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The New Heuristic method for Placement and Initialization of capacitor in Distribution system for Reducing losses

Mohammad Hossein Ranjbari[1],Rezvaneh Dalili[1], Mojtaba Pishvaei[2]
[1]Department of Eectronic Engineering, Science and Research Branch, Islamic Azad University, Khomein, Iran.
[2]Department of Electrical Engineering, Tafresh University,Tafresh,Iran.
Email: ranjbari4526@gmail.com

ABSTRACT
In this paper, a heuristic method has been presented for placement and initialization of the capacitor. Goal of capacitor placement is to reduce losses and improve voltage profile. In this method, we have used mathematical rules for determining extremum. Relations for placement and determination of capacity of a capacitor have been mentioned and the relations have been expanded. For simultaneous placement and initialization of two capacitors, placement has been also performed. Effect of the capacitor on voltage profile has been also studied. In this paper, it has been shown that the proposed method is able to place more than one capacitor unlike other heuristic methods. To show authenticity of the proposed method, method of studying all possible solutions has been also simulated in each step, the results of two methods have been compared with each other. In addition, results of the proposed method have been also compared with results of the papers which have been recently published for better comparison. The studied systems are IEEE 33 and 69-bus networks.
Keywords: *Heuristic method, placement and initialization, capacitor, losses, voltage profile*

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INTRODUCTION

Studies show that 13% of the active losses occur in distribution system [1]. Losses in power systems include two parts of active and reactive losses. Reactive flow in distribution network increases losses of active power and reduces capacity of lines [2]. Proper installation of capacitor causes release of capacity of the equipmentsinstalled in the distribution system, power factor correction and improvement of voltage profile by compensating for a part of the charge reactive flow while reducing energy losses[3]. The capacitor was first used in 1914 for power factor correction but it didn't attract attention due to economic issues, high volume and weight but the capacitors with smaller volume and size and lower price were manufactured in 1939[4]. Like any other phenomenon, installation of capacitor has some disadvantages in addition to some advantages for the system such as increase of power system complexity, harmonic creation, overvoltage and increase the risk of short circuit in the network [3]. For this reason, different technical and economic parameters should be considered for installing capacitor in the system. Different methods have been presented for placement and determination of the capacitor [5&6] which can be divided into 4 classes of Analytical, Numerical programming, Heuristic and AI-based method [7]. Analytical method is one of the primary methods which was introduced for placement and initialization of capacitor. In this method, mathematical rules and principles are used for optimization [7]. For example, optimal place, capacity and number of capacitor are determined using this method in [8]. Objective function in this paper is reduction of losses and peak power. In addition, limitations of voltage reduction have been also considered. Numerical programming was introduced gradually and after progress of computational systems. In this method, iterative techniques are used for optimizing objective function. This method is more accurate than the analytical methods but its computation time is long [7]. In [9], the goal is to maximize profit of losses reduction and optimization problem has been solved as mixed integer liner programming. Scientists introduced heuristic methods gradually after conducting

more studies. These methods which were obtained based on experience have better convergence speed than other presented methods and their answers are more accurate. Weakness of this method is that only one capacitor is used for placement and initialization and if this method is applied for determining capacity of more capacitors , computational accuracy will be reduced since place and capacity of the second capacitor are obtained in the presence of the first capacitor in the network [7], [10]. In [11],author has studied reduction of costs after use of the capacitor and considered profit resulting from losses reduction. Harmonic limitations have been also considered. Therefore, both economic and technical parameters were considered. In this paper, a method similar to MMS method which is analytical method has been used for placement and initialization of only one capacitor. In [12], initialization and placement of capacitor have been done based on parameter of losses and with sensitivity analysis method which an analytical method. But many studies have been recently conducted in the field of algorithm-based optimization such as GA and PSO. These methods have optimal accuracy but they converge lately due to their more computations than the analytical method and problem of convergence is created for the real systems which have many limitations [7]. For examplein [13] two parameters of losses and harmonics of the system have been studied and objective function has been optimized using PSO algorithm. In [14], placement and initialization of the capacitor have been done based on parameters of reliability and losses. Objective function is profit caused by improvement of these parameters. The method which has been used for optimization is PSO algorithm. In [15], genetic algorithm has been used for placement and determination of capacity of capacitor to increase profit in the network.
The method which has been presented in this paper for placement and initialization of the capacitor is a heuristic method but it is able to determine simultaneous location and capacity of some capacitors unlike other heuristic methods which have been introduced for placement of the capacitor. For example, sensitivity analysis method determines place and capacity of the second capacitor in the presence of the first capacitor after determining the first suitable place. For this reason, this method has no optimal accuracy [12&16]. But the method presented in this paper has solved this problem. To show authenticity and accuracy of the presented method, method of studying all possible solutions has been also simulated and the obtained results of both methods have been compared with each other. One of the other advantages of this method is short computational time. Method of studying all possible solutions has optimal accuracy but its response time is very long and not suitable for large systems. In the present paper, results of this method have been determined using supercomputer. The analytical method presented in this paper also solves this problem.
This paper has been organized as follows: in Section 2, relations and proposed method are mentioned. In Section 3, the proposed algorithm is mentioned for placement and initialization of a capacitor and in Section 4, principles and relations for placement and initialization of two capacitors are presented. In Section 5, results of simulating and comparing the proposed method and method of studying all possible solutions are given. In addition, the obtained results have been compared with [16] and [17]. At the end , conclusion is given in Section 6.

Problem formulation

In this paper, we use relation (1) to calculate active losses [18]

$$P_L = \sum_{i=1}^{N}\sum_{j=1}^{N}[\alpha_{ij}(P_iP_j + Q_iQ_j) + \beta_{ij}(Q_iP_j \quad P_iQ_j)] \qquad (1)$$

Where Pi and Pj are injected active power of buses i, j, Qi and Qj are the reactive powers of buses i, j and N is the number of the system buses. α_{ij} and β_{ij} are defined as follows:

$$\alpha_{ij} = \frac{R_{ij}}{|V_i||V_j|}\cos(\delta_i \quad \delta_j) \quad (2)$$

$$\beta_{ij} = \frac{R_{ij}}{|V_i||V_j|}\sin(\delta_i \quad \delta_j) \quad (3)$$

Rij is the real part of entry ij from impedance matrix of the system, |Vi|and |Vj| are voltages of buses i and j, δi and δj indicate voltage angle in buses i and j.
In this paper, we didn't consider any limitation for place of the capacitor, so the capacitor can be placed in all buses. If a capacitor with capacity of Qcis installed in bus i, relation of the injected active and reactive power of the related bus is changed into relations (4) and (5).

$$P_i = P_{G_i} \quad P_{D_i} = \quad P_{D_i} \quad (4)$$

$$Q_i = Q_{G_i} \quad Q_{D_i} = Q_{c_i} \quad Q_{D_i} \quad (5)$$

The presence of capacitor changes factors α and β but since these changes are very small, they are ignored. Before calculating optimal capacity, load flow is necessary for one time and these factors should be determined. Based on these hypotheses, if we substitute two relations mentioned above in losses relation, relation (1) will be changed as follows:

$$P_L=\alpha_{ii}\left(P_i^{\,2}+Q_i^{\,2}\right)+\sum_{i=1}^{N}\sum_{\substack{j=1\\ i\neq j}}^{N}\begin{bmatrix}\alpha_{ij}\left(P_iP_j+Q_iQ_j\right)\\ +\beta_{ij}\left(Q_iP_j-P_iQ_j\right)\end{bmatrix} \quad (6)$$

$$P_L\ \ =\alpha_{ii}[\left(-P_{D_i}\right)^2+\left(Q_{C_i}-Q_{D_i}\right)^2+\sum_{i=1}^{N}\sum_{\substack{j=1\\ i\neq j}}^{N}\begin{bmatrix}\alpha_{ij}\left(\left(-P_{D_i}\right)P_j+\left(Q_{C_i}-Q_{D_i}\right)Q_j\right)\\ +\beta_{ij}\left(\left(Q_{C_i}-Q_{D_i}\right)P_j-\left(-P_{D_i}\right)Q_j\right)\end{bmatrix} \quad (7)$$

As you see, losses relation has been converted into a single variable function in terms of capacity of the capacitor installed in bus i. Minimum of this function is obtained by deriving it from the unknown parameter. Therefore, if we derive losses relations with respect to the injected power of the capacitor installed in bus i and consider result of the derivation equal to 0, optimal capacity of the capacitor installed in bus i will be obtained.

$$\frac{\partial P_L}{\partial Q_{c_i}}=0(8)$$

If we consider result of the derivation equal to zero , then we will have :

$$\frac{\partial P_L}{\partial Q_{c_i}}=2\sum_{j=1}^{N}\alpha_{ji}(\quad Q_j)+\beta_{ji}P_j=0 \qquad (9)$$

Relation (9) is rewritten as relation (10).

$$\alpha_{ii}Q_{c_i}=\sum_{j=1}^{N}\alpha_{ji}Q_j \qquad \beta_{ji}P_j\ (10)$$

In this relation, i is the number of the bus in which capacitor has been installed. Therefore, i is changed from 1 to N. By changing i from 1 to N, optimal capacity of the capacitor installed in the related bus will be determined. Therefore, the number of the calculated capacities is equal to N. In any case; we put the capacitor with the determined capacity in the mentioned bus and calculate losses after calculating load flow. At the end, minimum of the calculated losses is determined which is equivalent to optimal place and capacity for installation of the capacitor. Flowchart of this algorithm is given in Figure.

Simultaneous placement and initialization of two capacitors

To place and determine capacity of two capacitors simultaneously, we assume that two capacitors have been installed in buses x_1 and x_2 and with capacities of Q_{cx1} and Q_{cx2}, therefore, the injected active and reactive power of these buses is equal to:

$$P_{x_1}=\quad P_{D_{x_1}}(11)$$

$$Q_{x_1}=Q_{C_{x_1}}\quad Q_{D_{x_1}}\quad (12)$$

$$P_{x_2}=\quad P_{D_{x_2}}(13)$$

$$Q_{x_2}=Q_{C_{x_2}}\quad Q_{D_{x_2}}\quad (14)$$

If we substitute relations (11-14) in losses relations, we will have:

$$P_L=\alpha_{x_1x_1}\left(P_{x_1}^{\ \ 2}+Q_{x_1}^{\ \ 2}\right)+\alpha_{x_2x_2}\left(P_{x_2}^{\ \ 2}+Q_{x_2}^{\ \ 2}\right)+2\alpha_{x_1x_2}\left(P_{x_1}P_{x_2}+Q_{x_1}Q_{x_2}\right)$$
$$+2\beta_{x_1x_2}\left(Q_{x_1}P_{x_2}-P_{x_1}Q_{x_2}\right)\ +\sum_{i=1}^{N}\sum_{\substack{j=1\\ j\neq x_1,x_2}}^{N}\left[\alpha_{ij}\left(P_iP_j+Q_iQ_j\right)+\beta_{ij}\left(Q_iP_j-P_iQ_j\right)\right] \quad (15)$$

Relation (15) is rewritten as follows:

$$P_L=\alpha_{x_1x_1}\left(\left(-P_{D_{x_1}}\right)^2+\left(Q_{C_{x_1}}-Q_{D_{x_1}}\right)^2\right)+\alpha_{x_2x_2}\left(\left(-P_{D_{x_2}}\right)^2+\left(Q_{C_{x_2}}-Q_{D_{x_2}}\right)^2\right)$$
$$+2\alpha_{x_1x_2}\left(\left(-P_{D_{x_1}}\right)\left(-P_{D_{x_2}}\right)+\left(Q_{C_{x_1}}-Q_{D_{x_1}}\right)\left(Q_{C_{x_2}}-Q_{D_{x_2}}\right)\right)$$
$$+2\beta_{x_1x_2}\left(\left(Q_{C_{x_1}}-Q_{D_{x_1}}\right)\left(-P_{D_{x_2}}\right)-\left(Q_{C_{x_2}}-Q_{D_{x_2}}\right)\left(-P_{D_{x_1}}\right)\right)$$

$$+\sum_{i=1}^{N}\sum_{\substack{j=1\\ j\neq x_1,x_2}}^{N}\left[\alpha_{ij}\left(P_iP_j+Q_iQ_j\right)+\beta_{ij}\left(Q_iP_j-P_iQ_j\right)\right] \quad (16)$$

In this case, losses relation has been converted into two-variable relation which variables are capacities of the capacitors installed in buses x_1 and x_2. To determineextremum of this two-variable function, we act like the previous step. One of the methods of calculating extremum in a two-variable function is to determine critical points and calculate function for them. Therefore, losses relation is derived with respect to Q_{cx1} and Q_{cx2} and consider the result equivalent to 0. In this case, critical points of the losses function are determined. In the first step, losses relation is derived with respect to Q_{cx1} and the result is considered equal to 0, then, we will have:

$$\frac{\partial P_L}{\partial Q_{C_{x_1}}}=0 \quad (17)$$

$$\alpha_{x_1x_1}Q_{C_{x_1}}+\alpha_{x_1x_2}Q_{C_{x_2}}=\sum_{j=1}^{N}(\alpha_{jx_1}Q_j-\beta_{jx_1}P_j) \quad (18)$$

In the next step, we also derive losses relation with respect to $Q_{cx2}$and consider the result equal to zero, then, we will have:

$$\frac{\partial P_L}{\partial Q_{C_{x_2}}}=0 \quad (19)$$

$$\alpha_{x_2x_1}Q_{C_{x_1}}+\alpha_{x_2x_2}Q_{C_{x_2}}=\sum_{j=1}^{N}(\alpha_{jx_2}Q_j-\beta_{jx_2}P_j) \quad (20)$$

As it is evident, two equations (18) and (20) are two-variable equations. After sorting, system of linear equations is formed:

$$\begin{bmatrix}\alpha_{x_1x_1} & \alpha_{x_1x_2}\\ \alpha_{x_2x_1} & \alpha_{x_2x_2}\end{bmatrix}\begin{bmatrix}Q_{C_{x_1}}\\ Q_{C_{x_2}}\end{bmatrix}=\begin{matrix}\sum_{i=1}^{N}(\alpha_{ix_1}Q_i-\beta_{ix_1}P_i)\\ \sum_{i=1}^{N}(\alpha_{ix_2}Q_i-\beta_{ix_2}P_i)\end{matrix} \quad (21)$$

By solving system of Equation (21), optimal capacity of the capacitors installed in the related buses is calculated. In this Section, it was assumed that two capacitors have been installed in buses x_1 and x_2 and their equivalent optimal capacity was determined according to the relations. By changing x_1 and x_2, optimal capacity of the capacitors is determined for different buses. Therefore, the number of states is equal to N^2 state. In any state, equivalent losses of the capacitors were calculated after calculating their optimal capacity with (21) and finally, minimum losses are selected as the best state. Trend of this algorithm for simultaneous placement and initialization of two capacitors is as follows:

1- We consider the primary system in which there is no additional element. Zbus matrix is formed and factors α_{ij} and β_{ij} are determined after calculating load flow.
2- We assume that the number of bus in which the first capacity is installed is equal to x_1 and 1.
3- We assume that number of the bus in which the second capacitor is installed is equal to x_2 and 1.
4- Using Relation (21), optimal capacity of the capacitors installed in the mentioned buses is calculated.
5- We assume that these two capacitors are placed in the related buses and with the determined capacitors. After calculating load flow, the equivalent losses of these two capacitors are determined.
6- Losses calculated in step 5 are stored in the matrix with rows equivalent to place of the first capacitor and columns equivalent to place of the second capacitor.
7- We add number of the bus in which the second capacitor is installed(j=j+1).
8- If j is smaller than or equal to N, we return to step 4, otherwise, we go to step 9.
9- We add number of the bus in which the first capacitor is installed (i=i+1)
10- If i is smaller than or equal to N, we return to step 4, otherwise, we go to step 11.
11- Minimum entry of the losses matrix is determined which is equivalent to the best place and capacity for installing capacitors.

Therefore, the number of the calculated load flows is equal to N^2+1.

Since method of studying all possible solutions considers all permutations for installation of capacitor, it has good accuracy. In this paper, method of studying all possible solutions has been also simulated to mention truth of the proposed method and results of two methods have been compared with each other.

Studied systems
In this paper, two systems have been simulated. The first system is a standard 33-bus system [19] in which losses are equal to 211 kW before installation of the capacitor and the second system is a standard 69-bus system [20] in which initial losses are equal to 225 kW.

Simulation results
In this paper, a new heuristic method has been presented for placement and initialization of capacitor which is able to place and initialize more than one capacitor simultaneously unlike other analytical methods which have been presented up to now. To show truth of the presented method, algorithm for study of all possible solutions has been stimulated and in each step, results of two methods have been compared. Since the study method considers all possible solutions for installing capacitor, it has optimal accuracy but has no good rate of convergence and it requires long time to determine optimal place and capacity. In addition, results of both methods studied in this paper have been compared with results of the papers which have been published recently. For placement and initialization of a capacitor, results have been compared with two methods presented in [17] and the results have been also compared with the results [16] for simultaneous placement and initialization of two capacitors. Comparison of results in any solution indicates desirability of the presented heuristic method.

33-bus system
Results of the heuristic method are presented and all possible solutions are given in Table 1. In addition, results of reference [17] and [16] which have placed and initialized one and two capacitors for this system are given. For placement and initialization of a capacitor, the proposed method selects bus 30 with value of 1.2526 MVar as optimum. Method of studying all possible solutions also determines bus 30 as optimal place and optimal capacity of the capacitor to be 1.259 MVar. Comparison of the results of both methods indicates that the proposed method has high accuracy. On the other hand, the proposed method determines optimal capacity and place within 0.25 s but the method of studying all possible solutions determines optimal response within 48.7s, hence, the presented method has higher speed. In addition comparison of the obtained results with results of reference [17] also shows truth of the presented method.

To install two capacitors simultaneously, the proposed method selects buses 12 and 30 with capacities of 0.4396MVar and 1.065 MVar as optimum, respectively and method of studying all possible solutions determine these buses with capacities of 0.417MVar and 1.068MVar, respectively. But the presented method determines the optimal output within 2.9s and method of studying all possible solutions determines it within 14.125 hours, therefore, if the number of capacitors increases for placement, time of studying all possible solutions will become long and this shows inefficiency of this method. As it is evident, sensitivity analysis method [16] has determined buses 7 and 29 as optimal bus and with capacities of 0.85MVar and 0.875MVar. Losses are calculated 0.1419 MW using the proposed method and 0.1467 MW in sensitivity analysis method. Minimum voltage is 0.9295 in the proposed method and 0.9245 in sensitivity analysis method. Comparison of results of two methods indicates that the presented objective methods have more acceptable results.

As it is evident, losses are 0.211 MW before installing capacitor and are reduced after installing a capacitor and its value is 0.1514 MW in this state. The losses rate is the lowest when we have two capacitors and losses in this solution are 0.1419 MW. Comparison of maximum and minimum values of voltage before and after capacitor indicates that installation of capacitor improves voltage profile in addition to reduction of losses and also improves minimum voltage.

69-bus system
Results of 69-bus system are given in Table 2. For placement and installation of a capacitor, the proposed method determines bus 61 as optimal location and optimal capacity of the capacitor as 1.3301MVar. Method of studying all possible solutions also determines bus 61 with value of 1.330MVar as optimum. Comparison of these numbers shows accuracy of the presented method but the presented method reaches result within 1.084s and method of studying all possible solutions reaches result within 4.8 min. Method of studying all possible solutions has good accuracy but has no optimal response time. Comparison of two methods presented in [17] also increases accuracy of the presented method.

For simultaneous placement and initialization of two capacitors, the proposed method determines buses 17 and 61 with capacities of 0.370MVar and 1.262 MVar and method of studying all possible solutions also determines buses 17 and 61 with capacities of 0.362MVar and 1.275 MVar. But the presented objective method reaches result within 56.24s and method of studying all possible solutions reaches result within 257.9 hours. So, when the number of capacitors increases, the response time of method of studying all possible solutions will be elongated. As it is observed, installation of capacitor reduces losses.

Losses rate is 0.225 MW before installation of capacitor and 0.152 MW after installation of one capacitor and 0.1464 MW with two capacitors.

By comparing response time of 33-bus and 69-bus system, we conclude that the larger the system, the longer the response time of method for studying all possible solutions which will be exponentially increased. This shows inefficiency of this method for real systems. In addition, as mentioned in the previous section, heuristic methods which were introduced for placement and initialization of the capacitor are not efficient for placement of more than one element. As Tables (1&2) show, sensitivity analysis method doesn't select optimal capacity and bus properly.

Table 1.RESULT OF 33-BUS SYSTEM

Case	Method	Bus number	Capacity (MVar)	Loss (MW)	Loss reduction (%)	Vmax/Vmin
No capacitor				0.211		1/0.9038
1 C	Heuristic	30	1.2524	0.1514	28.25	1/0.9164
	Load flow	30	1.259	0.1514	28.25	1/0.9165
	Analytical	30	1.2298	0.1514	28.25	1/0.9162
	Golden section search algorithm	30	1.258	0.1514	28.25	1/0.9165
2 C	Heuristic	12 30	0.4396 1.065	0.1419	32.75	1/0.9295
	Load flow	12 30	0.417 1.068	0.1419	32.75	1/0.9288
	Loss sensitivity	7 29	0.850 0.875	0.1467	30.47	1/0.9245

Table 2.RESULT OF 66-BUS SYSTEM

Case	Method	Bus number	Capacity (MVar)	Loss (MW)	Loss reduction(%)	Vmax/Vmin
No capacitor				0.225		1/0.9092
1 C	Heuristic	61	1.3301	0.1520	32.44	1/0.9307
	Load flow	61	1.330	0.1520	32.44	1/0.9307
	Analytical	61	1.2920	0.1521	32.40	1/0.9302
	Golden section search algorithm	61	1.330	0.1520	32.44	1/0.9307
2 C	Heuristic	17 61	0.370 1.262	0.1464	34.93	1/0.9310
	Load flow	17 61	0.362 1.275	0.1464	34.93	1/0.9311
	Loss sensitivity	19 62	0.225 1.100	0.1493	33.64	1/0.9284

CONCLUSION

Installation of capacitor in power system reduces losses and improves voltage profile. On the other hand, reduction of losses and improvement of voltage profile depend on location and capacity of the installed capacitor. As a result, it is important to present a suitable method for determining optimal location and capacity of the capacitor. In this paper, a heuristic method has been presented for placement and initialization of capacitor in distribution system and for improvement of losses parameter. The proposed method determines optimum of the objective function based on mathematical principles and rules. Relations for placement and determination of capacity of a capacitor have been first mentioned and then the relation were expanded and corrected for simultaneous placement and initialization of two capacitors. To show accuracy of the proposed method, method of studying all possible solutions was also simulated and finally the obtained results were compared with each other. In addition, the results have been also compared with sensitivity analysis heuristic method, analytical method and Golden section search algorithm. Comparison of the results shows that the presented method can place and initialize two capacitors simultaneously unlike other heuristic methods. Since computational time will be elongated when the system is enlarged and the number of capacitors increases in method of studying all possible solutions, it is not suitable for placement despite its optimal accuracy. As results show, the proposed method has good speed and high accuracy.

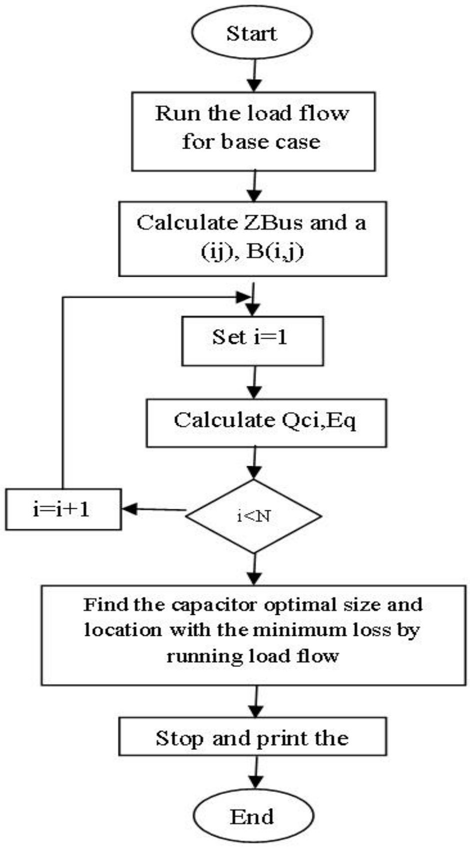

Figure. Flowchart of proposed method

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