Application of Improved Ant Colony Algorithm in Reconfiguration of Distributed Energy Distribution Network

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Abstract

Distribution network reconfiguration is an important way to reduce network loss in power system and distributed energy grid-connected can effectively solve the environmental pollution caused by traditional power generation, reduce power loss, and maximize power utilization. In this paper, an improved ant colony algorithm is proposed for distribution network reconfiguration with distributed energy. This algorithm improves the selection of optimal solution and pheromone updating of ant colony algorithm, so that it can accelerate the convergence speed, reduce the amount of calculation and shorten the time needed for solving the optimal solution.

Keywords: ant colony algorithm;distribution network reconfiguration; convergence rate; pheromone updating; length threshold.

Preface

With the development of China's economy, people's life and production of enterprises need a lot of electricity, which makes the demand for electricity in China increasing. This not only provides a good development environment for China's power industry, but also poses a severe challenge for China's power supply technology. Distribution network reconfiguration can improve the security, economy and power quality of distribution network operation. It is of great significance to the construction and application of domestic distribution automation system. It is an important means of operation and control of distribution system and plays an important role in distribution management system [4].

Distribution network reconfiguration is a multi-objective and non-linear hybrid optimization problem because there are a large number of sectional switches and tie-in switches in distribution network [14]. Because of the large number of control variables and the large scale of computation, the traditional ant colony algorithm has a dramatic increase in computing time, and the convergence speed is slow down, and it is easy to fall into premature. Because of the large number of control variables and the large scale of computation, the traditional ant colony algorithm has a dramatic increase in computing time, and the convergence speed is slow down, and it is easy to fall into premature [7].

Distribution Problem of Network Nodes in Distribution Network Reconfiguration with Distributed Energy, because the computational load is too large in the process of mathematical solution, it will consume a lot of time and can not ensure the convergence of the computational process. In order to solve the problem of computing speed, researchers have proposed many different methods to solve the problem of distribution network reconfiguration. In the artificial intelligence algorithm, the ant colony algorithm is used to solve the distribution network reconfiguration problem by means of positive feedback, distributed computing and greedy heuristic search, which can be

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independent of the initial structure of the network, and has strong adaptability and high search efficiency. In reference [3], the distribution network reconfiguration problem is transformed into the spanning tree problem from the graph theory topological structure, and a fast and effective method for solving the spanning tree of the graph is obtained based on the breaking circle method. When applying ant colony algorithm to solve the problem of distribution network reconstruction, the algorithm can get out of the local optimization problem by expanding the search range of the algorithm by selecting the randomization of the first branch and eliminating the heuristic of the slave group algorithm and improve the search effect of the algorithm.

In this paper, an improved ant colony algorithm is proposed to solve the distribution network reconfiguration problem, which optimizes the complex distribution network reconfiguration problem, speeds up the convergence speed, saves time, makes the whole system evolve continuously, and finally obtains the optimal reconfiguration scheme. Moreover, the influence of distance length on distribution network reconfiguration is only considered, and other factors are not considered.

I. Ant colony algorithm

1.1 Primitive ant colony algorithm

Ant colony algorithm (ACO) is a probabilistic algorithm which simulates the search behavior of ants in nature to find the optimal solution[5]. Ants can find the shortest route to food sources in different environments. Ants release a substance called "pheromone" along their path. Ants in the ant colony have the ability to perceive "pheromone". They walk along the path with high concentration of "pheromone", and each passing ant leaves "pheromone" on the road [10]. Ants find the shortest path mainly depending on pheromone and environment. Suppose there are two paths to food. At the beginning, the ant randomly chooses the path and returns immediately when it reaches the end. Ants on short distances have a short round trip time, fast repetition rate, less pheromone volatilization, and a large number of ants in a unit time, leaving more pheromones, which will attract more ants to come. So the concentration of pheromones on this road is getting higher and higher [13]. The opposite is true for long distances, so more and more ants choose shorter paths and finally find the optimal solution. This forms a mechanism similar to positive feedback, so that after a period of time, the whole ant colony will follow the shortest path to the food source [8].

The idea of ant colony algorithm is to express the feasible solution of the problem to be optimized by ant's walking path, and all the paths of the whole ant colony constitute the solution space of the problem to be optimized [9].Ants with shorter paths release more pheromones. As time goes on, the concentration of pheromones accumulated on shorter paths gradually increases, and the number of ants choosing this path is also increasing. Ultimately, the whole ant will concentrate on the optimal path under the action of positive feedback, which corresponds to the optimal solution of the problem to be optimized [12].

(1) Variable initialization of ant colony algorithm

Setting the size of ant colony to m and the total number of intersections to n,m ants are randomly placed at n intersections, and the starting point is assigned. The taboo table of each ant is the current intersection where the ant is located, and the pheromone concentration of each section of the path is initialized to C. Taboo tables enable ants not to walk at the same intersection repeatedly, improving efficiency.

(2) Constructive solution space

Probability of ants transferring from intersection i to intersection j at time t.

$$P_{ij}^{k}(t)=\begin{cases}\dfrac{[\tau_{ij}(t)]^{\alpha}[\eta_{ik}(t)^{\beta}]}{\sum_{s\not\subset R}[\tau_{ij}(t)]^{\alpha}[\eta_{ik}(t)^{\beta}]} & j\in R\\ 0 & j\notin R\end{cases} \quad (1)$$

$Tabu_k$ preserves the city collection J_k={N-$Tabu_k$} that each ant K has visited. α and β are system parameters, which represent the influence of pheromone and distance on ant path, respectively.*τ(i,j)*denotes the pheromone intensity on the path*L(i,j)*, and *η(i,j)*denotes the expected degree from city *i* to city *j*.It can be determined according to the heuristic algorithm, generally as $1/d_{ij}$. *α=0*algorithm evolves into the traditional stochastic greedy algorithm, and the nearest intersection has the greatest probability of being selected.*β=0*ant only determines the path according to the pheromone concentration, and the algorithm will converge quickly, so the path constructed is far from the actual target.Generally, 1-2 for *α* and 2-5 for *β* are suitable.

(3) Update pheromone

Update pheromones after all ants find a legitimate path

$$\tau_{ij}(t+1)=(1-\rho)\tau_{ij}(t)+\sum_{m}\Delta\tau_{ij}^{k}(t,t+1) \quad (2)$$

$$\Delta\tau_{ij}^{k}(t,t-1)=\begin{cases}Q/L_k & The\ ant\ goes\ through\ i,j\\ 0 & The\ ant\ doesn't\ go\ through\ i,j\end{cases} \quad (1)$$

ρ is the volatilization rate of pheromone. $\tau_{ij}(t)$ represents the pheromone concentration of ants on path *L(i,j)* during the t-th run. $\Delta\tau_{ij}^{k}$ represents the pheromone concentration of ant K placed on path *L (i,j)*.Q denotes that the trajectory left by ants is positive constant.L_k denotes the sum of the path lengths that ant K travels in this iteration.

(4) Output results

If the number of iterations is less than the predetermined number of iterations, and there is no degenerate behavior (all the solutions found are the same), step 2 is returned, otherwise the current optimal solution is output.

The intelligent behavior of ants benefits from their simple behavior rules, which give them diversity and positive feedback.When looking for food, diversity keeps ants from walking into dead ends and circulating indefinitely[6]. It is an innovative ability.Positive feedback keeps good information, which is a kind of learning reinforcement ability.The ingenious combination of the two makes intelligent behavior emerge. If the diversity is excessive and the system is too active, it will lead to excessive random motion and fall into chaotic state. If the diversity is insufficient and the positive feedback is too strong, it will lead to rigidity. When the environment changes, the ant colony can’t adjust accordingly[15].

The original ant colony algorithm has slow convergence speed, large computational complexity and long solving time [11]. In theory, all ants are required to choose the same route, which is the optimal route, but in practice, it is difficult to achieve this situation under the given number of cycles.

1.2 Improved ant colony algorithm

For the application of ant colony algorithm in distribution network reconfiguration, many researchers have proposed different methods to solve the problem of distribution network reconfiguration. At present, the main research and improvement direction is focused on optimization algorithm and optimization objectives.

In reference [1], an ant colony optimization algorithm is proposed to solve the distribution network reconfiguration problem in case of faults.By changing the closed state of the switch to change the network topology, the network loss is minimized.The algorithm does not depend on various initial parameters and is not easy to fall into local optimum. Compared with other methods, it has the advantages of good adaptability, high computational efficiency and good optimization effect.In reference [2], an improved ant colony algorithm based on direction pheromone is proposed to solve the problem of distribution network reconfiguration.A new pheromone updating strategy is proposed and a branch selection strategy with exploratory rate factor is added in the algorithm to accelerate the convergence speed and control accuracy of the ant colony algorithm and prevent the algorithm from falling into local optimum.In solving the problem, it has a very fast convergence speed and can find a better solution at the same time[3].An improved ant colony algorithm is proposed to solve the problem that the traditional ant colony algorithm is prone to stagnation and only gets the local optimal solution.Based on the idea of combining local pheromone updating with global pheromone updating, an improved ant colony algorithm for directional pheromone updating is proposed.The convergence speed of the improved ant colony algorithm is faster than that of the traditional ant colony algorithm, and the network loss value is smaller when the ant colony algorithm converges.This paper introduces an improved ant colony algorithm, which mainly improves the selection of the optimal solution and pheromone updating of the ant colony algorithm, so as to speed up the convergence speed, reduce the amount of calculation and shorten the time required for solving.

(1) Introducing length threshold

Based on the conventional mathematical model, the concept of length threshold is introduced to measure the validity of the total path length data.When the total path length of the ant is longer than the length threshold, the difference between the ant and the optimal solution is too large, and it is classified as invalid data.On the contrary, the valid data is less than the path length threshold. The maximum path length is defined as follows:

$$L_{\max} = \gamma * L_{avel} \tag{2}$$

$$\gamma = \frac{\sum_{m} | L_k - L_{avel} |}{m \times L_{avel}} + 0.8 \tag{3}$$

L_{avel} denotes the average length of the total path of all ants when the number of iterations is 1 and all ants find their own legal path.The formula is:

$$L_{avel} = \frac{\sum_{k=1}^{m} L_k}{m} \tag{4}$$

Wherein, the equation of L_k is:

$$L_k = L_k + D(j, i+1) \tag{5}$$

γis the limiting coefficient.$L_k$denotes the sum of the path lengths that ant k travels in this iteration.

(2) Adding pheromone update conditions

According to the known total path length, if the length of the path is invalid (longer than the length threshold), the pheromone concentration on the path will not be updated when the pheromone concentration is updated.Conversely, if the valid data (length less than length threshold), the pheromone concentration is updated.

(3) Update pheromone

After all ants find the legal path, the length of the path is compared with the length threshold, and pheromone updates are carried out in the following way

$$\tau_{ij}(t+1)=\begin{cases}(1-\rho)\tau_{ij}(t)+\sum_{m}\Delta\tau_{ij}^{k}(t,t+1) & L_k < L_{\max}\\ 0 & L_k \geq L_{\max}\end{cases} \quad (6)$$

ρ is the volatilization rate of pheromone, $\tau_{ij}(t)$ is the concentration of pheromone left on the path*L (i, j)* by ants in the second run of t. $\Delta\tau_{ij}^{k}$ represents the pheromone concentration of ant K placed on path *L (i, j)*.Q denotes that the trajectory left by ants is a positive constant, and L_k denotes the sum of the path lengths that ant k travels in this iteration.

II. Solution steps of distribution network reconfiguration

Step 1: Read the original data into the network to set parameters. The position of the energy node of the network is read into the position of the intersection where the ants walk. The number of ants and the total number of iterations of the whole system are preset, and the initial iterations are set to 1.

Step 2: Randomly assign m ants to n intersections as the starting point.

Step 3: Ants choose to traverse all intersections one by one until all ants have chosen their own path.

Step 4: If it is the first iteration, the length threshold is calculated and the valid data is obtained by comparison. If it is not the first iteration, the valid data is screened by comparing the feasible solution with the length threshold directly.

Step 5: If it is valid data, the path updates the pheromone, and the invalid data does not update the pheromone, and the optimal solution of this iteration is obtained.

Step 6: When the number of iterations does not reach the preset value, step 2 is returned to output the optimal solution after the preset value is reached.

After the above steps, the solution of distribution network reconfiguration with distributed energy can be completed, and the flow chart of the solution is shown in the figure1.

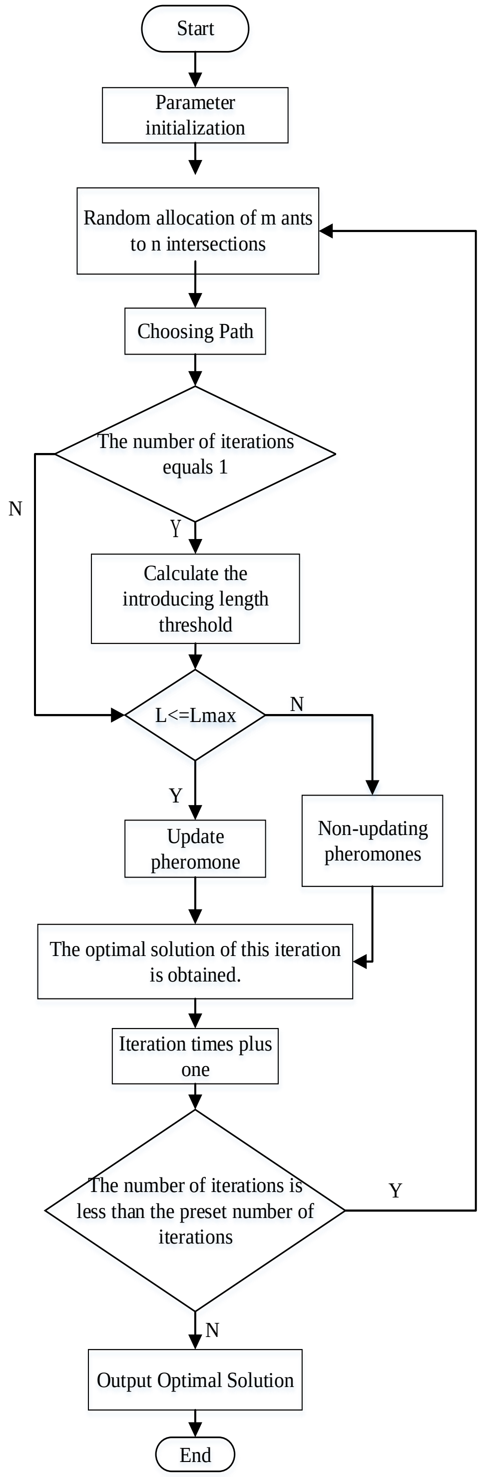

Figure 1: Solution flow chart

III. The example analysis

In order to verify the effectiveness of the improved ant colony algorithm in distribution network reconfiguration with distributed energy, in this paper, a 200-node distribution system is adopted as the simulation object. The proposed method is verified from the aspects of iteration times, calculation speed and pheromone concentration update.

The number of nodes in the system is 200, the ant colony size is 50, the maximum number of iterations is 100, the pheromone volatile factor is 0.2, the pheromone importance factor is 1, the heuristic function importance factor is 5, and the constant coefficient is 10. Based on MATLAB 2016 software for simulation calculation, the results of the planning before and after the improvement are as follows:

Figure 2 and Figure 4 are the three-dimensional and two-dimensional result maps before the improvement respectively. Figure 3 and Figure 5 are the three-dimensional and two-dimensional result maps after the improvement respectively.

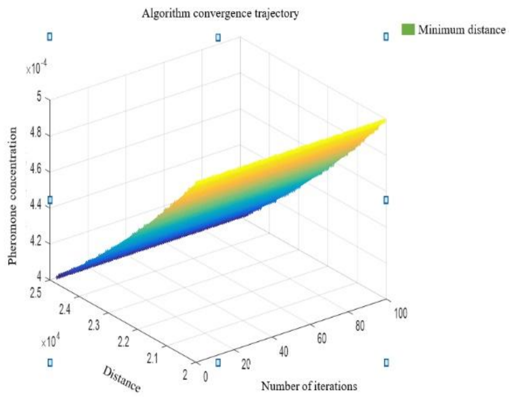

Figure 2: 3d schematic diagram of operation results of improved former ant colony algorithm

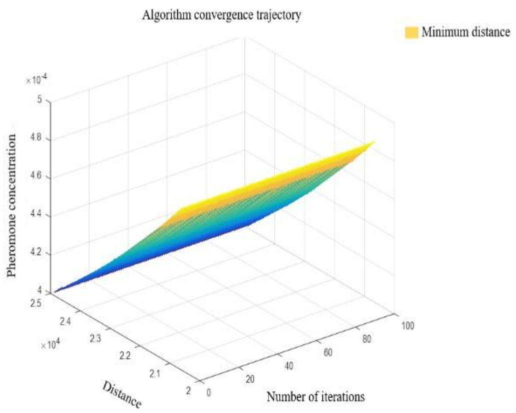

Figure 3: 3d schematic diagram of improved ant colony algorithm operation results

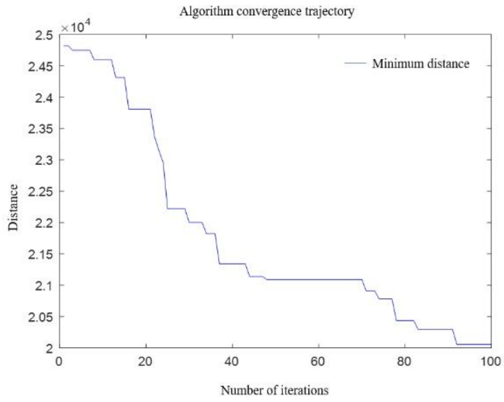

Figure 4: two-dimensional schematic diagram of operation results of improved former ant colony algorithm

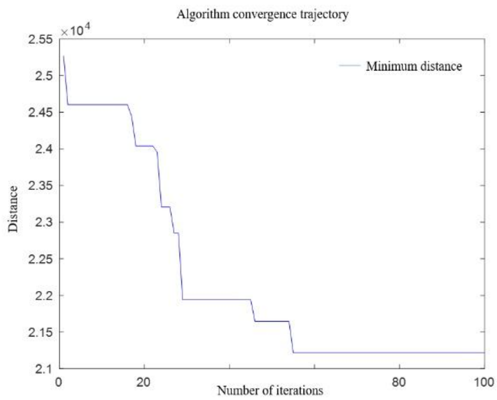

Figure 5: two-dimensional schematic diagram of improved ant colony algorithm operation results

According to the figure, the execution time of the original algorithm in figure 2 and figure 4 is 77.064 seconds, and the number of convergence iterations is 92; Figure 3 and Figure 5 improved ant colony algorithm program execution time is 52.795 seconds, and the number of convergence iterations is 55 times. The execution time of the improved ant colony algorithm is 31% shorter than that of the original ant colony algorithm. The number of iterations is also significantly reduced.

The simulation results of repetitive operation are as follows.

Figure 6 and Figure 8 are the three-dimensional and two-dimensional result maps before improvement, and Figure 7 and Figure 9 are the three-dimensional and two-dimensional result maps after improvement, respectively.

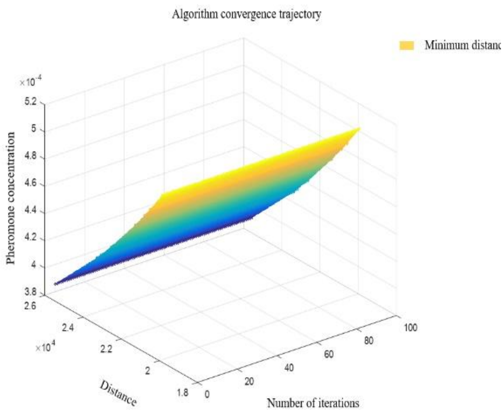

Figure 6: 3d schematic diagram of the operation results of improved former ant colony algorithm

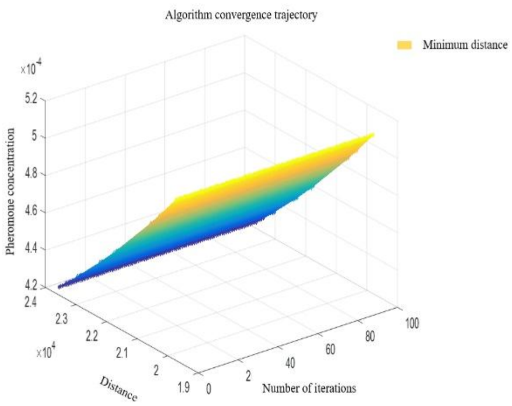

Figure 7: 3d schematic diagram of improved ant colony algorithm operation results

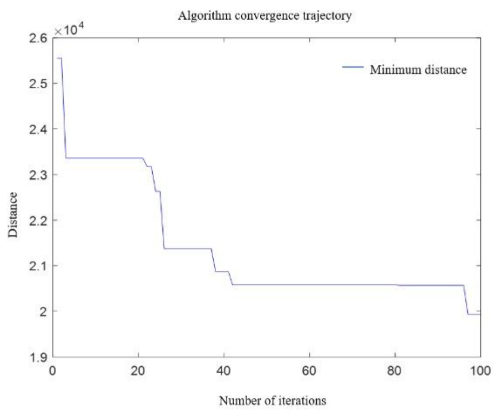

Figure 8 two-dimensional schematic diagram of operation results of improved former ant colony algorithm

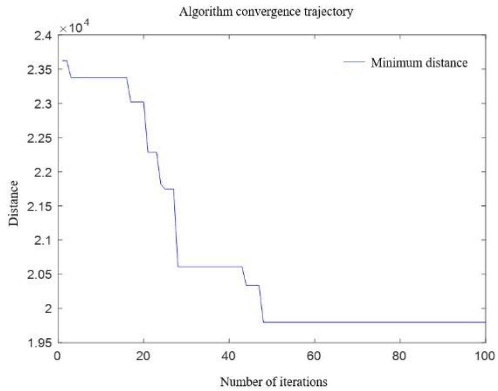

Figure 9: two-dimensional schematic diagram of improved ant colony algorithm operation results

According to the figure, the execution time of the original algorithm in figure 6 and figure 8 is 97.469 seconds, and the number of convergence iterations is 97 times; figure 7 and figure 9 improved ant colony algorithm program execution time is 54.27 seconds, convergence times is 48 times. By contrast, the improved ant colony algorithm has shorter program execution time, 44 percent faster than the original ant colony algorithm, it converges faster, the number of iterations is also reduced when convergence, optimize its line distribution. So it turns out that, the improved ant colony algorithm can effectively shorten the running time of the program when solving the problem of distribution network reconfiguration, speed up convergence.

IV.conclusion

This paper starts from the shortcomings of the original ant colony algorithm, in view of the shortcomings of original ant colony algorithm in the calculation of distribution network reconfiguration with distributed energy, such as long time and slow convergence rate, an improved ant colony algorithm is proposed. For the previous ACO solving process, the range was too wide. Finally, it was decided to introduce a length threshold to delete some invalid data, narrow it down. And then for the pheromone update condition, propose new ways to update pheromones, only if the current path length is valid data, that is, when the path length is less than the length threshold, to update the pheromones, otherwise it doesn't update the pheromones, it speeds up the convergence of the algorithm, it simplifies the calculation.

Take distribution network reconfiguration with distributed energy as an example for simulation, according to the comparative analysis of simulation results, when solving the problem of distribution network reconfiguration with distributed energy, the improved ant colony algorithm proposed in this paper has a faster convergence speed than the traditional ant colony algorithm, it takes less time, the efficiency of the algorithm is improved, can more effectively solve the optimal line, and it's feasible, it is more suitable to solve the problem of distribution network reconfiguration with distributed energy.

The improved ant colony algorithm proposed in this paper only considers the factor of path length, distribution network restructuring is a complex problem, not just by distance, fluctuations in peak power consumption, the distribution of reactive power will affect the path selection during the reconfiguration of distribution network. We're going to look at a number of different factors, how to choose a more appropriate length threshold to improve the universality of the improved ant colony algorithm, expand its application range.

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