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Optimal capacitor placement and sizing via artificial bee colony

Mohd Nabil Muhtazaruddin[a*], Jasrul Jamani Jamian[b], Danvu Nguyen[a]
Nur Aisyah Jalalludin[a], Goro Fujita[a]

[a] *Shibaura Institute of Technology, 3-7-5, Toyosu, Tokyo 135-8548, Japan*
[b] *Universiti Teknologi Malaysia, Skudai, Johor Bahru 81310 UTM, Malaysia*

Abstract

To achieve a more economical distribution system in the future, several methods have been introduced by researchers to accomplish that goal. Among the most commonly used method is to install the capacitors. It operates by supplying reactive power into the system to improve the performance of voltage, thereby reducing power losses. Nevertheless, the location and the size of the capacitor still issues to be resolved by the utilities. Various methods have been introduced to coordinate the capacitor without affect the performance of the distribution system. Basically, the most popular approach used to determine the location of capacitors is based on sensitivity analysis. This approach operates by placing the capacitor at each node in the system and selects the node that gives higher power losses reduction. Meanwhile, the size of capacitor is determined by using the optimization techniques in obtaining optimal values. However, calculation for both location and size in separate analysis could lead the solution trapped in local optimum. Therefore, this paper is investigated a solution to determine the location and size of capacitor simultaneously by using Artificial Bee Colony (ABC). The effectiveness of proposed method is tested on 33-bus and 69-bus test system and compared with other methods. Based from the obtained results, simultaneous approach reduces the power losses by 34.29% and 35.44% for 33-bus and 69-bus test system, respectively. Moreover, the proposed method gives a better voltage improvement compared to the base case.

Keywords: Artificial bee colony, capacitor placement, meta-heuristic optimization, power loss reduction

1. Introduction

Towards having an efficient distribution system, many researchers and engineers have proposed various solutions to reduce power losses in the network. Furthermore, the current trend indicates that electrical energy tariff is expected to increase year by year; consequently, reduction of power losses is necessary. Generally, one of the approaches to minimize the power losses in the distribution is to install the capacitor. However, the effectiveness to reduce the power losses can be achieved if the capacitor is placed in a suitable location with appropriate size.

Traditionally, the computation of capacitor size and location performed in a separate analysis, which means different approach is applied to each of them. Most of popular technique used to determine the location of capacitor is sensitivity analysis [1]-[6]. This technique works by selecting a node that has a high value of power loss reduction when power reactive supplied to that node. On the other hand, the calculation for capacitor size is usually based on the optimization method, for instance, Particle Swarm Optimization (PSO) [1], [2], Artificial Bee Colony (ABC) [3], [4], plant growth simulation algorithm (PGSA) [5], [6], Genetic Algorithm (GA) [7], [8] and Simulated Annealing (SA) [9]. Nevertheless, determination of capacitor size and location separately could lead the solution trapped in local optimum due to the calculation of the capacitor size based on the predetermined location.

* Manuscript received June 14, 2013; revised July 18, 2013.
Corresponding author. Tel.: +8180-4607-5124; *E-mail address*: na11502@shibaura-it.ac.jp.

ABC is one of optimization techniques under mete-heuristic classification and works by imitating the behaviour of bees in finding food around hives. This method is proposed by Karaboga [10] in 2005. Furthermore, one of advantages ABC is that it involved with only two control parameter (limit and maximum cycle) rather than others methods consists many control parameter and difficult to obtained effective values [11].

Capacitor coordination can be formulated as a combinatorial optimization that involved with two discrete variables which are capacitor size and location. In addition, the objective function may vary depending on the goals of the study. Since the aim of this research paper is to minimize the total power losses in the distribution, therefore objective function can be expressed as power losses reduction.

In this paper, simultaneous approach for capacitor coordination is proposed by using the ABC and formulated as a combinatorial optimization. Main focus of this paper is to reduce the real power losses while maintain all the constraint within permissible limit. The proposed method is tested on the 33-bus and 69-bus test system by using MATLAB programming.

The rest of the paper is organized as follows: Section 2 explains the problem formulation in this paper; Section 3 describes brief of the ABC; Section 4 expressed the problem formulation of ABC in capacitor coordination; Section 5 presents simulation results and discussion. Section 6 concludes the paper.

2. Problem Formulation

The aim of this manuscript to reduce the power losses in distribution network by means calculate optimal values of capacitor size and location whilst maintain all constraints within acceptable limit. Therefore, objective function can be formulated as

$$\min f\left(x_{location}, x_{size}\right) = \sum_{i=1}^{n} P_{realloss,i} \tag{1}$$

where $x_{location}$ is the capacitor location (discrete variable), x_{size} is the capacitor size (discrete variable), n is the number of lines, and $P_{loss,i}$ is the power losses at each line i.

Subjected to

a) Voltage constraint:

$$V_{j,\min} \le V_j \le V_{j,\max} \tag{2}$$

where $V_{j,min}$ and $V_{j,max}$ are minimum and maximum voltage at bus j, and

b) Size of capacitor constraint (discrete variable).

In order to have an appropriate size of capacitor, the selection of the values is based on practical size in the market [1] which is 300 kVar, 600 kVar, 900 kVar, 1200 kVar, and 1500 kVar.

3. Overview of Artificial Bee Colony Optimization

Artificial bee colony or simply known as the ABC optimization is one of the new optimization introduced by Karaboga [10] in 2005. Basic principle of this optimization is follows the behaviour of bees finding food surrounding the hive. Generally, the bees can be divided into three main groups which are employed bees, onlooker bees and scout bees. Each of these groups has different goals and task in search of food.

The process of finding the food start with scout bees randomly determine the location of food area with the size of population is equal with employed bees. Status of scout bees changed to employed bees once they found the food sources in the food area. Based on information from all food sources, the employed bees return to hive to exchange information with onlooker bees in the dancing area. In this area, they will performance a special dance which known as waggle dance and duration of the dancing depends on the richness of food sources (nectar amount) as in (3).

$$Fitness_i = \frac{1}{1+\sum_{i}^{n} P_{realloss,i}} \tag{3}$$

where $Fitness_i$ is a quality of the selected food sources

After shared the information, the employed bees return back to the previous food area but at different food source location by using (4) and evaluate the richness of food sources:

$$X_{ij}^{new} = X_{ij}^{old} + Random \times (X_{ij}^{old} - X_{kj}) \tag{4}$$

where X_{ij}^{new} and X_{ij}^{old} are new and previous value of parameter, respectively. *Random* is random number generated between −1 and 1 and X_{kj} is other value of parameter that is selected randomly.

Based on the previous value of fitness, they compare it with the current value and select the best fitness only. With the same previous process, the employed return to the hive and shared with the onlooker bees. The selection of the food sources by the onlooker based on probability value is given as

$$P_i = \frac{Fitness_i}{\sum_{j=1}^{k} Fitness_j} \tag{5}$$

where P_i is a probability value of onlooker bees select food source at i and k is total number of employed bees.

All of the processes are repeated until stopping criteria (maximum cycle) are met, but if the food sources abandon (limit) by the employed, they will change the status back to scout bees and find a new food area.

4. Formulation of ABC in Capacitor Coordination

Fig. 1 shows flow chart of ABC in solving capacitor coordination. As previously discussed in section 2, the scout bees will generate randomly initial population with the size of onlooker bees. Suppose that total numbers of parameter to be optimized are two and can be expressed as X_i=($X_{location}$, X_{size}) with i is total number of onlooker bees. Based on the initial population, each of capacitor will be placed in the test system and calculate the fitness value by using (3).

In the next process of ABC, the employed bees will modify original values of each X_i based from (4) and determine new value of fitness. From the new set of results, comparisons are made by using greedy selection approach with the previous ones and select only high value of fitness. Based on the new values of fitness, probability values are calculated by using formula in (5) for selection in employed bees phase and save the lowest objective function. All of these steps are repeated until maximum cycle reached. However, if a solution of X_i doesn't give better result than previous ones for a specified number (limit), the solution will be abandon and replace with the new X_i at random value.

The proposed capacitor coordination by using ABC is summarized as follows:

Step 1: Randomly generated initial population, x_i consisting of capacitor size and location.

Step 2: Calculate total power losses and fitness value, $Fitness_i$ by using (3) for each solution of x_i.

Step 3: Compute new value of x_i by using (4) and calculate the new $Fitness_i$.

Step 4: Apply greedy selection (only higher $Fitness_i$ is saved) between previous and new $Fitness_i$.

Step 5: Calculate probability, P_i value by using (5).

Step 6: Compute new value of x_i by using (4) and calculate the new $Fitness_i$.

Step 7: Apply greedy selection and save the best fitness value.

Step 8: If the number of trial (limit) had been exceeded, one scout bee is assigned to replace the solution, x_i with the new ones randomly.

Step 9: Memorize the best results so far.

Step 10: Repeat the process from step 3 to 9 until maximum cycle.

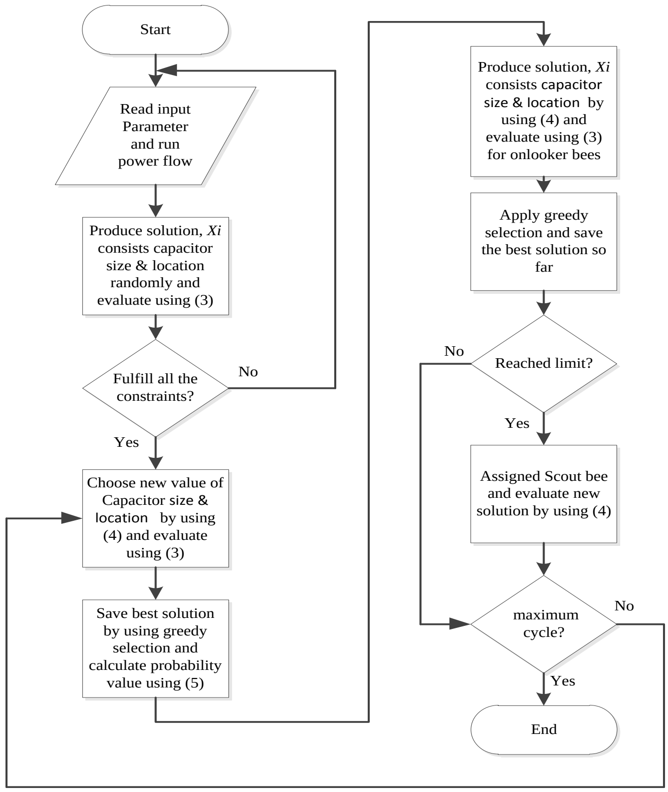

Fig. 1. Flow chart of ABC algorithm in solving capacitor coordination problem.

5. Results and Discussions

The proposed method is applied to 33-bus and 69-bus test system. Both of the system is connected to the substation of 132/12.66 kV rated at 100MVA (base power) with secondary side as base voltage. All the loads are presumed to be invariant during analysis. In the simulation, three case studies are considered to validate the proposed method as shown in Table 1 by using MATLAB programming.

Table 1. Description of case studies

Case	Explanation
1	Original network and set as a base case.
2	Determine optimal size and location of single capacitor simultaneously.
3	Determine optimal size and location of three capacitors simultaneously.

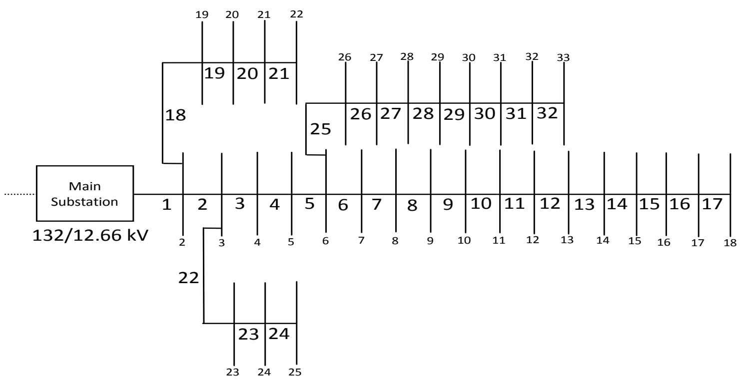

Fig. 2. 33-bus test system configuration.

5.1. 33-bus system

Fig. 2 shows 33-bus test system consists of 33 buses and 32 lines with the total load on the system are 3.715 MW and 2.300 Mvar. All the details parameter of line and bus data can be obtained in [12].

Table 2 shows simulation results for all cases. An initial power loss without any reactive compensation in test system is 203.19 kW as showed in the case 1. Based on the simulation results obtained, the optimal location for case 2 is located at bus 30 with the size of 1200 kvar, whereas for case 3, the best locations are placed at bus 13 (300 kvar), 24 (600 kvar) and 30 (900 kvar). It can be observed that the reduction of power reduction can be greatly reduced with the increasing number of capacitors. This can be proved by referring to the results in case 3, the percentage of reduction of power losses at about 34.29% compared to the case 1 and followed by case 2 gives percentage of loss reduction at 23.16%.

Voltage profile for all the cases is depicted in the Fig. 3. It can be seen that the case 3 has a better voltage profile compared with cases 1 and 2. These results can be verified by looking at the minimum voltage in Table 3 which the case 2 only shows improvement of minimum voltage by 1.33%, while for the case 3 is 2.53%. This is because of the increase in number of capacitors can help to provide enough reactive power to the system. Thus, helps in improve the voltage profile.

Table 3 shows a comparison of the proposed method with other references according to power losses reduction, capacitor location, size as well as total size of capacitor. Based on the obtained results, it can be clearly seen that the proposed method outperformed other methods in term of quality solution. Furthermore, total size of capacitor is smaller than others methods despite having almost the same value of power losses reduction. Therefore, the proposed can save the cost of installation and maintenance of the capacitor.

Table 2. Summary of result for 33-bus system

Parameter	Case 1	Case 2	Case 3
Power losses, kW	203.19	143.93	133.52
Optimal capacitor location	-	30	13,24,30
Optimal capacitor size, kvar	-	1200	300,600,900
Loss reduction (%)	-	23.16	34.29
Minimum voltage, p.u	0.9101	0.9222	0.9331
Total capacitor size, kvar	-	1200	1800

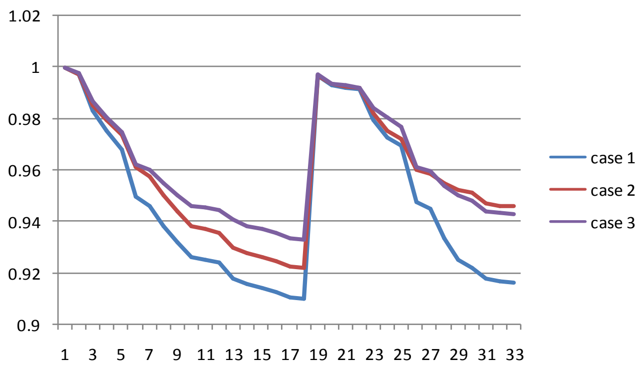

Fig. 3. Voltage profile for 33-bus system.

Table 3. Comparison with other methods for 33-bus system

Parameter	Case 3	PGSA [5]	GA [7]
Power losses, kW	133.52	135.4	135.5
Optimal capacitor location	13,24,30	6,28,29	8,15,20,21,24,26,27,28
Optimal capacitor size, kvar	300,600,900	1200,760,200	300,300,300,300,300,300,600,300
Total capacitor size, kvar	1800	2160	2700

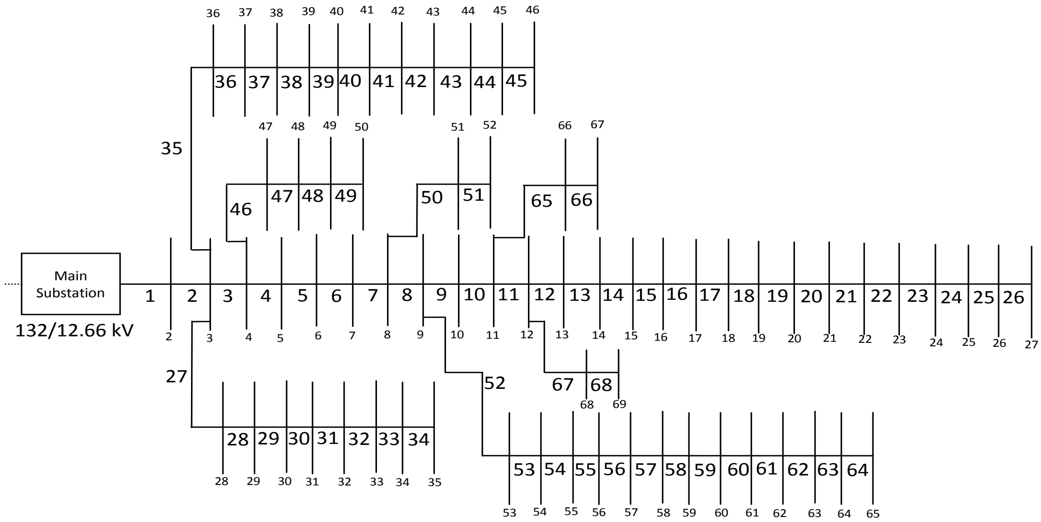

Fig. 4. 69-bus test system configuration.

Table 4. Summary of result for 69-bus system

Parameter	Case 1	Case 2	Case 3
Power losses, kW	225.06	152.76	145.29
Optimal capacitor location	-	61	11,18,61
Optimal capacitor size, kvar	-	1200	300,300,1200
Loss reduction (%)	-	32.12	35.44
Minimum voltage, p.u	0.9092	0.9288	0.9308
Total capacitor size, kvar	-	1200	1800

5.2. 69-bus system

The second test system is a 69-bus system as shown in the Fig. 4. The system consists of 69 lines and 68 branches and all the related of the system can be obtained in [13]. The total load of the system is 3.803 MW and 2.697 MVar.

Simulation results for 69-bus system are presented in Table 4. As in previous results for 33-bus system, it can be clearly seen that the power losses reduction can be achieved by increasing the number of capacitor in the distribution system. Results for the case 2 showed that the percentage of power losses reduction is 32.12% only and further reduction can be obtained in the case 3 which is 35.44%. The optimal location of capacitor for case 2 is at bus number 61 (1200 kvar), whereas the locations for case 3 are 11 (300 kvar), 18 (300 kvar) and 61 (1200 kvar).

Fig. 5 shows voltage at each bus for all cases. It can be observed that the case 3 shows significant voltage improvement compared to the cases 1 and 2. In addition, the minimum voltage for the case increased by 0.0216 p.u of the base case, while the case 2 is only 0.0196 p.u.

In order to verify the effectiveness of the proposed method, several comparisons were made with other methods as shown in Table 5. Based on the results obtained, the proposed shows better results in term power losses reduction at 145.29 kW compared to reference in [5] and [3] are of 152.48 kW and 146.75 kW, respectively. So, this proves that the determination of capacitor location and size simultaneously give superior results compared to other methods.

Table 5. Comparison with other methods for 69-bus system

Parameter	Case 3	PGSA [5]	ABC [3]
Power losses, kW	145.29	152.48	146.75
Optimal capacitor location	11,18,61	46,47,50	59,61,64
Optimal capacitor size, kvar	300,300,1200	241,365,1015	100,600,700
Total capacitor size, kvar	1800	1621	1400

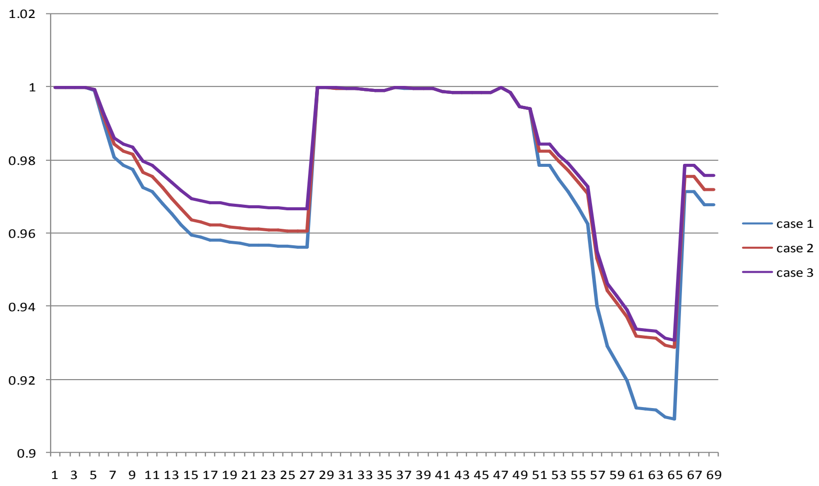

Fig. 5. Voltage profile for 69-bus system

6. Conclusion

In this paper, ABC optimization is introduced to determine the optimal size and location of capacitor simultaneously. Several case studies are considered to test the effectiveness of the proposed method. Based from the obtained results, the proposed method gives better power losses reduction and improvement of voltage profiles. Furthermore, several comparisons have been made with other references and simulations results showed the proposed method outperformed other methods.

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