A New Method For Fault Section Location Based on Zero-Mode Of Fault Current Phase

Shengjian Li¹∗, Jianwen Zhao², Rui Bian²

¹Jiangxi Electric Power Research, Jiangxi, China
²Xian University Of Science And Technology, Xian, China

*Corresponding author e-mail: 421304122@qq.com

Abstract. When there is a single-phase fault appearing in an indirect grounding electric power system, in order to quickly locate the ground fault section. So here, a new method is proposed which is based on the original localization algorithm. The method of phase section positioning is based on the zero mode of current’s phase, when the fault is in this section, there is an opposition before and after the detection point. The simulation model was built by MATLAB, and the simulation conclusion are same as the theoretical proof.

1. Introduction
Suppose there is a single-phase fault appeared in a 10Kv distribution network, because the fault current is very small, which increases the difficulty of fault detection. At the same time, due to the complex structure of the power distribution system, the fault section positioning problem has not been well resolved, affecting the reliability and economy of power supply.

After years of development, the fault line selection technology has achieved good results in the field. Although the positioning blind area is eliminated to some extent, it will still be affected by the grounding resistance. In this paper, the transient symmetry component method and the sequential network model are used to analyze the polarity difference of the zero mode current in the fault point’s upstream and downstream, and obtain a fault segment localization algorithm.

2. Analysis of fault location in electric power system
This chapter not only analyzes the principle of fault location positioning, but also the possibility of using zero mode current polarity to find the section of the fault.

2.1. Single phase fault section location algorithm in electric power system
The normal operating electric distribute system operates in a three-phase symmetrical manner, and the current and voltage of each phase are both symmetrical. When the distribute power system faults, the symmetry of the voltage and current of each phase is destroyed, so the three-phase will be asymmetry in the electric system. In this chapter, we use the instantaneous symmetrical component method to solve the problem of current in the line when there is a single-phase fault occurs in the electric distribute system. Decomposition of the asymmetry three-phase as one-mode, two-mode, and zero-mode.

\[
\begin{bmatrix}
i_a^+ \\
i_a^- \\
i^0
\end{bmatrix} = \frac{1}{3} \begin{bmatrix}
1 & s_{120} & s_{240} \\
1 & s_{240} & s_{120} \\
1 & 1 & 1
\end{bmatrix} \begin{bmatrix}
i_a \\
i_b \\
i_c
\end{bmatrix}
\] (1)
In Formula (1), the one mode of component is \( i_a \), the two mode of component is \( i_b \), and the zero mode of component is \( i_0 \). The potentials in the three-phase lines are symmetrical when the line is in normal operation, and when the three-phase voltage is added, the consequence to become 0. When the line is in normal operation, \( \dot{U}_0 = 0 \), after a single-phase fault appeared on the network, \( \dot{U}_0 = \frac{\dot{E}_c}{1 + j2\omega RC} \), so there is a zero-mode current as shown in Figure 1.

![Figure 1. The distribution of normal line current and fault line current](image)

According to the KCL:

\[
\dot{I}_{D0} = \dot{I}_0 + \dot{I}_0'
\]  

(2)

In Equation 2, the zero-mode current in point D of fault is \( \dot{I}_{D0} \), the zero-mode current before fault point is \( \dot{I}_0 \), and the zero-mode current after fault point is \( \dot{I}_0' \). It can be inferred from Fig. 8 that the zero sequence current direction is opposite before and after the fault point D.

2.2. Analysis of Location Faults Section of Electric System when Occurring Single Phase Fault

Most of the outlets in the distribution system are radial networks, and the transmission lines are shorter and have smaller diameters. The ratio of the every phase capacitance to the ground capacitance is 0.2 to 0.33. The phase-to-phase capacitance of the line which can be ignored is estimated 0. The fault of the power network is complex, which makes the analysis process more intuitive and highlights the characteristics of the fault. It only takes into account the capacitance of the line to the ground, and will not affect the correctness of fault section positioning. Based on the above simplification, a simplified network diagram for a single-phase fault of a resonant grounding system can be obtained, as shown in the figure 2.

![Figure 2. Concentration parameter model for single-phase fault in electric system](image)

In Figure 2, the system has three simple branches. Now suppose that the fault appears in the branch 3. Install four detection points in the branch three. The four detection points will branch. 2 is divided into a few sections, which are Section 3, Section 2, Section 3, respectively.
At this time, the zero sequence voltage is \( \bar{U}_0 = \frac{-\dot{U}}{1 + 3j\omega R C_z} \), and the capacitor current in each section is: \( 3 \bar{I}_0 = 3j\omega C_0 \bar{U}_0 (i = 1, 2, 3, \ldots) \), so the zero-sequence current detected at each detection point is:

\[
\begin{align*}
\bar{I}_1 &= \bar{I}_{01} + \bar{I}_{02} + \bar{I}_{03} & \text{The direction is from the bus to the line.} \\
\bar{I}_2 &= \bar{I}_{02} + \bar{I}_{03} & \text{The direction is from the line to the bus} \\
\bar{I}_3 &= \bar{I}_{03} & \text{The direction is same as } I_1.
\end{align*}
\]

In order to further clarify the fault characteristics of ungrounded systems with single-phase grounding, the symmetric component decomposition of each part of the model is needed to obtain a separate sequential network equivalent model for each part of the network. The zero sequence network model is used to obtain the zero sequence. The neutral Ungrounded System Single Phase Earthing Sequence Network Model is shown in Figure 3 as well as the current phase relationship.

![Instantaneous positive sequence network](image1)

(a) Instantaneous positive sequence network  
(b) Instantaneous negative-sequence network

![Instant zero-sequence network model](image2)

(c) Instant zero-sequence network model  
(d) Zero-sequence current phase

**Figure 3.** When Single-phase faults occurs in Neutral point system grounding sequence network

It can be seen that when a single-phase ground fault appeared in a neutral point electric system, all nodes in the zero-sequence current direction of the non-faulted line are the same, but there is some difference in size. For the faulty line, the fault current flows through the nodes before and after the fault point. This part of the current contains the sum of the currents of all non-faulted lines. The neutral voltage \( \bar{U}_0 \neq 0 \), This can be seen as a voltage source at the point of failure, providing zero-mode current to both ends of the line bus and forming a loop through the capacitance to ground. Therefore, the direction of the zero-mode current on two sides of the fault point is opposite, that is, the phase difference is 180°, which is the most important theoretical cornerstone for the fault location of single phase electric system.

If the bus-to-line direction is regarded as the positive direction of the zero-mode current, the zero-mode current on the fault sections lags the zero-sequence voltage by 90°, and the zero-mode current on the non-faulted path leads to a zero-sequence voltage by 90°.

3. Fault Section Localization Algorithm Based on Zero Mode Current Phase Method

The principle of fault location in the usual algorithm is: Suppose there is a single-phase fault appearing in the electric power system, there is a zero-mode current in the line and the phase of the zero mode current before and after the fault point is opposite. Therefore, the zero-sequence current
phase information can be obtained, and fault section location is performed by judging whether the phases of the zero-mode currents at the two adjacent sampling points are opposite with both side. When the phases of the zero-mode currents obtained by the adjacent two zero-sequence current acquisition systems are opposite, it means that the fault occurs between these two zero-sequence current acquisition systems; otherwise, it indicates that the fault is not in this range.

3.1. The Fault section positioning algorithm

This chapter analyzes single-phase faults in electric systems and uses a zero-mode current phase criterion. The phase criterion and the phase of judge measures of the zero-mode current is: the bus-to-line direction is the positive direction of the zero-sequence current, then the zero-mode voltage after the zero-mode current on the fault path is 90°, and the zero-mode current of the normal-work path leads the zero-sequence voltage 90 °, then the fault-phase zero-mode current and normal-work phase current are 180° out of phase.

Set the zero-sequence current to \( D_n \), and sample 20 points, set the sampling frequency to 1kHz, that is, the sampling interval is 0.01s. The 20 points obtained by sampling are compared one by one. When \( nD_0 \) and \( 1+nD_0 \) (1≤n≤19) two-point symbols are different, the comparison is stopped and the value of n is recorded.

\[
\Delta t/0.02s = \theta/360° \quad (3)
\]

When \( nD_n \geq 0 \) and \( D_n +1 < 0 \), we can get:

\[
\Delta T = [n + (n + 1)] \times \Delta t = (n + \frac{1}{2}) \times \Delta t \quad (4)
\]

\( \Delta t = 0.001s \), put \( \Delta T \) it into:

\[
\theta = \frac{\Delta T \times 2\pi}{0.02s} = (n + \frac{1}{2}) \times 18° \quad (5)
\]

When \( nD_n \geq 0 \) and \( D_n +1 > 0 \), we can get:

\[
\Delta T = \frac{[-n -(n + 1)]}{\left(\frac{n + 1}{2}\right) \times \Delta t} \quad (11)
\]

\( \Delta t = 0.001s \), put \( \Delta T \) into formula 9 can be obtained:

\[
\theta = \frac{\Delta T \times 360°}{0.02s} = (n + \frac{1}{2}) \times 18° \quad (6)
\]

The collected phase values are compared one by one, until it is found that the adjacent phase values are opposite, then it can be concluded that the ground fault appeared in this zone. For MATLAB simulation, how to collect the phase information of the detection point is the key, the first is to establish a simulation model to connect the zero-sequence current acquisition module to the acquisition module in the simulation model, set the number of collection points, and zero sequence current information for the faulty line. The acquisition is performed, and the collected zero-mode current information is registered in the acquisition module. Then, the zero-sequence current information collected in the acquisition module is extracted by an algorithm using an FFT algorithm, and the zero-mode current information of each detection point is zero-crossed. Phase comparison, until \( n \geq 0 \), \( n+1 \leq 0 \) or \( n \leq 0 \), \( n+1 \geq 0 \), the comparison is stopped, and then the phase zero comparison is performed on the zero point of the adjacent detection point. The fault section is judged by the current phase criterion.

3.2. The Realization of Zero Sequence Current Phase Method

The fault location monitoring center judges whether the system is faulty by monitoring the bus voltage in real time, and determines the type of the fault at the time of fault. When the system fails, the
fault location monitoring center summons the fault current information of each detection point, centralizes the fault current information collected at the detection point, runs the fault location algorithm, and finally determines the current information uploaded to the fault location monitoring center according to the fault detection point. The line between which two (or several) detection points the fault occurred.

![Distribution network fault location system]

**Figure 4.** Distribution network fault location system

4. Simulation

In order to verify the location algorithm, a 10 kV distribution grid neutral ungrounded system established in the MATLAB model file in Chapter 2 is used. Simulate the influence of different factors on the fault feature quantity, including the grounding resistance, the initial phase angle of the fault and different fault distances, and then use the Fourier algorithm in the MATLAB file to obtain the data, so as to obtain the fault segment determination result.

In the 10kV distribution system model of MATLAB, there are three outgoing lines on the bus, the length of line 1 is 18km, the line 2 is 20km, and line 3 is a branch line. Among them, Positive sequence and negative sequence resistance, inductance, capacitance of per kilometer respectively is $R = 0.132 \Omega / \text{km}$, $L = 1.009 \text{mH} / \text{km}$, $C = 0.0061 \mu \text{F} / \text{km}$, and for each kilometer, the zero sequence resistance is $R = 0.232 \Omega / \text{km}$, the zero sequence inductance is $L = 5.044 \text{mH} / \text{km}$, and the zero capacitance of is $C = 0.038 \mu \text{F} / \text{km}$. Load parameters: active power is $P = 10000 \text{W}$, inductive reactive power is $Q = 4000 \text{var}$, capacitive reactive power is $Q = 0 \text{var}$. Different grounding resistances, different initial angles, and different fault distances were separately verified by simulation.

4.1. Grounding resistance = 0 (metallic grounding), fault distance is 10km away from the beginning of the line, and the initial phase angle is different

The simulation results in Table 1.

| Failure angle | Detection point 1 and Detection point 2 | Detection point 2 and Detection point 3 | Detection point 3 and Detection point 4 | Fault Section |
|---------------|------------------------------------------|------------------------------------------|------------------------------------------|---------------|
| Initial phase 0° | -0.0015° | 179.9934° | 0.0012° | Section 2 |
| Initial phase 30° | -0.0014° | 179.9854° | 0.0011° | Section 2 |
| Initial phase 60° | -0.0015° | 179.9855° | 0.0011° | Section 2 |
| Initial phase 90° | -0.0015° | 180.0070° | 0.0012° | Section 2 |

As shown in Table 1, It can be concluded that after changing the initial phase of failure, there is little effect on the phase difference between adjacent detection points.

4.2. The fault distance is 10km from the beginning of the line, the initial phase is 0°, and the grounding resistance is different.

The simulation results in Table 2.
Table 2. Zero-sequence current phase difference between adjacent detection points with different grounding resistance

| Earthing resistance | Detection point 1 and Detection point 2 | Detection point 2 and Detection point 3 | Detection point 3 and Detection point 4 | Fault Section |
|---------------------|----------------------------------------|----------------------------------------|----------------------------------------|--------------|
| 0                   | -0.0015°                               | 179.9934°                             | 0.0012°                               | Section 2    |
| 100                 | -0.0015°                               | 179.9929°                             | 0.0012°                               | Section 2    |
| 500                 | -0.0015°                               | 179.9931°                             | 0.0012°                               | Section 2    |
| 3000                | -0.0015°                               | 179.9930°                             | 0.0012°                               | Section 2    |

As shown in Table 2, changing the ground resistance has no effect on the phase difference between adjacent detection points.

4.3. The initial phase is 0°, the ground resistance is 0, and the fault distance is different

The simulation results in Table 3.

Table 3. Zero-sequence current phase difference between adjacent detection points at different fault distances

| Fault Distance (km) | Detection point 1 and Detection point 2 | Detection point 2 and Detection point 3 | Detection point 3 and Detection point 4 | Fault Section |
|---------------------|----------------------------------------|----------------------------------------|----------------------------------------|--------------|
| 5                   | 180.0030°                              | 0.0020°                               | 0.0013°                               | Section 1    |
| 10                  | -0.0015°                               | 179.9934°                             | 0.0012°                               | Section 2    |
| 15                  | -0.0015°                               | -0.0029°                              | 179.9708°                             | Section 3    |

As can be seen from Table 3, after changing the fault distance, the fault section has changed because the fault point is in different monitoring sections.

In summary, when a fault appeared in the system, the fault characteristics obtained in Chapter 2 are not influenced by any fault's condition. This proves the correctness of using the zero-sequence current phase method.

5. Conclusion

In summary, First of all, through theoretical derivation of the principle of fault location of phase method and calculation of steady-state zero-sequence current phase of line faults. Second, using MATLAB to write a phase-based single-phase ground fault segment positioning algorithm. Finally, the simulation model is established by MATLAB. The simulation consequence reflect that the characteristics of the characteristics obtained by the simulation are in good agreement with the theoretical analysis.

References
[1] Li Runxian. Grounding technology of medium-voltage grid system. Beijing: China Electric Power Press, 2002
[2] Yao Huan Nian, Cao Meiyue. Resonance grounding of power systems. Beijing: China Electric Power Press, 2000
[3] He Jiali, Song Congming. The principle of relay protection in power system. Beijing: Water Conservancy and Electric Power Press, 1985
[4] Lyon W V. Transient analysis of alternating current machinery [M]. New York, USA Technology Press of MIT and John Wiley & Sons Inc, 1954.
[5] Iravani M R, Karimi-Ghartemani M. Online estimation of steady state and instantaneous symmetrical components [J]. 2003, 150(5): 616-622.