OPTIMAL CAPACITOR PLACEMENT USING FUZZY AND ARTIFICIAL BEE COLONY ALGORITHM FOR MAXIMUM LOSS REDUCTION

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Abstract – This paper presents a new methodology using fuzzy and Artificial Bee Colony Algorithm (ABCA) for the placement of capacitors on the primary feeders of the radial distribution systems to reduce the power losses and to improve the voltage profile. A two-stage methodology is used for the optimal capacitor placement problem. In the first stage, fuzzy approach is used to find the optimal capacitor locations and in the second stage, Artificial Bee Colony Algorithm is used to find the sizes of the capacitors. The sizes of the capacitors corresponding to maximum loss reduction are determined. The proposed method is tested on 15-bus, 34-bus and 69-bus test systems and the results are presented.

Keywords – *Capacitor placement - fuzzy approach – Artificial Bee Colony Algorithm -loss reduction*.

1. INTRODUCTION

Studies have indicated that as much as 13% of total power generated is wasted in the form of losses at the distribution level [1]. Radial distribution systems are typically spread over large areas and are responsible for a significant portion of total power losses. Reduction of total power loss in distribution system is very essential to improve the overall efficiency of power delivery. This can be achieved by placing the optimal value of capacitors at proper locations in radial distribution systems. Capacitors are installed at strategic locations to reduce the losses and to maintain the voltages within the acceptable limits.

Application of shunt capacitors to the primary distribution feeders is a common practice in most of the countries. The advantages anticipated include boosting the load level of the feeder so that additional loads can be carried by the feeder for the same maximum voltage drop, releasing a certain KVA at the substation that can be used to feed additional loads along other feeders and reducing power and energy losses in the feeder.

The objective of the capacitor placement problem is to determine the locations and sizes of the capacitors so that the power loss is minimized so that loss reduction is maximized. Even though considerable amount of research work was done in the area of optimal capacitor placement [2]-[15], there is still a need to develop more suitable and effective methods for the optimal capacitor placement.

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Although some of these methods to solve capacitor allocation problem are efficient, their efficacy relies entirely on the goodness of the data used. Fuzzy logic provides a remedy for any lack of uncertainty in the data. Fuzzy logic has the advantage of including heuristics and representing engineering judgments into the capacitor allocation optimization process. Furthermore, the solutions obtained from a fuzzy algorithm can be quickly assessed to determine their feasibility in being implemented in the distribution system.

H. Ng *et al.* [10] proposed the capacitor placement problem by using fuzzy approximate reasoning. In the first stage, the method proposed by H. Ng *et al.* [9] is adapted to determine the optimal capacitor locations using fuzzy logic.

Karaboga.D [16] proposed a new meta heuristic approach called artificial bee colony algorithm, It is inspired by the intelligent foraging behavior of honey bee swarm. In the second stage, the algorithm proposed by Karaboga.D [16] is adapted to determine the optimal capacitor sizes using artificial bee colony algorithm.

The proposed method is tested on 15, 34 and 69 bus test systems and results are obtained.

2. TOTAL REAL POWER LOSS IN A DISTRIBUTION SYSTEM

The total I^2R loss (P_L) in a distribution system having *n* number of branches is given by

$$P_L = \sum_{i=1}^{n} I_i^2 R_i \quad (1)$$

Here I_i is the magnitude of the branch current and R_i is the resistance of the *ith* branch respectively. The branch current can be obtained from the load flow solution. The branch current has two components, active component (I_a) and reactive component (I_r). The loss associated with the active and reactive components of branch currents can be written as

$$P_{La} = \sum_{i=1}^{n} I_{ai}^2 R_i \quad (2)$$

$$P_{Lr} = \sum_{i=1}^{n} I_{ri}^2 R_i \quad (3)$$

Note that for a given configuration of a single source radial network, the loss P_{La} associated with the active component of branch currents cannot be minimized because all active power must be supplied by the source at the root bus. However, supplying part of the reactive power demand locally can minimize the loss P_{Lr} associated with the reactive component of branch currents. This paper presents a method that minimizes the loss due to the reactive component of the branch current by optimally placing the capacitors and thereby reduces the total loss in the distribution system.

3. IDENTIFICATION OF OPTIMAL CAPACITOR LOCATIONS USING FUZZY APPROACH

This paper presents a fuzzy approach to determine suitable locations for capacitor placement. Two objectives are considered while designing a fuzzy logic for identifying the optimal capacitor locations. The two objectives are: (i) to minimize the real power loss and (ii) to maintain the voltage within the permissible limits. Voltages and power loss indices of distribution system nodes are modeled by fuzzy membership functions. A fuzzy inference system (FIS) containing a set of rules is then used to determine the capacitor placement suitability of each node in the distribution system. Capacitors can be placed on the nodes with the highest suitability.

For the capacitor placement problem, approximate reasoning is employed in the following manner: when losses and voltage levels of a distribution system are studied, an experienced planning engineer can choose locations for capacitor installations, which are probably highly suitable. For example, it is intuitive that a section in a distribution system with high losses and low voltage is highly ideal for placement of capacitors. Whereas a low loss section with good voltage is not ideal for capacitor placement. A set of fuzzy rules has been used to determine suitable capacitor locations in a distribution system.

In the first step, load flow solution for the original system is required to obtain the real and reactive power losses. Again, load flow solutions are required to obtain the power loss reduction by compensating the total reactive load at every node of the distribution system. The loss reductions are then, linearly normalized into a [0, 1] range with the largest loss reduction having a value of 1 and the smallest one having a value of 0. Power Loss Index value for n_{th} node can be obtained using equation (4).

$$PLI(n) = \frac{lossreduction(n) - lossreduction(\min)}{lossreduction(\max) - lossreduction(\min)} \quad (4)$$

These power loss reduction indices along with the p.u. nodal voltages are the inputs to the Fuzzy Inference System (FIS), which determines the node more suitable for capacitor installation.

In this paper, two input and one output variables are selected. Input variable-1 is power loss index (PLI) and Input variable-2 is the per unit nodal voltage (V). Output variable is capacitor suitability index (CSI). Power Loss Index range varies from 0 to 1, P.U. nodal voltage range varies from 0.9 to 1.1 and Capacitor suitability index range varies from 0 to 1.Five membership functions are selected for PLI. They are **L, LM, M, HM and H**. All the five membership functions are triangular as shown in Figure 1. Five membership functions are selected for Voltage. They are **L, LN, N, HN and H**. membership functions are trapezoidal and triangular as shown in Figure 2. Five membership functions are selected for CSI. They are **L, LM, M, HM and H**. These five membership functions are also triangular as shown in Figure 3.

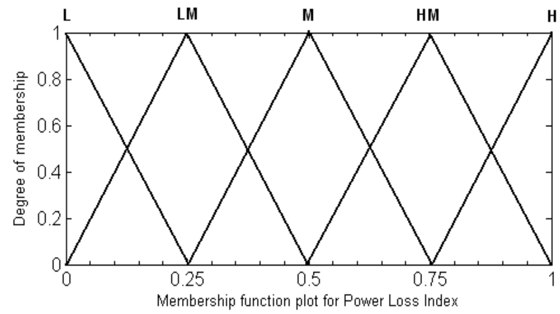

Figure 1. Membership function plot for P.L.I.

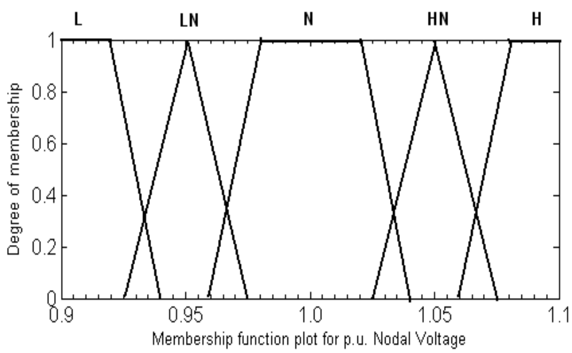

Figure 2. Membership function plot for p.u. nodal voltage

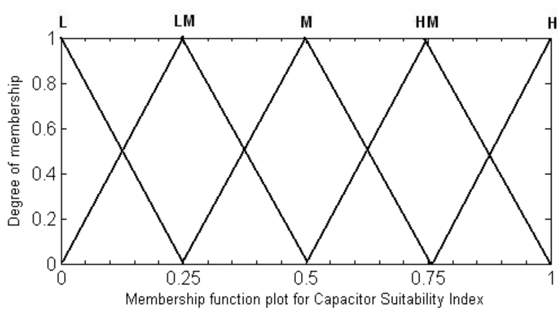

Figure 3. Membership function plot for C.S.I.

For the capacitor allocation problem, rules are defined to determine the suitability of a node for capacitor installation. Such rules are expressed in the following form:

IF premise (antecedent), THEN conclusion (consequent) for determining the suitability of capacitor placement at a particular node, a set of multiple antecedent fuzzy rules has been established. The inputs to the rules are the voltage and power loss indices and the output is the suitability of capacitor placement. The rules are summarized in the fuzzy decision matrix in Table I. The consequents of the rules are in the shaded part of the matrix.

Table I. Decision matrix for determining the optimal capacitor locations

AND		Voltage				
		L	LN	**N**	HN	**HH**
PLI	L	LM	LM	L	L	L
	LM	M	LM	LM	L	L
	M	HM	M	LM	L	L
	HM	HM	HM	M	LM	L
	H	H	HM	M	LM	LM

4. OVERVIEW OF ARTIFICIAL BEE COLONY ALGORITHM (ABCA)

In the ABC algorithm [16], the colony of artificial bees contains three groups of bees: employed bees, onlookers and scouts. A bee going to the food source visited by it previously is named an employed bee and a bee waiting on the dance area for making decision to choose a food source is called an onlooker. A bee carrying out random search is called a scout.

In the ABC algorithm, first half of the colony consists of employed artificial bees and the second half constitutes the onlookers. For every food source, there is only one employed bee. In other words, the number of employed bees is equal to the number of food sources around the hive. The employed bee whose food source is exhausted by the employed and onlooker bees becomes a scout.

In the ABC algorithm, each cycle of the search consists of three steps: sending the employed bees onto the food sources and then measuring their nectar amounts; selecting of the food sources by the onlookers after sharing the information of employed bees and determining the nectar amount of the foods; determining the scout bees and then sending them onto possible food sources.

At the initialization stage, a set of food source positions are randomly selected by the bees and their nectar amounts are determined. Then, these bees come into the hive and share the nectar information of the sources with the bees waiting on the dance area within the hive. At the second stage, after sharing the information, every employed bee goes to the food source area visited by her at the previous cycle since that food source exists in her memory, and then chooses a new food source by means of visual information in the neighborhood of the present one. At the third stage, an onlooker prefers a food source area depending on the nectar information distributed by the employed bees on the dance area. As the nectar amount of a food source increases, the probability with which that food source is chosen by an onlooker increases, too. Hence, the dance of employed bees carrying higher nectar recruits the onlookers for the food source areas with higher nectar amount. After arriving at the selected area, she chooses a new food source in the neighborhood of the one in the memory depending on visual information. Visual information is based on the comparison of food source positions. When the nectar of a food source is abandoned by the bees, a new food source is randomly determined by a scout bee and replaced with the abandoned one.

In our model, at each cycle at most one scout goes outside for searching a new food source and the number of employed and onlooker bees were equal. The probability P_i of selecting a food source i is determined using the following expression:

$$P_i = \frac{fit_i}{\sum_{n=1}^{SN} fit_n} \quad (5)$$

Where fit_i is the fitness of the solution represented by the food source i and SN is the total number of food sources. Clearly, with this scheme good food sources will get more onlookers than the bad ones. After all onlookers have selected their food sources, each of them determines a food source in the neighborhood of his chosen food source and computes its fitness. The best food source among all the neighboring food sources determined by the onlookers associated with a particular food source i and food source i itself, will be the new location of the food source i. If a solution represented by a particular food source does not improve for a predetermined number of iterations then that food source is abandoned by its associated employed bee and it becomes a scout, i.e., it will search for a new food source randomly. This tantamount to assigning a randomly generated food source (solution) to this scout and changing its status again from scout to employed. After the new location of each food source is determined, another iteration of ABC algorithm begins. The whole process is repeated again and again till the termination condition is satisfied.

The food source in the neighborhood of a particular food source using equation (6) is determined by altering the value of one randomly chosen solution parameter and keeping other parameters unchanged. This is done by adding to the current value of the chosen parameter the product of a uniform variate in [-1, 1] and the difference in values of this parameter for this food source and some other randomly chosen food source.

$$v_{ij} = x_{ij} + u(x_{ij} - x_{kj}) \quad (6)$$

where u is an uniform variate in [-1, 1]. If the resulting value falls outside the acceptable range for parameter j, it is set to the corresponding extreme value in that range.

5. ABC ALGORITHM FOR CAPACITOR SIZING PROBLEM

After identifying the n number of capacitor locations using fuzzy approach, the capacitor sizes in all these n capacitor locations are obtained by using the Artificial Bee Colony Algorithm (ABCA).The proposed artificial bee colony algorithm is summarized as follows:

Step 1. Initially [SN x n] number of Bee population (x_{ij}) are generated randomly within the limits Qmax and Qmin where SN is the population size and n is the number of capacitors. Each row represents one possible solution to the optimal capacitor-sizing problem and the numbers of employed Bees are equal to onlooker Bees .

Step 2. By placing all the n capacitors of each Bee at the respective capacitor locations and load flow analysis is performed to find the total real power loss P_L . The same procedure is repeated for the SN number of Bees. Evaluate fitness value for each Bee by using the equation (7),

$$fitness(i) = \frac{1}{1 + powerloss(i)} \quad (7)$$

Step 3. Generate new population (solution) v_{ij} in the neighborhood of x_{ij} for employed bees using equation (6) and evaluate the fitness of them;

Step 4. Apply the greedy selection process between x_{ij} and v_{ij} by comparing the fitness of them;

Step 5. Calculate the probability values P_i for the solutions x_{ij} by means of their fitness values using the equation (5);

Step 6. Produce the new population's v_{ij} for the onlookers from the employed bee's population, selected depending on P_i by applying roulette wheel selection process, and evaluate the fitness of all the onlooker bees;

Step 7. Apply the greedy selection process for the onlookers between x_{ij} and by comparing the fitness;

Step 8. Maximum fitness , Minimum fitness and average fitness values are calculated. Error is calculated using the equation
Error = (maximum fitness - average fitness)
If this error is less than a specified tolerance then go to Step 11

Step 9. The bee corresponding to minimum fitness is a scout and replace it with a new randomly produced solution x_{ij} for the scout bees using the following equation

$$x_{ij} = Q\min + rand(0,1) * (Q\max - Q\min) \quad (7)$$

Step 10. The iteration count is incremented and if iteration count is not reached maximum then go to step 2.

Step 11.The capacitor sizes corresponding to maximum fitness(Best Bee) gives the optimal capacitor sizes in n capacitor locations and the results are printed

6. RESULTS

Fuzzy approach is used to find the optimal capacitor locations and ABCA is used to find the optimal capacitor sizes for maximum loss reduction. Convergence criterion of ABCA is error must be less than 0.000000001.

6.1. Results Of 15-Bus System

The proposed algorithm is applied to 15-bus system [12]. Optimal capacitor locations are identified based on the C.S.I. values. For this 15- bus system, five optimal locations are identified. Capacitor sizes in the five optimal locations, total real power losses before and after compensation

Table 2. Results of 15-bus system

Bus No.	Capacitor size in KVAR
4	345
6	265
7	143
11	300
15	143
Total KVAR	1196
Total power loss in KW(before)	61.7933
Total power loss in KW(after)	29.9077
% of loss reduction	51.60

6.2 Results of 34 bus system

The proposed algorithm is applied to 34-bus system [7]. Optimal capacitor locations are identified based on the C.S.I. values. For this 34-bus system, seven optimal locations are identified .Capacitor sizes in the seven optimal locations, total real power losses before and after compensations are shown in Table 3.

Table 3. Results of 34-bus system

Bus No.	Capacitor size in KVAR
20	968
21	145

22	144
23	143
24	143
25	143
26	228
Total KVAR	1914
Total power loss in KW(before)	221.7210
Total power loss in KW(after)	167.9074
% of loss reduction	24.27

6.3. Results of 69-Bus System

The proposed algorithm is applied to 69-bus system [4]. Optimal capacitor locations are identified based on the C.S.I. values. For this 69-bus system, two optimal locations are identified. Capacitor sizes in the two optimal locations, total real power losses before and after compensation
are shown in Table 4.

Table 4. Results of 69-bus system

Bus No.	Capacitor size in KVAR
61	1123
64	207
Total KVAR	1330
Total power loss in KW(before)	225.0021
Total power loss in KW(after)	151.7069
% of loss reduction	32.57534

The results show that 50.052 % reduction in power loss for 15-bus system, 23 % reduction in power loss for 34-bus system and % reduction in power loss for 69-bus system is possible as shown in Tables 2, 3 and 4 respectively and bus voltages are also improved substantially.

6. CONCLUSIONS

In this paper, a two-stage methodology of finding the optimal locations and sizes of shunt capacitors for reactive power compensation of radial distribution systems is presented. Fuzzy approach is proposed to find the optimal capacitor locations and ABCA method is proposed to find the optimal capacitor sizes. Based on the simulation results, the following conclusions are drawn:

By installing shunt capacitors at all the potential locations, the total real power loss of the system has been reduced significantly and bus voltages are improved substantially. The proposed fuzzy approach is capable of determining the optimal capacitor locations based on the C.S.I. values. The proposed ABCA method iteratively searches the optimal capacitor sizes effectively for the maximum power loss reduction.

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