacitor banks for size and site planning of distributed generation in distribution system were presented. In order to 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 SA. 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 active power losses and reactive power losses in study system.

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