Fault Location Method of Distribution Network Based on FTU Information Comparison and Search

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Abstract. This paper analyses the characteristics of common methods of fault location using feeder terminal unit (FTU) in AC distribution network. When missing report and false alarm of FTU happen, the matrix method will be wrong, although the intelligent optimization algorithm has a certain fault tolerance rate, but it is easy to fall into local convergence and achieve more complexity. Aiming at the above problems, this paper presents a comparative information search method, obtained by using the distribution network topology of the FTU reservation information compared with the actual reporting information, fault calculation similarity of each area, so as to search the most similar regional information reporting information and reservation, which can effectively reduce the fault location time and improve the accuracy of fault location finally, the normal operation of the distribution network will come. It simulates the single fault of each region in a 5 power distribution system, and the introduction of conditional probability to achieve the missing report and false alarm of FTU, after checking a lot and systematically, it proves that the method is simple and effective, and has a high fault tolerance rate.

1. Introduction
Fault location in distribution network plays an important role in ensuring the quality of power supply and improving the reliability of the system. With the improvement of the automation level in the distribution network, a large number of automatic terminal devices, such as feeder terminal unit (FTU), are applied to the distribution network. When faults happen, FTU uploads the fault information, such as the magnitude and direction of the fault current, the fault voltage and the fault time, and the switch state messages, and the main station passes the corresponding fault determination. The location method is used to process information and locate the fault area, which effectively improves the speed and accuracy of fault location. But because most of the FTU is installed outdoors, there are many unfavorable factors, such as bad environment, electromagnetic interference, communication error, and the misjudgement of hardware in FTU, which can cause the distortion or lack of the fault information uploaded by FTU, which leads to fault location error and affects the safe operation of the system [1].

At present, there are two ways to locate fault location using FTU information: direct algorithm and indirect algorithm. The two algorithms usually use FTU to detect the overcurrent to determine whether there is a fault in the area, and then use the corresponding algorithm to locate the fault.
The most typical algorithm of the direct algorithm is the matrix algorithm. According to the network topology and the fault information uploaded by the FTU, the network topology matrix and the fault information matrix are obtained. Then the fault determination matrix is deduced and the fault section is determined. Reference [2] considers the direction of fault current and redefines the fault information matrix, which can be applied to the complex situation of multiple power multiple faults, but it has the same amount of calculation and can’t judge the fault of the terminal. The new matrix algorithm proposed in reference [3] is applicable to multiple power systems. The principle of judgment is simple, intuitive, and the computation speed is fast. The above algorithm requires high accuracy for uploading information from FTU. In the face of FTU omission and false positives, false location is inevitable.

The indirect algorithm forms the evaluation function based on the fault current information reported in FTU and the topology structure of the distribution network, and then uses the intelligent optimization algorithm to find the optimal solution of the evaluation function and realize the fault location. Reference [4] uses genetic algorithm to solve the evaluation function. The algorithm is simple and has the ability of global search. But the efficiency is low, and the selection of the parameters depends mostly on the experience. It is easy to fall into "precocious" in the face of large-scale computation. Reference [5] is solved by ant colony algorithm. It has strong robustness and good search ability, but its convergence speed is slow, and it is easy to fall into local optimum.

Therefore, in order to solve the problem that the fault tolerance rate of the matrix method is low, the intelligent algorithm is complicated and easy to fall into local convergence, this paper proposes a fault location method based on the comparison search using the information of FTU, and compares the overcurrent information matrix uploaded by the FTU fault with the overcurrent information matrix formed according to the network topology, then carries out the whole area search to realize the fault location. The condition probability is introduced to simulate the situation of FTU false report and false alarm, and the calculation method of the similarity value of the fault area and the scheme to improve the accuracy of the location are proposed, which can reduce the influence of the false report error of the FTU. The accuracy and feasibility of the method are proved by extensive simulation checking on MATLAB.

2. Research method of fault location

2.1. Summary

Because most of the faults in distribution network are single faults, and this method focuses on FTU’s missing report and false alarm. If we consider multiple faults and FTU’s omission and false reports, we will have high uncertainty and lead to fault location errors.

According to the distribution network topology of Fig.1, the circuit breaker, segment switch and contact switch in the network are looked as nodes and numbered, such as the number 1-5; the area between the switches is numbered, and the letter is A-D; the traditional power is numbered for G1 and G2. The positive direction of the distribution network is determined. For the single power network, the positive direction of the network is the direction of the power outflow of the power supply. For the complex distribution network of multi power supply, a reference power is needed. The positive direction of the network is the direction of the power flow from the assumed power to the whole network. Select G1 as the reference power, and get the positive direction of the network as shown in Figure 1 arrow.

The fault location method is as follows: according to the topology of distribution network in Figure 1, the ideal fault information matrix D, which is reported by FTU when a single heavy fault occurs in each section, can be obtained and stored in the control master station. After the fault of the distribution
network, the fault current can be detected by the FTU installed in the circuit breakers, the segment switch and the contact switch, and uploads it to the control master station to form the information matrix G. The discriminant matrix P is obtained by the Eq. (1):

\[ P = D - G \]  

By judging the information in P, the fault area can be obtained, but the actual running FTU is affected by various factors, which leads to the error of the information matrix G. Therefore, in view of these problems, a function of similarity value calculation is constructed to describe the similarity between the actual information of FTU reporting and the ideal information of various regional faults, and then through the search in the whole region, the solution of the condition is obtained and the fault area is obtained.

2.2. The ideal fault information matrix D

When the overflow information is measured by FTU and is the same as the positive direction of the network, 1 is reported to the control main station; when the overflow information is measured by FTU, and when the network is the opposite direction, -1 is reported; when FTU has not detected the overflow information, 0 is reported.

In turn, a regional fault is assumed, and the amount of information reported in the FTU ideal at this time is obtained. For example, if the region a of Fig. 1 is faulty, the signal uploaded by FTU is 1, -1, -1, -1 and -1 in turn, and the ideal fault information matrix D can be formed after obtaining the information amount of the single heavy fault in all regions. The line mark of matrix D represents each area. The data of each row is the overflow information of each FTU in a region fault; the mark represents each FTU, and each column is the overflow information of a certain FTU for each area fault, that is:

\[ D(i, j) = d(j) \]  

Where \( D(i, j) \) is the information uploaded by FTU \( j \) when the area \( i \) has a fault, and \( d(j) \) is the ideal information uploaded by FTU \( j \).

According to Eq. (2), the matrix D formed by the distribution network in Fig.1 is as follows:

\[
D = \begin{bmatrix}
1 & -1 & -1 & -1 & -1 \\
1 & 1 & -1 & -1 & -1 \\
1 & 1 & 1 & -1 & -1 \\
1 & 1 & 1 & 1 & -1 \\
1 & 1 & 1 & 1 & 1
\end{bmatrix}
\]  

(3)

The data of the upper first column and the fifth column remain unchanged, because the amount of information reported on the FTU most close to the reference source is 1 regardless of the fault in any area; the amount of information reported by the FTU closest to the non-reference power is -1. These redundant information can’t help distinguish the fault area, so when the matrix D is formed, it can be deleted to reduce the dimension of the matrix. In order to form a square, this paper makes it easy to watch and only preserves the amount of information reported on the FTU most close to the reference source. Therefore, the first column is retained, the fifth column is deleted, and the matrix D is obtained, as shown in the following Eq. (4). In the case of more power supply, the FTU information which is closest to the reference source can be retained, and the information reported by the FTU which is closest to the non-reference power is deleted, and the redundancy is reduced and the square array is formed.

\[
D = \begin{bmatrix}
1 & -1 & -1 & -1 \\
1 & 1 & -1 & -1 \\
1 & 1 & 1 & -1 \\
1 & 1 & 1 & 1 \\
1 & 1 & 1 & 1
\end{bmatrix}
\]  

(4)

2.3. The information matrix G
In the actual operation, FTU also determines the overcurrent information and uploads according to the 
1.2, which is not the same as the dimension of the ideal fault information matrix D. In order to get the 
judgment matrix P, the amount of fault information will be extended in the main station, so that every 
element of the matrix G is equal to the actual information of the FTU, the number of rows of matrix G 
is equal to the number of the distribution network, the FTU corresponding to each column of matrix G 
and the FTU corresponding to the matrix D are the same, so that the ranks of the matrix G are the ranks 
of the matrix D. The number is the same that of the matrix D, which is shown in Eq. (5). The matrix 
G in this paper, like the matrix D, preserves only the FTU information closest to the reference power 
and removes the information that is closest to the FTU of the non-reference power source.

\[ G(m, j) = G(n, j) = g(j) \]  

Where \( G(m, j) \) is information uploaded by FTU \( j \) in the line \( m \), \( G(n, j) \) is information uploaded by 
FTU \( j \) in the line \( n \), and \( g(j) \) is the actual information uploaded by FTU \( j \).

When the area \( c \) fails in Fig. 1, the information reported by FTU is 1, 1, 1, and -1 in turn. According 
to the Eq. (5), the matrix G is shown as follows:

\[
\begin{bmatrix}
1 & 1 & 1 & -1 \\
1 & 1 & 1 & -1 \\
1 & 1 & 1 & -1 \\
1 & 1 & 1 & -1 \\
\end{bmatrix}
\]  

\[ (6) \]

2.4. The discriminant matrix \( P \)
The matrix \( P \) is based on Eq. (1), and according to the meaning of the matrix D’s row and column, P's 
row labels represent each region, and the column labels represent each FTU. If the region \( c \) in Fig. 1 has 
a fault, the matrix \( P \) at this time is as follows:

\[
\begin{bmatrix}
0 & -2 & -2 & 0 \\
0 & 0 & -2 & 0 \\
0 & 0 & 0 & 0 \\
0 & 0 & 0 & -2 \\
\end{bmatrix}
\]  

\[ (7) \]

When FTU does not have the missing report and false alarm, the information in the ideal report 
should be consistent with the actual amount of information, so the area of the line corresponding to the 
0 element in the matrix \( P \) is the fault area. The third rows in Eq. (7) are all 0, that is, the corresponding 
area \( c \) fails.

The actual operation of FTU is affected by various factors. It is easy to miss the report and false 
report, resulting that \( G \) is wrong and there is no row whose elements are all 0 in \( P \). The similarity between 
the actual amount of information reported in FTU and the amount of information that is reserved in this 
area is still the highest, so the sum of the element absolute values of the lines representing the fault areas 
in the matrix \( P \) may be the least. According to the above analysis, the calculation method of similarity 
value is put forward, the absolute value of each element in the matrix \( P \) and the similarity value of each 
region are calculated, and the corresponding region of the line with the smallest similarity is the fault 
area, which is to satisfy the condition.

\[
\sum_{j=1}^{n} |p_{x,j}| = \min \sum_{j=1}^{m} |p_{x,j}| 
\]  

\[ (8) \]

Where \( p_{i,j} \) is the element of row \( i \) and column \( j \) in matrix \( P \), \( m \) is the number of regions, \( n \) is the 
number of FTU reported, \( x \) is the amount to be solved. The corresponding area of row \( x \) is the fault area.
3. The conditional probability of FTU misreporting and omissive reporting

In the previous literature, when discussing the influence of FTU misreporting on its methods, there is no systematic demonstration, and the FTU of misreporting is chosen by human beings, and the simulation examples are less. It is difficult to verify the influence of the randomness of false report on its method.

In view of the above problems, we need to make FTU omission and false positives happen randomly instead of human control, so we introduce conditional probability. When FTU needs to report 1 or -1, there is a missing report according to probability; when FTU needs to report to 0, false positives happen according to probability, and the conditional probability is shown in the following Eq. (9) - (11). The specific parameter design is given in the algorithm verification.

\[
\begin{align*}
P(g(j)=1|d(j)=1) &= a \\
P(g(j)=0|d(j)=1) &= b \\
P(g(j)=-1|d(j)=-1) &= c \\
P(g(j)=0|d(j)=-1) &= d \\
P(g(j)=0|d(j)=0) &= e \\
P(g(j)=1|d(j)=0) &= f \\
P(g(j)=-1|d(j)=0) &= g
\end{align*}
\]

(9)

(10)

(11)

Each FTU has a certain probability of missing and false reports. Taking Eq. (9) as an example, when FTU needs to be reported to 1, probability \(a\) will correctly report information 1, but there is a probability of \(b\) missing report and uploading 0.

By introducing this condition, the missing reports and false positives of all FTU can be completely realized according to probability, and a large number of simulation checking computations can be carried out. Statistics of a large number of simulation results, the final accuracy of the fault location is more credible.

4. Simulation verification

To verify that the proposed algorithm can be applied to multi section complex distribution network, the five power distribution network, as shown in Figure 1, contains 30 nodes and 26 regions, in which \(G_1-G_5\) is a traditional power supply, and the number 1-30 is a circuit breaker, a segment switch, a contact switch with FTU, and the alphabet \(a-z\) as the required location. Set \(G_1\) as the reference power, and draw the positive direction of the network as shown in the diagram.

![Fig.2 Structure diagram of 30 node distribution network](image)

Conditional probability is introduced to simulate and verify the randomness of FTU missing and false positives. In the simulation, the parameters in the Eq. (9) - (11) are set as follows: \(a=0.9\), \(b=0.1\), \(c=0.9\), \(d=0.1\), \(e=0.9\), \(f=0.05\), \(g=0.05\).
A large number of checking shows that the accuracy rate of the fault region is still high when the false alarm is missed in FTU, but it is still possible to increase the correct rate by expanding the fault area. In fact, although the probability of misreporting of single FTU is not high, as the complexity of network topology increases and the number of measurement and control points increases, the probability of error is very high in all information reported in FTU, which will greatly affect the accuracy of fault location. Therefore, after getting the matrix Sum, it is possible to search several regions with the smallest similarity value as possible fault regions, and to ensure the correct fault interval through the expansion of the fault interval.

5. Conclusion
In this paper, a fault location method for distribution network based on FTU information comparison search is proposed. The fault location is searched by comparing the overcurrent information matrix uploaded by FTU and the ideal information matrix formed according to the network topology. Aiming at the problem of FTU missing report and false alarm, we introduce conditional probability to achieve missing report and false report, and propose a correction method for calculating similarity values. By searching for the minimum value of similarity, the whole area is searched to identify the fault area. This method is simple and efficient, and has higher fault tolerance than matrix method, and does not need complex iteration of artificial intelligence algorithm. It does not have the disadvantage of slow computing efficiency and easy to fall into local optimal. A large number of computations are carried out through MATLAB. The results of the calculation prove the feasibility of the algorithm. It is found that the correct rate of fault location can be greatly improved by expanding the fault area.

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