Fault Diagnosis Method of Fault Indicator Based on Maximum Probability

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Abstract. In order to solve the problem of distribution fault diagnosis in case of misreporting or failed-report of fault indicator information, the characteristics of the fault indicator are analyzed, and the concept of the minimum fault judgment area of the distribution network is developed. Based on which, the mathematical model of fault indicator fault diagnosis is evaluated. The characteristics of fault indicator signals are analyzed. Based on two-in-three principle, a probabilistic fault indicator combination signal processing method is proposed. Based on the combination of the minimum fault judgment area model, the fault indicator combination signal and the interdependence between the fault indicators, a fault diagnosis method based on maximum probability is proposed. The method is based on the similarity between the simulated fault signal and the real fault signal, and the detailed formula is given. The method has good fault-tolerance in the case of misreporting or failed-report of fault indicator information, which can more accurately determine the fault area. The probability of each area is given, and fault alternatives are provided. The proposed approach is feasible and valuable for the dispatching and maintenance personnel to deal with the fault.

1. Introduction

With the gradual advancement of the construction of smart distribution network, the distribution network operation safety and fault outage time have been paid more and more attention.

Feeder automation is an effective measure for fault diagnosis and isolation of distribution network. The fault indicator has the characteristics of small size, low price and no power outage installation. As important feeder terminal automation equipment; it is widely used in the current distribution network [1-6]. At present, there are three kinds of fault diagnosis methods for feeder automation based on fault indicator: uniform matrix method, probability estimation method and artificial intelligence method. In practical applications, due to the changing field environment, such as temperature, humidity change, dust, etc., the acquisition device accuracy of the fault indicator will be damaged. The situation will lead to failed-report of fault indicator information in distribution normal operation and misreporting fault indicator signal in distribution fault. Due to a large number of false signals, fault diagnosis error is frequently produced. Feeder automation lost its original significance.

A method of calculating the fault judgment matrix by using the network description matrix and the fault information matrix was proposed in the paper [7]. A multi section fault diagnosis method based on reliability was proposed in the paper [8]. Based on artificial intelligence, genetic algorithm and ant colony algorithm were proposed in the literature [9-10]. A fault diagnosis method based on the
principle of least deviation was proposed in the paper [11]. However, these methods are not a good solution to fault diagnosis of non-perfect information. According to the characteristics of fault location in distribution network, this paper presents a method of fault indicator fault diagnosis based on maximum probability.

2. Characteristic of fault indicator and establishment of minimum fault judgment area model

There are more than 6 kinds of fault indicator short-circuit fault diagnosis conditions, and the current market general equipment, at least 2 kinds of decision conditions will be selected. The first condition is that the fault indicator flows through the abrupt fault current and lasts for a certain time. The second condition is that the fault indicator detects the pressure loss. Based on these two conditions, the feeder short-circuit fault is determined by the fault indicator, the fault flop is activated, and the fault signal is sent to the DMS.

Substation outlet breaker, user demarcation switch or feeder multi-level protection switch is defined as the power switch. The minimum connection between the fault indicator and the power switch is called the minimum fault judgment area. There are only the non-power switch, disconnect switch, feeder section and distribution transformer in the minimum fault judgment area, and there is no other intelligent terminal equipment. The fault indicator constituting the minimum fault judgment area is called an adjacent fault indicator.

Fig.1 shows a distribution network. It consists of two feeders; STA1 and STA2 are substations; SP1 to SP3 are distribution room. The graphs #1 to #7 are the buses of substations, substations and distribution room. S1 and S10 are substation outlet switches. S9 is the user demarcation switch. The graphs S2 to S8 and S11 to S19 indicate the load switches of distribution room and the ring main unit room. S20 is a contact switch. T1 to T13 are distribution transformers. D1 to D13 are the disconnect switches. FI0 to FI16 are fault indicators.

![Figure1. A simple distribution network](image)

According to the above definition, the minimum fault judgment area of the feeder with S1 as the outlet switch in Figure 1 is shown in Table 1:

| Area W₁ | Area W₂ | Area W₅ | Area W₄ | Area W₅ | Area W₆ | Area W₇ |
|---------|---------|---------|---------|---------|---------|---------|
| S1,FI0  | FI0,FI1 | FI1,FI2 | FI2,FI3 | FI3,S9  | S9,FI4,FI5 | FI4     |
| Area W₈ | Area W₉ | Area W₁₀| Area W₁₁| Area W₁₂| Area W₁₃| Area W₁₄|
| FI5,FI6 | FI6~FI8 | FI7     | FI8~FI10| FI9,FI11| FI10    | FI11    |

3. Fault signal processing of fault indicator based on probability
In practical application, the fault indicator will cause a large number of signal false positives because of the influence of the fault indicator installation location, manufacturing process, operation maintenance and so on.

If both the fault flop signal and the current mutation signal are used at the same time, the fault judgment result will be worse because it is not possible to determine which signal is correct. For example, the exact probability of a fault flop signal is $P(A)$, the exact probability of a current mutation signal is $P(B)$, and the exact probability $P(U)$ in both cases will become $P(A)P(B)$, It is clear that $P(U)$ will be less than $P(A)$ or $P(B)$.

If the failure flop signal ($A$), the current mutation signal ($B$), and the field strength mutation signal ($C$) are considered simultaneously, the result of the two same trend signals is the final result based on two-in-three principle. Table 2 shows the probability distributions for each case. $P_i$ ($i=1~8$) represents the probability, 1 means that there is signal, 0 means no signal, the correct probability of single signal is 95%.

| case | A   | B   | C   | $P_i$     | case | A   | B   | C   | $P_i$     |
|------|-----|-----|-----|----------|------|-----|-----|-----|----------|
| 1    | 0   | 0   | 0   | 0.000125 | 5    | 1   | 0   | 0   | 0.002375 |
| 2    | 0   | 0   | 1   | 0.002375 | 6    | 1   | 0   | 1   | 0.045125 |
| 3    | 0   | 1   | 0   | 0.002375 | 7    | 1   | 1   | 0   | 0.045125 |
| 4    | 0   | 1   | 1   | 0.045125 | 8    | 1   | 1   | 1   | 0.857375 |

Based on two-in-three principle, it can be seen from Table 2 that the signal judgment under the case of 1, 2, 3, 5 is wrong. The error probability is the probability sum of four cases, it is 0.00725. Conversely, the correct probability of signal judgment is 0.99275. Figure 2 can be a very intuitive response to probability distribution of eight cases. It can be seen that the accuracy of the signal based on the ‘two-in-three’ principle is much higher than that based on the single signal.

4. Fault diagnosis method of fault indicator based on maximum probability

When each fault occurs, the fault indicators on the upstream and downstream of the fault area will be accompanied by different fault alarm information. If the actual alarm information of the fault indicator is similar to the simulated alarm information of each fault indicator assuming a region fault, it is possible to determine that the fault may occur in the hypothetical area, the greater the similarity, the
greater the probability of fault occurrence in the region, which is the fault diagnosis thought of fault indicator based on maximum probability.

In the case of an open-loop distribution network, when a fault occurs, a mutation fault current and mutation field strength will flow through the main path between the fault area upstream and the power switch, causing the power switch to trip and the fault indicator flop. All fault indicators downstream of the faulted area do not experience fault current, and the fault indicators do not flop.

In the case of a close-loop distribution network, when a fault occurs, a mutation fault current and mutation field strength will flow through the main path between the fault area upstream and the power switch, causing the power switch to trip and the fault indicator flop. The fault indicators on other non-main path do not experience fault current, so they should not act.

From the above analysis, all the fault indicators are divided into two categories, one is the main path fault indicator, and the other is the non main path fault indicator.

Therefore, in the case of existing fault indicator alarm information, the maximum fault area of the maximum conditional probability is the biggest possible area of short-circuit fault, which is described as follows:

Suppose there are \( m \) fault indicators to divide the feeder into \( n \) minimum fault judgment areas. The fault information reported by each fault indicator is processed by the method described in Section 2 to form matrix \( L \).

\[
L = [l_1, l_2, l_3, \ldots, l_m]
\]

Assuming that the fault occurs in the \( i \) minimum fault judgment area \( x_i \), the fault information that each fault indicator should report forms the matrix \( K_i \).

\[
K_i = [k_{i1}, k_{i2}, k_{i3}, \ldots, k_{im}]
\]

Wherein, \( l_j=1 \) and \( k_{ij}=1 \) express fault signal on the first \( j \) fault indicator; \( l_j=0 \) and \( k_{ij}=0 \) represent the first \( j \) fault indicator failure signal, \( j=0,1,2,\ldots m \), it is the number of fault indicators.

If the simulated fault signal \( k_{ij} \) of the fault indicator \( j \) is the same as the actual fault signal \( h_i \), the prior probability is \( P(\alpha) \). If the simulated fault signal \( k_{ij} \) is different from the actual fault signal \( h_i \), the prior probability is \( P(\beta) \).

Fault indicator signal error situation is generally divided into two kinds, one is misreporting, that is, the fault current flows through fault indicator and fault information is not reported; one is failed-report, that is, the fault current does not flow through fault indicator and fault information is reported. If the probability of fault indicator \( j \) misreporting fault information is \( p_{Mf} \), the probability of correctly reporting fault information is \( 1-p_{Mf} \). Assuming the probability of fault indicator \( j \) failed-report fault information is \( p_{Ej} \), the probability of not failed-report fault information is \( 1-p_{Ej} \). According to operating experience, \( p_{Mf} \) is generally 0.1~0.2, \( p_{Ej} \) is generally 0.05~0.10 [12].

From the above, fault indicator can be divided into experienced fault current and non-experienced fault current two kinds, its fault information completely correct probability is called a priori probability \( P(\alpha) \).

\[
P(\alpha_j) = 1 - (p_x p_{Mf} + p_x p_{Ej})
\]

Fault information of fault indicator completely error probability is called a priori probability \( P(\beta) \).

\[
P(\beta_j) = p_x p_{Mf} + p_x p_{Ej}
\]

In engineering, the prior probability \( P(\alpha) \) can be 0.8999~0.9495, the prior probability is \( P(\beta) \) can be 0.0505~0.1001.

The conditional probability of a minimum fault judgment area \( x_i \) under the constraint of the existing fault indicator information matrix \( L \) can be written as

\[
\delta(x_i | L) = \frac{g(x_i) + f(x_i)}{m}
\]

\[
g(x_i) = \sum_{j=1}^{m} (l_j \cap k_{ij}) P(\alpha_j)
\]
\[ f(x_i) = \sum_{j=1}^{m} (I_j \oplus k_j) P(\beta_j) \]  

(7)

where \( \oplus \) is XNOR, \( \oplus \) is XOR, \( g(x_i) \) is the prior probability sum of the fault indicator which is exactly the same as the actual fault signal, and \( f(x_i) \) is the prior probability sum of the fault indicator which is completely different from the actual fault signal.

The relative probability of failure in the minimum fault judgment area \( x_i \) can be written as:

\[ P(x_i | L) = \frac{\delta(x_i | L)}{\sum_{i=1}^{n} \delta(x_i | L)} \times 100\% \]

(8)

Obviously, the minimum fault judgment area of the maximum \( P(x_i|L) \) is the region of the maximum possible failure.

5. Case analysis

In the distribution network shown in Figure 1, if the minimum fault judgment area W12 (FI9, FI11) fails, it will cause the switch S9 to trip and the fault indicators FI5, FI8, FI9 to send fault signals, but other fault indications fail to send the fault signal. It can be seen that the fault indicator FI6 misses the fault signal. The fault indicator's prior probability \( P(\alpha) \) is 0.9 and the prior probability \( P(\beta) \) is 0.1.

Assume that each fault indicator signal has been combined by the method described in section 2. According to the method described in section 3 when the area W6 failure, the formula (1)~(7) shows:

\( \delta(W_6) = (0.9 \times 6 + 0.1 \times 2) / 8 = 0.7 \)

Assuming that the region W7 fails, the formula (1) ~ (7) shows:

\( \delta(W_7) = (0.9 \times 4 + 0.1 \times 4) / 8 = 0.5 \)

Similarly, assuming the areas W8~ W14 failures, the conditional probabilities of the respective regions are shown in Table 3:

| Area | Area W6 | Area W7 | Area W8 | Area W9 | Area W10 |
|------|---------|---------|---------|---------|---------|
| \( \delta(x_i | L) \) | 0.7      | 0.5     | 0.7     | 0.6     | 0.5     |
| \( P(x_i | L) \) | 12.281%  | 8.772%  | 12.281% | 10.526% | 8.772%  |

| Area W11 | Area W12 | Area W13 | Area W14 |
|----------|----------|----------|----------|
| \( \delta(x_i | L) \) | 0.7 | 0.8 | 0.6 | 0.6 |
| \( P(x_i | L) \) | 12.281% | 14.031% | 10.526% | 10.526% |

The relative probabilities of areas W6, W7 can be written as:

\( P(W_6) = 0.7 / 5.7 = 12.281\% \quad P(W_7) = 0.5 / 5.7 = 8.772\% \)

From Table 3, it can be concluded that the probability of area W12 is the largest, which is 14.031%, which is the most likely fault area. The probability of the area W9, W13, W14 is the second, is the fault alternative. The probability of the area W7 and the area W10 is the smallest, which is the least likely fault area.

6. Conclusion

This paper analyzes the characteristics of fault indicator, puts forward the concept of minimum fault judgment area of distribution network, and establishes the fault indicator mathematical model based on the minimum fault judgment area. The characteristics of fault indicator signal are analyzed. Based on the principle of ‘two-in-three’, a signal processing method of fault indicator based on probability is presented.
Combined with the minimum fault judgment model and the fault indicator combination signal, a fault diagnosis method based on maximum probability is proposed. This method has good fault-tolerance in the case of misreporting or failed-report information, it can determine the fault area more correctly, and give the probabilities of each area. It provides a convenient alternative fault plan, scheduling maintenance personnel quickly troubleshoot.

7. References
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