A Comparison of Ant Colony Optimization Algorithms Applied to Distribution Network Reconfiguration

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***Abstract*— This paper presents a comparative study of three Ant Colony Optimization (ACO) algorithms applied to Distribution Network Reconfiguration Problem. The original ACO algorithm called the Ant System (AS) and two of its variants viz. MAX-MIN Ant System (MMAS) and Ant Colony System (ACS) were used to minimize active power loss in distribution systems. The algorithms were coded in MATLAB and numerical experiments were conducted on two benchmark systems. The results indicate that even though all the three algorithms are capable of solving distribution network reconfiguration problem, ACS is found to perform better for larger systems.**

Keywords— Distribution network reconfiguration, Ant Colony Optimization algorithm, Ant System, Max-Min Ant System, Ant Colony System.

I. Introduction

Distribution Systems consist of many inter-connected radial circuits. By changing the status of tie and sectionalizing switches the configuration of a given distribution system can be changed. The crux of a feeder reconfiguration problem lies in identifying the tie and sectionalizing switches that are to be opened and closed, respectively so as to achieve the maximum possible reduction in losses. Solving this problem is not easy even for a simple distribution network because of large number of switching options. Also, there are multiple constraints that shall not be violated while finding an optimal or near optimal solution to the distribution network reconfiguration problem. During the last few decades, a number of studies employing different methods are reported on distribution network reconfiguration [1- 5], [11-18].

Out of the various algorithms reported to solve the network reconfiguration, one of the latest and the most versatile algorithm is the Ant Colony Optimization (ACO) [6-10],[19, 20]. It is a meta-heuristic, iterative algorithm used to solve different combinatorial optimization problems. In ACO, solution for a problem is obtained by exchanging information through a communication scheme that is similar to the one adopted by real ants.

In the paper, three ant algorithms namely Ant System (AS), Max-Min Ant System (MMAS) and Ant Colony System (ACS) are compared in terms of their ability to solve distribution network reconfiguration problem.

Section II of the paper summarizes the mathematical formulation of the problem. Section III describes the three ant algorithms used in the study. Section IV provides an overview of the results obtained. The discussions and conclusions are presented in Section V.

II. Distribution Network Reconfiguration

Mathematically, distribution system reconfiguration problem is a complex optimization problem. This is because distribution network topology has to be radial and power flow constraints are non-linear in nature.

Many algorithms have been developed to solve the reconfiguration problem. B. Morton and I. M. Y. Mareels [4] proposed an exhaustive, brute-force search method. A. Merlin and H. Back [3] proposed a branch-and-bound type heuristic method to determine the network configuration with minimum losses. The method proposed by S. Civanlar et al. [1] involved a branch-exchange type algorithm. M. E. Baran and F. F. Wu [2] developed search techniques based on the idea of branch exchange for the reconfiguration. D. Shirmohammadi and H. Y. Hong [5] proposed a method which calculates optimal power flow.

In addition to above, several works based on algorithms like genetic algorithm [11], simulated annealing [12], particle swarm optimization method [13] and artificial bee colony algorithm [14] are available in literature.

Objective function for distribution network reconfiguration can be written as follows [17]:

$$Min\,F = Min\left(P_{T,Loss} + \lambda_V . S_{CV}\right) \tag{1}$$

Subject to the constraint:

$$V_{\min} \le |V_i| \le V_{\max} \tag{2}$$

where, $P_{T,Loss}$ is the total real power loss of the system, λ_V is the penalty constant, S_{CV} is the squared sum of the violated voltage constraints, $|V_i|$ is the voltage magnitude of bus i and $V_{\min}, V_{\max}$ are the minimum and maximum bus voltage limits respectively.

Other constraints such as network should be radial and all the nodes should be supplied with power also should be satisfied.

III. Ant Colony Optimization Algorithms

Ant algorithms are adapted from the natural behaviour of ant groups. They identify and bring food to the nest by the help of pheromone trail. The method was first applied to the Travelling Salesman Problem by M. Dorigo and L. M. Gambardella [6]. Later, the method was applied to other optimization problems like vehicle routing problem [19] and quadratic assignment problem [20].

Several variants of Ant algorithms have been proposed over the years [6-10]. General aspects of the original Ant System and the two of its most successful variants: MAX-MIN Ant System and Ant Colony System are given below.

A. Ant System

Mathematical model of Ant System can be explained as follows.

At first, each ant placed on a starting state, will build a full path from the beginning to the end state through repetitive application of state transition rule which is given by [7]:

$$p_k(i,j) = \begin{cases} \dfrac{[\tau(i,j)]^{\alpha}[\eta(i,j)]^{\beta}}{\sum_{m \in J_k(i)}[\tau(i,m)]^{\alpha}[\eta(i,m)]^{\beta}}, & if\ j \in J_k(i) \\ 0, & otherwise \end{cases} \quad (3)$$

Where τ is the pheromone which is deposited on the edge between node i and node j, η is the inverse of the edge distance, $J_k(i)$ is the set of nodes that remain to be visited by ant k positioned on node i and α and β are parameters signifying the importance of trail intensity and visibility respectively.

Once all ants have terminated their tour, the amount of pheromone on edge is modified through offline updating rule which is given by [7]:

$$\tau(i,j) = (1-\rho)\tau(i,j) + \sum_{k=1}^{m} \overset{k}{\Delta\tau_{ij}} \quad (4)$$

$$\overset{k}{\Delta\tau_{ij}} = \begin{cases} 1/L_k, & \text{if ant k used edge (i,j) in its tour} \\ 0, & \text{otherwise} \end{cases} \quad (5)$$

Where ρ is the evaporation rate, m is the number of ants and $\overset{k}{\Delta\tau_{ij}}$ is the pheromone deposited on edge (i,j) by ant k whose has covered a length of L_k.

B. Max-Min Ant System

In this variant of ACO algorithms, only the best ant updates the pheromone trails. Also, the pheromone trails are bound between a specified maximum and minimum values. The offline pheromone update rule is given by [9]:

$$\tau_{ij} = \left[(1-\rho)\tau_{ij} + \Delta\tau_{ij}^{best}\right]_{\tau_{min}}^{\tau_{max}} \quad (6)$$

Where τ_{max} and τ_{min} are the upper and lower values of the pheromone respectively.

C. Ant Colony System

In this algorithm, a local update rule is introduced to update the pheromone deposits. The local pheromone update is performed by all the ants after each construction step. While constructing its tour, an ant modifies the amount of pheromone on the visited path by applying local updating rule which is given by [6]:

$$\tau(i,j) = (1-\rho)\tau(i,j) + \rho\tau_0 \quad (7)$$

Where τ_0 the initial pheromone is level and ρ is a heuristically defined parameter.

Once all ants have terminated their tour, the amount of pheromone on edge is modified again through global updating rule which is given by [6]:

$$\tau(i,j) = (1-\rho)\tau(i,j) + \sigma\delta^{-1} \quad (8)$$

Where δ is the distance of the globally best tour from the beginning of the trail and $\sigma \in [0,1]$ is the pheromone decay parameter.

IV. Simulation Results

Numerical experiments on distribution network reconfiguration were conducted on two benchmark reconfiguration systems (Civanlar system and Baran and Wu system) using the three ACO algorithms explained above. All the three algorithms were coded in MATLAB (version 2010a) and executed on a personal computer with Intel core i3 processor (3.5 GHz) and 4GB RAM. Performance of all the three ACO algorithms for solving the reconfiguration problems in terms of best solution, success rate and CPU time were compared. Each control parameters of various algorithms viz. trail intensity factor (α), visibility factor (β), pheromone trail decay co-efficient (ρ), heuristic parameter (q), number of ants, (n) and number of iterations (N) were assigned same values:

A. Experiment 1

The first experiment was conducted on a three feeder system known as Civanlar system [1]. The system is shown in Figure 1. The system consists of three feeders which are connected to a root node, thirteen sectionalizing switches and three tie switches. Open switches are represented by dotted lines, and closed switches by solid lines.

The system load is taken constant. The base values of power and voltage are 100MVA and 23kV. The original system has tie switches numbered as 15, 21 and 26 and the power loss is 511.4kW. Power flow calculations for the study is done using a set of non-iterative equations called Distflow branch equations [2]. The control parameters used for all the algorithms for reconfiguration of Civanlar system are given in Table I.

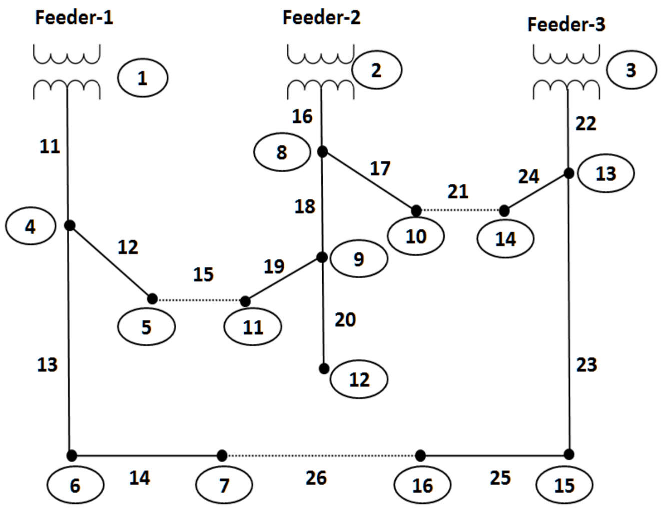

Fig. 1. *Civanlar System*

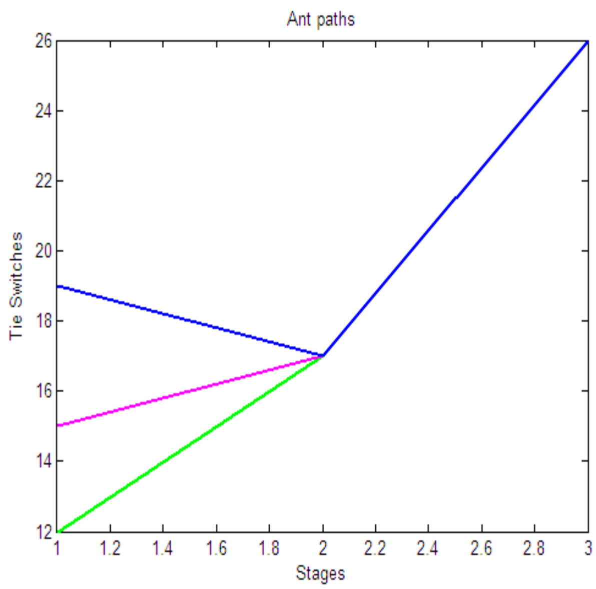

Fig. 2. *Ant paths for reconfiguration of Civanlar system*

TABLE I. CONTROL PARAMETERS USED

Parameter	AS	MMAS	ACS
Trail intensity factor, α	1	1	1
Visibility factor, β	5	5	5
Pheromone trail decay coefficient, ρ	0.5	0.5	0.5
Heuristic parameter, q	10	10	10
Number of ants, n	3	3	3
Number of iterations, N	100	100	100
Pheromone decay coefficient, ϕ	-	-	0.5

It was observed that all the three ACO algorithms could effectively find the best solution for the reconfiguration problem of Civanlar system. Figure 2 shows a typical plot of ant paths corresponding to last iteration of all the three algorithms.

Summary of the results obtained for the reconfiguration carried out for Civanlar system using Ant Search algorithm, Max-Min Ant Search algorithm and Ant Colony Search algorithm is given in Table II.

The results show that out of the three algorithms used for the reconfiguration of Civanlar system, Max-Min Ant System produced best results with respect to rate of success and CPU time used.

TABLE II. SUMMARY OF RESULTS

Specifications	AS	MMAS	ACS
Tie-switches	19,17,26	19,17,26	19,17,26
Power Loss (kW)	438.82	438.82	438.82
Average power loss (kW)	561.25	522.60	543.58
CPU time (s)	0.2964	0.3021	0.3089
Average CPU time (s)	0.2954	0.283	0.3022
Success percentage	94	98	95

B. Experiment 2

The second experiment was conducted on a 33 bus system known as Baran and Wu system [2]. The system is shown in Figure 3. The system has 33 buses, 37 branches and 5 tie-lines. Original system consists of tie switches numbered 33, 34, 35, 36 and 37 and the base values of the system are 100MVA and 12.66kV.

The control parameters used for all the three algorithms for reconfiguration of Baran and Wu system are given in Table III.

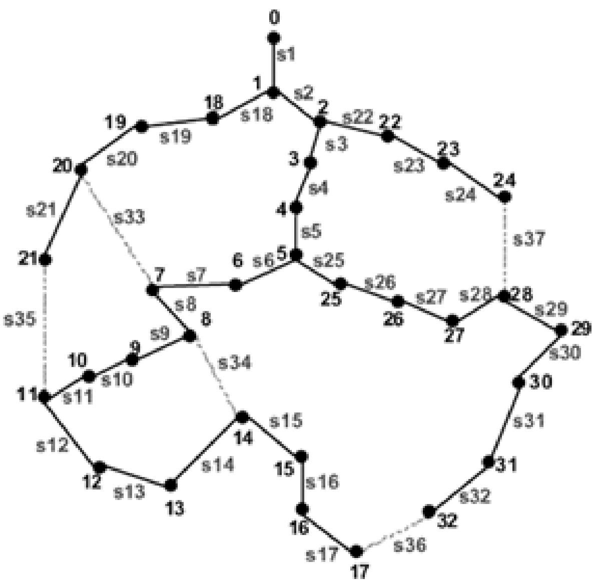

Fig. 3. *Baran and Wu system*

TABLE III. CONTROL PARAMETERS USED

Parameter	AS	MMAS	ACS
Trail intensity factor, α	1	1	1
Visibility factor, β	8	8	8
Pheromone trail decay coefficient, ρ	0.5	0.5	0.5
Heuristic parameter, q	10	10	10
Number of ants, n	5	5	5
Number of iterations, N	100	100	100
Pheromone decay coefficient, ϕ	-	-	0.4

TABLE IV. SUMMARY OF RESULTS

Specification	AS	MMAS	ACS
Tie-switches	7,37,32,14,9	7,37,32,14,9	7,37,32,14,9
Power Loss (kW)	141.81	141.81	141.81
Average power loss (kW)	176.71	172.54	169.23
CPU time (s)	1.95	1.87	1.82
Average CPU time (s)	2.05	2.01	1.93
Success percentage	88	91	94

Summary of the results obtained for the reconfiguration carried out for Baran and Wu system using Ant Search algorithm, Max-Min Ant Search algorithm and Ant Colony Search algorithm is given in Table IV. Total loss reduction achieved due to network reconfiguration of the system is 19.75%.

Experimental results showed that out of the three algorithms used for the reconfiguration of Baran and Wu system, Ant Colony System provides best results with respect to rate of success and CPU time used.

V. CONCLUSIONS

Reconfiguration of two benchmark distribution systems was carried out using Ant Search, Max-Min Ant System and Ant Colony System. To compare the performance, same parameter values were used for all the three algorithms. Even though all the three algorithms were found to be capable of solving both the benchmark systems, it emerged that ACS yielded optimal solution more number of times compared to others for the larger distribution system viz. Baran and Wu system whereas MMAS performed marginally better for the relatively smaller Civanlar system.

In Max-Min Ant System, only the global best solution of each iteration is updated. Therefore only good solutions are reinforced. This makes the search more focused. Upper and lower bounds on pheromone trails in this method avoid stagnation of the search. For small systems these rules of MMAS assures global optimal solution within lesser number of iterations.

Local updating rule of Ant Colony Search algorithm ensures search diversification of the ants in a given iteration. This makes the algorithm more suitable for large systems because for such systems an extensive search of possible solutions should be done before converging to a common solution.

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