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Allocation of capacitor banks in distribution systems using multi-objective function

Noradin Ghadimi

Department of Electrical Engineering, Ardabil Branch, Islamic Azad University, Ardabil, Iran.

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This paper develops an optimal placement method in order to size and site capacitor banks in IEEE 33 bus test system. The proposed method in order of optimization in this article is Evolutionary programming and the objective function is composed of two parts. 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 Evolutionary programming 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, Evolutionary programming (EP) 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 feasibility of proposed method this optimization in three cases – one capacitor bank, two capacitor banks, and three capacitor banks- will be accomplish.

Key words: Capacitor Placement, evolutionary programming, multi-objective function, optimization.

INTRODUCTION

Capacitors have been widely employed in radial distribution systems for reactive power compensation. Reactive power compensation is necessary in voltage profile correction and reduction of active and reactive loss power (Chung-Fu, 2008). Therefore, the capacitor banks can have intricate effect on the power-flow, voltage profile, stability and quality of power supply for customers and electricity suppliers. The benefits greatly depend on how the capacitors are installed and dispatched in distribution feeders. This problem is termed the general capacitor placement and scheduling problem. If this sizing and sitting do not have the appropriate location and value, the profile of voltage, active and reactive losses may be will be increased (Noradin, 2012).

Various attempts from different perspectives have been made to solve the capacitor placement problem. In Noradin (2012) the optimization problem is considered as a nonlinear programming problem as continuous variables by treating the capacitor sizes and the site. Fuzzy logic (FL) has shown good results for capacitor bank allocation when combined with GAs under sinusoidal operating conditions in order to loss reduction in Ng et al. (2000) with consideration of capacitor sizes as discrete variables and applying dynamic programming to find the optimal solution (Duran, 1968). In Gallego et al. (2001), the solution of this problem was formulated by the gradient method combined with a clustering algorithm that may be fast, but does not guarantee finding the global optimized solution.

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

E-mail: ghadimi.noradin@gmail.com. Tel: +98-914-702-8949.

Baran et al. (1989) modeled the problem of loss reduction and load balancing as an integer programming problem. A harmonic power flow method that considers harmonic couplings caused by the nonlinear loads was used in 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. The Genetic Algorithm (GA) is used in (Mendes et al., 2005) to solve the optimization problem to select the optimal point of capacitor banks for radial distribution system.

In this paper, Evolutionary programming (EP) 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 present in Kashem et al. (2000). Objective functions are gathered to form a multi objective optimization problem. The objective function is formed by combining real power losses and voltage profile of the mention 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 are consider in this paper as 0.7 and 0.3 respectively.

Objective functions formulation

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

Real power loss formulation (RPL)

Buses voltage, line currents and real power loss in system lines is calculated from the output results of power-flow which is used by Newton-Raphson in this paper.

If v_i is *ith* bus voltage and v_j is *jth* bus voltage that is 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, Z_{ij} is the impedance between *ith* and *jth* buses, the transmission power between the *ith* and *jth* buses and vice versa calculated by:

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

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

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

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

Total loss power in power system is defined by:

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

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

$$RPL = \frac{P_{Loss}^{Total}}{P_{Loss}^{nominal}} \tag{7}$$

where, $P_{Loss}^{nominal}$ 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, the closer the index to zero the better 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 as follow:

1) 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.

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

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

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

3) Voltage Limits: the voltage limits depend on the voltage regulation limits that should be satisfied.

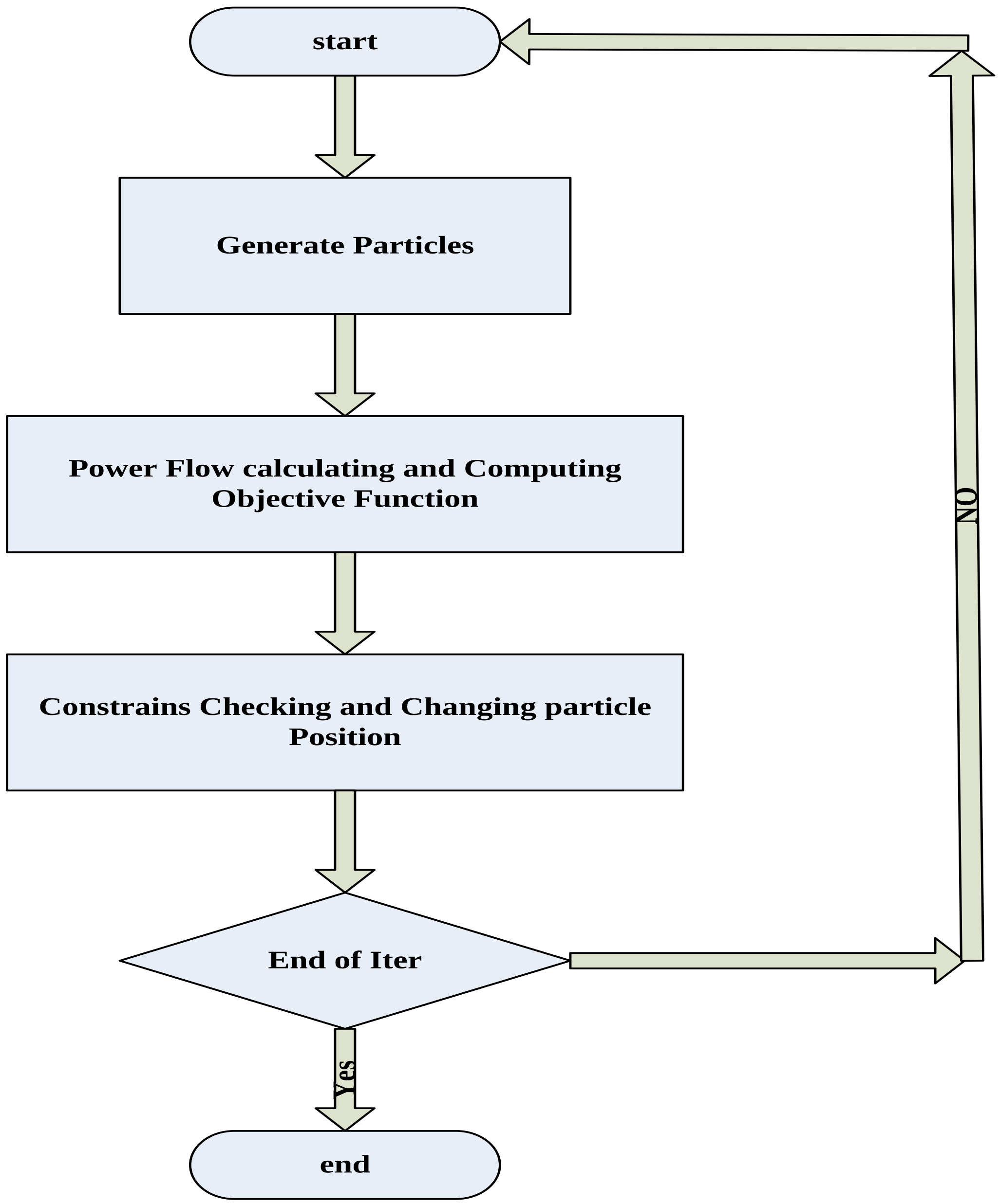

Figure 1. Optimization flowchart in EP.

$$V_i^{\min} \leq V_i \leq V_i^{\max} \quad (11)$$

This paper employs Evolutionary Programming 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.

Evolutionary programming algorithm

In this optimization method like the other methods the initial points are selected in the stochastic manner as shown in the flowchart of the Figure 1. As it can be seen from the figure, after selecting these points, for each of them the power flow will be accomplished and the objective function will be calculated. Therefore, this point are checked in the constraints and any of them which is not within this viable solution zone should be eliminated and for the points within this area the value of the objective function should be determined; and in the next state, particles are moved within this area and if the omitted particles are more, new particles will be regenerated and this process is continued until the selection of the optimum point (So et al., 2000a).

Particles' changes are done according to the Gauss normal distribution. These changes are expressed in Equation (12).

In Equation (12) xi is the ith particle position in the current state, $x_i^{'}$ is the position of the particle in the next stage. $N_i(0,1)$ is the

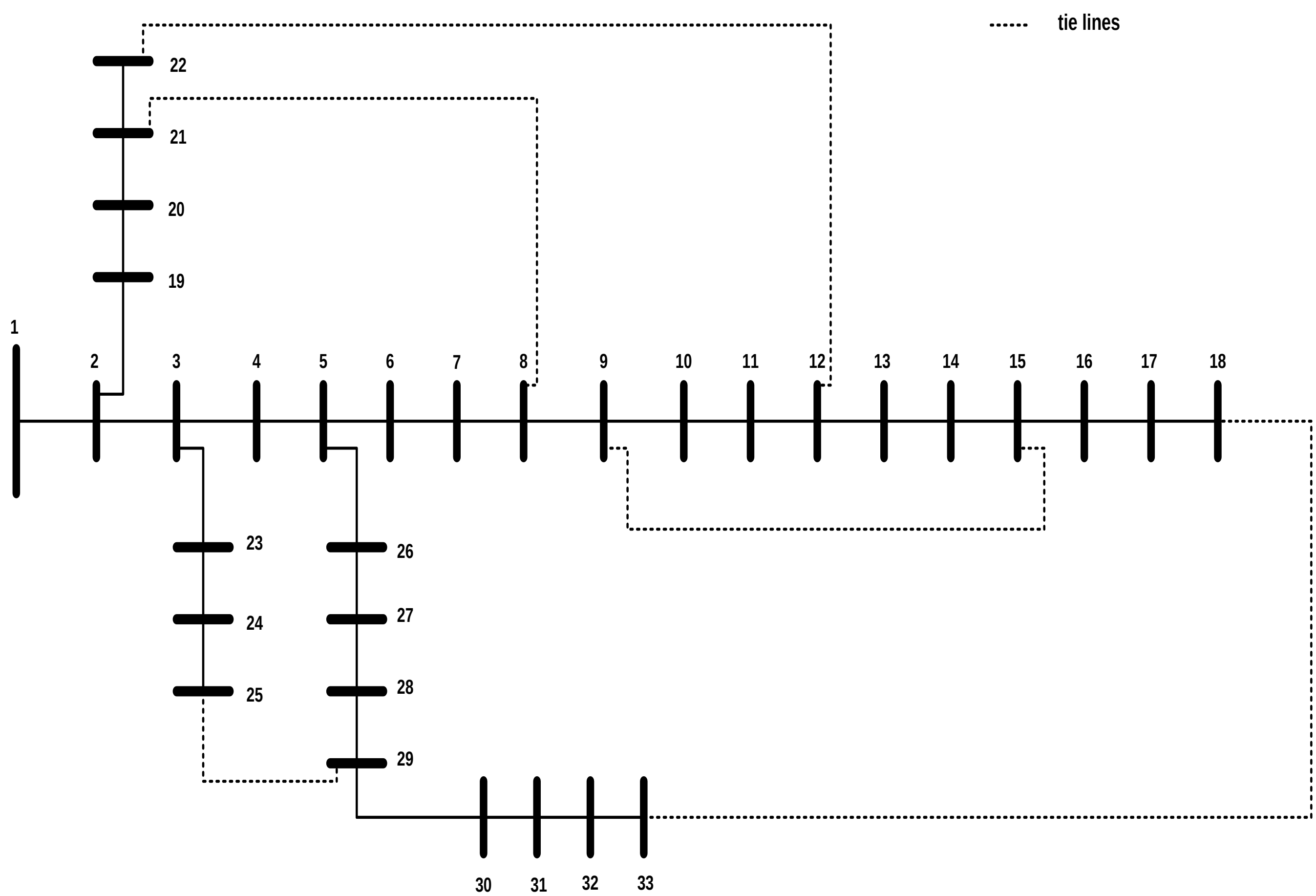

Figure 2. IEEE 33 bus study system with tie lines in Kashem et al. (2000)

Gauss normal distribution, and σi is a weighted function obtained from Equation (13). βi is the movement coefficient; here it is equal to 1, γi is the offset value adjusted in zero, and Φ(x) is the value of objective function for the particle in the previous stage which is affected by the next movements (So et al., 2000b).

$$x_i^{'} = x_i + \sigma_i.N_i(0,1) \tag{12}$$

$$\sigma_i = \sqrt{\beta_i.\Phi(x) + \gamma_i} \tag{13}$$

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 part of this work, we investigate how capacitor placement affects system power loss reduction and voltage profile enhancement. The placement of only a single capacitor, two capacitors and three capacitors are considered. To demonstrate the utility of the proposed placement algorithm, a 33-bus test system with tie lines that are present in Kashem et al. (2000) and shown in Figure 2 is considered and the system details are given in Table 1.

At first, this paper assumed that one capacitor unit of size varying between 25 kVAr to 10 MVAr will be placement in mention network. The results of this study are shown in Table 2 and Figure 3. Table 2 shows the power loss of the network with capacitor and without capacitor. With the comparing of power loss in two cases that is obvious the capacitor placement can have effect in power loss in the 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 effected in all buses voltage.

In other cases, two capacitor banks of size between 25 kVAr to 10 MVAr too are considered in order to locate the mentioned system. Results of this case are presented in Table 3 and Figure 4. 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, it is obvious that the two capacitor placement results in line power losses and voltage profile is better

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

Branch nom	Sen. node	Rec. node	Active Power of Rec. node (kW)	Reactive Power of Rec. node (kVAr)	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

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

Number of capacitor	Capacitor size	Capacitor site	Network loss (kW)
Without capacitor	------	------	70.2
One capacitor	1317.0	15	67.9 kW

than one capacitor bank and without capacitor in study system.

In the next study, we assume that three capacitor banks in order to optimal placement are considered. The results of this study are represented in power system. The results of line power loss that are present in Table 4 depicted in this case of power loss become less than other cases and in Figure 5 the voltage profile is shown. The voltage profile in this case is better than the previous cases.

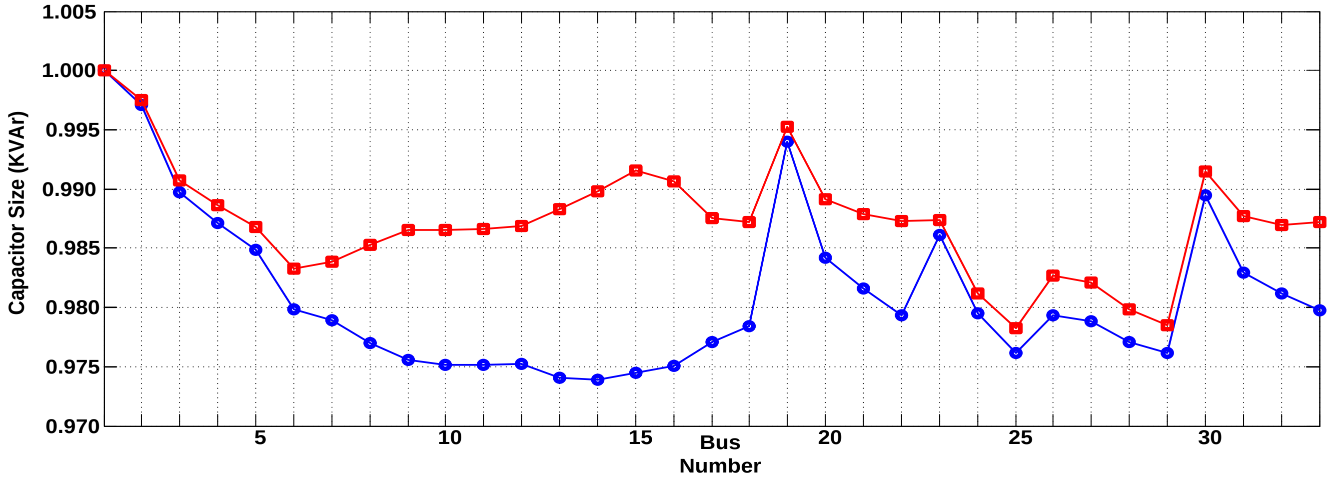

Figure 3. Voltage profile of study system with a single capacitor bank and without capacitor.

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

Number of capacitor	Capacitor size		Capacitor site		Network loss (kW)
Without capacitor	------		------		70.2
One capacitor	1317.0		15		67.9
Two capacitor	986.5	1215.3	7	16	66.3

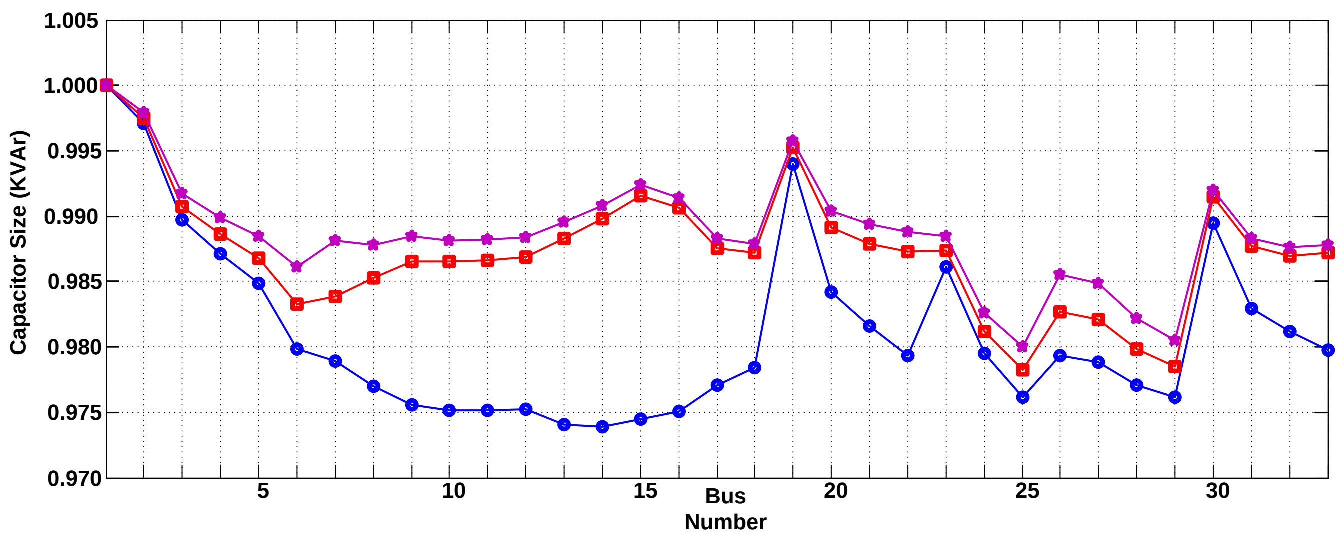

Figure 4. Voltage profile of study system with two capacitor banks - single capacitor bank and without capacitor.

Conclusion

In this paper, a different approach based on Evolutionary Programming in order of Multi-objective optimization analysis, including one, two and three capacitor banks, for size-site planning of distributed generation in distribution system was presented. In solving this problem, at first the 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 EP. The proposed optimization algorithm was applied to the 33-bus test system with tie lines.

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

Number of capacitor	Capacitor size			Capacitor site			Network loss (kW)
Without capacitor	------			------			70.2
One capacitor	1317.0			15			67.9
Two capacitor	986.5	1215.3		7	16		66.3
Three capacitor	1017.8	571.2	1187.7	2	7	15	65.6

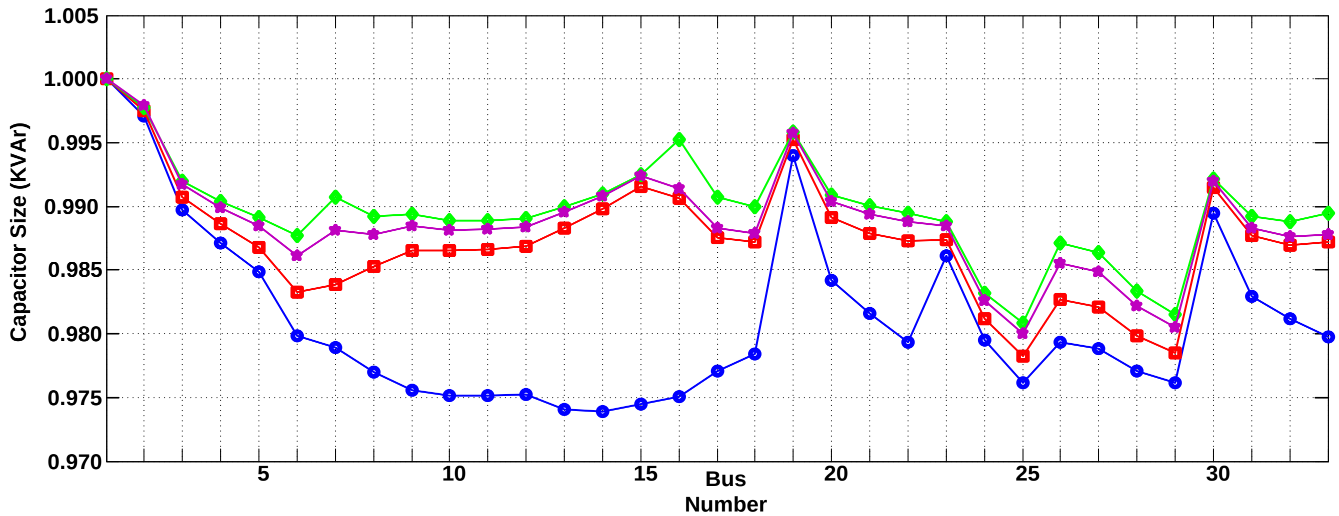

Figure 5. Voltage profile of study system with three capacitor banks- two capacitor banks - single capacitor bank and without capacitor.

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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