A Method of Fault Section Location in Distribution Networks Based on Comprehensive Criteria

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Abstract. In order to solve the problem that the traditional single location method has a relatively small scope of application, a method of fault section location in distribution networks based on comprehensive criteria is proposed. Firstly, fault direction measures are proposed to characterize the severity of fault information in different sections. Then the reliability of fault direction measures is quantitatively determined to measure its compliance with the fault law. Based on different prominence of criteria under diverse conditions, criterion measures are proposed to judge the reliability of different criteria. Finally, the fault index of each section is obtained. Simulation results indicate that the method is adaptable to complicated conditions such as different angles of the initial voltage at the fault point, transition resistance and so on.

1. Introduction
Due to the weak currents at the fault point of the small current grounding system and the instability of the fault arc, the problem of fault localization has not been effectively solved. In fact, the method based on a single location criterion has several defects.

The method based on zero sequence currents is only applicable to the neutral ungrounding system, which fails to adapt to the central system in the arc suppression coil grounding system [1, 2, 3]. The method based on zero sequence current harmonics is suitable for both the neutral ungrounded system and arc suppression coil grounding system [3]. But there are fewer high-order harmonic components in the system. Therefore, the application of this method in practical systems is greatly limited. Though the transient method is not affected by the neutral grounding modes [5, 6, 7], under the condition of small fault phase angle and high fault resistance, the method of fault location fails because of the small transient component.

Thus, a method with the fusion of multiple criteria is appropriate to achieve accurate location. In this paper, a fault location method for distribution networks based on comprehensive criteria is proposed, avoiding the disadvantages of a single criterion. Only FTU measurements of zero sequence currents are needed, without measuring voltages, so the investment of equipment can be reduced.
2. Fault Direction Measures and the Reliability Based on Zero Sequence Fundamental Currents

2.1. Fault Direction Measures Based on Zero Sequence Fundamental Currents

In the fault line of a neutral ungrounded system, phases of currents on both sides of the fault section are opposite, with a phase difference of $\pi$. And phases of currents on both sides of a non-fault section are same, with a phase difference of zero. Based on this, fault direction measures of zero sequence fundamental currents are defined to characterize the possibility of each section as the fault section.

The number of measuring points on the fault line is $n$, The section number is the number of measuring point upstream. Fault direction measures of the section $i$ is defined as

$$\alpha_i = \text{abs}(\theta_{1,i} - \theta_{1,i+1}) / 3.3(i < n)$$

(1)

Where, $\theta_{1,i}$ ($i = 1, 2, 3... n$) are phases of zero sequence fundamental currents at each measuring point. In order to ensure the value of the direction measures is within 1, the difference between phases is compared to 3.3 considering the measurement deviation.

If values of $\alpha_i (i < n)$ are all less than the setting threshold $\pi / (2 * 3.3) = 0.476$, the fault section is considered as the $n$-th.

$$\alpha_{\text{max}} = \text{max}(\alpha_i)(i < n)$$

(2)

$$\alpha_n = \begin{cases} 0.95(\alpha_{\text{max}} < 0.476) \\ 0.05(\alpha_{\text{max}} \geq 0.476) \end{cases}$$

(3)

2.2. Reliability of Direction Measures

The amplitude of zero sequence fundamental currents at the measuring points is used to characterize the reliability of the direction measures $\eta_{1,i}$:

$$\eta_{1,i} = A_{1,i} / A_{1,\text{max}}$$

(4)

$A_{1,i}$ represents amplitude of zero sequence fundamental currents at the $i$-th measurement point. $A_{1,\text{max}}$ is the maximum of $A_{1,i}(i = 1, 2, 3... n)$.

3. Fault Direction Measures and the Reliability Based on Zero Sequence Harmonic Currents

Fault direction measures of zero sequence fifth harmonic currents is similar to that of zero sequence fundamental currents.

$$\beta_i = \text{abs}(\theta_{2,i} - \theta_{2,i+1}) / 3.3(i < n)$$

(5)

$$\beta_n = \begin{cases} 0.95(\text{max}(\beta_i) < 0.476) \\ 0.05(\text{max}(\beta_i) \geq 0.476) \end{cases}$$

(6)

$$\eta_{2,i} = A_{2,i} / A_{2,\text{max}}$$

(7)
4. Fault Section Measures Based on Transient Currents

When a single-phase-to-ground fault occurs in the system, the difference of values of transient currents on both sides of the fault section is large, but the difference of values of transient currents on both sides of a non-fault section is small. Fault section measures based on transient currents are defined as

$$D_i = \sum_{k=1}^{N} |I_{n_0}(k)|$$

(8)

Samples in the first half cycle of zero sequence currents are superimposed. $I_{n_0}(k)$ are the sample values of the zero sequence currents at the $i$-th measurement point, $N$ is the number of samples in the first half of the period, and $D_i$ are the sum of the absolute values of the zero sequence currents samples at the $i$-th measurement point. The definition of the fault section measures based on transient currents is

$$\Delta D_i = \text{abs}(D_i - D_{i+1})$$

(9)

$$\eta_{k,i} = \Delta D_i / \text{max}(\Delta D_i)$$

(10)

5. Criterion Measures and Section Fault Indexes

Different criteria play different roles in different conditions. In this paper, the measures of the $k$-th criterion are determined by the difference between the maximum and the second largest value ($k = 1, 2, 3$).

If the serial numbers of the zero sequence fundamental criterion, the zero sequence fifth harmonic criterion and the transient criterion are 1, 2, 3 respectively, there is the $k$-th criterion measure.

$$\eta_k = (\eta_{k,i_{\max}} - \mu_{k,i_2}) / \sum_{i=1}^{n}(\mu_{k,i_{\max}} - \mu_{k,i_2})$$

(11)

$\mu_{k,i_{\max}}$ is the maximum of $\eta_{k,i}$ in the $k$-th criterion, and $\eta_{k,i_2}$ is the second largest one. So, according to the definition, $\eta_k \in (0, 1)$. Each criterion measure characterizes the reliability of a certain criterion, which is a dynamic indicator depending on specific fault conditions.

In summary, the indicators of direction measures $\alpha$ and $\beta$ characterize the possibility of each section as the fault section. The greater the value is, the more likely to be the fault zone the section is; $\eta_{k,i}$ characterizes the reliability of direction measures, The greater the value is, the more reliable direction measure is. Therefore, $\alpha, \eta_{k,i}$ and $\beta, \eta_{k,i}$ represent the quantitative indicators of the two criteria of zero sequence fundamental wave and zero sequence fifth harmonic wave. Combining with the criterion measure index $\eta_i$, section fault indexes $P_i$ to assess the probability that a section is the fault section in neutral ungrounded system are obtained from the following equation.

$$P_i = \alpha_{i_1}\eta_{i_1} + \beta_{i_2}\eta_{i_2} + \eta_{i_3}\eta_{i_3}$$

(12)

And section fault indexes $P_i'$ in an arc suppression coil grounded system are

$$P_i' = \beta_{i_1}\eta_{i_1} + \eta_{i_2}\eta_{i_2} + \eta_{i_3}\eta_{i_3}$$

(13)
6. Simulation and Results

An neutral ungrounding system is taken as a case to verify the fault section location method. There is a 10kV bus with four feeders, the positive sequence and zero sequence parameters of the line are respectively $R_1=0.17\Omega/km$, $L_1=1.21mH/km$, $C_1=9.2nF/km$; $R_0=0.23\Omega/km$, $L_0=5.48mH/km$, $C_0=5.6nF/km$. The lengths of L1 to L4 are respectively 50 km, 100 km, 150 km and 200 km. The six sections of L4 are S1 to S6 respectively, and the length distribution ratio is 1: 4: 2: 3: 2: 2. A single-phase-to-ground fault is set in the L4. The angle of the initial voltage at the fault point is 80º, and the fault transition resistance is 200Ω.

![Simulation system](image1)

**Figure 1.** Simulation system.

![Waveforms](image2)

**Figure 2.** Waveforms of zero sequence currents for each section.

Figure 2 shows the waveforms of zero sequence currents at each measuring point of L4. Fault direction measures and the reliability obtained by proposed zero sequence fundamental criterion, the zero sequence fifth harmonic criterion and the transient criterion are shown in Table 1.
Table 1. Fault direction measures and the reliability.

| Criterion number | 1  | 2  | 3  | Pi  |
|------------------|----|----|----|-----|
|                  | α1,i | η1,i | β2,i | η2,i | η3,i | Pi  |
| S1               | 0.0008 | 0.6065 | 0.0007 | 0.6013 | 0.1717 | 0.0618 |
| S2               | 0.0023 | 0.6226 | 0.0018 | 0.6581 | 0.2878 | 0.1041 |
| S3               | 0.0008 | 0.7576 | 0.0006 | 0.7861 | 0.7437 | 0.2661 |
| S4               | 0.9495 | 1.0000 | 0.9540 | 1.0000 | 1.0000 | 0.9689 |
| S5               | 0.0034 | 0.3249 | 0.0027 | 0.2262 | 0.1805 | 0.0665 |
| S6               | 0.0500 | 0.1125 | 0.0500 | 0.1423 | 0.1093 | 0.0561 |

Table 1 shows that in this fault condition, all three criteria can correctly identify the fault section S4. In the term of validity of criteria, the relative difference is not big, indicating that the credibility is relatively high.

In the second case, a metal grounding fault is set, when the angle of the initial voltage at the fault point is set to 5°. Other parameters remain unchanged. Figure 3 shows waveforms of zero sequence currents for each section of L4.

Table 2. Fault direction measures and the reliability.

| Criterion number | 1  | 2  | 3  | Pi  |
|------------------|----|----|----|-----|
|                  | α1,i | η1,i | β2,i | η2,i | η3,i | Pi  |
| S1               | 0.0009 | 0.6034 | 0.0007 | 0.6010 | 0.3723 | 0.0331 |
| S2               | 0.0021 | 0.6221 | 0.0019 | 0.6578 | 0.4853 | 0.0441 |
| S3               | 0.0010 | 0.7553 | 0.0005 | 0.7852 | 0.9565 | 0.0838 |
| S4               | 0.9493 | 1.0000 | 0.9532 | 1.0000 | 1.0000 | 0.9558 |
| S5               | 0.0024 | 0.3239 | 0.0023 | 0.2252 | 0.4453 | 0.0416 |
| S6               | 0.0510 | 0.1223 | 0.0005 | 0.1423 | 0.2464 | 0.0457 |

Criterion measures 0.4850 0.4280 0.0870

Figure 3. Waveforms of zero sequence currents for each section.
As is shown in Table 2, because the angle of the initial voltage at the fault point is close to 0°, the transient zero sequence component is low, which makes fault section measures difficult to be identified. The measuring values of the transient criterion show that measures of some non-fault sections are relatively close to that of the fault section, which easily leads to misjudgment. Due to the low criterion measures of the transient criterion, the method plays a less important role in the comprehensive criteria. Therefore, even if the transient criterion lapses, the overall judgment is still correct.

7. Conclusion
Aiming at the problem of single-phase grounding fault location in distribution networks, this paper proposes a method to locate the fault section in a distribution network based on comprehensive criteria. Through a large quantity of simulation verification, we come to the following conclusions:

1) Utilization of multiple criteria avoids the deficiencies of using a single criterion. And the method has good adaptability to complex conditions such as different angles of the initial voltage at the fault point and transition resistance.

2) In this paper, both fault direction measures and the reliability are proposed, which will make full use of the characteristic information.

3) There is no need for FTU to measure voltages. Measurement of zero sequence currents is enough. The method simplifies the design and construction of segment switches, reducing the investment of equipment.

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