Single-phase Earth Fault Section Location Based on Differences’ Characteristics of Zero-sequence Currents in Distribution Network

Xiuming Hu¹,², *, Xudong He¹,², Dan Xu¹,², Yuqiong An¹,², Yi Zhang¹,², Mei Li¹,², Situo Zhou¹,², Yuan Li¹,², Xiong Huang¹,²

¹Huanggang Power Supply Company State Grid, Huanggang 438000, China
²Hubei Electric Power Co, Ltd State Grid, Wuhan 430000, China

*Corresponding author: hbhgsunshine@163.com

Abstract. When a single phase earth fault occurs in distribution network, the difference between the transient zero-sequence currents at the head of the non-faulty section before the fault point is small, and the non-faulty section after the fault point also has this feature, but the difference between the zero-sequence currents at the head of the section before and after the fault point is big. Based on this, a method for comparing the single-phase grounding fault section location in distribution network based on the difference of the transient zero-sequence current was proposed. Based on the known distribution network structure, the fault section table was compiled, then the transient zero-sequence currents difference at the head of each section were compared, the fault section could be selected. The simulation by PSCAD/EMTDC verified the reliability of the method.

Keywords: Section location, distribution network.

1. Introduction
The distribution network is directly connected to users and is a vital link in the transmission of electric energy. After a single-phase fault occurs in the neutral ungrounded system, it is allowed to operate for 1 to 2 hours with the fault. To ensure safety, the fault line should be found in the shortest possible time, and the fault section should be determined in order to deal with the fault in time. With the rapid economic and social development, the network structure of the distribution network has become more and more complex. A line often contains cable lines and overhead lines, which brings serious difficulties and challenges to the traditional methods to find fault section. At present, commonly used methods for locating fault sections include zero sequence admittance method, traveling wave method, line voltage and zero mode current method, etc. The zero-sequence admittance method analyzes the constraint relationship between the zero-sequence current and the voltage of the characteristic frequency band. It needs to increase the voltage transformer, which increases the cost, and the signal transmission error will cause the algorithm to have a large error. The traveling wave method is susceptible to external interference and is currently being distributed It can not be applied in power grids. The method of using line voltage and zero-mode current ignores the attenuation effect of high-frequency components, it is approximated that the difference between the frequency components is 90°, which also has large error.
In this regard, this paper proposed a fault section location method based on the comparison of transient zero-sequence current differences, and the correctness of the method was verified through simulation in PSCAD/EMTDC.

2. Analysis of the transient zero sequence current difference after single-phase earth fault

The topology of a single-phase fault fault in a neutral ungrounded system was shown in figure 1. There were 4 outgoing lines, namely lines 1, 2, 3, 4, and line 1 had 4 feeder terminal unit (FTU) a, b, c, d, which were installed before the location of the section circuit breakers. The TFU a is at the beginning of the outgoing line 1.

![Figure 1. Simplified diagram of neutral ungrounded system](image1)

When a single-phase earth fault occurs at point f on line 1, the corresponding zero-sequence network was shown in figure 2.

![Figure 2. Zero-sequence network diagram](image2)

In figure 2, Ca, Cb, Cc, Cd, CT, C2, C3, and C4 respectively are the equivalent capacitance to the ground of each section line. The direction indicated by the arrow in the figure is the reference direction of the zero-sequence current. Define the section a to represent the line between a and b, and so on. The zero sequence current at the head of section a and section b has the following relationship as the equation (1):

\[ i_{0a} = i_{0b} + i_a \]
In equation (1), the zero sequence current at the head of section a equal to the sum of the zero-sequence currents of the non-fault lines:

\[ i_{0a} = i_{02} + i_{03} + i_{04} + i_T \]  

(2)

And \( i_a \) is the capacitance current of the section a.

Due to the short distance of the section a, the capacitance current of section a can be ignored compared to the capacitance current of the non-fault lines. That is:

\[ i_{0a} \approx i_{0b} \]  

(3)

The equation (3) shown that the zero-sequence currents of different section before fault point f had less difference. The zero-sequence currents of different section after fault point f also had similar features. That is:

\[ i_{0c} \approx i_{0d} \]  

(4)

But the zero-sequence currents at the head of the section before and after the fault point f did not had this features. In fact, the direction of the current \( i_a \) and the direction of the current \( i_c \) were opposite. Just as shown in Figure 2,

\[ i_f \approx i_{0c} - i_m \]  

(5)

The simulation model of the distribution network shown in figure 2 was established in PSCAD/EMTDC, a single-phase earth fault occurred at the point f on the section b, and the transient zero-sequence currents at the head end of the four different sections were shown in figure 3. It can be seen that the simulation result verified the analysis above.

![Figure 3. Zero-sequence currents of different sections](image)

3. Location principle

Based on the above analysis, this paper proposed a section location method based on the comparison of the transient zero-sequence currents’ difference characteristics. Specific steps were as following:

First, for a given distribution network diagram, compile the corresponding section table. For example, the following figure 4 shows a distribution network with branch line.
There were 4 feeder terminal units installed on the line 1, they were a, b, c and d which was installed on the branch line. Then there were 4 sections: section 1 represented the line between a and b, section 2 represented b and line between c, section 3 represented the line after c, section 4 represented b the branch line. The branch line was connected at the end of section 1.

Take the transient zero-sequence currents detected by the FTU in different sections to get the difference:

\[
\begin{align*}
i_{k1} &= i_{0a} - i_{0b} \\
i_{k2} &= i_{0a} - i_{0c} \\
i_{k3} &= i_{0a} - i_{0d} \\
i_{k4} &= i_{0b} - i_{0c} \\
i_{k5} &= i_{0b} - i_{0d} \\
i_{k6} &= i_{0c} - i_{0d}
\end{align*}
\]  

In equation (6), \(i_{0a}\) is the transient zero-sequence current of section 1 detected by the FTU a, and so on. Then get the absolute maximum value in 5ms, and sort these absolute values from small to large, the possible fault section could be selected by analyzing the smallest to the largest value. For example, if \(i_{k1}^{\max}\) was the smallest, it showed that the zero-sequence current difference between section 1 and section 2 was very small, and the fault can only occurred at section 2 or section 3. The fault section table was showed as follows.

| Smallest value | Possible fault section |
|---------------|------------------------|
| \(i_{k1}^{\max}\) | 2 or 3                 |
| \(i_{k2}^{\max}\) | 3                      |
| \(i_{k3}^{\max}\) | 4                      |
| \(i_{k4}^{\max}\) | 1 or 3 or 4            |
| \(i_{k5}^{\max}\) | 1                      |
| \(i_{k6}^{\max}\) | 1 or 2                 |
Second, when there were 2 or more possible fault section just like the smallest value was \( i_{k1}^{max} \) or \( i_{k4}^{max} \) or \( i_{k6}^{max} \) in the table 1, the second smallest value need to be find, and its’ possible fault section should be selected. Find out the repeated fault section from the possible fault sections corresponding to the minimum value and to the second smallest value. If the repeated fault section is not unique, find the possible fault sections corresponding to the third smallest value until the repeated fault section is unique. The unique section is the fault section determined by this method proposed by the paper.

4. Simulation Verification

In order to further verify the feasibility of the location method in this paper, a distribution system as shown in figure 4 was built in PSCAD/EMTDC simulation software. The rated voltage of the transformer high and low voltage side were 110kV and 10.5kV. The outgoing line 1 was mixed by cable and overhead line, outgoing line 2 and outgoing line 3 were both overhead lines, and outgoing line 4 was a cable line.

Section 1 was a cable line with a total length of 1.6km, section 2 was an overhead line with a total length of 1.2km, section 3 was an overhead line with a total length of 3km, and branch line section 4 was an overhead line with a total length of 2km. FTU a, b, c and d were installed at the head of each section, and the sampling frequency was set 10kHz.

When a single-phase earth fault occurred at a distance of 1km from FTU a on section 1, the differences’ absolute value of transient zero-sequence currents in the four sections were shown in figure 5.

![Figure 5. Differences’ absolute values](image)

From figure 5, the 6 maximum absolute values in 5ms after fault occurred at 200ms were sorted as:

\[
\begin{align*}
&i_{k4}^{max} < i_{k5}^{max} < i_{k6}^{max} < i_{k3}^{max} < i_{k1}^{max} < i_{k2}^{max}
\end{align*}
\]  

(7)

Compared to the table 1, first, section 1 or 3 or 4 could be selected as the possible fault section, second, section 1 as the possible fault section, the repeated section was section 1, and then section should be the fault section which was consistent with the reality.
When the single-phase earth fault occurred at a distance of 0.2km from FTU b on section 2 at 215ms or a distance of 2.5km from FTU c on section 3 at 203ms or a distance of 1.34km from FTU d on section 4 at 203ms, the 6 maximum absolute values in 5ms after fault occurred at 200ms were respectively sorted as equation (8) to (10):

\[ i_{k1}^{\text{max}} < i_{k3}^{\text{max}} < i_{k2}^{\text{max}} < i_{k4}^{\text{max}} < i_{k5}^{\text{max}} < i_{k6}^{\text{max}} \]  

\[ i_{k1}^{\text{max}} < i_{k4}^{\text{max}} < i_{k2}^{\text{max}} < i_{k3}^{\text{max}} < i_{k5}^{\text{max}} < i_{k6}^{\text{max}} \]  

\[ i_{k4}^{\text{max}} < i_{k3}^{\text{max}} < i_{k2}^{\text{max}} < i_{k1}^{\text{max}} < i_{k6}^{\text{max}} < i_{k5}^{\text{max}} \]  

Compared the above 3 equations to the table 1, section 2, section 3, and section 4 could be selected, which were all consistent with the reality.

After many simulations, the correctness of the method proposed in this article had been verified. Due to paper’s space limitation, this article did not give every simulation result.

5. Conclusion
This paper analyzed the difference between the transient zero-sequence currents of each section after a single-phase earth fault occurs, and find that the absolute value of the zero-sequence current difference on both sides of the fault point is large, and the difference between the section before or after the fault point is small. Then a single-phase earth fault section location method based on the absolute value comparison of the zero-sequence current difference was proposed. Simulations verify the correctness of the method proposed. This article did not consider the transient zero-sequence current error caused by signal interference, so further experimental verification is needed.

References
[1] Guobing Song, Guang Li, Yeyun Yu, et al. Single-Phase Earth Fault Section Location Based on Phase Current Fault Component in Distribution Network. Automation of Electric Power System, vol.35, no. 21, pp. 84-90, 2011. (in Chinese)
[2] Feng Yan, Qixun Yang, Zheng Qi, et al. Study on Fault Location Scheme for distribution network based on traveling wave theory. Power System Technology, vol. 24, no. 9, pp. 37-43, 2004. (in Chinese)