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Optimal Capacitor Placement with Modified Cultural Algorithm

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ABSTRACT
Nowadays, distribution, sub transmission and financial investment networks are developing. Owing to the increment of the cost of fuel and production in power plants, and considering the fact that declining the loss is much more economic than boosting the production, the importance of prevention the waste of this national wealth becomes clearer than before. Therefore, this issue prompts the electrical systems designers to design electrical networks with the minimum loss. One reason for decrement of voltage and high loss is insufficient amount of reactive power in the network which can be made up by use of capacity placement. The capacitor installation needs cost and planning. In this paper, using optimal capacitor placement, the decrement of cost and loss of capacitor placing is studied. To perform this project, a new modified cultural evolutionary algorithm is used. This algorithm is based on the population and belief space and the belief space is divided to a variety of sections. These sections illustrate different regions of knowledge which permeate to the population space and assist to find the desired solution. The proposed algorithm is implemented on the three radial distribution networks, i.e. 9, 22 and 69 bus networks, and ultimately the obtained results are compared with some comparable projects. It is observed that the proposed algorithm has performed better than the other heuristic algorithms to solve the placing problem.
Key Words— *Capacitor, loss reduction, radial distribution network, modified cultural algorithm*

INTRODUCTION

Since distribution networks include a large share of losses in power systems, loss reduction in such networks is a fundamental problem in reducing costs of the overall network. One of the essential methods of loss reduction in distribution systems is optimum use of capacitors, so that besides loss reduction, network voltage profile is enhanced as well. Use of capacitors is possible with two methods of parallel (shunt) and series in the network. One of the benefits of capacitor placement is reactive power reduction in all of the power system from manufacturer to consumer, which ultimately leads to reduced investment for the use of real power. So far, many researchers have been studying the capacitor placement. Reference [1], using mathematical analytical method, has done optimal capacitor allocation in distribution feeders for loss reduction. Profit gained from the reactive power has been investigated in many studies [2, 3]. In [4], the optimal size and location of capacitor banks have been calculated, using genetic algorithm. In [5], the method of particle swarm optimization has been used for optimal capacitors allocation in radial distribution systems. Reference [6], using particle swarm, has attempted capacitor placement to increase reliability. In [7], fuzzy evolutionary approach has been used for solving the problem of capacitor placement. Target function is to improve the voltage profile, for this purpose, a membership function has been used, and the results obtained from this study indicate that the fuzzy-reasoning approach has been successful in solving this problem. References [8] and [9] have benefited from heuristic search method for finding the best capacitor location in the distribution system. In reference [10], a new heuristic method has been used for reactive power compensation. In [11], reliability of the system and optimal capacitor allocation is studied in the vicinity of unbalanced loads. The algorithm proposed in this paper, is modified cultural heuristic algorithm. This algorithm was first proposed by R. G. Reynolds [12]. So far, this algorithm has been implemented for solving optimization problems with different objectives. In addition, cultural algorithm has been applied to solve several problems on power systems. Reference [13], using cultural algorithm and improved differential evolution, has addressed economic load distribution. Moreover, in [14], for short-term scheduling of cascade hydraulic power stations, the particle swarm optimization based on cultural algorithm has been used. In paper [15], the problem of scheduling electrical generator is solved with multi population cultural algorithm.

Statement of the Problem

Target function of this research is to enhance profitability by reducing the real power losses in the distribution system, thereby improving the voltage profile. The critical bases must first be identified; then capacitors are placed in critical bases so that reactive power compensation be applied to the system. In this study, Gauss–Seidel load distribution method has been used [16]. The total power loss of feeder branches is defined by Equation 1.

$$\boldsymbol{P_{loss,t}} = \sum_{i=1}^{nb} \boldsymbol{P_{loss,i}} \qquad (1)$$

In equation (1), Ploss,t is the network total loss, Ploss,i is line i loss and nb is network all branches, and in order to improve voltage profile, the possible combination of capacitors is used in radial feeders. Maximum size of each capacitor can be calculated with equation (2):

$$Q_{max}^{c} = LQ_{0}^{c} \quad [17] \qquad (2)$$

Q0c is the smallest amount which can be contained in the capacitor. And L is an integer. {K1c,K2c,…KLC} is a set of possible capacitor costs, which is defined as {Q0c,2Q0c,…,LQ0c} [17]. The objective of the optimization is to obtain the size and exact location of the capacitor on the base. The result of this optimization is the loss reduction of real power and costs related to the capacitor placement. The cost is measured using equation (3):

$$F = K_p\left(\boldsymbol{P_{T_{loss}}}\right) + \sum_{j=1}^{n} \boldsymbol{K_j^c Q_j^c} \qquad [\mathbf{17}] \qquad (\mathbf{3})$$

Kp is cost of real power loss per unit with ($/KW) unit and Kjc is cost of capacitor per unit with (($/KVAr) unit, j is indicative of the base on which the capacitor is installed. In this problem, we also have voltage limit:

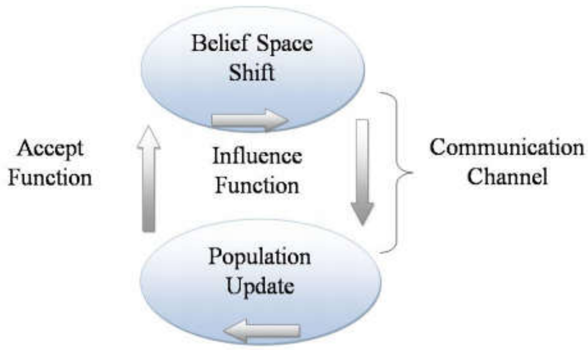
$$V_{min} \leq |V_i| \leq V_{max} \qquad i = 1,2,\ldots..m \qquad (4)$$

Description of cultural algorithm (CA)

Cultural algorithm is a high level search technique. This evolutionary algorithm follows cultural evolution algorithm of society. Society is composed of different classes and levels. Each class has its own norms and behaviors, which are transmitted to the next generation by their parents. People's awareness and knowledge and definition of these norms depend on each government's policy [18]. Awareness and knowledge of cultural algorithm is called belief space. This space in cultural algorithm is divided into several sections. These sections indicate various areas of the population's knowledge of search space. Belief space is updated after every search done by the best people of population [19]. A superior class or elite exists in society, according to whom society's norms are selected and defined. This specific class is chosen based on knowledge or wealth. People can be selected by using a qualification function. This function, similar to what occurs in genetic algorithms, evaluates the performance of each individual in the population.

Communication Protocol

Cultural algorithm requires communication protocol or communication channel. This communication protocol acts as an interface between population space and belief space, and includes two functions, influence function and accept function. The influence function leads the population in the direction of belief space and the accept function updates belief space. Figure 1, in the form of a diagram, describes communication channel [20].



Figure(1): Communication Channel

Belief space consists of various areas of knowledge, which include: normative knowledge, domain specific knowledge, situational knowledge, constraint knowledge and history knowledge. These fields of knowledge are resources that guide the population towards optimal solution. Normative knowledge and constraint knowledge are the ones which update population space [21].

Modified Cultural Algorithm (MCA)

Modified cultural algorithm is based on cultural algorithm. As mentioned before, CA is formulated according to socio-cultural developments in society. Cultural algorithm includes two basic and substantial components, belief space and society's people or population space. These two components are connected with a communicative process, communicative protocol in the algorithm includes two functions, the influence function and the accept function. These functions assist belief space and population space to update and change. Cultural algorithm seeks the best parent, which is the global best. The best parent has the highest amount and is placed on the top of algorithm range in the band and, likewise, the worst parent, being assigned the lowest value, is placed at the bottom of the algorithm in the band. If a parent is found with higher value than the best parent, then the inequality direction is reversed and the new parent in the band is placed on top of the range. If a parent's value is equal to the best parent, then the operators of mutation and random selection enter into action.

In modified cultural algorithm, similar to cultural algorithm, the best parent is the global best. Nevertheless, the selection of the best parent would be somewhat different. In this case, the best parent (as the global best), is elected, separately, in each iteration and the belief space will be updated each time. Of all the resources of cultural algorithm knowledge, modified cultural algorithm is formulated and made with situational knowledge (SK) and history knowledge (HK) [22, 23, 24, 25, and 26]. In the modified version, besides the operators of mutation and random selection, we have the operators of multiplication, addition, replacement and unchanged as well. And the influence function works by affecting situational knowledge.

Modified Cultural Algorithm in the Solution of Placement Problem

In this section, how to solve the placement problem with modified cultural algorithm is briefly explained. It is also demonstrated how the influence function works in belief space and how the optimal value of the capacitor can be found in search space (the population). Situation space is generated from population space and is the combination of 0 and 1, at random (Figure 2 matrix space).

$$Capacitor\ Value = \{a, b, c, \dots\dots, h, \dots\dots, x, y, z\} \qquad (5)$$

Population matrix has M1 rows and N1 columns. Numbers of the rows are indicative of all feeder bases and each column in this matrix points to members of population space. Binaries 0 and 1 are, respectively, indicative of the presence and absence of capacitor on the feeder. As an example, $\mathrm{N1} = [0\ 1\ 0\ 1\ 1 \dots 0\ 1]^{\mathrm{T}}$ column shows that capacitors are placed on the 4, 5, and … bases. Each member of population space is defined as capacitors location.After the population matrix, the amount matrix or capacitor value is stated. This matrix is randomly selected from a set of capacitor real amounts. For example, the random matrix can be assumed as$[\mathrm{r\ y\ h\ k\ p} \dots \mathrm{f\ z}]^{\mathrm{T}}$, after multiplying with population matrix we will have: $[0\ \mathrm{y}\ 0\ \mathrm{k\ p} \dots 0\ \mathrm{z}]^{\mathrm{T}}$. The population matrix is multiplied by the value matrix (fig. 2).

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$$\begin{bmatrix} 1 & 1 & . & . & 1 & . & . & 1 \\ 1 & 0 & . & . & 1 & . & . & 0 \\ 0 & 1 & . & . & 0 & . & . & 1 \\ 1 & 1 & . & . & 0 & . & . & 0 \\ . & . & . & . & . & . & . & . \\ . & . & . & . & . & . & . & . \\ 0 & 1 & . & . & 1 & . & . & 1 \\ 1 & 0 & . & . & 0 & . & . & 1 \end{bmatrix} \Rightarrow PS = \begin{bmatrix} f & r & . & . & h & . & s \\ q & 0 & . & . & k & . & e \\ 0 & d & . & . & 0 & . & t \\ w & i & . & . & 0 & . & y \\ . & . & . & . & . & . & . \\ . & . & . & . & . & . & . \\ 0 & n & . & . & a & . & l \\ b & 0 & . & . & 0 & . & m \end{bmatrix}$$

Figure (2):Population matrix after multiplication (PS)

Subsequently, with the multiplied matrix PS and equation (1), the total real power losses are calculated and, using equations (3) and (4), the costs related to the capacitor are measured.

$$capacost = \{ a1, b1, c1, \dots \dots, h1, \dots \dots, x1, y1, z1\}$$

Belief Space

Belief space is a scheme or theory, which gives the search speed. During replication, the best person is selected and belief space is updated. The best selection from belief space or Blfbest is considered zero in the first stage; this means that no base has any capacitors in the first stage. Therefore:

$$\text{Blfbest} = [0\ 0\ 0\ \ 0\ 0 \dots 00]^T$$

Suppose after several repetitions of the matrix, the best choice would be$[\text{m b e} \dots \text{u s}]^T$. Blfbest matrix is indicative of the fact that the installed capacitor in base one is m kilo and capacitor in the second base is b kilo. SK retains location and size of the best capacitors position and HK, based on the SK information, is developed and formed accordingly. If, after several repetitions, no significant change occurred in cost reduction and improvement of losses, the best size of capacitors and the total number of installation points are saved in HK.

Communicative Protocols

A communicative protocol is formed out of the influence function and the accept function. This section has already been covered.

Accept Function

The accept function modifies and, or, updates the knowledge of belief space. The best person is selected among population, based on performance. The best person assists in the improvement of belief space and replaces Blfbest.

Influence Function

As pointed out before, the influence function guides the population in the direction of belief space.

1. Performance of influence function in situational knowledge

When the optimal points are found in belief space, these points are, in fact, the same points which influence the mode space and this is, exactly, the concept of the influence function. SK considers the desired bases with 0 and 1. SK is column axis which merely indicates the location of the capacitors and is introduced as F_{eff}. In space population matrix, 50% of the total population remain unchanged (unchanged operator), which lie on the left side of the population matrix. 12.5% to 20% of the population people are under the influence of F_{eff} function. 30% to 37.5% of the elements in each row change due to the use of effective factors in each column. This can be done by multiplying or adding (the operators) the column effective factor to the rows. In this study, a 9 based system has been investigated.

As stated earlier, half of the population remains unchanged. Random selection method for problems which are solved by algorithms such as MCA is not appropriate and is not able to find the optimal point. The unchanged half of the matrix should be modified with F_{eff}. The eighth and ninth elements of each row should be multiplied by F_{eff} column elements (using multiplication operator). The ninth person changes its position with the seventh person on the left of the population matrix (using the replacement operator). Eleventh and Ninth People of each row are added together (addition operator). This process can be expressed in a mathematical way as thus:

Unchanged

offspring = parent

Replacement

$\text{offspring} = f_{eff}$

Multiplication

$\text{offspring} = \text{parent} \times f_{eff}$

Addition

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$$\text{offspring} = \text{parent} + f_{eff}$$

Numerical Studies and Analysis of Results

To solve the problem of capacitor placement, the modified cultural algorithm has been used and tested on three systems, 9 bases, 22 bases and 69 bases. In these three systems, the objectives of minimizing the real power losses and costs related to the capacitor placement have been studied.

9-base Distribution System

Before compensation of losses, real power of 9-base distribution system in the test (Figure 4) is 783.61 kW. And the losses resulting from costs are estimated 132.875 dollars. The best voltage profile is registered as 0.9929 per unit. After capacitor placement on bases 2, 3, 4, 5, 7 and 9, real power losses significantly decrease and reach 550.7387 kW. Furthermore, cost induced losses decreases to 104.579 dollars and the best voltage profile reaches level 1.006 per unit.

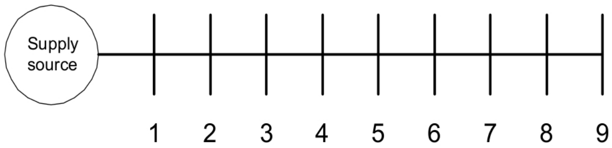


Figure (4): 9- bus radial distribution system

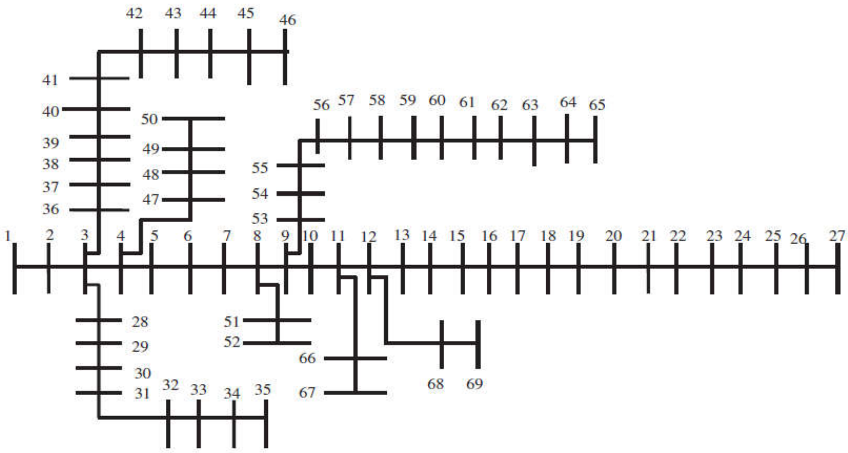


Figure (7): 69-base radial distribution system

Q_c MCA	Q_c Reference [33]	Q_c Reference [32]	Q_c Reference [31]	Q_c Reference [30]	Q_c Reference [29]	Reference [28]	Q_c Reference [27]	Initial conditions without capacitor	Base number
3300	3600	3600	3300						2
2850	4050		3900	2850	3300	1050			3
1950	450	4050		2100	1800	1050	2100		4
1200	1200		1200	1050	1050	1950	2500		5
									6
300		600							7
	150								8
450	600		900	900	900	900	900		9
550.7387	681.28	686	689	691.6	692	70	707	783.61	Real power losses(KW)

Table 1: Comparison with other methods for 9-bus system

104579	**116320**	**117095**	**117330**	**117479**	**117571**	**119420**	**119736**	**132875**	**Cost $(US)**
0.9003	**0.90014**	**0.9003**	**0.9006**	**0.9000**	**0.90004**	**0.9029**	**0.9000**	**0.8375**	**Lowest voltage (PU)**
1.006	**1.007**	**1.007**	**1.006**	**1.001**	**1.0012**	**1.000**	**1.000**	**0.9929**	**Highest voltage (PU)**

Table 2: Comparison with other methods for 9-bus system

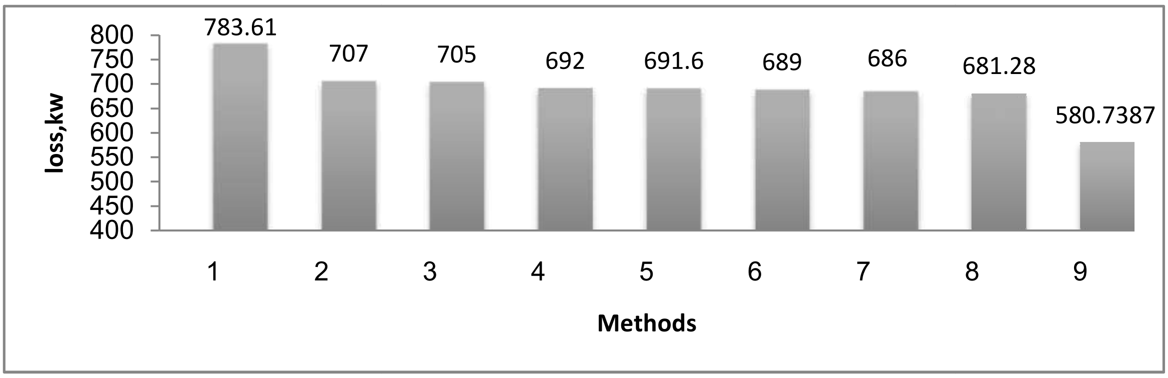
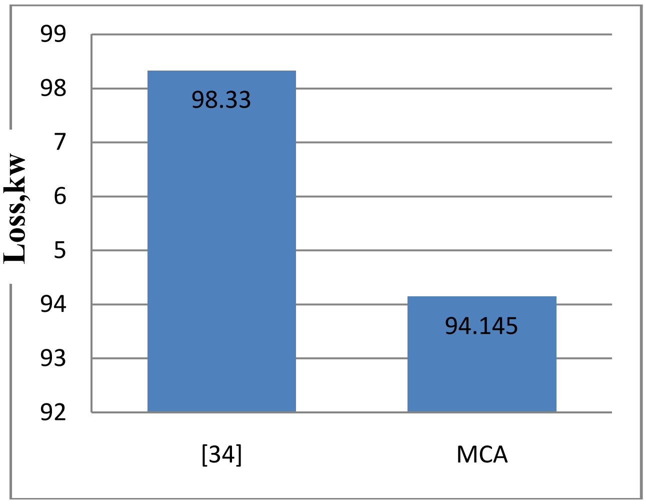


Figure (5):Comparing losses in 9-bus system

Results of capacitor placement with modified cultural algorithm on 22-base distribution system



MCA	Reference[34]	Reference[35]	method
1800	1800	1600	Set of capacitors (KVAR)
120.20	147	156.52	Losses (KW)
78944.34	95727	8912.6	Cost (US $)

Table (3): results of capacitor placement with modified cultural algorithm on 69-base distribution system
Figure (6) – comparing losses in 22-base distribution system

MCA	reference [34]	
2,7,10,15	4,13,16,17	Base number
400	300	Capacitor (KVAR)
94.145	98.33	Losses (KW)
4344.57	5575.59	Cost (US $)
1.0 and 0.9532	1.0 and 0.9701	V_{mim},V_{max}

Table (4): results of capacitor placement with modified cultural algorithm on 22-base distribution system

Radial 69-base distribution system

This time, the modified cultural algorithm has been implemented on 69-base system:

CONCLUSION

Due to economic value of benefits obtained from loss reduction, considering costs of installation and retaining capacitors, it has been observed that the use of capacitors in distribution systems has an economic justification. This paper, offers a valuable method for solving the problem of optimal capacitor placement. Objective function includes two parts, reducing capacitor placement costs and reducing real power losses, which has been used in other references as well. Comparing results obtained from modified cultural algorithm with other studies is an indication of the efficiency of this algorithm.

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