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A New Ant Colony-Based Method for Optimal Capacitor Placement and Sizing in Distribution Systems

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Abstract: In this study, the Ant Colony Optimization (ACO) method is applied to solve the optimal capacitor placement problem in electric distribution systems. An effective and simple power flow method used with the ACO is tested on the 9-bus test system. The obtained capacitor placement results using ACO are compared with other optimization methods.

Key words: Ant colony optimization, capacitor placement, sweep load flow

INTRODUCTION

Shunt capacitors in distribution networks are used for various purposes, namely, power loss reduction, voltage profile improvement along feeders and increasing maximum transmitted power in cables and transformers. For power loss reduction, shunt capacitors which are widely installed in power distribution networks are used by compensating the reactive power. However, installation of shunt capacitors in distribution networks requires consideration on the appropriate location and size of these capacitors. Thus, capacitor placement is becoming important so as to maximize the saving due to the loss reduction through the proper installation of shunt capacitors while minimizing shunt capacitor costs.

Many techniques have been developed for solving the capacitor placement problem in which these techniques can be classified in the categories; analytical, numerical programming, heuristic and artificial intelligence-based techniques (Ng and Salama, 2000). Das (2002) applied genetic algorithm to find the optimum capacitor locations and sizes of fixed and switched capacitors at various load levels. Fuzzy logic (Masoum, 2004) and particle swarm optimization (Parkash and Sydulu, 2007) have been applied to solve the capacitor placement problem by optimally locate and size the capacitors in radial distribution systems. The problem was classified as a nonlinear integer optimization problem with both potential capacitor location and size being discrete.

Another popular evolutionary search method is the ant colony which begins to search among a population in parallel ways and it measures the competence of each individual population based on a cost function until convergence. Annaluru (2004) applied the ant colony algorithm for solving the capacitor placement and sizing problem in which the Newton-Raphson power flow method is used to calculate the cost function. However, it is well known that the Newton-Raphson power flow is a very time consuming method.

In this study, we solve the capacitor placement problem by using the combined ant colony algorithm and the backward/forward sweep power flow method. This power flow method is suitable for radial distribution systems and is effective in speeding up the computing time without difficulties in getting converged solutions. The proposed algorithm has been tested on the IEEE 9-bus system and the results are compared with other optimization methods.

MATERIALS AND METHODS

Backward/ forward sweep power flow: One of the necessary calculations for planning and operation of power systems is power flow which is basically solving a set of non-linear equations. For radial distribution networks, a simpler power flow method called as the backward/forward sweep power flow (Teng, 2000) is used because the method does not require the formation of the Jacobian matrix. In this method, the relationship between the Bus current Injections and the Branch Currents is represented by the matrix [BIBC] and the relationship between the Branch Currents and Bus Voltages is represented by the matrix [BCBV]. The above mentioned matrices [BIBC] and [BCBV] are then multiplied to obtain the relationship between the voltage deviation, [V] and the bus current injections [I], which is given by [DLF].

$$\left[\Delta V\right] = [BCBV][B] = [BCBV][BIBC][I] = [DLF][I] \quad (1)$$

The backward/forward sweep power flow method at the k iteration considers equations:

$$I_i^k = \left(\frac{P_i + jQ_i}{V_i^k}\right)^* \quad (2)$$

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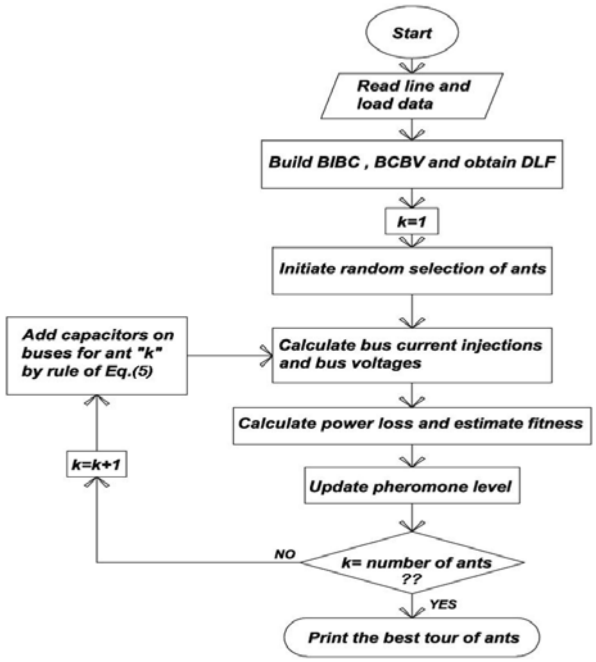

Fig. 1: The Solution procedure for the capacitor placement problem using ACO

$$\left[\Delta V^{k+1}\right]=\left[DLF\right]\left[I^{k}\right] \tag{3}$$

The total power loss is given by:

$$p_{loss}=\sum_{i=1}^{n}\frac{R_i\cdot\left(P_{\Sigma,i}^2+Q_{\Sigma,i}^2\right)}{\left|V_i^2\right|} \tag{4}$$

where R_i is resistance of the branch i; $P_{\Sigma,i}$ is active power at bus i ; $Q_{\Sigma,i}$ is reactive power at bus i and V_i is voltage at bus i .

Ant colony optimization for capacitor placement: The ant algorithm has been created inspired by the behavior of ants in nature in which they can find the shortest path from house to food. Biologists have found that ants have the ability of pheromone trails in which they can communicate with each other and transfer information of path. Initially, a group of ants do the initial random searches and make constant density trails in their movement time. As a result, the density of trails in shorter paths gradually increase and this would be helpful for the next searches. These trails lead ants towards whatever shorter routes.

In the ant colony algorithm, the move probability distribution defines probabilities $P_{ij}^{k}(t)$ to be equal to 0 for all moves which are infeasible as in the tabu list of ant k (a list containing all moves which are infeasible for ants k starting from state i), otherwise, the probability is computed using:

$$P_{ij}^{k}(t)=\begin{cases}\dfrac{T_{ij}^{a}\cdot\eta_{ij}^{b}}{\sum\limits_{il\notin tabu_k}T_{il}^{a}\cdot\eta_{il}^{\beta}} & if\,(ij)\notin tabu_k\\ 0 & Otherwise\end{cases} \tag{5}$$

where η_{ij} is the attractiveness of the move, T_{ij} is the trail level of the move, α and ß are user defined parameters ($0\le\alpha$, $ß\le 1$).

The algorithm updates the density of trails after random initializing and sending the first group of ants. The updating equation of trails is given by:

$$T_{ij}=(1-\rho)T_{ij}+\sum_{k=1}^{m}\Delta T_{ij}^{k} \tag{6}$$

where m is the number of ants and (ρ, $0\le\rho\le 1$) is a user-defined parameter called as evaporation coefficient, and $\Delta T_{i,j}^{k}$ represents the sum of the contributions of all ants that used move (ij) to construct their solution. $\Delta T_{i,j}^{k}$ is the amount of trail laid on edge (ij) by ant k, which can be computed by:

$$\Delta T_{ij}^{k}=\begin{cases}\dfrac{Q}{F_k} & if\ ant\ use(ij)\ in\ its\ tour\\ 0 & otherwise\end{cases} \tag{7}$$

Table 1: Load data

Bus#	1	2	3	4	5	6	7 8 9
P(kW)	1840	980	1790	1598	1610	780	1150 980 1640
Q(kvar)	460	340	446	1840	600	110	60 130 200

Table 2: Feeder data at 60Hz

Bus# j	0	1	2	3		4	5	6	7	8
Bus# j+1	1	2	3	4		5	6	7	8	9
Rj,j+1(S)	0.123	30.014	0.7463	0.6984	1.9831	0.9053	2.0552	4.7953	5.3434	
Xj,j+1(S)	0.412	70.605	1.205	0.6084	1.7276	0.7886	1.164	2.716	3.0264	

Table 3: Yearly cost of fixed capacitors

I	1	2	3	4	5	6	7	8	9
Capacitor size (kvar)	150	300	450	600 750 900 1050 1200 1350					
Capacitor cost($/kvar)	0.5	0.35	0.253	0.22	0.276	0.183	0.228	0.17	0.207
I	10	11	12	13	14	15	16	17	18
Capacitor size (kvar)	1500	1650	1800	1950	2100	2250	2400	2550	2700
Capacitor cost($/kvar)	0.2	0.19	0.187	0.21	0.176	0.197	0.17	0.19	0.187
I	19	20 21	22	23	24	25	26	27	
Capacitor size (kvar)	2850	3000	3150	3300	3450	3600	3750	3900	4050
Capacitor cost($/kvar)	0.18	0.18	0.195	0.17	0.188	0.17	0.183	0.18	0.179

Table 4: Comparisons of capacitor placement results

Bus	Before capacitor placement	Concept of ensuring losses reduction	PSO	Fuzzy logic	Fuzzy reasoning	Proposed ACO
1	-	0	0	0	0	1800
2	-	3000	0	3600	0	1650
3	-	0	0	0	1050	1200
4	-	2850	1182	4050	1050	1800
5	-	1200	1174	1650	1950	1200
6	-	300	0	0	0	450
7	-	150	0	0	0	0
8	-	150	264	600	0	450
9	-	450	566	0	900	450
Power loss (kW)	783.8	684	696.21	686	704.26	678.73
Capacitor cost ($/year)	-	1149.1	1309.1	1152.5	1191.1	1741.2
Total cost ($/year)	131,675	116,111	118,582	117,035`	119,508	115,768

where Q is a constant parameter and F_k is the objective function produced by the kth ant.

In applying the ant algorithm for solving the capacitor placement problem, the objective function is for finding the location and size of shunt capacitors in a radial distribution system so as to maximize the saving due to the power loss reduction. To solve the optimal capacitor placement problem, we consider:

$$F_k = \text{Minimize}\{\text{Year power loss cost} + \text{Yearly capacitor cost}\} \quad (8)$$

The best capacitor placement at the buses is found by the Ant Colony Optimization (ACO) in which the best

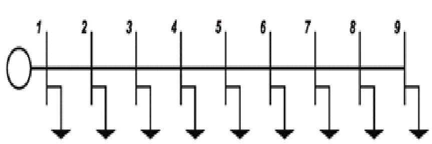

Fig. 2: Nine bus feeder

tour leads to a maximum power loss reduction. Here, the backward/forward sweep power flow is applied for computing the power loss. The flowchart shown in Fig. 1 describes the procedure involved in solving the capacitor placement problem using the ACO.

RESULTS AND DISCUSSION

The performance of the ACO in solving the capacitor placement problem is validated on the 9-bus test system shown in Fig. 2. The load data and the feeder data are as shown in Table 1 and 2, respectively. In this study, as the number of buses is nine, the ants should travel between the capacitors and find the optimum placement of the fix capacitors at the buses. The details of the sizes and costs of the capacitors are tabulated as given in Table 3. The space between the buses and the capacitor choices is calculated by using $Q_C = 150\times i^{\ (kvar)}$, i = 0, 1, 2… 27 and the results are as shown in Fig. 3.

The capacitor placement results in terms of capacitor sizes, capacitor locations, power loss and total costs using the ACO method are compared with other methods using

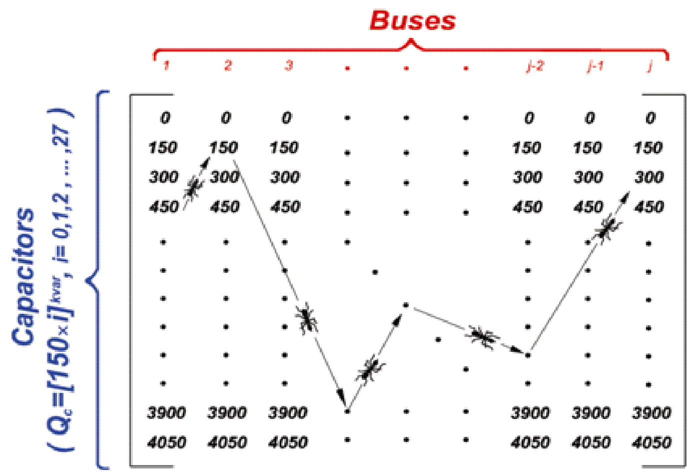

Fig. 3: Capacitor placement space using ACO

concept of Ensuring Losses Reduction (Hamada, 2008) , PSO (Parkash and Sydulu, 2007), fuzzy logic (Mekhamer, 2003) and fuzzy reasoning (Ching-Tsong, 1996) as shown in Table 4. From the results, it can be seen that the optimal capacitor locations identified by the proposed ACO method are greater than the other methods. However, the power loss and total cost is greatly reduced by the ACO method as compared to the other optimization methods.

CONCLUSION

The application of ACO for determining the optimal location and size of shunt capacitors in a distribution network has been presented. The backward/forward sweep power flow is also used to obtain faster power flow solutions. The proposed ACO has been validated on the 9 bus radial distribution system and the obtained results showed that the ACO method gives greater reduction in power loss and total costs compared to the other optimization methods.

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