Research on Fault Location of T-type Transmission Line Based on Wavelet Transform

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Abstract. In order to ensure the stable operation of the power system and solve the influence of uncertain factors such as traveling wave velocity on the transmission line, this paper proposes a new fault location method that is not affected by the wave velocity for the T-type transmission line. The method first determines the branch where the fault is located, and the faulty branch can be determined only by the time when the initial traveling wave of the fault voltage reaches the three ends of the T-type transmission line and the length of the three branch lines. Then, the location of the fault point is determined according to the time when the initial voltage traveling wave reaches the three-terminal of T-type transmission line. Finally, simulation is conducted in matlab/simulink. The simulation results show that this method can accurately locate the fault point.

1. Introduction
With the rapid development of smart grids, T-type transmission lines are increasingly appearing in power systems. Therefore, it is very important to study the fault location of T-type transmission lines. Now, there are many domestic and foreign scholars working on the fault location of T-type transmission lines. The main research methods are impedance and traveling wave method. The traveling wave method is hardly affected by the transition resistance and the line parameters and is simple in principle [1-4].

For the fault location of T-type transmission line, it is necessary first to determine the branch where the fault is located, and then can be accurately located. In [5], a combination of the precise location of the fault and the choice of the failure branch, this positioning method may make the faulty branch unable to be identified and cannot be located. The judgment of the fault branch in [6] and [7], is determined by the double-end fault location principle, and then the fault point is located. However, in [8], the influence of travelling wave velocity on fault localization is not taken into account. In [9], compares the accuracy of discrete wavelet transform, Hilbert transform, S transform, HS transform, TT transform for fault location of T-type transmission lines, but the wave speed is set to 298258.27 km/s in these papers, which significantly increased the error of fault location. Aiming at the influence of traveling wave velocity on fault location error, a new fault location method is proposed, which is not affected by wave velocity. This method greatly improves the accuracy of fault location.

2. Wavelet transform

2.1. The definition of wavelet transform
The telescopic translation operation of the wavelet transform is performed by multi-scale refinement of the signal (function), and the signal is subdivided at a high frequency, and the frequency subdivision occurs at a low frequency. In this way, any details of the signal can be revealed [10].

Continuous wavelet transform, also known as integral wavelet transform, can be defined as

\[
W_f(a,b) = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} f(x) \psi_{a,b}(x) dx = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} f(x) \psi\left(\frac{x-b}{a}\right) dx
\]  

(1)

Where \(a\) is the scale parameter or expansion parameter, and is a positive real number. \(b\) is a translation parameter, and its value can be any real number.

2.2. The singularity theory of wavelet transform

The singularity used in this paper refers to the sudden change of the signal amplitude at a certain moment, which makes the signal discontinuous. By performing wavelet transform on the singular point, the modulus maximum value is obtained [11].

Set a non-negative integer \(n\), \(n \leq a < n+1\), if there are two constants \(C > 0\) and \(x_0 > 0\) and an \(n\)-order polynomial \(P_n(x)\), for \(x \in (x_0 - \delta, x_0 + \delta)\), there is

\[
|f(x_0 + x - P_n(x))| \leq C|x|^{n}\]  

(2)

Then the function is called Lipschitz \(\alpha\) at the \(x_0\) point. If the Lipschitz exponent \(\alpha\) of the function on \(x_0\) is less than 1, then the function is said to be singular at that point.

3. Fault location

The model of the T-type transmission line is shown in figure 1. Since there is coupling between the phases in the three phase transmission line, the traveling wave component on each phase is not independent. In this paper, the Clarke transform is used to carry out the phase-model transformation of the traveling wave [12], and finally the transformed \(\alpha\)-mode component is used for analysis to obtain the time when the initial traveling wave of the fault reaches the three terminals of the line.

3.1. T-type transmission line fault branch determination

For a T-type transmission line, when it fails, there are many kinds of transmission paths of the traveling wave in the line. It is difficult to determine which traveling wave is a reflected wave and which is a refracted wave at the line port. In view of this situation, the paper only needs to know the time when the initial traveling wave of the fault reaches the three terminals of the line to complete the fault location. Let the time when the initial traveling wave arrives at the three terminals of the line are \(t_m\), \(t_n\), and \(t_p\). The time when the fault occurs is \(t_f\), the traveling wave speed is \(v\), and the lengths of the three segments of TM, TN, and TP are \(L_{tm}\), \(L_{tn}\), and \(L_{tp}\).

![Figure 1. The model of T-type transmission line.](image-url)
When the fault occurs in the TM segment, there is
\[
\begin{align*}
    v(t_M - t_0) + x_1 &= L_{TM} \\
    v(t_N - t_0) - x_1 &= L_{TN} \\
    v(t_P - t_0) - x_1 &= L_{TP}
\end{align*}
\]
(3)

Where \( x_1 \) is the distance from the fault point to node T, \( x_1 > 0 \).

When the fault occurs in the TN segment, there is
\[
\begin{align*}
    v(t_M - t_0) - x_2 &= L_{TM} \\
    v(t_N - t_0) + x_2 &= L_{TN} \\
    v(t_P - t_0) - x_2 &= L_{TP}
\end{align*}
\]
(4)

Where \( x_2 \) is the distance from the fault point to node T, \( x_2 > 0 \).

When a fault occurs in the TP segment, there is
\[
\begin{align*}
    v(t_M - t_0) - x_3 &= L_{TM} \\
    v(t_N - t_0) - x_3 &= L_{TN} \\
    v(t_P - t_0) + x_3 &= L_{TP}
\end{align*}
\]
(5)

Where \( x_3 \) is the distance from the fault point to node T, \( x_3 > 0 \).

When equation (3) is established, the fault occurs in the TM segment, where \( x_1 > 0 \) and there is a uniquely determined value, and equations (4) and (5) are not valid. The same analysis of equation (4) and (5). When equations (3), (4) and (5) are established simultaneously, the fault occurs at the node T. Therefore, fault branches can be determined by equations (3), (4) and (5).

3.2. Precise positioning of T-type transmission lines

When the fault branch is determined according to section 3.1, the specific location of the fault can be judged according to \( t_M, t_N, t_P \) and \( t_0 \). In view of that the measurement error will be affected by the speed of the fault traveling wave, a fault location method which is not affected by the wave speed is proposed in this paper. The specific process is as follows:

When the fault occurs in the TM segment, let \( x_M, x_N \) and \( x_P \) be the estimated distance from the fault point to M terminal, N terminal and P terminal, then
\[
\begin{align*}
    x_M &= v(t_M - t_0) \\
    x_N &= v(t_N - t_0) \\
    x_P &= v(t_P - t_0)
\end{align*}
\]
(6)

Set the actual distance from the fault point to the M terminal to be \( x_{Md1} \), according to \( x_M, x_N \) we can obtain
\[
\frac{x_M + x_N}{L_{TM} + L_{TN}} = \frac{x_M}{x_{Md1}}
\]
(7)

Then we can obtain
\[
x_{Md1} = \frac{(L_{TM} + L_{TN})(t_M - t_P)}{t_M + t_N - 2t_0}
\]
(8)

Set the actual distance from the fault point to the M terminal to be \( x_{Md2} \). According to \( x_M, x_P \) the same reason we can obtain
\[
x_{Md2} = \frac{(L_{TM} + L_{TN})(t_M - t_P)}{t_M + t_P - 2t_0}
\]
(9)

In order to improve accuracy, the final fault distance of \( x_Md \) is the average value of \( x_{Md1} \) and \( x_{Md2} \).
When the fault occurs in the TN and TP segments, the final fault distance deduction process is similar to the TM segment.

4. The simulation analysis

In order to verify the accuracy of the method, according to figure 1, 110kv simulation circuit is constructed in matlab/simulink, where \( L_{TM} = 150km \), \( L_{TN} = 200km \) and \( L_{TP} = 100km \), the total simulation time is 0.06s, and the fault start time is 0.03s. The fault occurs when the TM segment is short-circuited to the A-phase at a distance of 40 km from the M terminal, and the transition resistance is 10 \( \Omega \).

The line parameters are:
\[
\begin{align*}
    r_1 &= 0.02083\Omega/km, \\
    r_0 &= 0.1148\Omega/km, \\
    L_1 &= 0.8984mH/km, \\
    L_0 &= 2.2886mH/km, \\
    C_1 &= 12.94nF/km, \\
    C_0 &= 5.23nF/km
\end{align*}
\]

After performing the Clarke transformation on the M terminal voltage, voltage \( \alpha \)-mode waveform and results of wavelet transform modulus \( \alpha \) on M terminal are shown in figure 2 and figure 3 respectively.

![Figure 2](image1.png)  
**Figure 2.** Voltage \( \alpha \) modulus waveform on M-side.

![Figure 3](image2.png)  
**Figure 3.** M-terminal \( \alpha \) mode waveform.

After performing the Clarke transformation on the N terminal voltage, voltage \( \alpha \)-mode waveform and results of wavelet transform modulus \( \alpha \) on N terminal are shown in figure 4 and figure 5 respectively.

![Figure 4](image3.png)  
**Figure 4.** Voltage \( \alpha \) modulus waveform on N-side.

![Figure 5](image4.png)  
**Figure 5.** N-terminal \( \alpha \) mode waveform.
After performing the Clarke transformation on the P terminal voltage, voltage α-mode waveform and results of wavelet transform modulus α on P terminal are shown in figure 6 and figure 7 respectively.

**Figure 6.** Voltage α mode waveform on P-side.

**Figure 7.** P-terminal α mode waveform.

From figure 3, figure 5 and figure 7, we can get $t_m=0.030197s$, $t_N=0.031527s$, $t_p=0.031034s$. From the T-type transmission line decision rule, the fault occurs at the TM end, and $x_{md}=40.0012$ can be obtained by formula (10), the error is 1.2m.

In this paper, fault location is carried out for different branches, different fault types and different transition resistances. The details are shown as follows.

**Table 1.** Simulation results at different fault locations of different branches.

| Fault branch | Fault location /km | $t_m$ /s | $t_N$ /s | $t_p$ /s | Branch judgment | $x_{md}$ /km | Fault error /m |
|--------------|--------------------|----------|----------|----------|----------------|--------------|----------------|
| TM           | 120                | 0.030591 | 0.031133 | 0.030641 | TM 119.9547    | 45.3         |
| TM           | 70                 | 0.030345 | 0.031379 | 0.030866 | TM 70.0525     | 52.5         |
| TN           | 45                 | 0.031502 | 0.030222 | 0.031256 | TN 45.0653     | 65.3         |
| TN           | 175                | 0.030862 | 0.030862 | 0.030616 | TN 174.9831    | 16.9         |
| TP           | 25                 | 0.031108 | 0.031354 | 0.030123 | TP 24.9814     | 18.6         |
| TP           | 80                 | 0.030387 | 0.031084 | 0.030394 | TP 79.9945     | 5.5          |

It can be seen from table 1 that the method proposed in the paper can correctly judge the fault location in different branches and different fault positions, and greatly reduce the error of fault location. The fault error is within 100m, which well satisfies the requirements.

**Table 2.** Simulation results of different fault types at 60km TN segment.

| Fault type | Fault branch | Fault location /km | $t_m$ /s | $t_N$ /s | $t_p$ /s | Branch judgment | $x_{md}$ /km | Fault error /m |
|------------|--------------|--------------------|----------|----------|----------|----------------|--------------|----------------|
| A-G        | TN           | 60                 | 0.031428 | 0.030296 | 0.031182 | TN 60.0870     | 87           |
| AB         | TN           | 60                 | 0.031428 | 0.030296 | 0.031182 | TN 60.0870     | 87           |
| AB-G       | TN           | 60                 | 0.031428 | 0.030296 | 0.031182 | TN 60.0870     | 87           |
| ABC        | TN           | 60                 | 0.031428 | 0.030296 | 0.031182 | TN 60.0870     | 87           |

It can be seen from table 2 that for the same branch and the same fault location, the method proposed in the paper is not affected by the fault type.

**Table 3.** Simulation results of different transition resistances at 47km of TP segment.

| Transition resistance /Ω | Fault branch | Fault location /km | $t_m$ /s | $t_N$ /s | $t_p$ /s | Branch judgment | $x_{md}$ /km | Fault error /m |
|--------------------------|--------------|--------------------|----------|----------|----------|----------------|--------------|----------------|
| 20                       | TP           | 47                 | 0.030999 | 0.031246 | 0.030231 | TP 46.9353     | 64.7         |
| 50                       | TP           | 47                 | 0.030999 | 0.031246 | 0.030231 | TP 46.9353     | 64.7         |
| 350                      | TP           | 47                 | 0.030999 | 0.031246 | 0.030231 | TP 46.9353     | 64.7         |
It can be seen from table 3 that for the same branch and the same fault location, the method proposed in the paper is not affected by the transition resistance.

5. Conclusion
In this paper, the fault location of T-type transmission lines is studied. The fault location method proposed in this paper excludes the influence of wave velocity on the measurement results. In addition, the singularity theory of wavelet transform is utilized, which makes the measurement error reduced.

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