Study of distribution network fault location based on IACA

Xue Liu, Jun Jia and Jian Wang
State Grid Taizhou Power Supply co., Ltd. No. 2 Fenghuang West Road, Hailing District, Taizhou City, Jiangsu Province 225300, China

Abstract: The probability of the distribution network fault is the highest in power network. Correct fault location of distribution network is very important for the reliability of power supply. A simplified model of distribution network is established in the paper. Then the switching function and evaluation function are introduced for distribution network fault location. Because of some defects in fault section location of distribution network in ACA (Ant Colony Algorithm), the IACA (Improvement Ant Colony Algorithm) method is proposed. The results of an example shows that the method was correct and effective.

1. Introduction

Distribution network is the final part of the whole power system which faces the customers directly and the probability of the distribution network fault is the highest in power network. With the development of society, people's demand for reliability of power supply is getting higher and higher. When the distribution network fails, it is very important to improve the reliability of power supply if the fault location can be carried out quickly and accurately and power supply can be restored in time.

At present, fault location, isolation and automatic recovery of power in non-faulty areas mainly rely on distribution automation technology. However, there are significant differences in the application degree of distribution automation among different regions. In areas not covered by distribution automation, power supply companies mainly rely on fault telephone complaints and manual inspection of power lines to achieve fault location. In areas covered by distribution automation, the fault occurrence section judgment is based on the information collected by the RTU and SCADA system.

For overhead line distribution network, there are two main methods of fault location: one is based on recloser and segmenter in early stage, the other is FTU-based fault location, which is widely used nowadays.

The advantages of the former are simple operation and easy to complement, the disadvantages are circuit breakers having more splits and reducing the service life of circuit breakers.

The latter methods are matrix algorithm and artificial intelligence algorithm. The principle of matrix algorithm is simple and the matrix algorithm is suitable for simple distribution network, but the disadvantage of it is poor fault tolerance. Artificial intelligence algorithm has good fault tolerance ability, including genetic algorithm(GA), particle swarm optimization(PSO), ant colony algorithm(ACA), etc. GA is an adaptive heuristic probabilistic global search algorithm and has good robustness. However the method is prone to premature convergence, has large amount of computation and has low computational efficiency. ACA forms the optimal path through the accumulation and update of pheromone, has positive feedback function and self-heuristic search, and can avoid the premature of the algorithm. But the algorithm is easy to trap into local optimum.

The paper combines the topology of the distribution network, improves the ACA, and accurately locates the distribution network faults.
2. Switching function and evaluation function for distribution network fault location

2.1 Switching function

When the distribution network fails, fault current will be detected in segmented switches and contact switches on distribution lines and will be uploaded to the main control station. The positioning program in the main control station has stored the status values of FTU in various fault situations, and compares the uploaded detection value with the pre-stored state value. If the two values are identical, judging that the location is faulty.

The paper uses switching function to determine the status value of the control points by a simple distribution network model shown in Figure.1.

![Figure.1 A simple distribution network model](image)

In Figure.1, $S$ is the power supply, 1~6 are the control points, $V_1$~$V_6$ are the status values of the control points, $a$~$f$ are the sections of the line, $V_a$~$V_f$ are the status values of these sections. The status value is 1 representing that the control point or the section have fault current.

The status value of the control points is shown in formula (1):

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

(1)

From formula (1), the following rules can be obtained:

$$
\begin{align*}
V_i &= V_m & i \text{ is the end control point} \\
V_i &= V_j \lor V_k \ldots \lor V_Z \lor V_m & i \text{ is not the end control point}
\end{align*}
$$

(2)

In the formula, $V_m$ is the status value of the downstream segment of control point $i$, $V_i$ is the status value of control point $i$, $Z$ is sub-control collection of control point $i$.

If two sections of a line are simultaneously identified as faults, only set the status value of the fault section closest to the power supply point to 1.

2.2 Evaluation function

The evaluation function can reflect the deviation between the hypothetical fault situation and the actual fault information transmitted by FTU. The optimal solution is obtained by evaluating various possible solutions through evaluation function. The evaluation function can be expressed as:

$$
F_i = \sum_{j=1}^{N} |V_j - V_j^*|
$$

(3)

In the formula, $F_i$ is the evaluation function value of the $i$-th possible solution, $N$ is the number of control points, $V_j$ is the actual status value of $j$-th control point, $V_j^*$ is the expected status value.
There is a possibility of misjudgment by using formula (3). So according to reference [5], establishing the evaluation function (4) to avoid misjudgement.

$$F = \sum_{j=1}^{N} |V_j - V'_j| + \omega \sum_{j=1}^{M} |V'_j|$$  \hspace{1cm} (4)

In the formula, $M$ is the number of the sections; $V'_k$ is the status value of section $k$; $\omega$ is the weight, and its value is from 0 to 1.

3. Improved ant colony algorithm (IACA)

When ACA is searching for optimal solution, the method wants to expand the searching space, but also wants to focus on areas with high fitness. By balancing the two aspects, the algorithm can converge to global optimum efficiently. Based on the idea, the paper makes the following improvements to the ACA of the distribution network fault location.

3.1 Setting of the initial pheromone

The faults in distribution network are mostly single-point or double-point faults, the initial pheromones of distribution network including $n$ sections can be set as:

$$a_0 = b_0 = \frac{3}{n} = 1 - \frac{3}{n}$$  \hspace{1cm} (5)

In the formula, $a_0$ is the initial pheromone concentration of fault lines, $b_0$ is the initial pheromone concentration of non-fault lines.

Bring the evaluation function into the initial pheromone formula to construct dynamic function shown as:

$$\tau_i(a_0) = \frac{3}{n} \cdot \frac{3}{\alpha F_i}$$  \hspace{1cm} (6)

$$\tau_i(b_0) = \left(1 - \frac{3}{n}\right) \cdot \frac{3}{\alpha F_i}$$  \hspace{1cm} (7)

In the formula, $\alpha$ is the dynamic adjustment coefficient; $F_i$ is the evaluation function of when the $i$-th section fails.

3.2 Update the local pheromone concentration

The probability of choosing fault lines $P_{i(a)}$ is shown as:

$$P_{i(a)} = \frac{\tau_{ia}}{\tau_{ia} + \tau_{ib}}$$  \hspace{1cm} (8)

The probability of choosing fault lines $P_{i(b)}$ is shown as:

$$P_{i(b)} = \frac{\tau_{ib}}{\tau_{ia} + \tau_{ib}}$$  \hspace{1cm} (9)

After each ant has completed the section between all the control points, update the local pheromone concentration, the method is shown as:

$$\begin{align*}
\tau_k &= \tau_k + \frac{s}{F} \\
&= \begin{cases} 
0.005 & n_c \leq 10 \\
0.01 & 10 < n_c < 20 \\
0.015 & n_c \geq 20 
\end{cases} 
\end{align*}$$  \hspace{1cm} (10)

In the formula, $\tau_k$ is the pheromone concentration after local updating, $s$ is the pheromone enhancement coefficient, $n_c$ is the iterative number.
3.3 Introducing interference strategy
When updating pheromones, piecewise function is used and convergence rate is accelerated, however, it brings about the problem of premature convergence. To avoid this problem, interference strategy is introduced. When the solution of the algorithm is stable at a value, randomly select a fault section in the optimal path and replace the section with its adjacent section. So a new path is formed, recalculate the evaluation function. If the value of the new evaluation function is less than the original solution, it is updated to the optimal path.

3.4 Update the global pheromone
At the end of each iteration, if the result of this iteration is better than the previous optimal solution, Then the global pheromone update is

\[
\tau_u = \rho \tau_u + \frac{Q}{L}, \quad u = 1, 2, \cdots, n
\]

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

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

In the formula, \(\tau_u\) is the pheromones on the optimal path of this iteration, \(\tau_u'\) is the pheromones on the optimal path before updating, \(\rho\) is the pheromone volatilization coefficient, \(Q\) is the pheromone enhancement coefficient.

4. Example
Take the distribution network as an example for verification shown in Figure 2. In the figure, \(T\) is power supply, and the distribution network has 25 nodes.

To verify the effectiveness of the method of the paper, set single point fault, two point fault and three point fault to the distribution network. The fault conditions and calculation results are shown in Table 1.

![Figure 2 A distribution network model with 25 nodes](image)

Table 1 The results of the example

| The fault section | The status value of control points | The optimal solution | Output fault section |
|------------------|----------------------------------|----------------------|---------------------|
| \(f_{13}\) | \{1100000000001110000000000000\} | \{000000000000001000000000000\} | \(V_{13}\) |
| \(f_{12}, f_{23}\) | \{1111111100110000000000100\} | \{000000000000001000000000000\} | \(V_{12}, V_{23}\) |
| \(f_{8}, f_{14}, f_{21}\) | \{1111111111110000011000000000\} | \{000000000000001000000000000\} | \(V_{8}, V_{14}, V_{21}\) |

From Table 1, whether it is a single point fault or multiple points fault, the IACA can determine the
fault accurately. The IACA is feasible in fault location of distribution network.

5. Conclusion
A simplified model of distribution network was established in the paper. Then the switching function and evaluation function were introduced for distribution network fault location. Because of some defects in fault section location of distribution network in ACA, the IACA method was proposed. The results of an example showed that the method was correct and effective.

References
[1] W. Qiu, M. Jia, W. Wang. Application of the improved ant colony algorithm to distribution network fault location[J]. Shandong Electric Power, 2017, 44 (8):19-22.
[2] D. Shan, L. Zhang. Fault location system of distribution network based on ant colony algorithm[J]. Information Technology, 2019, 6:87-90.
[3] Q. Zhao, B. Zhang, S. Lyu, et al. A CNN-SIFT hybrid pedestrian navigation method based on First-Person vision [J]. Remote Sensing, 2018, 10(8) : 1229.
[4] Z. Xiao, H. Lu, D. Wang. L2-RLS-Based Object Tracking[J]. IEEE Trans. Circuits Syst. Video Techn, 2014, 24(8):1301 – 1309.
[5] Z. Wei, H. He, Y. Zheng. A Refined genetic algorithm for the fault sections location, 2002, 22(4):127-130.
[6] F. Kan, R. Ju, Y. Ju. The Research of Ant Colony Algorithm in Distribution Network Fault Location[J]. Electric Technology, 2015, 3: 40-44.
[7] Z. Wu, W. Cui, Yu Long, et al. Post evaluation and rationality analysis of distribution network investment [J]. Proceedings of the CSU – EPSA, 2016, 28(12) :96 - 102.
[8] Z. He, S. Yi, Y. Cheng, et al. Robust object tracking via key patch sparse representation[J]. IEEE transactions on cybernetics, 2017, 47(2):354-364