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OPTIMAL PLACEMENT OF DISTRIBUTED GENERATION AND CAPACITOR IN DISTRIBUTION NETWORKS BY ANT COLONY ALGORITHM

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Abstract- In this paper optimum size and location of capacitors and distributed generations (DGs) are determined simultaneously in a radial distribution network. The objective function includes power losses reduction and voltage profile improvement using ant colony algorithm. Allocation capacitors and of DGs should be carefully determined with the consideration of different planning incentives. It shows the importance of installing the exact amount of capacitors and of DGs in the best suitable location. Studies also show that if the capacitors and of DGs are connected at non-optimal locations or have non-optimal sizes, the system losses will increase. The proposed method is tested for IEEE 33-bus system, by connecting suitable size of DG, capacitor, and DG and capacitor simultaneously at the optimal location of the system. The results show a considerable reduction in the total power loss in the system and improved voltage profiles of all the buses.

Keywords: DG, Capacitor, Ant Colony Algorithm, Loss Reduction, Voltage Profile.

I. INTRODUCTION

Due to the low voltage level and high current in distribution networks, the largest power loss portion among the 3 power system sections, which are generation, transmission, and distribution, belongs to the distribution section, such that the line losses at the distribution level constitute about 5%-13% of the total power generation [1].

Hence, many efforts have been made to decrease the losses in distribution networks. The capacitor placement and the usage of distributed generation (DG) resources are among those efforts to mitigate this problem.

In current years, a lot of work has already been done in the electric power system infrastructure and market related to it by using distribution generation. Distributed generation, is usually defined as a small-scale power generation facility that is usually connected or installed to the distribution system. While on the other hand to reduce the cost of service, the DGs usually use different modular technologies which are located around a utility's service area. Distributed generation is a technique, which minimizes the amount of power loss in transmission lines by generating the power very close to load centre.

In present times, use of DG systems in large amounts in the different power distribution systems have become very popular and is growing on with fast speed [2]. Some of the main advantages while installing DGs in distribution level are peak load saving enhanced system security and reliability, improved voltage stability, grid strengthening, reduction in the on-peak operating cost, reduction in network loss etc. [3, 4].

DGs are applied in the different power distribution systems because of energy efficiency or rational use of energy, diversification of energy sources, availability of modular generating plant, ease of finding locations for smaller generators, shorter construction time and lower capital costs comparatively for smaller plants, and its proximity of the generation plant to heavy loads, which reduces the transmission costs [5].

Many technologies are used for DG sources such as photo voltaic cells, wind generation, combustion engines, and fuel cells etc. [6, 7]. Usually, DGs are attached with the already existing distribution system and lots of studies are performed to find out the best location and size of DGs to produce highest benefits [8, 9, 23 and 24]. The different characteristics that are considered to identify an optimal DG location and size are the minimization of transmission loss, maximization of supply reliability, maximization of profit of the distribution companies etc. [10].

Due to wide-ranging costs, the DGs are to be allocated properly with best size to enhance the performance of the system in order to minimize the loss in the system and to improve different voltage profiles, while maintaining the stability of the system [11]. The effect of placing a DG on network indices will be different based upon its type and location and load at the connection point [12]. There are many varieties of potential benefits to DG systems both to the consumer and the electrical supplier that allow for both greater electrical flexibility and energy security [13].

Shunt capacitors have been commonly employed to locally compensate for the reactive power in the network and, in consequence, reduce the power loss in the lines and improve the voltage profile. Optimal capacitor placement and sizing was applied to minimize the power loss in many previous researches, such as in [14-17]. In [18], capacitor placement was applied as a multiobjective problem to reduce the annual cost sum of the power loss and the capacitors, as well as to improve the voltage profile. Moreover, in [19], it was shown that shunt capacitors can enhance the system reliability as lines redundant in distribution networks. Therefore, capacitors are applied as an effective economic tool to improve the network performance by providing appropriate placement.

In this paper, the ant colony algorithm is applied to determine the optimal location and size of DGs and capacitors for power losses reduction and voltage profile improvement.

II. ANT COLONY ALGORITHM

The ant colony algorithm (ACO) imitate of real ants. As is well known, real ants are capable of finding the shortest path from food sources to the nest using visual cues. Also, they are capable of adapting to changes in the environment, for example, finding a new shortest path once the old one is no longer feasible due to a new obstacle.

Moreover, the ants could manage to establish shortest paths through the medium that is called "pheromone". The pheromone is the material deposited by the ants, which serves as critical communication information among ants, thereby guiding the determination of the next movement. Ant trial that is rich of pheromone will thus become the goal path. The process is illustrated in Figure 1-a, the ants are moving from food source *A* to the nest *B* on a straight line. Once an obstacle appears as shown in Figure 1-b, the path is cut off.

The ants will not be able to follow the original trial in their movements. Under this situation, they have the same probability to turn right or left. Figure 1-c depicts that the shorter path will collect larger amount of pheromone than the longer path. Hence, more ants will be increasingly guided to move on the shorter path. Due to this autocatalytic process, very soon all ants will choose the shorter path.

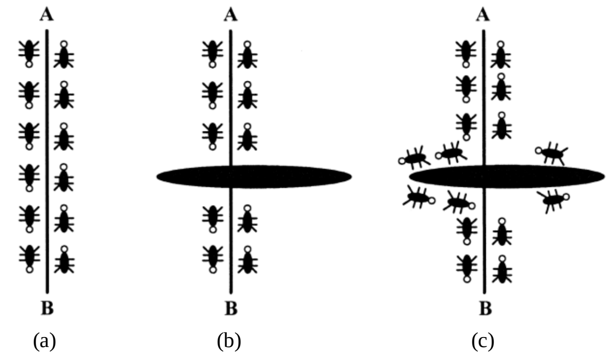

Figure 1. Behavior of ants to find optimal path [21]

As illustrated in Figure 1, by the guidance of the pheromone intensity, the ants select preferable path. Finally, the favorite path rich of pheromone become the best tour, the solution to the problem. At first, each ant is placed on a starting state. Each will build a full path, from the beginning to the end state, through the repetitive application of state transition rule. While constructing its tour, an ant also modifies the amount of pheromone on the visited path by applying the local updating rule. Once all ants have terminated their amount of pheromone on edge is modified again through the global updating rule. In other words, the pheromone-updating rules are designed so that they tend to give more pheromone to paths which should be visited by ants. In the following, the state transition rule, the local updating rule, and the global updating rule are briefly introduced [20, 21].

A. State Transition Rule

The state rule used by the ants system, called a random-proportional rule, is given in Equation (1) [21], which gives the probability with which ant *k* in node *i* chooses to move to node *j*.

$$P_{ij}^{k}(t)=\begin{cases}\dfrac{\tau_{ij}^{\alpha}(t).\eta_{ij}^{\beta}}{\sum\limits_{s\in j_k(i)}\tau_{is}^{\alpha}(t).\eta_{is}^{\beta}} & if \quad j\in j_k(i)\\ 0 & \text{otherwise}\end{cases} \tag{1}$$

where τ is the pheromone which deposited on the edge between nodes *i* and *j*, η the inverse of the edge distance, $j_k(i)$ the set of nodes that remain to be visited by ant *k* positioned on node *i*, α is the weight of the pheromone concentration and β is a parameter that determines the relative importance of pheromone versus distance. Equation (1) indicates that the state transition rule favors transition toward nodes connected by shorter edges and with greater large amount of pheromone.

B. Updating Rule

While constructing its tour, each ant modifies the pheromone by the local updating rule. This can be written below [21]:

$$\tau(i,j)=(1-\rho)\tau(i,j)+\rho\tau_0 \tag{2}$$

where τ_0 the initial pheromone has a value and ρ is a heuristically defined parameter; the local updating rule is intended to shuffle the search process. Hence, the desirability of paths can be dynamically changed. The nodes visited earlier by a certain ant can be also explored later by other ants. The search space can be therefore extended. Furthermore, in so doing, ants will make a better use of pheromone information. Without local updating, all ants would search in a narrow neighborhood of the best previous tour.

C. Global Updating Rule

When tours are completed, the global updating rule is applied to edges belonging to the best ant tour. This rule is intended to provide a greater amount of pheromone to shorter tour, which can be expressed below [21]:

$$\tau(i,j)=(1-\delta)\tau(i,j)+\sigma\delta^{-1} \tag{3}$$

where δ is the distance of the globally best tour from the beginning of the trial and $\sigma\in[0,1]$ is the pheromone decay parameter. This rule is intended to make the search more directed; therefore the capability of finding the optimal solution can be enhanced through this rule in the problem solving process [20].

D. Proposed Method

The computational procedures of the proposed method are mainly composed of power loss calculation, bus voltage determination, and ant colony application. The objective function of the problem can be described as [21]:

$$\min F = \min(p_{Loss}) \tag{4}$$

At first, the colonies of ant are randomly selected and the initial fitness in different permutations was estimated. The initial pheromone value τ_0 of is also given at this step. Then, the fitness of ants, which is defined as objective function, is estimated and the pheromone can be added to the particular direction in which the ants have chosen. In this time, by roulette selection method, fitness with higher amount of pheromone will be easy to find. The ants of reconfiguration are based on level of pheromone and distance. A greater $\tau(i,j)$ means that there has been a lot of traffic on this edge; hence it is proportional to loss inversion and a greater $\eta(i,j)$ indicates that the closer node should be chosen with a higher probability. In placement of DG and capacitor, this can be seen as the difference between the initial total power loss and the new total power loss [21].

$$\eta(i,j) = P_{Loss(initial)}(i,j) - P_{Loss(new)}(i,j) \tag{5}$$

$$\tau(i,j) = \frac{1}{P_{Loss(new)}(i,j)} \tag{6}$$

While constructing a solution of placement of DG and capacitor problem, ants visit edge and change their pheromone level by local updating rule of Equation (2). After n iteration, all ants have completed a tour; the pheromone level is updated by applying the global updating rule of Equation (3) for the trial that belongs to the best selected path. Therefore, according to this rule, the shortest path found by the ants is allowed to update its pheromone. Also, this shortest path will be saved as a record for the later comparison with the succeeding iteration. Then, if all ants have selected the same tour, the process is satisfactory and acceptable; otherwise, repeat the outer loop [20].

III. SIMULATION RESULTS

The test system for the case study is radial distribution system with 33 buses, 5 tie-lines (looping branches), as shown in Figure 2. The network base voltage is 12.66 KV and the base apparent power is 10 MVA. The network data, including the resistance and reactance of the lines and the loads connected to nodes, were presented in [22].

For comparison, we had investigated three cases for this application example.

These three cases are as follows:

- Case 1: optimal placement and sizing of capacitors.
- Case 2: optimal placement and sizing of DGs.
- Case 3: simultaneous optimal placement and sizing of capacitors and DGs.

Capacitors and DGs are commercially available in discrete sizes. In Tables 1 and 2 the size of capacitors and DGs are given:

Table 1. Capacitor sizes

No.	Capacitor Size (Kvar)	No.	Capacitor Size (Kvar)
1	150	6	900
2	300	7	1050
3	450	8	1200
4	600	9	1350
5	750	10	1500

Table 2. DG sizes

No.	DG Sizes (KW)	No.	DG Sizes (KW)
1	250	5	1250
2	500	6	1500
3	750	7	1750
4	1000	8	2000

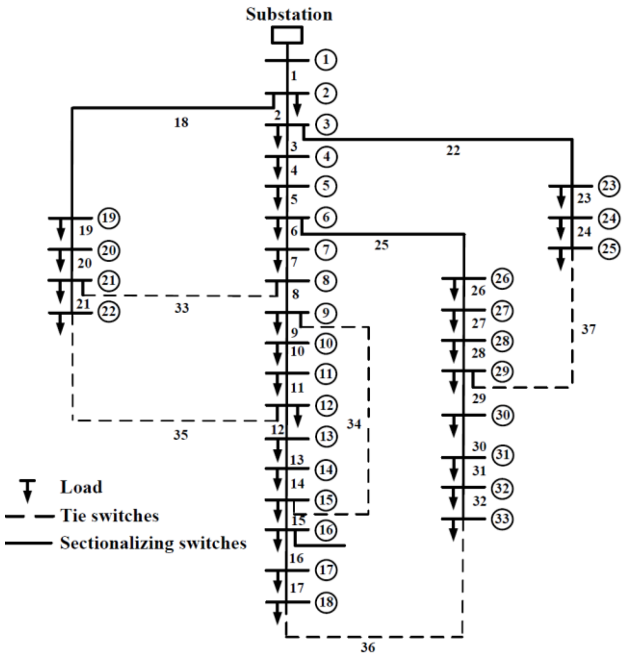

Figure 2. Test system of 33-bus radial distribution [22]

The ant colony algorithm is applied in this system for placement of capacitor and DG for improving voltage profile and reducing loss. In Table 3 the locations and sizes of capacitors and DGs are given.

The analysis shows that the real power losses and minimum bus voltage in initial network were 202.71 KW and 0.9130 pu but after installation capacitors and DGs, the power loss is reduced to 48.43 KW and minimum bus voltage is increased to 0.9476 pu. The simulation results of the ant colony algorithm and genetic algorithm (GA) for 33-bus system have been shown in Tables 4. From the numerical results, it is observed that loss reduction obtained by ACO is less than GA in total cases.

Figure 3 shows the voltage profile of the buses before and after DG and capacitor (case 3) installation in the 33-bus test system. It can be observed that the voltage profile has been improved significantly by installing the DGs and capacitors in total buses.

Table 3. The location of capacitors and DGs with proposed method

Main items	Base Case	Case 1	Case 2	Case 3
Maximum bus voltage (pu)	1	1	1	1
Minimum bus voltage (pu)	0.9130	0.9432	0.9453	0.9476
Capacitor added on bus 30 (Kvar)	-	900	-	900
Capacitor added on bus 10 (Kvar)	-	300	-	-
Capacitor added on bus 25 (Kvar)	-	150	-	150
Capacitor added on bus 22 (Kvar)	-	150	-	450
DG added on bus 16 (KW)	-	-	500	250
DG added on bus 30 (KW)	-	-	750	-
DG added on bus 8 (KW)	-	-	250	250
DG added on bus 20 (KW)	-	-	-	250
DG added on bus 29 (KW)	-	-	-	500
DG added on bus 5 (KW)	-	-	-	250
Power loss (KW)	202.71	135.83	87.26	48.43

Table 4. Present the best results achieved by the ACO and GA

Main items	ACO	GA
Total power loss (KW) of Base case	202.71	202.71
Total power loss (KW) of Case 1	135.83	137.098
Total power loss (KW) of Case 2	87.26	92.47
Total power loss(KW) of Case 3	48.43	51.92
Present of loss reduction of Case 3	76.31%	74.38%

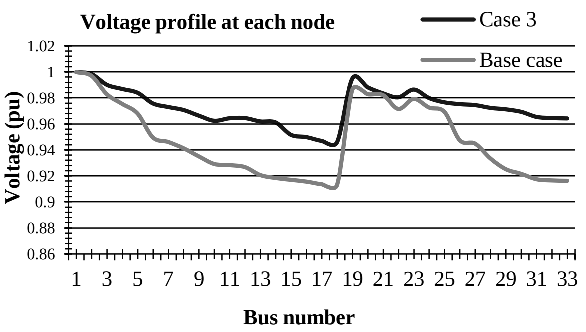

Figure 3. Voltage profile after and before installation of DG and capacitor in 33 bus system

IV. CONCLUSIONS

In this paper, the optimal placement of DGs and capacitors simultaneously was identified by using ant colony algorithm for IEEE 33-bus system. The comparison was made without DG & capacitor and with DG, with capacitor and with DG & capacitor in term of total power loss and voltage profile of system. The total power loss in base case was 202.71 KW and after connecting DG and capacitor in the system, the power loss was reduced to 48.43 KW, thus total loss was reduced by 76.31% of total power losses in the system. The simulation results show that the optimal operation of network occurs in the simultaneous expansion planning of the DGs and capacitors.

NOMENCLATURES

P_{ij}^{k} : The probability with which ant k in node i chooses to move to node j.

τ_{ij} : The pheromone which deposited on the edge between nodes i and j.

η_{ij} : The inverse of the edge distance between nodes i and j.

α :The weight of the pheromone concentration.

β :The relative importance of pheromone versus distance.

ρ :Evaporation rate

σ : Pheromone decay

P_{Loss} : Power loss

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BIOGRAPHY

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