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Distribution Network Reconfiguration for Optimal Operation of Distributed Generation with Ant Colony Algorithm

***Abstract**. This paper introduces one of applications of the Ant colony algorithm to solve the optimal network reconfiguration problem with Distributed Generation (DG) for power loss reduction and voltage profile improvement. DGs, such as fuel cells and solar cells, etc., are going to be installed in the demand side of power networks for reducing power losses, network reinforcement, improving network efficiency and reliability. Network reconfiguration is performed by altering the topological structure of distribution feeders. By reconfiguring the network, voltage stability can be maximized for a particular set of loads in distribution networks. The performance of the proposed method was investigated on two distribution networks consisting of 33 and 10 buses.*

***Streszczenie.** W artykule przedstawiono algorytm optymalnej rekonfiguracji sieci dystrybucji energii, zawierającej rozproszone generatory energii, z wykorzystaniem algorytmu mrówkowego. Metoda wpływa na zmniejszenie strat mocy oraz wahań napięcia sieci. Weryfikację przeprowadzono na dwóch sieciach przesyłowych, zawierających 33 i 10 linii. (**Zastosowanie algorytmu mrówkowego w optymalizacji rekonfiguracji sieci dystrybucji energii, zawierającej źródła rozproszone**)*

Keywords: Distribution network, Distributed generation, Reconfiguration, Ant colony.
Słowa kluczowe: sieć dystrybucji, generacja rozproszona, rekonfiguracja, kolonia mrówek.

1. Introduction

Distribution networks are normally configured radially. In distribution networks two types of switches are generally used, one is the normally closed switches, which connect line sections, and the other normally open switches on the tie-line, which connect two feeders or loop type laterals. The former type is called sectionalizing switches and the latter type is referred to as tie switches. Those two types of switches are designed for both protection and configuration management. Network reconfiguration is the process of changing the topology of distribution networks by opening or closing of these two types of switches [1].

Recently, many distributed power generation networks are installed in demand side and are directly connected to the distribution network. In such a power distribution network, many complicated problems may occur: for example, voltage increase at the end of a feeder, demand supply unbalance in a fault condition, power quality decline or voltage wave distortion in demand side. On the other hand, the main reasons for the increasingly widespread use of dispersed generation can be summed as following:

-DG unit are closer to customer so that transmission and distribution costs are reduced.

-The latest technology has made available plants ranging in capacity from 10KW to 15MW.

-DG plants yield fairly good efficiencies especially in cogeneration and combined cycles.

-It is easier to find sites for small generators.

-Natural gas, often used as fuel in DG stations is distributed almost everywhere and stable prices are to be expected.

-Usually DG plants required shorter installation times and the risk investment is not so high.

For these reasons, the first signs of a possible technological change are beginning to arise on the international scene [2].

So far, in distribution networks without DGs, various algorithms to determine the optimal configuration have been proposed [3-8]. To restructure primary feeders for loss reduction, a simple formula which removes the need to conduct many load flow studies, was presented in [3] as a planning and/or real-time control tool. Approximate power flow and loss reduction formula with varying degree of accuracy were developed in [4-5] to aid the search for optimal feeder configuration. These methods can also be applied to the load balancing problems. Using a basic current profile concept, the global optimality condition of the problem and two solution algorithms were presented in [5-6] to determine the open switch positions for loss reduction. Feeder reconfiguration is also proposed to increase the reliability of distribution network [7-8]. The impacts of DG in the distribution feeder reconfiguration were shown in [9-11]. But this paper discusses network reconfiguration with DGs but the installation node and capacity of DGs in this paper are not considered [12-13]. The ant colony algorithm is used to solve the problem [14-17].

2. Ant Colony Algorithm

The ant colony algorithm 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. More over, 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 Fig.1. In Fig.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 Fig.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. Fig.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.

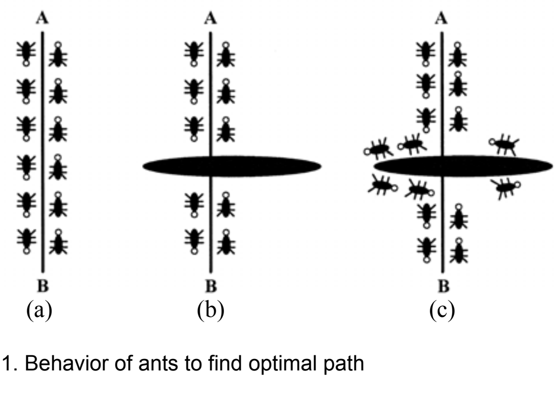

Fig. 1. Behavior of ants to find optimal path

As illustrated in Fig.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 [1].

2.1 State Transition Rule

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

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

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.

2.2 Updating Rule

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

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

That 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.

2.3 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:

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

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 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 [1].

3. Proposed method

The computational procedures of the proposed method are mainly composed of power-loss calculation, bus voltage determination, and ant colony application. The computational procedures find a series of configuration with different status of switches such that the objective function is successively reduced. The objective function of the problem can be described as:

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

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 the network reconfiguration study, this can be seen as the difference between the initial total power loss and the new total power loss.

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

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

While constructing a solution of the reconfiguration problem, ants visit edge and change their pheromone level by local updating rule of (2). After n iteration, all ants have completed a tour; the pheromone level is updated by applying the global updating rule of (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 [1].

In reconfiguration problem some constrains should be considered:

- Distribution network should be composed of radial structure.
- All nodes should be energized.
- Voltage magnitude at each node must lie with their permissible range.

4. Simulation Results

The proposed method of loss reduction was tested on two distribution networks consisting of 33 and 10 buses. The results obtained in these networks are briefly described in following sections.

4.1 33-bus network

The network is consisting of 3 feeders, 33 load points and 5 tie switches. The data of 33 bus test system is taken from [19].The initial configuration of 33-bus test is shown in Fig. 2.

The network power total loss is 0.2027 MW. The load of the system is assumed to be constant. Four cases are considered i.e. initial network without DGs/with DGs and optimum network (after reconfiguration) without DGs/with DGs. Results on the 33-bus distribution network as shown in Table 1. In the case study, DGs are installed in heavy loaded node [9], [12].Optimal network with DG has been showed in Fig.3.

Fig.4 shows buses voltage profile at each node for initial network without DG and optimal network with DG. As shown, total of the bus voltage have been improved after reconfiguration. The installation node and capacity of DGs in this paper are not optimum value. The reason is that owners of DGs determine the installation location and capacity of it to improve their economic benefits. Generally, the owners of DGs are individuals and non-utilities. Therefore, these are not controllable. If owner of DGs is utility, then the choice of locations is important because the additional DGs may cause an increase of power losses. The determination method for finding the best location can be solved by optimization techniques [13].

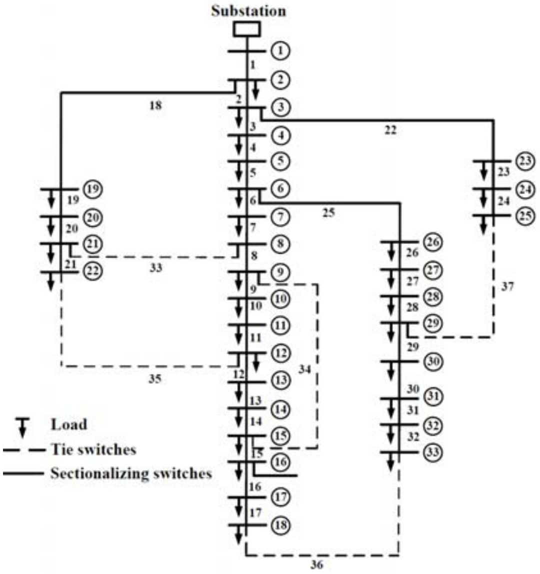

Fig. 2. Initial network without DG

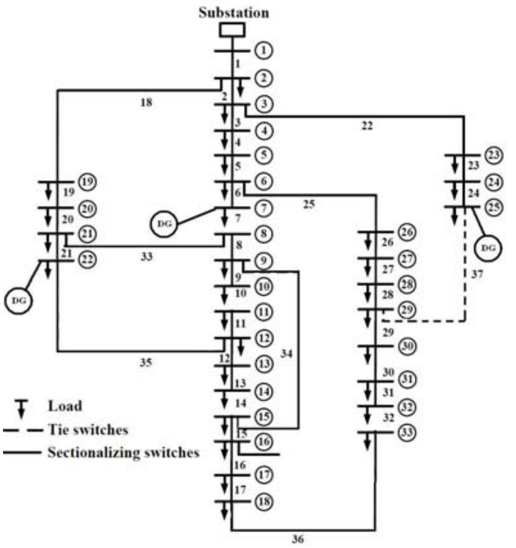

Fig. 3. Optimal network with DG

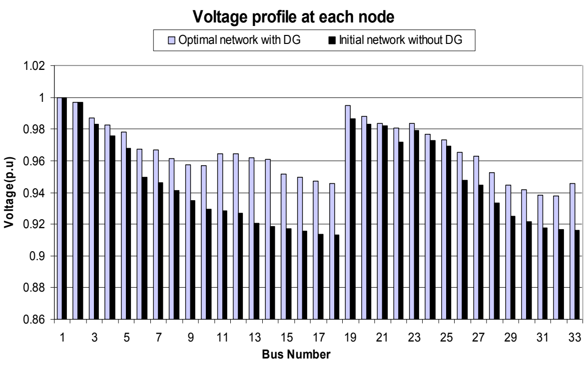

Fig. 4. Voltage profile at each node for initial network without DG and optimal network with DG

Table 1. Final results of ant colony dismounting on 33-bus network

Main items	Initial network without DG	Optimal network without DG	Initial network with DGs	Optimal network with DG
Tie switches	33-34-35-36-37	7-9-14-32-37	33-34-35-36-37	7-10-14-32-37
Maximum bus voltage (p.u)	1	1	1	1
Minimum bus voltage (p.u)	0.9130	0.9375	0.92	0.9448
DG added on bus 7 (KW/P.F)	-	-	200/0.9	200/0.9
DG added on bus 22 (KW/P.F)	-	-	100/0.9	100/0.9
DG added on bus 25 (KW/P.F)	-	-	400/0.9	400/0.9
Power loss (MW)	0.20271	0.13968	0.15977	0.13141
Loss reduction (%)	-	31.09	21.18	35.17

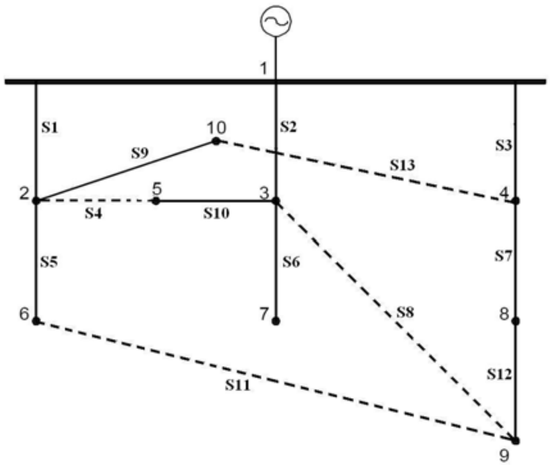

Fig. 5. Initial network without DG

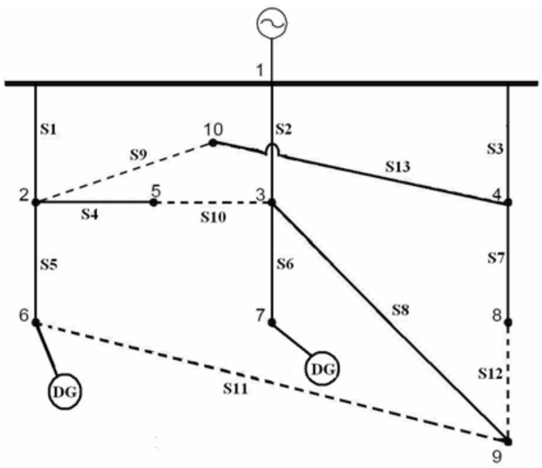

Fig. 6. Optimal network with DG

4.2 10-bus network

The 10-bus test network is consisting of 3 feeders, 9 load points and 4 tie switches. The data of 10 bus test system is taken from [18].The initial configuration of 10-bus test is shown in Fig. 5. In this example DGs generally connect with buses with have heavy loads and are far away from the substation. Results on the 10-bus distribution network as shown in Table 2. Optimal network with DG has been showed in Fig.6.

Table 2. Final results of ant colony dismounting on 10-bus network

Main items	Initial network without DG	Optimal network without DG	Initial network with DGs	Optimal network with DG
Tie switches	4-8-11-13	9-10-11-12	4-8-11-13	9-10-11-12
Maximum bus voltage (p.u)	1	1	1	1
Minimum bus voltage (p.u	0.9540	0.9617	0.9549	0.9677
DG added on bus 6 (w/P.F)	-	-	500/0.9	500/0.9
DG added on bus 7 (KW/P.F)	-	-	500/0.9	500/0.9
Power loss (Mw)	0.277	0.2682	0.1849	0.1687
Loss reduction (%)	-	3.2	33.21	39.35

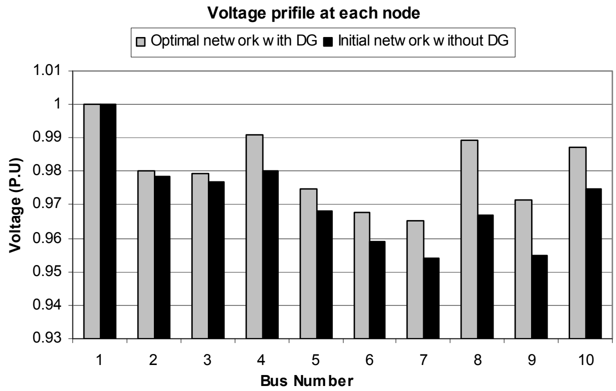

Fig. 7.Voltage profile at each node for initial network without DG and optimal network with DG

Fig.7 shows buses voltage profile at each node for initial network without DG and optimal network with DG. The outcomes represent that installation of reconfiguration and DG unit considerably improves the voltage profile.

5. Conclusion

Nowadays, distributed generation have an effective role in power distribution networks. In this paper the impact of DGs, in feeder reconfiguration, has been considered. ant colony algorithm was employed as the solution tool of reconfiguration of distribution networks with DGs. The proposed algorithm leads to better results with and without DGs. In order to verify the performance of the proposed algorithm, the algorithm was applied to on two distribution network. The computational results show the validity of the proposed formulation for the reconfiguration problem and demonstrate the performance of the proposed algorithm. It is also shown that reconfiguration not only decrease total loss of network but also have positive effects on voltage profile.

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