DG Allocation with Consideration of Costs and Losses in Distribution Networks Using Ant Colony Algorithm

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ABSTRACT:
Because of the great benefits of distributed generation (DG) resources, such as inexhaustible and nonpolluting, they have more influence in the power industry, especially in distributed networks. DGs such as photovoltaic panels, wind turbines, fuel cells and micro gas turbines, etc. are going to be used in demand side of power systems. Such DGs can decrease power losses if they are placed properly in the distribution networks. In this paper presents ant colony algorithm for optimal placement and sizing of DGs in radial distribution networks for the purpose of cost minimization. The objective function embraces the cost of power losses and installed DGs cost. By applying the proposed method, the economic cost and power losses are decreased to a considerable degree while enhancing the voltage profile. Algorithm to optimize the objective function written in Matlab and simulation results are investigated on a real case study from a section of Tehran distribution network consisting of 13 buses.

KEYWORDS: Distributed generators, Ant colony algorithm, Cost minimization, Loss reduction, Voltage profile improvement.

1. INTRODUCTION

DG is a type of electricity production which is close to the load center and is linked to the distribution network. The majority of the advantages of DG justify the planning of electric systems at presence of DG.

Some significant reasons for the increasingly widespread utilize of DG could be summarized as follows [1]-[32]:

- DG units are near to customers. Hence Transmission and Distribution costs are reduced.
- The latest technology has produced available plants with high efficiency and expanded ranging in capacity.
- It is comfortable to find sites for small generators.
- Natural gas as fuel in DG stations is easily accessible and costs are more stable.
- Usually DG plants need shorter installation times and the investment risk is not too high.
- DG plants produce fairly good efficiencies especially in cogeneration and in combined cycles.
- The liberalization of the electricity market causes to creating opportunities for new utilities in the power generation unit.
- DG suggests greater values as it supplies a flexible way to select a wide range of combinations of cost and reliability.

Many complex problems may take place if DGs are not installed correctly. Examples are: voltage increase at the end of a feeder, demand supply unbalance in a fault situation, power quality decrease or voltage wave distortion in demand side, increase of power losses and reduction of reliability levels [2].

The optimal allocation and sizing of DG has been ceaselessly studied in order to obtain different aims.

Decreasing power losses as an objective function is very common in the optimal allocation of DG [3-7]. In [8], the effect of load models has been considered in the DG planning. An enhanced particle swarm optimization algorithm (PSO) has been employed in [9-10] to supply an optimal size and location of DG willing to minimize real power loss. Analytical ways have been utilized in [11]-[13] to determine the optimal location and size of DG.

Improvement of voltage profile has been regarded as an objective function in [14], [15] to find an optimal allocation of DG. The impact of DG on the reliability of distribution system has been regarded in [16-23]. A reliability model of DG for implementing it in the new competitive environment has been demonstrated in [16]. In [17] a market mechanism, mentioned to as Reliability Options for DG (RODG) has been described, which supplies distribution system operators with an optional to the investment in new distribution facilities. Allocation of DG in the distribution system with penetration of wind turbine has been considered in [18]. In [19] the effect of DG and load on the reliability of system has been discussed. The hourly reliability worth has been united in [20] for optimal operating decision of DG. Monte Carlo simulation (MCS) and analytical technique have been also occupied in [21-22] to evaluate the adequacy assessment of distribution system including renewable DG units such as wind and solar. In [23] reliability performance for distributed generation within a feeble grid distribution system has been regarded.

While these methods can easily handle separate variables, they have several disadvantages.

A major disadvantage of these methods is speed and the fact that they utilize certain control parameters that may be system dependent and difficult to determine.

However, installation of DG units in non-optimal places may causes an increase in system losses and a bad effect on voltage profile and other parameters which may cause to a growth of costs, and consequently an opposite effect on what is expected. Choosing the best places for installation of DG units and their preferable sizes in large distribution networks is a complex multimodal and combinatorial optimization problem.

Therefore, using an optimization method which is capable of exhibiting the best solution for a given distribution network, would help system planning engineers [24], [25-32].

In the present paper, Ant colony algorithm based on artificial intelligence is used to optimize the size and place of presented DGs. Power loss and DG cost are two important factors that this paper considerers them as objective function where DG size and place are optimization variables.

2. ANT COLONY ALGORITHM

The ant colony algorithm emulate of real ants. As is well known, real ants able to find the shortest path from food sources to the nest using visual cues. Also, they are able to changes in the environment, for example, finding a new shortest way once the old one is no longer possible due to a new impediment. In addition, the ants could manage to found shortest ways through the medium that is called “pheromone”. The pheromone is the material left by the ants, which serves as important communication information among ants, therewith guiding the definition of the next movement. Ant trial that is rich of pheromone will thus become the goal way. The procedure is demonstrated in Figure 1-a, the ants are moving from food source A to the nest B on a straight line. Once an impediment appears as shown in Figure 1-b, the way is cut off [31].

The ants will not be capable of following the original trial in their movements. Under this situation, they have the same probability to rotate right or left. Figure 1-c describes that the shorter way will collect larger amount of pheromone than the longer way. Hence, more ants will be increasingly guided to ambulate on the shorter way. Because of this autocatalytic process, very soon all ants will select the shorter way [26].

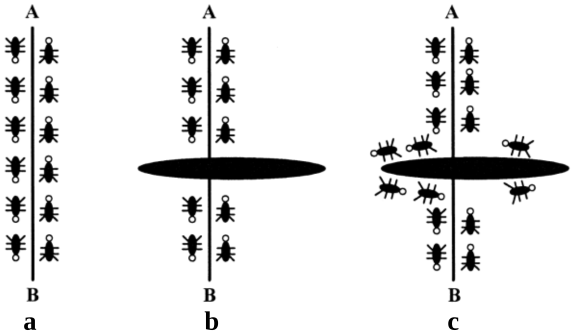

Fig. 1. Manner of ants to find optimal way

As demonstrated in Figure 1, by the guidance of the pheromone intensity, the ants select preferable way. Eventually, the favorite way rich of pheromone become the best tour, the solution to the problem. At first, each ant is placed on a starting condition. Each will build a full way, from the beginning to the end state, through the repetitive application of state transition law. While constructing its tour, an ant also modifies the amount of pheromone on the visited way by applying the local updating law. Once all ants have terminated their amount of pheromone on edge is changed again through the global updating law. In other words, the pheromone-updating rules are designed so that they tend to give more pheromone to ways which should be visited by ants. In the following, the state transition law, the local updating law, and the global updating law are briefly introduced [26-29], [30].

2.1. State Transition Law

The state law used by the ants system, called a random-proportional law, is given in (1) [26], which give the probability with which ant k in node i selects to move to node j.

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

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

2.2. Updating Law

While constructing its tour, each ant changes the pheromone by the local updating law. This can be written below:

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

That τ_0 the initial pheromone has a value and ρ is a heuristically defined parameter; the local updating law is intended to shuffle the search process. Therefore, the desirability of ways can be dynamically changed. The nodes visited earlier by a specific 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.

2.3. Global Updating Law

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

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

That 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 law is intended to make the search more directed; hence the capability of finding the optimal solution can be enhanced through this law in the problem solving process [26].

2.4. Problem Description

The DGs placement problem is the definition of the location, number and sizes of DGs to be put on a distribution network with consideration minimizing the cost and improving voltage profile. Mathematically, the objective function of the problem can be described as:

$$\min\ F = \min(Cost) \tag{4}$$

$$I_{K,K+1} \le I_{K,K+1,\max} \tag{5}$$

$$V_{\min} \le |V_K| \le V_{\max} \tag{6}$$

Where $Cost$ includes the cost of power loss and DGs placement, and will be debated further later.

$$Cost = K_p P_{Loss} + \sum Cost_{DG} \tag{7}$$

Here, K_p is the equivalent cost per unit of power loss in (\$ / kW) and is selected to be in 168 (\$ / kW), and $Cost_{DG}$ is the sum of the installed DG units cost.
The capital cost of the DG units is different because of their types [28].
At first, the colonies of ant are randomly chosen and the initial opportuneness in different permutations was estimated.
The initial pheromone value τ_0 of is also given at this step. Then, the opportuneness 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, opportuneness with higher amount of pheromone will be easy to find [32].
The ants of DG 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; therefore it is proportional to cost inversion and a greater $\eta(i,j)$ exhibits that the closer node should be chosen with a higher probability. In placement of DG, this can be seen as the difference between the initial total cost and the new total cost [32].

$$\eta(i,j) = Cost_{initial}(i,j) - Cost_{new}(i,j) \tag{8}$$

$$\tau(i,j) = \frac{1}{Cost_{new}(i,j)} \tag{9}$$

While constructing a solution of placement of DG problem, ants visit edge and change their pheromone level by local updating law of (2). After n iteration, all ants have completed a tour; the pheromone level is updated by applying the global updating law of (3) for the trial that belongs to the best selected way.
Hence, according to this law, the shortest way found by the ants is permitted to update its pheromone.
Also, this shortest way will be saved as a record for the later comparison with the succeeding iteration. Then, if all ants have chosen the same tour, the process is satisfactory and acceptable; else, repeat the outer loop [32].

3. CASE STUDY

A real case study is selected from a part of Tehran distribution network. The single line diagram of the network is illustrated in Figure 2. This is a MV feeder with 13 buses from 63/20 KV Khoda-Bande-Loo substation. Table 1 and 2 provide the data of lines and buses. It is assumed in this paper that the load level is in peak condition (10536+ j 5992) kVA [24]-[31].

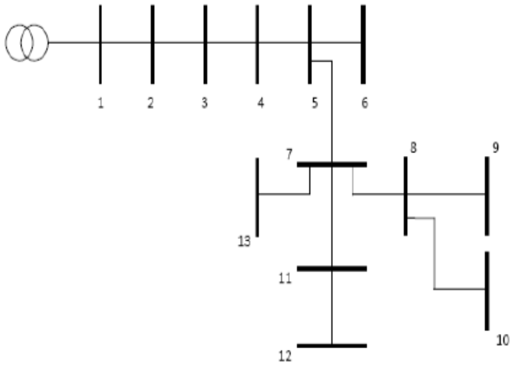

Fig. 2. Single line diagram of feeder of Khoda-Bande-Loo substation

Table. 1 Line information

From	To	R(ohm)	X(ohm)
1	2	0.176	0.138
2	3	0.176	0.138
3	4	0.045	0.035
4	5	0.089	0.069
5	6	0.045	0.035
5	7	0.116	0.091
7	8	0.073	0.073
8	9	0.074	0.058
8	10	0.093	0.093
7	11	0.063	0.050
11	12	0.068	0.053
7	13	0.062	0.053

Table. 2 Bus information

Bus number	P(kW)	Q(kVAR)
1	0	0
2	890	468
3	628	470
4	1112	764
5	636	378
6	474	344
7	1342	1078
8	920	292
9	766	498
10	662	480
11	690	186
12	1292	554
13	1124	480

4. NUMERICAL RESULTS

In order to have a clear comparison, sum of power losses of the base case is calculated. This amount is equal to 175.58KW.

For installing DG units in the network, the available capacities and cost of them are illustrated in Table 3 [27] and the maximum number of units is three.

The ACO control parameters for the study are set experimentally using information from several trial runs as follows:

Number of ants: 35

Maximum number of iteration: 100

The weight of the pheromone concentration (α): 0.95

Parameter that determines the relative importance of pheromone versus distance (β): 0.9

The pheromone decay parameter (σ): 0.95

Table. 3 Characteristics of DG units

Capacity (KW)	Capital cost ($)
500	1500
1000	1061
1500	866
2000	750

To exhibit the effect of installation of DG units on operating parameters of the test system, one DG is installed in the first step. The prepared program is continue and specifies that the best place and the best capacity of DG unit for as much as minimum cost are bus 8 and 2000 KW. In this case, total cost of network is 21287$ and amount of power losses is 123.40 KW. The consequences clarify that installing a DG unit could significantly decrease total cost and power losses.

In the next step, two DG units are considered for installing in the network. In this case, connecting two DG units with 2000 KW capacity to the bus 8 and bus 12, is the best solution of the problem. Once again, total cost and the sum of line losses drops. The total cost and the sum of power losses reach to 15685$ and 84.42 KW, respectively.

The solution of allocating three DG units to the network is installation of three units of 2000 KW in buses 8, 12, and 13. The total cost in this case is 12166$ and the sum of active power losses reduces to 59.02 KW.

Table. 4 Comparison of power losses and total cost

	Base case	1 DG	2 DG	3 DG
Total cost($)	29500	21481	15685	12166
Power losses(KW)	175.58	123.40	84.42	59.02

Figure 3 shows the voltage profile of the buses in the base case and after three DGs installation in the network.

It can be observed that the voltage profile has been improved significantly by installing the DGs in total buses.

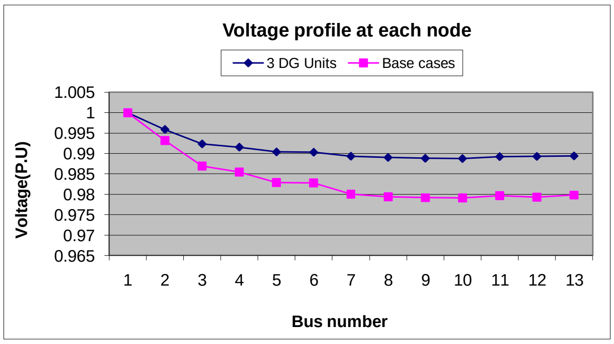

Fig. 3. Voltage profile after and before installation of DGs in 13 bus network

5. COMPARISON OF VARIOUS HEURISTIC OPTIMIZATION TECHNIQUES

The number of the heuristic optimization techniques applied to solve the optimal DG placement problem such as ACO, PSO, GA, tabu search and fuzzy are the most popular optimization techniques for solving the optimal DG placement problem in the last decade. The ACO is the most common technique applied due to its benefits which include simple implementation, small computational load, and fast convergence. ACO is effective for solving many problems for which it is difficult to find accurate mathematical models.

However, the ACO algorithm is tending to relapse into local minima and premature convergence when solving complex optimization problems.

6. CONCLUSIONS

Ant colony algorithm has been presented in this paper for the DGs placement of distribution networks. This method was inspired by observation of the behaviors of ant colonies.

The algorithm for optimal placement of DGs was identified on a distribution feeder with 13buses from Khoda-Bande-Loo of Tehran city. The proposed method seeks the most effective buses to install compensation DGs so that a minimum total cost. The obtained results show that the DG placement not only reduces the total costs but also reduces loss and voltage profile improvement of network is considered. This effect of DG placement on distribution network is the main motivation behind DG inclusion in power distribution network planning.

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