Capacitor Placement in Distribution Networks Using Ant Colony Algorithm

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Abstract:- This paper presents a new method for determining capacitor placement in distribution networks. The capacitor placement problem consist of finding places to install capacitor bank in an electrical distribution network aiming to reduce losses due to the compensation of the reactive component of power flow. The capacitor placement is hard to solve in sense of global optimization due to the high non linear and mixed integer problem. To solve the problem efficiently, this paper focuses on ant colony algorithm. The approach is multilevel. Two seperate tables of pheromones are maintained by the algorithm. Ants generate solution stochastically, based on these pheromone tables. The pheromone tables are updated priodically, so that pheromone accure more along better solutions. We conclude that the proposed approach is an effective approach for optimally placing capacitors in a distribution network.

Keyword: capacitor placement, distribution networks, ant colony system, optimization

1. Introduction

Capacitors are often installed in distribution network for reactive power compensation to carry out power and energy loss reduction, voltage regulation, system security improvement and system capacity release. Economic benefits of the capacitor depends mainly on where and how many capacities of the capacitor are installed and proper control schemes of the capacitors at different load levels in the distribution network [1].

The problem of capacitor placement in a distribution network consists of finding sizes, location and the number of capacitors that have to be placed on the network. This is one of the combinational optimization problems with the size of search space is being equal $(k+1)^n$, where *n* is the number of buses on distribution network and *k* is the number of possible capacitor sizes that can be placed on the network. This problem has traditionally been solved using mathematical non linear and mixed integer programming techniques. A capacitor placement techniques can be found in [2]. Among various approaches, the metaheuristics play a relevant role, since exact optimization methods are not suitable for tacking real world instances. Focusing only on metaheuristic methods, [3-6] propose different methods for capacitor placement problem.

This paper presents a new approach base on ant colony system (ACS). Ant colony optimization, which is based on the foraging behavior of ants, has been successfully employed to solve many classic combinatorial optimization problems like the travelling salesman problem, quadratic assignment problem and the network routing problem[7-8]. Given its efficiency in solving the discrete optimization problems it can be very helpful in solving the problem of optimal placement of capacitors, which can be modeled as a discrete problem. In this paper present a methodology for employing the ant colony optimization to the capacitor selection problem. We assume that the system is a balanced three phase distribution network. The next section of the paper discucc the ant colony algorithm, formulation of the capacitor placement problem and how the ant colony optimization technique can be employed to solve it. This method was tested on a practical radial distribution network with **22** buses and the results have been presented.

2. Basic Concepts Of ACS Algorithm

This main concepts and procedures of ACS are introduced in this section. ACS simulates the behavior of real ants [7-9]. Real ants are able to find the shortest path between a food source and their home colony. They also have the ability to adapt the enviroment changes, for example, finding a new shortest path once the old one is no longer feasible due to a new obstacle. The studies of real ants reveal that they communicate via pheromones. Ants deposits a certain amount of pheromone when it walks. An ant tends to choose a path positively correlated trail evaporates over time, i.e., it looses intensity if other ants lay down no more pheromone. If many ants choose a certain path and lay down pheromones, the intensity of the trail increases and thus this trail attracts more and more ants.The process can easily be illustrated by Fig. 1. Fig.1(a) shows that ants are moving in a straight line, which connects a food source and their home colony. Once an obstacle appears in the straight line as shown in Fig. 1(b), the enviroment changes and the ants that are just in the front cannot continue following the pheromone trail. Therefore, those ants have same probability to choose the path to point C or D. Later on, those ants choose the shorter path around the obstacle will move faster than ants choose the longer path. The pheromones on the shorter path will be reconstructed more rapidly and this will cause more ants to same path due to the positive feedback.

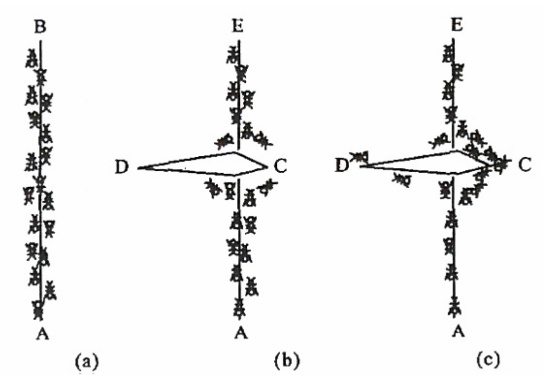

Fig1. An Example of ACS

The full procedures of the ACS algorithm can be summarized as:

1. Initialize the ACS-based optimization problem. Construct searching space including the states and stages of the optimization problem and set the ant number and the parameters of the ACS algorithm.
2. Find the paths for the ant dispatch. Each ant choose the states to complete a tour according to a probabilistic sate transition rule. Ants prefer to move to states, which are connected by shorter edges with a high amount of pheromone. Once all ants have finished their tour, some fitness functions of the optimization problem can be used to evaluate the performance of the ants.
3. Update the pheromones of edges between each stage. The pheromone trail of each edge will evaporate over time, i.e., it looses intensity if no more pheromone is laid down by other ants. For those edges that ants traveled in this iteration, their pheromone intensity can be updated by the pheromone-updating rule. Global and local pheromone updating rules are generally to update the pheromone trail.
4. Define the convergence criteria of the problem. This process is iterated until the tour counter reaches the maximum pre-defined number of iterations or all ants make the same tours.

The full procedure is problem-dependent; it is difficult to find a single searching space, configuration, consideration and parameters of ACS algorithm that can satisfy every optimization problem. It needs to take the specific factors of each optimization problem into account to design a good ACS algorithm.

3. Problem Formulation

The mathematical model of the optimal capacitor placement of distribution systems can be expressed as follows:

$$\min COST \qquad (1)$$

subject to

$$V_{\min} \le |V_i| \le V_{\max} \qquad (2)$$

where $|V_i|$ is the voltage magnitude of bus *i*, and $V_{\min}$ and $V_{\max}$ are the minimum and maximum voltage limits, respectively. In this study, voltage limits are ±5 volts.

The objective function in (1) is an overall cost relating to power loss and capacitor placement. The voltage magnitude at each bus must be maintained between its minimum and maximum voltage limits. To avoid the complex iteration process for power flow analysis, a set of simplified feeder-line flow formulation is applied. Considering the single-line diagram depicted in Fig. 2, the following set of recursive equations is used for power flow computation [10]:

$$P_{i+1} = P_i - P_{Li+1} - R_{i,i+1}.\frac{\left(P_i^2 + Q_i^2\right)}{\left|V_i\right|^2} \tag{3}$$

$$Q_{i+1} = Q_i - Q_{Li+1} - X_{i,i+1}.\frac{\left(P_i^2 + Q_i^2\right)}{\left|V_i\right|^2} \tag{4}$$

$$\left|V_{i+1}\right|^2 = \left|V_i\right|^2 - 2\left(R_{i,i+1}.P_i + X_{i,i+1}.Q_i\right) + \left(R_{i,i+1}^2 + X_{i,i+1}^2\right)\frac{\left(P_i^2 + Q_i^2\right)}{\left|V_i\right|^2} \tag{5}$$

where P_i and Q_i are the real and reactive powers flowing out of bus *i*, and P_{Li} and Q_{Li} are the real and reactive load powers at bus *i*. The resistance and reactance of the line section between buses *i* and *i+1* are denoted as R_{i+1} and X_{i+1}, respectively.

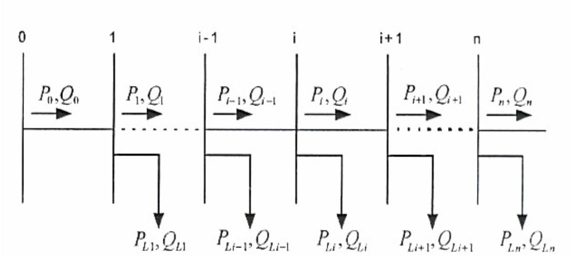

Fig 2. Single line diagram of a main feeder

The power loss of the line section connecting buses *i* and *i+1* may be computed as:

$$P_{Loss}\left(i, i+1\right) = R_{i,i+1}.\frac{\left(P_i^2 + Q_i^2\right)}{\left|V_i\right|^2} \tag{6}$$

The total power loss of the feeder $P_{T,Loss}$ may then be determined by summing up the losses of all line section of the feeder, which is given by

$$P_{T,Loss} = \sum_{i=0}^{n-1} P_{Loss}\left(i, i+1\right) \tag{7}$$

Considering the real-word capacitors, there exits a fine number of standard sizes Q_0^C. Beside, the cost per kvar varies from one size to another.

In general, capacitors of larger size have lower unit prices. The available capacitor size is usually limited to:

$$Q_{\max}^C = LQ_0^C \tag{8}$$

where L is an integer. Therefore, for each installation location, there are L capacitor size $\left\{ Q_0^C, 2Q_0^C, ..., LQ_0^C \right\}$ available. In this study, 4 sizes of capacitors (*5,10,15,25 kVar at 380 volt*) are used. Given the annual unit capacitor installation cost for each compensated bus, the total cost due to capacitor placement and power loss change is writen as

$$COST = K_P P_{T,Loss} + \sum_{i=1}^{n} K_i^C Q_i^C \tag{9}$$

where K_P is the equivalent annual cost per unit of power loss in $Rial/(kW - year)$, and *Rial* is a fictional monetary unit. The constant K_i is the annual unit capacitor installation cost. And $i = 1,2,...,n$ are the indices of buses selected for compensation. The bus reactive compensation power is limited to

$$Q_i^C \le \sum_{i=1}^{n} Q_{Li} \tag{10}$$

where Q_i^C is the reactive power compensated at bus *i*.

4. Numerical Examples

The proposed ant colony algorithm optimization approach has been implemented in MATLAB and run on a pentium IV, processor. The test system is a **22** bus radial distribution network as shown in figure 3. For the network and load data one is referred to Table 1. The program uses the based on network topology load flow method to calculate the cost function given in (1).

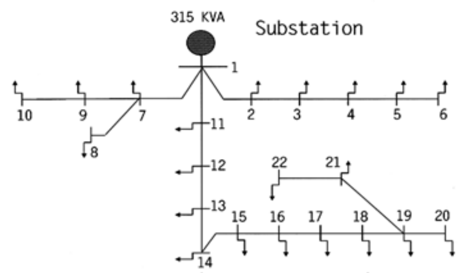

Figure3. single line diagram of test network

After running the program, Tabel 2 shows the placement of capacitor at the buses, total cureent and total power losses in Genetic Algorithm (GA), Complex Genetic Algorithm and Tabu Search (GA-TS) and ACS algorithm. Total current and total power losses at network whitout capacitor and the ideal network (reactive power at the loads = 0) are 432.82 A, 12963 watt and 399.54 A, 11069 watt respectively .

In this study for the example network and with considering of the cost for the planning study *10* years long and interest rate *15%*, inflation rate *15%*, *kWh.cost = 120* Rials (0.015 $), the reduction cost of investment cost of losses for *3* years was equal to cost of investments and the fitness will be *14120000* Rials (1765 $) for *10* years period.

power		Impedance of Section	Number of Customer		Bus Number
kW	*kVar*		Single	Three	
0	0	…	0	0	1
2.7	0.9	0.016+j0.039	1	0	2
2.7	0.9	0.015+j0.04	5	1	3
7.2	2.7	0.015+j0.038	5	1	4
16.2	6.3	0.017+j0.041	2	0	5
58.5	27	0.017+j0.041	3	0	6
7.2	2.7	0.015+j0.039	2	0	7
18.9	8.1	0.013+j0.037	4	0	8
7.2	2.7	0.014+j0.04	4	1	9
24.3	10.8	0.017+j0.042	1	0	10
0	0	0.015+j0.039	3	1	11
12.6	5.4	0.016+j0.041	1	4	12
18	7.2	0.016+j0.041	1	1	13
5.4	1.8	0.015+j0.038	1	0	14
8.1	3.6	0.015+j0.038	1	0	15
5.4	1.8	0.016+j0.041	1	1	16
10.8	4.5	0.013+j0.044	1	3	17
15.3	6.3	0.015+j0.039	10	7	18
2.7	0.9	0.012+j0.035	1	1	19
12.6	4.5	0.014+j0.039	2	3	20
20.7	9	0.015+j0.041	1	1	21
7.2	2.7	0.016+j0.041	9	0	22

Table1. Specification of test network

Bus Number	Capacitor (*kVar*)	Bus Number	Capacitor *(kVar)*	Bus Number	Capacitor (*kVar*)
5	10	5	10	5	10
6	25	6	25	6	25
8	10	9	15	9	15
10	15	13	10	13	15
17	15	17	15	17	15
21	15	21	15	21	15
22	5	-	-	-	-
Total Current=408.6578 (A)		Total Current=400.6455 (A)		Total Current=399.9976 (A)	
Power Losses=11169 (watt)		Power Losses=11127(watt)		Power Losses=11108(watt)	

Table 2. Capacitor placement results

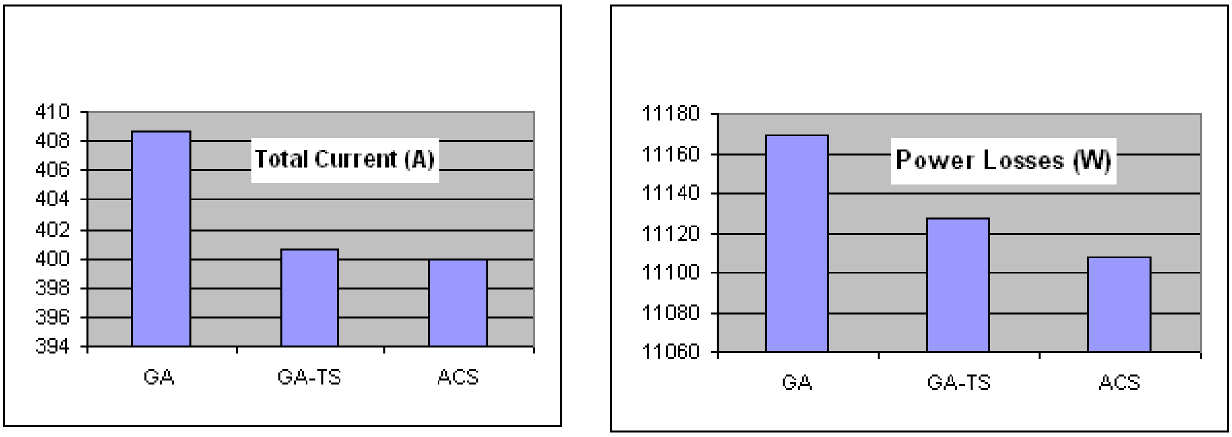

Figure4. Comparsion beetwen three method

5. Conclusion

In this paper, implementation of GA, GA-TS and ACS to the optimal placement of capacitor bank has been illustrated. The proposed an ant colony approach to detemine optimal placement of capacitors in a real 22 bues radial distribution network. The result showed the ACS is a proper optimization method for optimal placement of capacitors bank in distribution network. The economic study showed the investments costs will be compensated in a few 3 years by reduction costs of losses. The approach can be applied to other practical problems requiring complex decision making as well.

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