Research on IACA of distribution network fault location

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Abstract: In power system, the probability of distribution network failure is the highest, which will directly affect the power consumption experience of customers. The timely and accurate fault location of distribution network is very important to improve the reliability of power supply. In this paper, firstly, the switch function and evaluation function of distribution network fault location are discussed. ACA (Ant Colony Algorithm) algorithm has some defects such as premature convergence. In order to solve this problem, the IACA (Improvement Ant Colony Algorithm) method is proposed. Finally, the feasibility and effectiveness of the new method are verified by establishing a simple distribution network model.

1. Introduction

As the terminal part of power system, distribution network directly faces the electricity users and has the highest failure probability. With the rapid development of economy and society, the request of power reliability and power quality to electricity users becomes increasingly higher than before. When the power system faults occurred in the distribution network, the fast and accurate fault location and restoration of power supply are the key factors of improving power supply reliability.

For China's distribution network automation system, fault location, fault isolation and power recovery are mainly accomplished by feeder automation. However, the development of China's power grid is uneven among provinces, and the development degree of distribution automation is also different. For example, in less developed areas of distribution network automation, power supply companies mainly rely on fault phones and manual inspection of lines to achieve fault location. In the regions where the automation of distribution network is well developed, the fault section is determined mainly by the information collected by RTU and SCADA systems.

The fault processing modes in overhead lines have different ways, and different kinds of equipments are widely used nowadays, such as fault indicators, segmenters and reclosers, feeder terminal units (FTU), remote terminal units (RTU), transformer terminal units (TTU) and so on.

Early fault processing modes do not rely on communication, the principles are simple and the modes are easy to implement. However, the disadvantage of the modes is that the manufacturing capacity of the equipment is required to be higher.

Nowadays, most of the new automation devices widely used rely on intelligent algorithms, such as matrix algorithm and artificial intelligence algorithm, which is more complex than the former algorithm. The advantage of matrix algorithm is suitable for distribution network with simple structure and the principle is not complicated, but the disadvantage of the algorithm is that it has low fault tolerance and depends on the reliability of the equipments.

There are many kinds of artificial intelligence algorithms which are widely used, including particle swarm optimization (PSO), genetic algorithm (GA) and ant colony algorithm (ACA), etc. The PSO is a kind of of uncertain algorithms and does not depend on the strict mathematical properties of the optimization problem itself, but the method is easy to produce premature convergence. Genetic
Algorithm (GA) was first proposed by John Holland in the United States in the 1970s. The Algorithm was designed and proposed according to the evolution law of organisms in nature. It is a computational model of biological evolution that simulates the natural selection and genetic mechanism of Darwinian biological evolution. It is a method of searching the optimal solution by simulating the natural evolution process. Genetic algorithms have been widely used in combinatorial optimization, machine learning, signal processing, adaptive control and artificial life. The advantage of genetic algorithm is that it has the characteristics of group search. Its search process starts from an initial population P(0) with multiple individuals, on the one hand, it can effectively avoid searching some unnecessary points. The disadvantages of genetic algorithm are as follows: the algorithm is prone to irregularities and inaccuracies in coding; The efficiency is usually lower than other traditional optimization methods. Premature convergence is easy to occur.

This paper combines the topology of distribution network, improves ACA, and accurately locates the fault of distribution network.

2. Switching and evaluation function for distribution network fault area

2.1 Switching function
When the overhead distribution line fails, the fault current will flow through the section switch and the interconnection switch between the two lines, and upload to the main distribution station through the communication equipment. The main control station judges the line fault based on the comparison between the actual value of the FTU uploaded by the communication device and the state value pre-stored by the system. If these two values are different, it is considered that the FTU location is not faulty; if the two values are the same, it is considered that the FTU location is faulty.

In this paper, an overhead distribution line model with branch lines is established, and the state value of FTU is represented by a switching function, as shown in Figure 1.

![Switching and evaluation function for distribution network fault area](image)

**Figure.1 A simple distribution network model**

In Figure 1, S denotes the power supply, 1~6 denote the location of FTU, \( V_1 \sim V_6 \) denote the status values of the FTUs, \( a \sim f \) are the sections of the line, \( V_a \sim V_f \) are the status values of these sections. When there is fault current in the line, the status value of the FTU is represented by 1.

The status value of the FTUs is expressed as follows:

\[
\begin{align*}
V_6 & = V_f \\
V_5 & = V_6 \lor V_e = V_e \lor V_f \\
V_4 & = V_d \\
V_3 & = V_4 \lor V_e = V_e \lor V_d \\
V_2 & = V_3 \lor V_b \lor V_b = V_b \lor V_c \lor V_d \lor V_e \lor V_f \\
V_1 & = V_2 \lor V_a = V_a \lor V_b \lor V_c \lor V_d \lor V_e \lor V_f
\end{align*}
\]

(1)

According to equation (1), the following rules can be achieved as follows:
represents the end control point
represents not the end control point
\[ V_i = V_m \]
\[ V_i = V_j \lor V_k \lor \cdots \lor V_Z \lor V_m \]

Where, \( V_m \) is the status value of the line after FTU \( i \), \( V_i \) is the status value of FTU \( i \), \( Z \) is sub-control collection of FTU \( i \).

Assuming two sections of a line are recognized as faults at the same time, only the state value of the fault section closest to the power point is set to 1.

\[ \text{where}, \quad V_m, N, V_j, V_j^* \text{represent the evaluation function value of the } i\text{-th possible solution, the number of control points, the actual status value of } j\text{-th control point and the expected status value, respectively.} \]

\[ \text{Using equation (3) may lead to misjudgment. Thus, based on reference [5], the evaluation function (3) is optimized to the evaluation function (4) to avoid misjudgment.} \]

\[ F = \sum_{j=1}^{N} |V_j - V_j^*| + \omega \sum_{j=1}^{M} |V_i| \]

Where, \( M, V_k^* \) and \( \omega \) are the number of the sections; the status value of section \( k \); the weight, and its value is from 0 to 1, respectively.

3. Improved ant colony algorithm (IACA)

When ant colony algorithm is looking for the optimal solution, it not only needs to expand the search space, but also pay attention to areas with high adaptability. By balancing and optimizing these two aspects, the algorithm can quickly and effectively converge to the optimal state. Considering the idea, the following improvements are done to the ACA of the distribution network fault location.

3.1 Setting of the initial pheromone

The probability of single-point or double-point failure in the distribution network is high, and the initial information element of the distribution network can be set as (assuming the network is divided into \( n \) segments):

\[ a_0 = b_0 = \frac{3}{n} = 1 - \frac{3}{n} \]

Where, \( a_0 \) and \( b_0 \) are the initial pheromone concentration of fault lines and the initial pheromone concentration of non-fault lines, respectively.

The way of dynamic function is to bring the initial information element formula into the evaluation function:

\[ \tau_i(a_0) = \frac{3}{n} \frac{3}{\alpha F_i} \]

\[ \tau_i(b_0) = \left(1 - \frac{3}{n}\right) \frac{3}{\alpha F_i} \]

Where, \( \alpha \) and \( F_i \) are the dynamic adjustment coefficient and the evaluation function of when the \( i\)-th section fails, respectively.

3.2 Update the local pheromone concentration
The probability of choosing fault lines $P_{(a)}$ and $P_{(b)}$ are presented as follows respectively:

$$P_{(a)} = \frac{\tau_{ia}}{\tau_{ia} + \tau_{ib}}$$

$$P_{(b)} = \frac{\tau_{ib}}{\tau_{ia} + \tau_{ib}}$$

The local information element concentration is updated after each ant has walked all the intervals. The update method is:

$$\tau_k = \tau_k + \frac{s}{F} \quad k = 1, 2, \ldots, n$$

$$s = \begin{cases} 
0.005 & n_c \leq 10 \\
0.01 & 10 < n_c < 20 \\
0.015 & n_c \geq 20 
\end{cases}$$

Where, $\tau_k$, $s$ and $n_c$ are the pheromone concentration after partial updating, the pheromone enhancement coefficient, and the iterative number, respectively.

### 3.3 Introducing interference strategy

When the information elements are updated, the use of piecewise function makes the convergence speed faster, but it also leads to premature convergence. The interference strategy is introduced inorder to avoid the problem. When the result of the algorithm is stable at a certain value, the method of randomly selecting the fault part in the optimal path and replacing the part with its adjacent part is adopted. After optimization, a new data path is formed so that the evaluation function can be recalculated. If the result of the original evaluation function is larger than that of the new evaluation function, the new result is regarded as the best path.

### 3.4 Update the global pheromone

At the end of each iteration, if the previous best iteration result is not as good as the new iteration result, the global information element is updated. The updated formula is

$$\tau_u = \rho \tau_u' + \frac{Q}{L} \quad u = 1, 2, \ldots, n$$

$$\rho = \begin{cases} 
0.66 & n_c \leq 10 \\
0.70 & 10 < n_c \leq 20 \\
0.85 & n_c > 20 
\end{cases}$$

$$Q = \begin{cases} 
0.05 & n_c \leq 10 \\
0.06 & 10 < n_c \leq 20 \\
0.15 & n_c > 20 
\end{cases}$$

In the formula, $\tau_u$ is the information element iterated out of the optimal path, $\tau_u'$ is the information element on the best path before updating, $\rho$ is divergence coefficient of information elements, $Q$ is enhancement coefficient of information elements.

### 4. Example

The distribution network is as an example for verification, as shown in Fig. 2. As can be seen, there are 25 nodes for the distribution network.
In order to verify the implementation effect of the optimized ant colony algorithm, single point fault, two-point fault and three-point fault are set in the distribution network. Table 1 shows the fault conditions and calculation results.

![Diagram of a distribution network model](image)

**Figure 2.** 25 nodes in a distribution network model

**Table 1.** The results

| The fault section | The status value of control points | The optimal solution | Output fault section |
|-------------------|-----------------------------------|----------------------|---------------------|
| $f_{13}$ | [1100000000011000000000000000000] | [0000000000010000000000000000000] | V_{13} |
| $f_{12}$ | [11111110001000000000000100] | [0000000000010000000000000000000] | V_{12} V_{23} |
| $f_{8}$ | [11111110001110000001100000000000000] | [0000000010000010000000010000000000] | V_{8} V_{14} V_{21} |

According to the results of Table 1, IACA can accurately determine the single point fault and the more complex multi-point fault of distribution network. Through the actual distribution network example, IACA can be applied in the fault location of distribution network.

**5. Conclusion**

In this paper, firstly, the switch function and evaluation function of distribution network fault location were discussed. ACA algorithm had some defects such as premature convergence. In order to solve this problem, the IACA method was proposed. Finally, the feasibility and effectiveness of the new method were verified by establishing a simple distribution network model.

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