Single Phase to Ground Fault Section Location Based on Characteristics of Traveling Wave Refraction and Reflection

Yan-gang SHI¹*, Zi-jia HUI¹, Ze-yu GU² and Yong-zeng LI²

¹School of Electrical Engineering, Xi'an Jiaotong University, Xi'an, China
²State Grid Zhongwei Electric Power Company, Zhongwei, China

*Corresponding author

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Abstract. For single phase to ground fault in distribution networks, fault locating using traveling wave measured at one terminal only need to detect the arrival time of the initial wave head of the line mode and the zero mode. But the zero mode wave velocity is unstable. This paper proposes a fault section location method using only line mode traveling wave. It analyzes wave refraction and reflection performance at the fault point, the branch point and the end of the line. The path differences between reflected waves and the initial incident wave are estimated through Hilbert Huang Transform by indexing the arrival time of the initial wave and reflected waves, if the line mode wave velocity is assumed. Combined with the topology of distribution network, the possible propagation paths can be obtained to identify the fault section. The effectiveness of the proposed method is verified by experiments in the actual distribution network.

Introduction

In the distribution networks, the probability of occurrence of single phase to ground fault accounts for more than 80% of all types of faults. When single phase grounding occurs, it is of great significance to find fault location timely to improve power supply reliability. Fault location method based on transient traveling wave signal has been widely concerned because it is not affected by fault types, transition resistance and neutral grounding mode[1-2].

Modern traveling wave positioning methods are generally divided into single-ended method and double-ended method. The double-ended method uses the difference of arrival time of line mode traveling wave head between the two end measurement points to achieve fault location, requiring accurate global positioning system (GPS) on the time device [3]. Since the reflected wave from the fault point is difficult to identify, the single-ended method based on the initial traveling wave and the fault point reflected wave is difficult to apply in the actual distribution network [4,5]. Another single-end positioning method is based on the velocity difference between line mode and zero mode wave. But the zero mode wave velocity is unstable with the fault distance and the traveling wave frequency, and the error is large [6-8].

The line mode traveling wave is easy to obtain and its velocity is stable [7], from which the time of the initial wave and each reflected waves arriving at the same measuring point can be obtained, as well as the time difference between reflected waves and the initial wave. And combined with the line mode traveling wave velocity, the distance differences are obtained. As distribution network topology is known, the possible traveling paths of traveling waves are determined, and then the fault section is located.

Propagation Characteristics of Fault Traveling Wave

According to the superposition principle, the single phase to ground fault of the distribution line is equivalent to the fault instantaneously add a pulse signal source at the fault point, and the fault traveling wave propagates along the line to both sides of the fault point. According to the wave
propagation theory, when the fault traveling wave encounters the fault point, the branch point and the end of the line where wave impedance is not continuous, catadioptric phenomenon happens.

Traveling wave measurement point is set at the substation or at the end of the line. After the fault occurs, the initial traveling wave arriving at the measurement point is transmitted directly from the fault point to the measurement point, and the propagation path is the shortest. The reflected wave is reflected at the discontinuity point of the wave impedance. The time to reach the measurement point has a certain delay with respect to the initial traveling wave. The propagation distance is the sum of the initial wave propagation path and the branch reflection path. Taking the 10 kV distribution network shown in Fig. 1 as an example, point M indicates the traveling wave measurement point in the substation. Point N represents the measurement point at the end of the line. When the single phase to ground fault occurs at point f on section E-I, the propagation paths of initial traveling wave and reflected traveling waves measured by point M are shown in Fig. 1.

Fig. 1 shows an example of traveling wave propagation paths, indicated by solid lines with arrows, and are identified as path 1 to 4 from the short to the long distance. And so on, traveling wave can also be reflected at branch E-F, branch B-C and other branches, no longer list.

The actual distribution network can be divided into different sections according to the branch nodes. In Fig. 1, for example, each two capital letters represent a section, a total of 10 sections. When the actual fault occurs, it is possible to obtain the path differences between reflected waves and the initial wave according to the measured traveling wave signal, assuming that the number of distance differences is n. In turn, it is assumed that the fault occurs in each section, and the propagation paths of reflected waves corresponding to each path difference are searched. If there is a propagation path corresponds to it, the path difference is reasonable. Otherwise, unreasonable. Suppose that the number of reasonable path differences is m, and m/n is used to express the reliability of the fault occurring in the section. At the same time, from the path differences between reflected waves and the initial wave the distance between fault point and the nearest branch point can be extracted, thereby locating the fault point.

**Fault Section Location Method**

According to the above analysis, this paper proposes a single phase to ground fault section location method based on traveling wave catadioptric characteristics. In combination with Fig. 1, the flow chart of the section location method is shown in Fig. 2.

The three phase coupled signal is decomposed into independent line and zero components using the Karen Bell transform:

\[
\begin{bmatrix}
F_0 \\
F_1 \\
F_2 \\
\end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 \\
1 & -1 & 0 \\
1 & 0 & -1 \\
\end{bmatrix} \begin{bmatrix} F_a \\
F_b \\
F_c \\
\end{bmatrix}
\]

Where \( F_a, F_b, F_c \) represent the three phase fault traveling wave signal, and \( F_0 \) represents the zero mode component of the fault traveling wave, and \( F_1 \) and \( F_2 \) both represent the line component.

Hilbert-Huang transform (HHT) is a new method for non-stationary signal analysis in recent years. It consists of two parts: Empirical Mode Decomposition (EMD) and Hilbert transform. The steps of using HHT to detect the time of the initial traveling wave and reflected waves arriving at the measuring point are as follows: firstly, the line mode traveling wave signal is decomposed by EMD, and a series of inherent modal components \( \text{imf1}, \text{imf2} \) are obtained; then Hilbert transform is performed on the \( \text{imf1} \) component, finding the relationship between instantaneous frequency and time. The time of first instantaneous frequency maxima corresponds to the arrival time of the initial traveling wave, and then the moments of other instantaneous frequency maximas correspond to the arrival time of each reflected waves.
The differences between the arrival time of reflected waves and the initial wave are multiplied by the line mode wave velocity, and path differences are obtained. The traveling wave velocity of the line model is related to the line parameters, which can be obtained by the calculation of line parameters or by the test method. From the literature [7], we can see that the line mode traveling wave along the overhead bare wire propagation velocity is similar to the speed of light.

According to the branch nodes, the distribution line is divided into different sections, and the reliabilities of the fault occurring in each section are calculated.

The specific method is as follows: For each section, it is assumed that the total number of path differences between reflected waves and the initial wave calculated from HHT is n, and if there are m path differences having the corresponding traveling wave propagation path in the known distribution network topology, the reliability P of the fault occurring in the section is calculated as:

\[ P = \frac{m}{n} \times 100\% \]

The standard value of reliability is set, and the section beyond the standard value is judged as the possible fault section. If the reliability standard value is too high, there may be no fault section meeting the requirements. While the value too low, the results meeting the requirements may be too much. In this paper the standard value of reliability is 85%.

Experimental Verification

In order to verify the practicability of the fault location method in this paper, a single phase to ground fault transient current traveling wave measurement experiment is carried out on a 10kV distribution network in Ningxia. Using the measured current traveling wave data, the fault section can be located. The schematic diagram of the actual distribution network is shown in Fig. 3.

![Figure 3. The schematic diagram of the actual distribution network.](image-url)
total length is about 8km, and the single phase grounding is located near the tower 40.

In the 10kV side of the substation, use high speed current traveling wave acquisition device in Fig. 4 to collect the current traveling wave, and the current signal is converted into the voltage signal to be measured with oscilloscope. The measured line mode current traveling wave’s shape is shown in Fig. 5.

It can be seen from Fig. 5 that when the single phase to ground fault occurs, line mode current traveling wave has obvious abrupt change, and the steady state is gradually recovered after about 3ms time. Using HHT to calibrate the arrival time of the initial wave and first 10 reflected waves with shorter path in the line mode traveling wave. According to the location method in this paper, calculation of reliability and fault distance occurred on the 11 selected sections in Fig.3 is shown in Table 1.

<table>
<thead>
<tr>
<th>Section</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reliability</td>
<td>40%</td>
<td>80%</td>
<td>60%</td>
<td>60%</td>
<td>90%</td>
<td>80%</td>
<td>90%</td>
<td>80%</td>
<td>80%</td>
<td>90%</td>
<td>80%</td>
</tr>
<tr>
<td>Fault distance/m</td>
<td>75</td>
<td>75</td>
<td>75</td>
<td>75</td>
<td>75</td>
<td>75</td>
<td>75</td>
<td>75</td>
<td>75</td>
<td>75</td>
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</tr>
</tbody>
</table>

It can be seen from Table 1 that if the reliability of occurring fault exceeding 85% is set as the judgment standard, the possible fault sections are section 5, 7 and 10. The real fault location is near the 40# tower, that is section 7 in Fig. 3, which is included in the positioning result. The fault location is between 39# and 41# from 39#75m.

The above results show that the fault location method can be used to locate the fault section when the single phase to ground fault occurs in the actual distribution network. However, since only one measurement data is used, the positioning result also includes two sections that do not have a fault, that is the "false fault section". From the theoretical analysis, it can be seen that it can effectively reduce or even eliminate the interference of "false fault section" when adding the number of measuring points. Next step the situation of multiple measuring points in the distribution network will be studied.

**Conclusion**

In this paper, a single phase to ground fault section location method based on fault traveling wave propagation is proposed. The fault current traveling wave measurement and fault location experiment in actual 10kv distribution network shows that the positioning method only uses the line mode traveling wave to give the fault occurrence section, reducing the complexity of the section location, and has certain practicability.

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Reference


