Fault Zone Location Based on Transient Phase Current and Zero Mode Current

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Abstract. To solve the problems of inaccurate location caused by unsynchronized measurement signals, high impedance grounding, and strong noise interference, in this paper, a novel fault location method based on the relationship between transient zero-mode current and transient phase current is proposed. Through analysis, the zero phenomenon is the main cause of misjudgment. The three-phase current of fault feeder detection point is obtained, the similarity between fault phase current and fault transient zero-mode current is calculated, and the segment location is conducted by using dichotomy method. Numerical simulation results demonstrate the effectiveness of the proposed method. This method can greatly reduce the probability of misjudgment and measurement difficulties, and improve detection efficiency.

1. Introduction

When a single-phase ground fault occurs in an ungrounded neutral point system, measures are required to reduce the capacitance current at the fault point if it exceeds the safe level. An arc suppression coil (or high resistance) can be added to the neutral point to reduce the capacitive current. Therefore, the resonance grounding system is used in this paper to study the fault section location problem.

A fault feeder identification method based on the comparison of the amplitude and polarity of the transient zero sequence current projection element is proposed in [2]. According to the propagation characteristics of the transient zero-mode signal, a criterion for feeder fault detection using the amplitude information of the transient zero-mode signal captured at both ends is proposed [3]. The morphological median filter is exploited to wrest unique fault features which are then fed as an input to a decision tree classifier to classify the fault type [4]. A decentralized fault detection technology suitable for resonant grounded power distribution systems is proposed [5]. A comprehensive identification method of multi-standard fault feeder based on transient zero sequence current polarity detection method, relative energy entropy and total transient current energy is proposed in [6]. However, the collection of fault information is generally realized by the feeder terminal unit (FTU), but the feeder automation system (FA) has a certain timing error when realizing the synchronization of the FTU fault information. The upstream current and the downstream current are opposite when a single-phase ground fault occurs. The current on all feeders is in the same direction when a fault occurs on the bus. But this rule is often misjudged, when the feeder has high impedance fault, strong noise interference or voltage zero crossing fault.

In this paper, a fault location method based on transient phase current and zero mode current is proposed. By analyzing the topological structure of the distribution network, extracting high-frequency characteristic components, using the characteristics of the transient zero-mode current component and
the transient fault phase current component, the similarity is calculated, and then the fault section is identified. Finally, simulation is conducted to verify the accuracy of the method.

2. Analysis of transient current of single-phase earth fault

According to the phase frequency characteristics of cables and overhead lines, the network structure of the distribution network is analyzed, and the equivalent circuit diagram of the distribution network is shown in Figure 1. For simplicity, only two feeders are shown in the figure.

\[
\begin{align*}
\text{Figure 1. Phase current distribution during single-phase grounding fault}
\end{align*}
\]

Since the three-phase power supply is symmetrical and the working conditions of the three power supplies are exactly the same, only phase A can be used for analysis. Assume that the positive direction of the distribution network is from the bus to the line, and vice versa.

Under normal condition, the three-phase current flowing through the faulted feeder can be expressed as

\[
\begin{align*}
i_{Np} = i_{NpC} + i_{NLp} = C_N \frac{d\left(u_0 + e_p\right)}{dt} + i_{NLp} 
\end{align*}
\]

where, \(N\) is 1,2, ...., \(n\) feeders; \(p\) is three phases of \(A\), \(B\) and \(C\); \(e_p\) is voltage of each phase, \(u_0\) is voltage of neutral point; \(C_N\) is the equivalent capacitance to ground of each phase of each line; \(i_{Np}, i_{NpC}, i_{NLp}\) are the starting current of each phase, the capacitance current to ground and the load current respectively.

The zero-mode current flowing through the faulted feeder is expressed as:

\[
\begin{align*}
3i_{N0} = i_{NA} + i_{NB} + i_{NC} = C_N \frac{d\left(3u_0 + e_A + e_B + e_C\right)}{dt} + i_{NLA} + i_{NLB} + i_{NLC} = 0
\end{align*}
\]

When a single-phase ground fault occurs (transition resistance is 0), assume that \(A\) phase is the fault phase, and the upstream phase current of the faulted feeder is:

\[
\begin{align*}
i'_{NA} = i'_{NAC} + i'_{NL4} + i'_{f1} = C_N \frac{d\left(u'_0 + e_A\right)}{dt} + i'_{NL4} + i'_{f1}
\end{align*}
\]

where \(i'_{NA}, i'_{NAC}, i'_{NL4}, i'_{f0}, u'_0\) are respectively the phase current at the beginning of the fault feeder upstream of the fault point after the fault, the capacitance current of each phase to the ground, the load current of each phase, the fault current component and the neutral point voltage.

The sound phase current upstream of the faulted feeder is
where \( i'_{Np}, i'_{NpC}, i'_{NLp} \) are respectively the phase current at the beginning of the faulted feeder upstream of the fault point after the fault, the capacitance current of each phase to the ground and the load current of each phase.

According to the superposition theorem, the initial equivalent network can be divided into the superposition of the power frequency equivalent network and the transient equivalent network. Since the line voltage of the system before and after the fault usually remains unchanged, the instantaneous load current before and after the fault is considered unchanged. The upstream transient equivalent fault phase current is

\[
\Delta i'_{Np} = i'_{Np} - i_{Np} = C_N \frac{d(u'_N - u_N)}{dt} + i_{f1} = C_N \frac{du'_N}{dt} + i_{f1}
\]

The transient zero mode current \( i'_{N0} \) satisfies:

\[
3i'_{N0} = i'_{Na} + i'_{Nb} + i'_{Nc} = C_N \frac{d(3u'_N + e_a + e_b + e_c)}{dt} + i'_{NLa} + i'_{NLb} + i'_{NLc} + i_{f1}
\]

Because the three-phase power supply is symmetrical and the zero-mode current before the fault is 0, according to equation (2), equation (7) can be simplified as

\[
3i'_{N0} = i'_{Na} + i'_{Nb} + i'_{Nc} = 3C_N \frac{du'_N}{dt} + i_{f1}
\]

According to the law of transient current transformation, it can be seen from the analysis of equations (6) and (8) that the transient equivalent fault phase current and the transient zero-mode current are both composed of the capacitance current to the ground and the ground fault component, expressed the form is consistent. The difference between equation (6) and equation (8) lies in the coefficient of the capacitance component to ground, while the line capacitance value is in units of \( 10^{-6} \). According to the formal characteristics of the equation, the two can be approximated as equal, that is, the upstream transient fault at the fault point. The phase current is similar to the transient zero mode current.

For the downstream of the fault point, according to the capacitor charging and discharging characteristics, the topology of the distribution network is analyzed. Before the fault, the phase A power supply charges the A phase-to-ground capacitor. After a single-phase ground fault occurs, the A-phase power supply is short-circuited, and the line A phase forms a loop between the ground capacitor and the fault ground point, and the A-phase ground capacitor discharges. The direction of the capacitor discharge is opposite to the current before the fault, that is, the direction of the A-phase transient current is negative. The two phases B and C are connected to the two-phase power supply of B and C. According to the Karen Bell transformation, the direction of the transient zero-mode current is positive and flows from the fault point to the end of the line. The zero-mode current is divided by the A phase discharge current and the B, C-phase charging current composition. It can be concluded that the A phase transient phase current downstream of the fault point is opposite to the transient zero mode current, and the similarity is low.

3. Segment positioning method

3.1. Similarity Judgment Principle

From the previous analysis, it can be known that the fault section can be judged by measuring the similarity between the transient fault phase current and the fault feeder transient zero-mode current. The similarity of a single detection point can be expressed by the correlation coefficient of the two currents, and the calculation formula is as follows

\[
\rho = \frac{\sum_{n=1}^{N} \Delta i'_{Na}(n) \cdot 3i'_{N0}(n)}{\sqrt{\sum_{n=1}^{N} \Delta i'_{Na}(n)^2 \cdot 3i'_{N0}(n)^2}}
\]
where, $\Delta i'_{Na}$, $3i'_{N0}$ are the fault phase current and the transient zero-mode current of 3 times at a single detection point respectively; $n$ is the sampling sequence, $N$ is the data length of the current signal. The sampling frequency is 20 kHz.

The correlation coefficient $\rho$ reflects the similarity of the two waveforms $\Delta i'_{Na}$ and $3i'_{N0}$. When the two signal waveform changes are the same, $\rho$ takes the maximum value of 1, and when the waveform changes are completely irrelevant, $\rho$ takes the minimum value of 0.

According to the actual line parameters, the topology of the distribution network is analyzed, and the fault location method is as follows.

Assuming that K1, K2, K3, and K4 are set up in sequence from the bus to the end of the fault line, K1 and K2 are compared. If K1 > K2, the fault area is (K1, K2); if K1 ≤ K2, then K2 and K3 are compared. If K2 > K3, the fault area is (K2, K3), if K2 ≤ K3, then K3 and K4 are compared, and so on. If K3 < K4, the fault point is before K1.

4. Simulation results

4.1. Distribution Network Simulation Model

PSCAD is used to establish a 10kV non-effective grounding system model corresponding to Figure 7 for simulation verification. Sections 3, 4, 10, 11 are cables, and the rest are overhead lines. The arc suppression coil is controlled by switch K, and the over compensation degree is 10% when it is switched on. Length of each section: L1 = 8 km, L2 = 12 km, L3 = 4 km, L4 = 6 km, L5 = 50 m, L6 = 6 km, L7 = 100 m, L8 = 50 m, L9 = 12 km, L10 = 4 km, L11 = 6 km. Main transformer parameters: UN1/UN2 = 110kV/11kV; SN = 6.3 MVA. The capacitance current of the whole network to ground is 32.1A.

Overhead line zero sequence parameters: R0 = 0.23 Ω / km, L0 = 5.478 mH/km, C0 = 0.008 u F/km; Overhead lines positive sequence parameters: R1 = 0.17 Ω / km, L1 = 1.21 mH/km, C1 = 0.00969 u F/km. Cable zero sequence parameters: R0 = 2.7 Ω / km, L0 = 1.0191 mH/km, C0 = 0.28 u F/km; Cable positive sequence parameters: R1 = 0.27 Ω / km, L1 = 0.2548 mH/km, C1 = 0.3391 u F/km.

Figure 2. Distribution network simulation model diagram

4.2. Simulation results

Using the simulation model shown in the Figure 2, we selected different initial phase angles, transition resistances and fault sections to perform dozens of sets of simulation verification, set a set of detection points K1, K2, K3 and K4, and some of the simulation data are as follows, as shown in Table 1 and 2.

It can be seen that for a single-phase grounding fault on an overhead line, the transient phase current upstream of the fault point is basically similar to the transient zero-mode current waveform, and the similarity does not increase with the distance between the detection point and the fault point and the fault the initial phase angle and transition resistance change, the similarity is low for the downstream and the similarity gradually increases with the increase of the distance from the fault point. The analysis of the data in Table 2 shows that when a single-phase ground fault occurs in a cable line, the basic law
is basically the same as that of an overhead line. The upstream similarity of the fault point is affected by the transition resistance. As the fault resistance increases, the similarity decreases, but the difference in the similarity between the two sides of the fault section is also more obvious, which is helpful for the detection of the fault section as a whole.

When a single-phase grounding fault occurs on an overhead line, take the 12th group of simulation waveforms as an example, fault location based on the law of fault current will cause misjudgment, the simulation waveform is shown in Figure 3.

![Figure 3. Simulation waveform of both sides of fault section](image)

| No. | Fault initial phase angle (°) | Transition resistance (Ω) | Fault detection point similarity | Fault location section |
|-----|------------------------------|---------------------------|---------------------------------|------------------------|
| 1   | 0                            | 0                         | K1 K2 K3 K4                      | (K2, K3)               |
| 2   | 5                            | 1                         | 1 1 0.7170 0.8867                | (K2, K3)               |
| 3   | 50                           | 1                         | 1 1 0.7771 0.8680                | (K2, K3)               |
| 4   | 500                          | 1                         | 1 1 0.7789 0.8033                | (K2, K3)               |
| 5   | 45                           | 0                         | 1 1 0.8122 0.9235                | (K2, K3)               |
| 6   | 5                            | 1                         | 1 1 0.7095 0.8693                | (K2, K3)               |
| 7   | 50                           | 1                         | 1 1 0.7696 0.8289                | (K2, K3)               |
| 8   | 500                          | 1                         | 1 1 0.9237 0.9328                | (K2, K3)               |
| 9   | 90                           | 0                         | 1 1 0.8414 0.9237                | (K2, K3)               |
| 10  | 5                            | 1                         | 1 1 0.5678 0.8378                | (K2, K3)               |
| 11  | 50                           | 1                         | 1 1 0.7433 0.8060                | (K2, K3)               |
| 12  | 500                          | 1                         | 1 1 0.9203 0.9340                | (K2, K3)               |

| No. | Fault initial phase angle (°) | Transition resistance (Ω) | Fault detection point similarity | Fault location section |
|-----|------------------------------|---------------------------|---------------------------------|------------------------|
| 1   | 0                            | 0                         | 0.9978 0.9987                   | (K2, K3)               |
| 2   | 5                            | 0.9970 0.9982              | 0.5436 0.5477                   | (K2, K3)               |
| 3   | 50                           | 0.9932 0.9962              | 0.6993 0.6993                   | (K2, K3)               |
| 4   | 500                          | 0.9504 0.9720              | 0.3850 0.3837                   | (K2, K3)               |
| 5   | 45                           | 0                         | 0.9967 0.9987                   | -0.2763 -0.1598        | (K2, K3)               |
In summary, when a single-phase grounding fault occurs in the distribution network, the method proposed in this article can accurately locate the fault section under different sections, different transition resistances, and different initial phase angles of the fault.

5. Conclusions
In this paper, a method based on the similarity between the transient phase current and the transient zero-mode current is proposed to locate the single-phase ground fault section of the distribution network. The advantages of this method are as follows:

(1) Only the phase current needs to be measured, and the detection device can be widely installed throughout the distribution network.

(2) The judgment data is calculated based on the data of the detection point itself, no precise synchronization is required.

(3) This method is highly reliable when the feeder has high impedance faults.

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