Fast Fault Location Method for Power Distribution Systems Based on Multi-source Information Fusion Technology

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Abstract. Considering that the information uploaded by distribution terminal is often lost or wrong in actual operation, which leads to misjudgement, this paper proposes a new fault location method based on multi-source information fusion technology. The advantage of this method is that multi-source information is used for fault location, which can avoid misjudgement caused by an abnormality of single source information. Firstly, the information uploaded from the remote terminal unit of the distribution automation system is used, and the user complaint information is converted into binary information. The fault information is formed based on the improved binary particle swarm optimization algorithm, and then the improved D-S evidence theory is used to fuse the positioning results of each fault information to obtain the final positioning result. The case study shows that the proposed method is effective and feasible, and can solve the problem when multi-source heterogeneous fault information has unrecognizable anomalies.

1. Introduction
Power distribution systems fault location is one of the important contents to realize distribution automation. At present, there are three main ways to locate faults in the power distribution systems, including using the distribution automation system, using fault indicator positioning, and using telephone complaint system positioning. After the power distribution systems fail, there are many systems for collecting fault information, and the types of information sent to the main station are numerous and complicated. How to mine fault information from massive, multi-source and heterogeneous information, obtain fault location results quickly and accurately, then give fault recovery opinions, and realize closed-loop control of fault location, isolation and recovery, which is still a problem to be solved.

At present, there are two main types of power distribution systems fault location methods: direct methods and indirect methods. Direct methods include the impedance-based method or traveling waves-based method [1-2], methods based on information from distribution automation terminals [3], fault location based on the voltage sag information [4], methods based on trouble calls from customers [5]. Indirect methods are various types of intelligent algorithms. Most of these methods use only one source of information for fault location, but a single source of information has its own drawbacks. A positioning error can result when information is lost or information is incorrect.

Based on the distribution automation information and user complaint information, this paper proposes a fast fault location method based on multi-source information fusion technology. The method of this paper solves the problem of mis-reporting or loss of information of power distribution terminal at key locations through multi-source information fusion technology, which can greatly
improve the tolerance of fault location in the power distribution systems. It is of great significance for shortening the blackout time, reducing the power outage range and improving the reliability of power supply, and is also the trend of the development of smart power distribution systems in the future.

2. The basic principle of binary particle swarm optimization

2.1. Basic principles of PSO algorithm

Particle swarm optimization (PSO) is a new intelligent optimization algorithm [6]. Suppose that in an N-dimensional search space, the position and flying speed of the ith example is $X_i$ and $V_i$ respectively, then the best position of each particle is denoted as $P_{best,i}$, and the best position of all particles in the group is denoted as $G_{best}$. For each iterative process, the particle updates its position and speed according to equation (1), as in

$$v_{in}^{m+1} = \omega v_{in}^m + c_1 r_1^m (P_{best,in}^m - x_{in}^m) + c_2 r_2^m (g_{best,in}^m - x_{in}^m)$$

where $x_{in}^m$ and $v_{in}^m$ are the position and velocity of particle $i$ in the $n$th dimensional space at the $(m+1)\text{th}$ iteration; $\omega$ is the inertia weight; $c_1$ and $c_2$ are the acceleration factors, both are positive real numbers; $r_1^m$ and $r_2^m$ is a generated random number between [0,1]; $P_{best,in}^m$ is the optimal individual particle position found in the $n$th dimensional space until the particle $i$ is iterated to the $m$th time, $g_{best,in}^m$ is the optimal individual particle position found in the $n$th dimensional space until the particle $i$ is iterated to the $m$th time.

2.2. Improvement of PSO algorithm

The above PSO algorithm is mainly for continuous function optimization problems. In order to solve the optimization problem of discrete or binary variables, this paper adopts an improved binary particle swarm optimization algorithm. In the binary particle swarm algorithm (BPSO) [7], the value of each $x_{in}^m$ of each particle in the state space is 0 or 1, and $v_{in}^m$ is the probability that $x_{in}^m$ takes 1. Calculate $v_{in}^m$ in equation (1) according to the following equation.

$$\begin{cases} x_{in}^{m+1} = 1 & r_{in}^{m+1} < \text{sigmoid}(v_{in}^m) \\ x_{in}^{m+1} = 0 & r_{in}^{m+1} \geq \text{sigmoid}(v_{in}^m) \end{cases}$$

$r_{in}^{m+1}$ in equation (2) is a generated random number between [0,1]. $\text{sigmoid}(v_{in}^m) = 1/(1 + e^{-v_{in}^m})$.

3. Basic principle of multi-source information fusion

Dempster-Shafer evidence theory (D-S evidence theory) is currently the most commonly used method in the field of information fusion. It is based on set theory and provides a method of evidence synthesis. It can fuse evidence provided by multiple evidence sources to make decision results more accurate.

3.1. The Basic definition of D-S evidence theory

The D-S evidence theory is based on the identification framework. For a problem, a collection containing all possible outcomes is called an identity framework, generally represented by $\Theta$, and $\Theta$ is a non-empty set. For any kind of recognition result, it can be represented by a subset of $\Theta$. For all possible subsets of $\Theta$, the set is called the power set and is recorded as $2^{\Theta}$.

3.2. Basic Probability Assignment

Basic probability assignment (BPA) is an important concept in evidence theory. The basic probability assignment is a mapping from the power set to the interval number $[0,1]$, such as $m: 2^{\Theta} \rightarrow [0,1]$. The basic probability assignment for a set $A$ is denoted as $m(A)$, which represents the degree of trust of
evidence $A$ rather than any subset of $A$. Other evidence supporting a subset of $A$ should be expressed as other BPAs. For example, for $B \subseteq A$, $m(B)$ represents the BPA of subset $B$, which has the following properties.

$$m(\emptyset) = 0$$

$$\sum_{A \subseteq 2^\Omega} m(A) = 1$$

### 3.3. The rule of D-S evidence theory fusion

The D-S synthesis is a rule that reflects the combined effect of evidence. Given several trust functions based on different evidence on the same recognition framework, if the evidence is not completely conflicted, a new trust function can be calculated using the D-S synthesis rule [8]. The synthesis formula is as shown in equation (5).

$$m(A) = \begin{cases} 
\frac{1}{1-K} \sum_{A_1 \cap A_2 = A} m_1(A_1) \cdot m_2(A_2) & A \neq \emptyset \\
0 & A = \emptyset 
\end{cases}$$

$$K = \sum_{A_1 \cap A_2 \neq \emptyset} m_1(A_1) \cdot m_2(A_2)$$

In equation (6), $K$ represents the conflict coefficient, and $K = 0$ represents no conflict, which is evidence of consistency. When $K \to 1$, the evidence is highly conflicting.

### 4. Fault location method based on D-S evidence theory

The fault information of the power distribution systems cannot directly use the D-S evidence theory for information fusion. It is necessary to process the fault information and construct a basic probability distribution function. In this paper, the binary particle swarm optimization algorithm is used to process the fault information, and the evidence used for information fusion is obtained.

#### 4.1. Using the information of distribution terminals to form the evidence

After the power distribution systems fail, the power distribution terminal installed at the head of each section can monitor the fault current. After comparing with the fault current setting value, discrete fault information is formed. Because the fault information uploaded by each power distribution terminal to the dispatching master station is a discrete 0-1 signal, the BPSO is used for global optimization to achieve fault location.

Therefore, the rational design of the evaluation function is the key to the accurate positioning of the power distribution systems faults by using the optimization algorithm [9]. The evaluation function used in this paper is as shown in equation (7) and equation (8).

$$F_i(A) = \sum_{j=1}^{N} |I_j - I_j'(A)| + \omega \sum_{j=1}^{N} |A(j,i)|$$

$$A_j'(S) = \prod_{i=1}^{N} D_i$$

In the equation (7) and equation (8): $I_j$ is the actual fault information uploaded by the power distribution terminal of the $j^{th}$ segment. $I_j'(A)$ is the desired state of each switch node. $N$ is the total number of feeder segments in the distribution network. $\omega \sum_{j=1}^{N} |A(j,i)|$ represents the total number of faulty segments that have occurred, in this article $\omega$ takes 0.5. $D_i$ represents the status value of all devices located downstream of the power distribution terminal.

After the function converges, the total number of times each particle appears and the final convergence result are normalized according to equation (9). Finally, it is possible to obtain a basic
probability distribution that can be used for information fusion by using distribution terminal information.

\[ m_i(r_i) = \frac{c_i(r_i)}{c_1(r_1) + c_2(r_2) + \cdots + c_N(r_N)} \quad i = 1, 2, 3 \cdots N \]  

(9)

In equation (9), \( m_i(r_i) \) is the basic probability distribution function, \( r_i \) is the particle in the particle group, and \( N \) is the number of selected optimal particles.

4.2. Using the information of power customer service system to form the evidence

After the fault occurs, the segment switch action isolates the fault area, and the isolated area loses power. The user will report the power outage to the power department. When a phone complaint is received, it is determined which phone point the user complains to which load point. The load point for receiving the complaint information is 1 and the load point for not receiving the complaint information is 0. At this point, the state solution of the N-segment feeder segment can also be transformed into an N-dimensional particle swarm optimization solution, but the evaluation function needs to be modified, as in:

\[ F_z(S) = \sum_{j=1}^{N_S} |B_j - B_j'(S)| + \omega \sum_{i=1}^{N_L} |S(i)| \]  

(10)

\[ B_j'(S) = \prod_{i=1}^{L_j} L_i \]  

(11)

\( B_j \) is the relevant information of the load point. \( B_j'(S) \) represents information of the load point determined by each particle vector, and its value is determined by (11). \( L_j \) represents the state corresponding to each section of the minimum path from the power supply to the load point. After the BPSO algorithm is optimized, the values of each particle and its number of occurrences in the iterative process can also be obtained. According to (12), the basic probability distribution formed by the power customer service system can be obtained.

\[ m_z(r_i) = \frac{c_2(r_i)}{c_1(r_1) + c_2(r_2) + \cdots + c_N(r_N)} \quad i = 1, 2, 3 \cdots N \]  

(12)

5. Case study

The feeder shown in figure 1 verifies the proposed fault location method, and the program of BPSO and multi-source information fusion is written by MATLAB. In the BPSO algorithm, the test records the number of occurrences of the same particle in the iterative process is recorded, and each particle value and its concentration value are output. The parameters are set as follows: the search space dimension is 15, the particle swarm size is 100, the maximum number of iterations is 100, and \( c_1 = c_2 = 1.494 \). In the D-S evidence theory, \( N \) is 6, that is, each evidence body selects the first six segment sets with the largest basic probability distribution, and these segment sets are used as the recognition frame \( \Theta \).

![Figure 1. Structure of power distribution system](image_url)
In figure 1, the feeders are divided into 16 sections. The first section of each line is equipped with a power distribution terminal (FTU or fault indicator with communication function), which can upload fault information to the master station. And there are 9 load points in the figure. Users at the load point can complain to the power customer service system and can locate faults based on these complaints. Assume that the interphase short circuit fault occurs in section (7,16), test the positioning result under the condition that the fault information is complete and part of the fault information is distorted. Since the initial population is randomly generated, each iteration process will be different. Therefore, the program is run continuously 2000 times, and the number of iterations of the result is counted as shown in Table 1.

**Table 1.** Multi-point fault location information.

| Input of distribution automation system | Test Result | Number of Iterations | Input of power customer service system | Test Result | Number of Iterations |
|----------------------------------------|-------------|----------------------|----------------------------------------|-------------|----------------------|
| 10110010010000001                      | 00000100000000001 | 1004                   | 01001000000000001                   | 012070      | 964                  |
| 1011001001000001                      | 00000000000000001 | 67                     | 01001000000000001                   | 964         | 147                  |
| 1011001001000001                      | 00000100000000000 | 79                     | 01000100000000001                   | 964         | 19                   |
| 10110000010000001                      | 00000100000000001 | 112                    | 01000000000000000                   | 964         | 361                  |
| 10110000010000001                      | 01000000000000000 | 241                    | 01000000000000000                   | 964         | 11                   |
| 10110010010000000                      | 00000100000000001 | 123                    | 01000000000000000                   | 964         | 68                   |
| 10110010010000000                      | 00000000000000001 | 334                    | 01000000000000000                   | 964         | 356                  |
| 10110000010000000                      | 00000100000000001 | 4                      | 01000000000000000                   | 964         | 61                   |
| 10110000010000000                      | 01000000000000000 | 47                     | 01000000000000000                   | 964         | 13                   |

When the power distribution terminals (FTU, fault indicator, etc.) of all sections work normally, that is, when the initial population $I_j$ is 10110010010000001, considering all types of user complaint information, the fault section set and its basic probability assignment can be obtained as shown in Table 2.

**Table 2.** Multi-point fault location result when information is complete.

| Sort of Possibilities | Fault section | $m_1$  | $m_2$  | Fusion result |
|-----------------------|---------------|--------|--------|---------------|
| 1                     | 7,16          | 0.8730 | 0.4405 | 0.8562        |
| 2                     | 7             | 0.0687 | 0.1805 | 0.0842        |
| 3                     | 16            | 0.0583 | 0.1780 | 0.0326        |
| 4                     | 7,10          | 0.0089 | 0.4121 | 0.0253        |
| 5                     | 3,7           | 0.0078 | 0.0293 | 0.0017        |

When the distribution terminal of the key part fails to report or misreport, considering all types of user complaint information, the fault section set and its basic probability assignment can be obtained as shown in Table 3.
Table 3. Multi-point fault location result when information is missing.

| Sort of Possibilities | Fault Section | $m_1$   | $m_2$   | Fusion Result |
|-----------------------|---------------|---------|---------|---------------|
| 1                     | 3,10          | 0.6812  | 0.0014  | 0.2054        |
| 2                     | 7,16          | 0.2764  | 0.4405  | 0.6842        |
| 3                     | 7,10          | 0.0274  | 0.4121  | 0.1326        |
| 4                     | 7             | 0.0389  | 0.4121  | 0.0263        |
| 5                     | 10            | 0.0154  | 0.1298  | 0.0199        |
| 6                     | 3,7           | 0.0059  | 0.0293  | 0.0016        |

Due to multiple key location information errors, the results of a single source location will get incorrect conclusions. After the multi-information source fusion, the conflict evidence can be re-modified and re-fused to obtain a reliable decision result. In this case, it is judged that the segment (7,16) is faulty, and the actual situation is reflected in the advantages of multi-information fusion.

6. Conclusion
In the actual operation of the site, the fault information uploaded by the distribution terminal is often not accurate enough. The existing fault segment location intelligent algorithm has certain fault tolerance, but when the information of the power distribution terminal in the key location is incorrect or there is a large number of missed reports, it often causes misjudgement, which affects the process of fault isolation and fault recovery. The fault location method based on multi-information source fusion technology proposed in this paper comprehensively utilizes the information of distribution automation system and the information of power customer service system, which makes fault location more rapid, accurate and efficient, and can still be used in extreme cases of critical information errors and get the correct result.

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