Offline Study on Loss Optimization in Distribution Networks Using Artificial Bee Colony (ABC) Algorithm

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***Abstract*—This paper present offline study on loss optimization in distribution networks using Artificial Bee Colony (ABC) algorithm. The study involves the development of Artificial Bee Colony (ABC) algorithm to implement loss minimization in a distribution system. Loss minimization can be achieved by performing network reconfiguration considering loss minimization as the objective function. The ABC algorithm was tested on 14-bus radial distribution system and was programmed in Matlab 7.0. Results obtained from the experiments indicated that loss minimization has been successfully achieved.**

***Index Terms*— radial distribution, sectionalizing switches, tie switches, employed bee, onlooker bee and scout bee.**

I. Introduction

THE distribution systems deliver power to the customers from a set of distribution substations and there are typically two type of distribution network use in distribution systems, radial and interconnect or mesh network. Radial networks have some advantages over meshed networks such as lower short circuit currents and simpler switching and protecting equipment. On the other hand, the radial structure provides lower overall reliability.

The radial structure of distribution networks is achieved by placing a number of sectionalizing switches in the network (usually referred to as tie switches) used to open the loops that would otherwise exist. These switches, together with the circuit breakers at the beginning of each feeder, are used for reconfiguration of the network when needed. Obviously, the greater the numbers of switches, the greater are the possibilities for reconfiguration and the better are the effects. Generally, network reconfiguration is needed to:

i) Provide service to as many customers as possible following a fault condition, or during planned outages for maintenance purposes.
ii) Reduce system losses, and balance the loads to avoid overload of network elements [l].

There are two types of switches used in radial reconfiguration distribution system; sectionalizing switches (normally closed) and tie switches (normally open). They are designed for both protections, to isolate a fault and configuration management in the system. Under normal operating conditions, feeders are frequently reconfigured by changing the open/closed state of each switch in order to reduce line losses or to avoid the overloading network branches. Since there are many candidate-switching combinations possible in a distribution system, finding the operating network reconfiguration becomes a complicated combinatorial to achieve the distribution system loss optimization.

Distribution system reconfiguration for loss reduction was first proposed by Merlin *et al* [1]. They employed a blend of optimization to determine the minimal-loss operating configuration for the distribution system represented by a spanning tree structure at a specific load condition. Since that, many methods were proposed such as heuristic algorithm, simulated annealing and genetic algorithm. Heuristic algorithm was used to employ a power flow for determining the minimum loss reconfiguration of radial distribution network. Simulated annealing used in solution procedure to search an acceptable non-inferior solution. Genetic algorithm was implemented to look for the minimum loss reconfiguration. Das [10] presents an algorithm based on the heuristic rules and fuzzy multi-objective approach for optimizing network reconfiguration.

In this paper, a new algorithm called artificial bee colony (ABC) algorithm that was proposed for the minimization of a power loss in the distribution system by [13] is studied. The artificial bee colony algorithm is a new metaheuristic approach, proposed by Karaboga [12]. It is inspired by the intelligent foraging behavior of honey bee swarm. The proposed method is tested on 14 buses for radial distribution system.

II. Methadology

A. Formulation for Loss Optimization

The network reconfiguration problem in a distribution system is to find a best configuration of radial network that gives minimum power loss while satisfying certain operating constraints. The objective function for the minimization of power loss is described as:

$$\text{Minimize } f = \min (P_{T,\,Loss}) \qquad \text{-------------------------(1)}$$

where $P_{T,\,Loss}$ is the total real power loss of the system. A set of simplified feeder-line flow formulations is employed. Considering the single-line diagram depicted in Figure 1, the recursive equations (2) to (4) are used to compute the power flow.

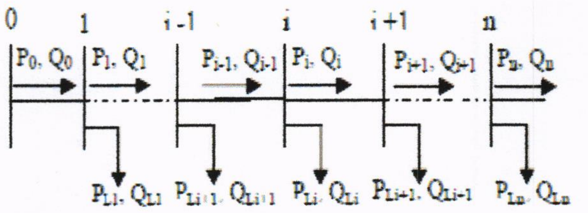

Figure 1 Single-line diagram of a main feeder.

Because of the complexity of the large scale distribution system, network reconfiguration problem is normally assumed as symmetrical system and constant loads. Therefore, the distribution lines are represented as series impedances of the value ($Z_{i,i+1} = R_{i,i+1} + jX_{i,i+1}$)) and load demand as constant and balanced power sinks $S_L = P_L + jQ_L$. The real and reactive power flows at the receiving end of branch i+1, P_{i+1}, and Q_{i+1}, and the voltage magnitude at the receiving end, $|V_{i+1}|$ is expressed by the following set of recursive equations:

$$P_{i+1} = P_i - P_{Li+1} - R_{i,i+1}.\frac{(P_i^2 + Q_i^2)}{|V_i|^2} \qquad \text{-----------(2)}$$

$$Q_{i+1} = Q_i - Q_{Li+1} - X_{i,i+1}.\frac{(P_i^2 + Q_i^2)}{|V_i|^2} \qquad \text{-----------(3)}$$

$$|V_{i+1}|^2 = |V_i|^2 - 2(R_{i,i+1}.P_i + X_{i,i+1}.Q_i) + (R_{i,i+1}^2 + X_{i,i+1}^2).\frac{(P^2 + Q^2)}{|V_i|^2} \qquad \text{----------(4)}$$

Equations (2) – (4) are known as the *Distflow equations*. Hence, if P_o, Q_o, V_o at the first node of the network is known or estimated, then the same quantities at the other nodes can be calculated by applying the above branch equations successively. This procedure is referred to as a *forward update*.

The power loss of the line section connecting between buses *i* and *i+1* is computed as

$$P_{Loss}(i) = R_i.\frac{(P_i^2 + Q_i^2)}{|V_i|^2} \qquad \text{-----------(5)}$$

The total power loss of the feeder *PF, Loss* is determined by summing up the losses of all line sections of the feeder, which is given by

$$P_{TLoss} = \sum_{i=0}^{n-1} P_{Loss}(i) \qquad \text{------------(6)}$$

where the total system power loss *PT, Loss* is the sum of power losses of all feeders in the system.

B. *Overview of Artificial Bee Colony Algorithm (ABC)*

In the ABC algorithm, the colony of artificial bees contains three groups of bees: employed bees, onlookers and scouts. A bee waiting on the dance area for making decision to choose a food source is called an onlooker and a bee going to the food source visited by it previously is named an employed bee. A bee carrying out random search is called a scout. In the ABC algorithm, half of the bee colony comprises employed bee and other half includes the onlooker bees. 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, and for this paper the food source is the total power loss, $P_{T,Loss}$ 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. This nectar information was represented by fitness value in the ABC algorithm. As the nectar amount of a food source increases, the probability of that food source is chosen also increases. 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. The determination of the new food source is carried out by the bees based on the comparison process of food source positions visually.

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 *Pi* of selecting a food source *i* is determined using the following expression:

$$Pi = \frac{fit_i}{\sum_{n=1}^{SN} fit_n} \qquad \text{-------------(7)}$$

where fit_i is the fitness of the solution represented by the food source *i* and *SN* is the total number of food sources.

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 sources *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. A scout bee will search for a new food source randomly. 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 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 random number between [-1, 1] and the difference in values of this parameter for this food source and some other randomly chosen food source. The value Vi of the selected parameter *j* in Vi is determined using the following formula:

$$V_{ij} = X_{ij} + u(X_{ij} - X_{kj}) \qquad \text{----------(8)}$$

where u is a random number between [-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.

The whole process of ABC algorithm can be summarized as follow:

1. In the first step, x_{ij} solution are randomly produced in the range of parameters that which the solution will represent the population.
2. In the second step, for each of employed bee, a new solution is produced by equation (8). After producing v_i, this new solution is compared to x_i and employed bee exploits the better source.
3. In the third step, an onlooker bee chooses a food source with the probability, P_i from equation (7) and produced a food source in selected food source site using equation (8).
4. In the last step, after all onlookers are distributed to the sources, the sources are checked whether need to be abandoned. The employed bee associated with the exhausted source becomes a scout and makes a random search in problem using equation:

$$x_{ij} = x_j^{min} + (x_j^{max} - x_j^{min}) * rand \qquad \text{--------(9)}$$

C. ABC Algorithm for Network Reconfiguration Problem

The proposed artificial bee colony algorithm is summarized as follows:

1. Read the line input data; Initialize MIC (Maximum Iteration Count) and base case as the best solution;
2. Construct initial Bee population (solution) x_{ij} as each bee is formed by the open switches in the configuration and the number of employed bees are equal to onlooker bees;
3. Evaluate fitness value for each employed bee by using the following the formula:

$$fitness = \frac{1}{1 + Power\ Loss}$$

4. Initialize cycle=1;
5. Generate new population (solution) v_{ij} in the neighborhood of x_{ij} for employed bees using equation (8) and evaluate them;
6. Apply the greedy selection process between x_i and v_i;
7. Calculate the probability values P_i for the solutions x_i by means of their fitness values using the equation (7);
8. Produce the new populations v_i for the onlookers from the populations x_i, selected depending on P_i and evaluate them;
9. Apply the greedy selection process for the onlookers between x_i and v_i;
10. Determine the abandoned solution, if exists, and replace it with a new randomly produced solution x_i for the scout using the equation (9).
11. cycle=cycle+1;
12. If cycle<MIC, go to step 5, otherwise go to step 13;
13. Stop.

The flowchart for the ABC algorithm was shown in the Figure 2 below.

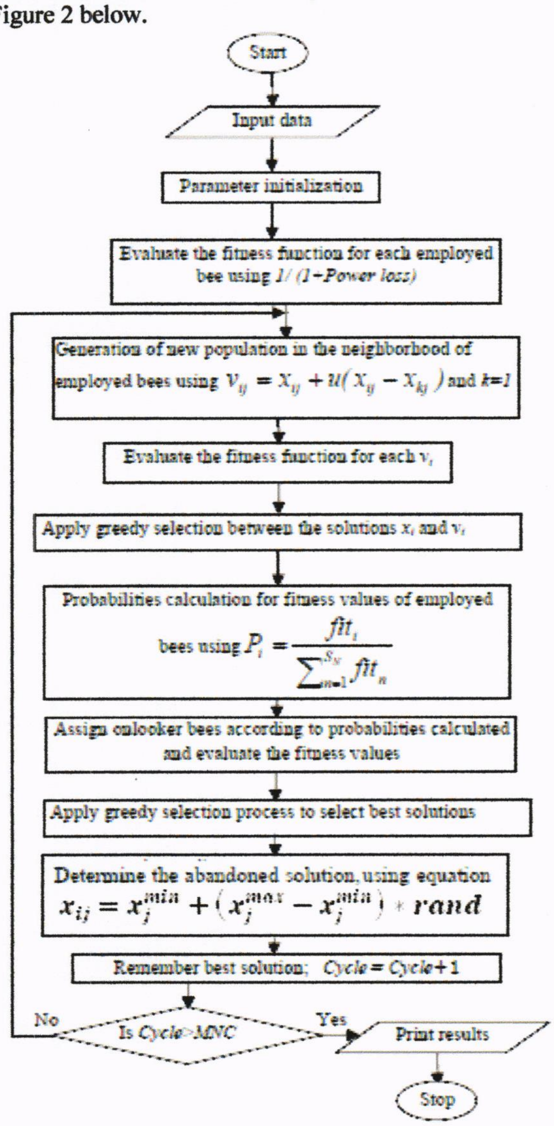

Fig 2: *Flowchart of the proposed algorithm*

D. *ABC Algorithm Implementing in Matlab 7.0*

The proposed method was tested on 14-bus radial distribution systems and results have been obtained to evaluate its effectiveness. For all these systems, the substation voltage is considered as 1.0 p.u. and all the tie and sectionalizing switches are considered as candidate switches for reconfiguration problem. The algorithm of this method was programmed in MATLAB7.0 environment.

14-bus system: The example is a three feeder, 14–bus radial distribution system [11], as shown in fig. 3. The input line and load data of the example system are shown in Table 1. The system consists of 13 sectionalizing switches (normally closed) and three tie switches (normally open). The solid line in fig. 3 represents the sectionalizing switches and a dotted line represents the tie switches. The tie lines of the system are 15, 21 and 26.

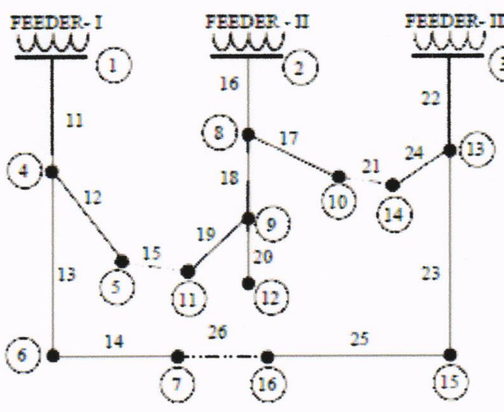

Fig 3: *Three feeder, 14 bus distribution system*

TABLE I INPUT DATA FOR 14-BUS SYSTEM

Bus to bus	Section Resistance (p.u)	Section Reactance (p.u)	End bus real Load (MW)	End bus reactive Load (MVAr)	End bus fixed capacitor (MVAr)
1-4	0.075	0.10	2.0	1.6	1.1
4-5	0.08	0.11	3.0	1.5	1.2
4-6	0.09	0.18	2.0	0.8	
6-7	0.04	0.04	1.5	0.2	
2-8	0.11	0.11	4.0	2.7	
8-9	0.08	0.11	5.0	3.0	1.2
8-10	0.11	0.11	1.0	0.9	
9-11	0.11	0.11	0.6	0.1	0.6
9-12	0.08	0.11	4.5	2.0	3.7
3-13	0.11	0.11	1.0	0.9	
13-14	0.09	0.12	1.0	0.7	1.8
13-15	0.08	0.11	1.0	0.9	
15-16	0.04	0.04	2.1	1.0	1.8
5-11	0.04	0.04			
10-14	0.04	0.04			
7-16	0.12	0.12			

The total active and reactive power loads on the system are 28.7 MW and 16.3 MVAr. The system load is assumed to be constant and base MVA and voltage ratings of the system are selected as 100 MVA and 11 kV. For this test case, the bee colony population size is taken as 30 and the number of employed bees is equal to onlooker bees. The scout bee is taken as 1. For this example maximum iteration count (MIC) is taken as 20. The optimal power loss after reconfiguration is obtained as 47.00 kW.

III. SIMULATION RESULT

TABLE 2: SIMULATION RESULTS OF 14-BUS SYSTEM

Item	Tie switches	Power Loss (kW)	Power loss reduction (%)	Fitness value	Time taken (sec)
Original Configuration	15,21,26	511.4	-	-	-
Proposed ABC	5,8,6	47.00	91	0.9995	0.11s

From the Table 2, it is observed that the optimal power loss obtained by the proposed ABC method is equal to 47.00 kW and occurred at tie switch 5, 8, 6. This minimum power loss occurs at highest fitness value with time taken to complete the simulation in Matlab 7.0 is 0.108s. The result is then compared with original configuration [13] as in Table 2. From the comparison it is observed that the power loss obtain in this paper, 47.00 kW is less than power loss obtain in the original configuration, 511.4 kW. The tie switch obtained (5, 8, 6) also different compared to the original configuration (15, 21, 26). From the power loss obtain, the power loss reduction using proposed ABC algorithm is 91% less than the original configuration.

IV. CONCLUSION

In this paper, a new population based artificial bee colony algorithm (ABC) has been studied to solve the network reconfiguration problem in a radial distribution system. The objective considered in this paper is minimization of real power loss subject to the radial network structure. Simulations are carried on 14 bus systems and the result is compared with the original configuration for the network reconfiguration. From the comparison, the proposed ABC algorithm is able to reduce power loss better than the original configuration. Therefore this paper can be considered successful in achieved its objective that is to reduce power loss in radial network.

This paper demonstrates the capability of artificial bee colony algorithm in solving network reconfiguration problem. Ideas presented in this paper can be applied to many other power system problems also.

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