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Optimal capacitor placement in radial distribution networks with artificial honey bee colony algorithm

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ABSTRACT
Electricity demand growth and low production capacity have prompted the distribution companies to take the loss of electricity networks into account more than before. One effective way to decline loss is optimal capacitor placement in distribution networks. By placing capacitors, the voltage profile and network capacity get better. Furthermore, the capacitors support the reactive power of network and improve the network ability in the full load time. Considering the importance of capacitor-placing, in this project, the optimal capacitor placement is accomplished using artificial bee colony algorithm. This optimization algorithm is based on collective intelligence and intelligent behavior of the bee population. This algorithm employing the combination of random and local search, permeate to the population space and find the desired solution. The proposed algorithm is implemented on the 9 and 34 bus systems, and finally the simulation results are compared with similar investigations in this field.
Keywords: *Capacitor, reactive power, loss, radial distributed network, artificial bee algorithm*

INTRODUCTION
Active power losses mean resistive or line losses. Active power losses can be reduced by several methods. We can reduce the losses greatly by reactive power compensation and shunt capacitor installation. Another ways to minimize losses are reconstructing and reconfiguring the network and using Flexible AC Transmission Systems[1]. In addition to size and location of capacitor, type of capacitor should also be specified to solve the problem of capacitor placement. After that, all feeders should be tested to identify sensitive buses; Moreover, it's impossible to install capacitor in all parts of the network. Generally, this problem in mathematics is a mixed non-derivable and non-linear integer optimization problem with a series of equal and unequal constraints. Since 1960, many researchers and engineers have worked on the problem of reducing losses, but they haven't proposed a proper and ideal plan to minimize the losses in power systems. Analytical methods have been used in all primary articles about capacitor-placing [1, 2]. In reference [3], searching for bacteria based on fuzzy logic has been proposed to solve the placement problem. In [4], system reliability and optimal capacitor allocation have been studied in the presence of unbalanced loads. Optimal capacitor placement in radial distribution system with fixed and switching capacitor has been studied in [5]. Shunt capacitor location and optimal size with a result of power coefficient correction and losses reduction in distribution feeder carried out in [6], and in the reference [7], a method for power coefficient correction has been prepared after the placement, and reactive power has been studied after the benefits from compensation. Optimization in this method has been performed based on annual income. The optimization problem is solved by genetic algorithm in [8]. Capacitor-placing with artificial honey bee colony algorithm has been used to reduce losses of radial distribution system in the presence of unbalanced loads [9].

Voltage Stability Index (*VSI*) [1]
Proper use of capacitor, obtaining size and optimal capacitor place, has a great role in losses reduction. As mentioned before, capacitors should be installed in sensitive buses. A new method to obtain sensitive

[1] - Voltage stability index

points or voltage collapse is suggested in reference [10]. *VSI* (j) value is defined by equation (1). That if *VSI* (j) value calculated for a bus was less than other buses, that bus would be the most susceptible one to voltage collapse. Therefore, all buses' *VSI* (j) value should be maximized to avoid the risk of voltage collapse. Figure (1) shows a simplified electrical equivalent of radial distribution system.

Equation (1): $$VSI(j) = |V_i|^4 - 4[P_j.X_{ij} - Q_j.R_{ij}]^2 - 4[P_j.R_{ij} + Q_j.X_{ij}].|V_i|^2$$

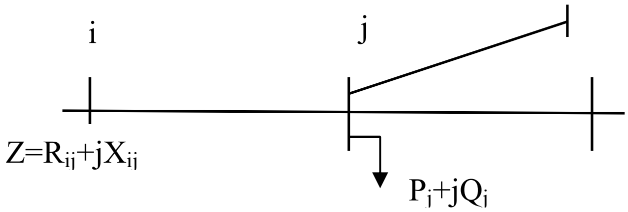

Figure (1): A simplified view of radial distribution system

Objective function

In this paper, the objective function is to reduce real power losses and costs of capacitor-placing [11-15].

Equation (2): $$F = F_{loss} + F_{capacity} + F_{cost}$$

Equation (3): $$F = K_A P_{loss} + K_e \sum_{j=1}^{L} T_j P_j + \sum_{i=1}^{ncap} (K_{di} + K_{cf} Q_{cfi})$$

In the equation (2), cost of energy losses, cost of required capacitor preparation, and cost of capacitors installation are equal to F_{loss}, $F_{capacity}$ and F_{cost}, respectively. In the equation (3), $\mathbf{K_A}$ is a cost of losses reduction per MW, $\mathbf{K_e}$ is a cost of losses reduction per MWh, $\mathbf{T_j}$ is an i^th^ level period of time in (h/year), $\mathbf{P_j}$ is the real power losses at i^th^ level, $\mathbf{K_{di}}$ is a cost of capacitor installation in i^th^ bus, $\mathbf{K_{cf}}$ is a cost of buying fixed capacitor, $\mathbf{K_{cs}}$ is a cost of buying switching capacitor, $\mathbf{Q_{cfi}}$ is a reactive power of fixed capacitors, and **ncap** is the number of sensitive buses that are suitable for installing capacitor.

1. **Limitation**

   Limitation or constraint is always with objective function in optimization problems. The objective function defined in previous section has voltage constraint (equation 4). This voltage limitation means that, voltage level during total optimization time is kept at the same level.

   Equation (4): $$V_{min} \leq |V_i| \leq V_{max}$$

   V_{min} is voltage range's low-band, V_{max} is voltage range's high-band, and V_i is ***rms*** voltage that is obtained by equation (5).

   Equation (5): $$|V_i| = \sqrt{\sum_{h=1}^{H} |V_i^h|^2} \quad , \; i = 2, 3, \dots, n$$

   n is the number of buses and V is ***rms*** voltage of i^th^ bus, regardless of bothersome harmonics.

Honey bee colony algorithm optimization[1]

Swarm Intelligence (SI) [2] is one of the artificial intelligence methods that is used for solving complex optimization problems. Swarm Intelligence is like ant colony, particles swarm, bacteria searching, and etc. ABC algorithm is a smart method of particles swarm that was first introduced by Karaboga and Basturk in 2005 [16, 17]. This algorithm was used as a practical algorithm in 2007 [16]. This is an imitation of honey bee real behavior searching for food and sharing food supplies. ABC algorithm has a simple concept and it is easy to implement. Since this algorithm has a few control parameters, therefore, it has been used to solve many optimization problems such as neural network training for pattern recognition, task timing for manufacturing machines, classifying optimization information of mechanical components design, multiple optimization, economic burden distribution, and etc. Simulation algorithm of honey bees' smart searching is very simple and strong. Bees are divided into three categories in ABC algorithm: worker bees, watch bees, and scout bees. Watch bees move randomly and look for food. After completion of the search space, each bee returns to the food location and does a rotating dance according to the food it has found. This dance represents the distance, location, and quality of the food. By using of this method, worker bees deliver information about food to watch bees. Half of the bees are worker bees and the rest are watch bees in ABC algorithm. One watch bee is assigned for each food supply and the rest of the bees stay around the hive.

Location of the found food indicates a possible solution to solve the optimization problem. And the quality of the food represents optimal solution's quality or the fitness function[2].
Actually, watch bees are working based on a probability function. These kind of bees select food according to the quality; the better the food quality, the greater the probability of being selected. The watch and worker bees are randomly distributed in the location of primary food supply through SN direction (solution) at the initial step of this algorithm, where SN is also, the number of worker and watch bees. It can be said that each solution is a D dimension vector. D is the number of optimization parameters. Nectar value obtained is a measure of fitness function. In the next step, bees find a new food supply near the previous one. V_i is the new food supply that is located near the X_i supply.

Equation (6): $$V_{ij} = X_{ij} + rand \times (X_{ij} - X_{kj}), \quad k \in \{1, 2, 3, \dots, m\}, \quad k \neq i, j \in \{1, 2, 3, \dots, D\}$$

k,j are indexes that are selected randomly. But these two indexes shouldn't be equal.

5-1. Fitness function

Watch bees select solution (food quality) based on nectar value or the fitness function. Probability function can be defined by using of equation 7 and 8.

Equation (7): $$P_i = \frac{fitness_i}{\sum_{i=1}^{m} fitness_i}$$

Equation (8): $$fitness = \begin{cases} \frac{1}{1+f(x_i)} & if\ f(x_i) \leq 0 \\ 1 + |f(x_i)| & else \end{cases}$$

In equation (8), f and $f(x_i)$ are cost function and cost function evaluation for x_i food supply, respectively.
If the food supply isn't suitable in watch bees view, that food supply will be removed and a new one is obtained through equation (9).

Equation (9): $$X_i = X_{min} + rand * (X_{max} - X_{min})$$

X_{max} is the upper limit and X_{min} is the lower limit of the **j** parameter. And ***rand*** is considered as a random number between [-1, 1].

1. **Applying algorithm to the problem of optimal capacitor placement**

This study aims to obtain the best size and place for capacitor in radial distribution system. ABC algorithm starts with generating initial population (food supplies) randomly in search space. In summary, the steps to run the algorithm and solve the problem are as follows:
ABC algorithm steps to solve placement problem:

1. System input parameters (system topology, lines, loads, and etc.).
2. Required parameters for the calculation of the objective function (K_{cs}, K_{cf}, K_{di}, K_e, K_a).
3. Input parameters of the ABC algorithm (such as the number of food supplies, and the total number of bees).
4. Set the **i^th^** level and T_j length of time.
5. Set the parameters of the capacitor (no capacitor was considered in this study for the low load level).
6. Load distribution is performed and saved, given the capacitor's parameters (step 5), real power losses calculation, buses voltage, cost function, and etc. Actually, this information is the system's information before running the algorithm.
7. Set the maximum number of capacitors to install at the target load level.
8. Generating initial population randomly (food supplies).
9. Performing load distribution, calculating cost and fitness function for each food supply.
10. Running ABC algorithm for each load level.
11. Specifying the best food supply with the best quality, the lowest cost, and saving that as the best solution (bestpop).
12. If the load level reached to the expected level, capacitor would install at that (bestpop) point.
13. Performing load distribution according to the capacitor that was installed in step 12. Calculating real power losses, energy losses, buses voltage, cost function and etc.
14. Determining the net profit of saving due to capacitor's installation in step 12. (Calculation of the net profit = expenses calculated in step 6 – expenses calculated in step 13)
15. Capacitor-placing has been implemented for all the algorithm's possible load levels, and real power losses, energy losses, buses voltage, cost function, and … are calculated for all the levels; otherwise, go back to step 4.

[2] - fitness

16. Determining the annual net profit after capacitor-placing for all the load levels (sum of all the calculation derived from step 14).
17. Terminating the algorithm.

Simulation results

The algorithm has been applied for 9-buses and 34-buses distribution systems to test its effectiveness. Results comparison with similar studies shows the good
performance of the algorithm in the sample systems.
The losses and expenses are calculated without capacitor-placing in the first step after performing load distribution. Real power losses had been estimated about 723.74 KW that changed to 677.53 KW after running the algorithm and capacitor-placing. Annual profit is about to 13.20%. In references [18] and [19], the annual profits are 9.94% and 10.13%, respectively.

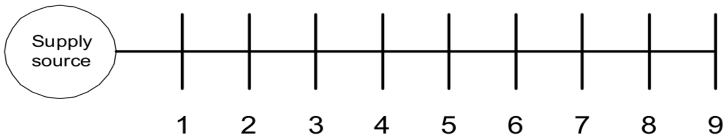

Figure (2): 9-bus radial distribution system

Algorithm	Before running algorithm	After running ABC	Reference [18]	Reference [19]
Real power losses (KW)	723.74	677.53	692.21	694.93
Annual expense	134674	125494	118582	118340
Annual net profit	-	17180	13091	13334

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

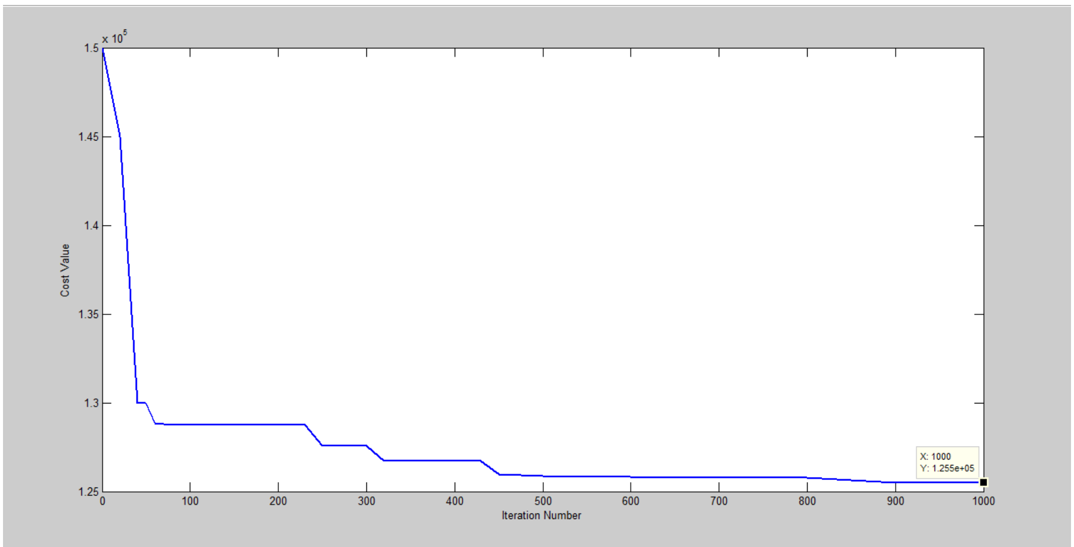

Figure (3): Convergence curve of cost of 9-bus system using artificial honey bee colony algorithm

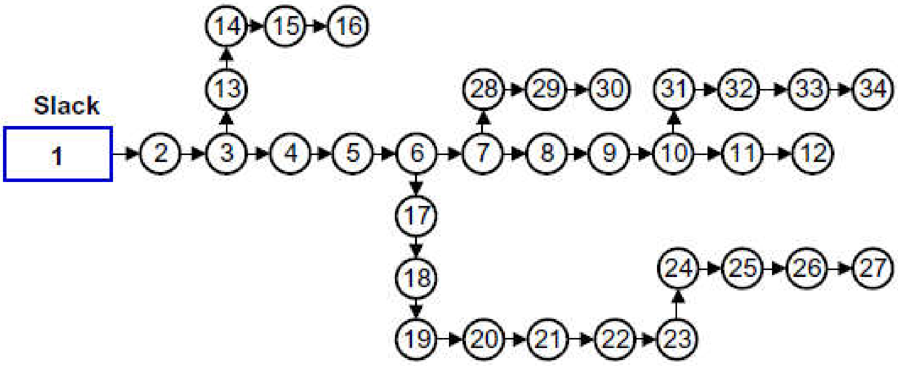

Figure (4): A 34-bus radial distribution system

The algorithm has been applied for a 34-buses distribution system in this part. Real power losses reached from 222.77 KW to 158.203 KW after running the algorithm. The annual net profit of ABC algorithm running is 26.52%, while reference [18]
and [19] net profits are 26.52% and 19.62%, respectively.

Algorithm	Before running algorithm	After running ABC	Reference [20]	Reference [21]
Real power losses (KW)	222.77	158.203	168.47	168.8
Annual expense	38243	28384	33182	29936
Annual net profit	-	9890	4089	7306
Maximum voltage (PU)	1	1	-	-
Minimum voltage (PU)	0.8475	0.95068	-	-

Table (5): Comparison of the algorithm running on a standard 34-buses system

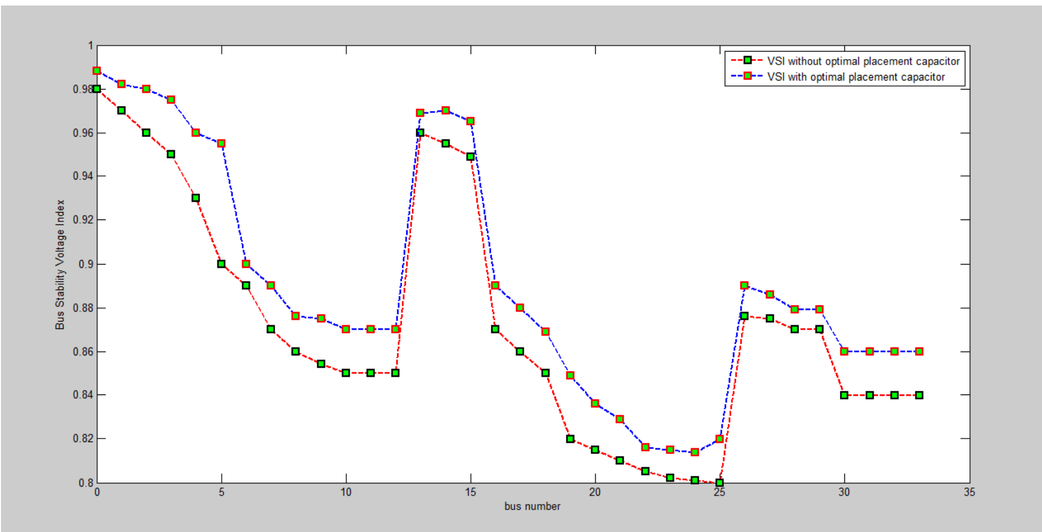

Figure (6): VSI value, 34-bus distribution system before and after using artificial honey bee colony algorithm

CONCLUSIONS

An economical method to solve the problem of optimal capacitor placement has been presented in this paper. The objective function includes three parts: minimizing real power losses, reducing the cost of capacitor preparation, and reducing the costs associated with the installation of capacitor. The objective function is met by considering voltage constraint and running the ABC algorithm. And the results of simulation show the effectiveness of this method compared with other studies. The amount of annual net profit has increased significantly.

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