Fault Location Approach for Teed Transmission Line Independent of Wave Speed

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Abstract. The uncertainty of traveling wave speed always causes big deviations to the fault location. In order to conquer the influence of traveling wave speed on transmission line fault location, a new method of fault location was presented in this paper. The method contains two main parts: the establishment of the identification matrix for the fault section and fault point location. Firstly, the arrival times of the initial fault traveling waves are used to form the identification matrix for the fault section, and the fault section can be identified according to characteristics of element in the formed identification matrix, and the matrix avoids the influence of wave speed; Secondly, a new locating algorithm without influence of wave speed was derived based on the principle of double-node traveling wave fault location. The simulation results show that the arrival time of initial fault traveling wave can be detected accurately, and then the fault section and the fault point can be located exactly by using the method proposed by this paper. And the method is unsusceptible to wave speed, fault type, transition resistance.

1. Introduction
The teed transmission line has the characteristics of large transmission power and heavy load. Once the fault occurs, it may cause a large area of electricity black-out. Therefore, accurate fault location is particularly important for the teed transmission lines [1]. The accuracy of the traveling wave method is affected by the traveling wave speed and the time when the traveling wave head reach the measuring point. However, the traveling wave speed is an uncertain. In different literatures, it is usually preset at 0.936 C~0.987 C. Obviously, presetting a value close to the speed of light as the wave speed for fault location calculation will greatly affect the fault location accuracy.

Literature [2] puts forward a method that uses fault indicators to identify fault section and then accurately locate fault point. Literature [3] and literature [4] firstly identify fault section according to the principle of double-node traveling wave ranging, and then locate the fault point. Literature [5] preset the wave speed as 298258.27km/s for calculation, then the location error is large.

In this paper, in order to solve the problem that the uncertainty of traveling wave speed affects fault location, a new method is proposed. The method contains two main parts: the establishment of the identification matrix for the fault section and fault point location. Firstly, the arrival times of the initial fault traveling waves are used to form the identification matrix for the fault section, and the fault section can be identified according to characteristics of element in the formed identification matrix; Secondly, a new locating algorithm without influence of wave speed was derived based on the principle of double-node traveling wave fault location.
2. The flowchart of the proposed method

The flowchart of the proposed method is shown in Figure 1. First of all, voltage signals are acquired from the M, N, P node, and the voltage signals are transformed to the aerial component through phase-mode transformation. Secondly, the time that the initial fault travelling wave arrive the measurement point will be detected by wave transform. Finally, the fault point will be calculated by using the proposed method in this paper.

![Flowchart of the proposed method](image)

Figure 1. The flowchart of the proposed method

3. Fault section identification

When a fault occurs in a teed transmission line, the propagation distance of the fault traveling wave in transmission line is proportional to the propagation time. Taking the fault on PR section (fault point is defined as d) as an example, the following equation can be established:

\[
\begin{align*}
L_{Md} &= L_{MR} + X = v(t_M - t_0) \\
L_{Nd} &= L_{NR} + X = v(t_N - t_0) \\
L_{Pd} &= L_{PR} - X = v(t_P - t_0)
\end{align*}
\]  

Where, \(L_{Md}\), \(L_{Nd}\) and \(L_{Pd}\) are respectively the distance from the fault point d to the M-node, N-node and P-node. \(L_{MR}\), \(L_{NR}\) and \(L_{PR}\) are respectively the distance from the R-node to the M-node, N-node and P-node and R node. \(t_M\), \(t_N\) and \(t_P\) are respectively the time the initial fault traveling wave reach the M-node, N-node and P-node. \(X\) is the distance between fault point d and R-node; \(T_0\) is the start time of the fault; \(V\) is the traveling wave speed. The matrix composed of \(L_{Md}, L_{Nd}\) and \(L_{Pd}\) is denoted as \(L^*=(L_{Md}, L_{Nd}, L_{Pd})\). The matrix composed of \(L_{MR}, L_{NR}\) and \(L_{PR}\) is denoted as \(L=(L_{MR}, L_{NR}, L_{PR})\). It is similar when the fault occurs on MR section or NR section.

In order to identify the fault section, a new identification matrix is proposed in this paper. In the matrix, the ratio between the fault distance calculated and the length between the measuring node of the section and the R node is taken as an element to form matrix D. The fault section is identified by comparing the size of element of the fault section identification matrix and 1, where,

\[
D = \frac{L'_{ij}}{L_{ij}} \quad i, j = 1, 2, 3
\]

The method proposed in this paper only needs the time \(t_M, t_N, t_P\) and line length independent of wave speed. Fault section identification rules are as follows:

- If \(D_{11}<1, D_{12}>1, D_{13}>1\), then the fault section is MR;
- If \(D_{11}>1, D_{12}<1, D_{13}>1\), then the fault section is NR.
If $D_{11} > 1$, $D_{12} > 1$, $D_{13} < 1$, then the fault section is PR;
If $D_{11}=1$, $D_{12}=1$, $D_{13}=1$, then the fault point is R node.

4. Fault point location

After the fault section is identified, $t_M$, $t_N$ and $t_P$ can be used to locate the fault point. Taking the fault occurs on PR section as an example, the fault distance $L_{PdM}$ and $L_{PdN}$ are calculated used the equations as follows:

\[
L_{PdM} = \frac{L_{MP} + v(t_p - t_M)}{2}
\]

\[
L_{PdN} = \frac{L_{NP} + v(t_p - t_N)}{2}
\]

\[
v = \frac{L_{MR} - L_{NR}}{t_M - t_N}
\]

The final fault distance $L_{Pd}$ is the average of the $L_{PdM}$ and $L_{PdN}$.

\[
L_{Pd} = \frac{L_{PdM} + L_{PdN}}{2}
\]

The method proposed in this paper only needs the time $t_M$, $t_N$, $t_P$ and the length of transmission line independent of wave speed, and makes the fault location more accurate. It is similar when the fault occurs on MR section or NR section.

5. Simulation

Model for a teed transmission line system is set up by MATLAB/Simulink. The main parameters are as follows: $L_{MR}$, $L_{NR}$, $L_{PR}$ are respectively 80km, 60km, 100km, the sampling frequency is 1MHZ, the start time of fault is 0.02s.

In this paper, db1 wavelet base is used to decompose the aerial mode component of fault voltage traveling wave of each measuring point. Under scale 1, the wavelet modulus maximum point is calculated. The first wavelet modulus maximum point is the moment when the fault traveling wave reach the measuring point. Taking A phase ground fault occurs through 200 transition resistance at 67km from the measuring point M node as an example, the wavelet transform results of M-node, N-node and P-node are shown in Figure 2.

![Wavelet Transform Results](image)

Figure 2. The wavelet transform results of M-node, N-node, P-node
Figure 2 shows that the times for the initial fault traveling wave reach the three measuring points detected by the wavelet transform are respectively $t_M=0.020231s$, $t_N=0.020251s$, $t_P=0.020387s$. $L^*=\{67.06,72.94,112.94\}$ and $D=\{0.83,1.21,1.129\}$ can be calculated. According to the identification rules of the fault section, it can be known that the fault occurs on MR section. Then, $L_{Md}=67.0588km$ is calculated, and the error is 58.8m. It can be seen that the error is less than 100m.

In this paper, simulation is carried out under the different fault points, different fault types and different transition resistances. The simulation results are shown in Table 1.

### Table 1. Fault location results based on the method proposed in this paper

| Fault section | Fault point(km) | Fault type | Transition resistance(Ω) | WT Fault section identification | Fault point Location(km) | Error(m) |
|---------------|-----------------|------------|--------------------------|-------------------------------|--------------------------|---------|
| MR            | 13              | AG         | 10                       | 20047                         | 20435                    | 20571   | MR      | 12.9412 | 58.8   |
|               | 34              | AB          | 50                       | 20117                         | 20366                    | 20499   | MR      | 33.8355 | 176.5  |
|               | 67              | ABG         | 200                      | 20231                         | 20251                    | 20387   | MR      | 67.0588 | 58.8   |
|               | 74              | ABC         | 500                      | 20255                         | 20227                    | 20363   | MR      | 74.1176 | 117.6  |
| NR            | 13              | AG         | 10                       | 20435                         | 20047                    | 20503   | NR      | 12.9412 | 58.8   |
|               | 26              | AB          | 50                       | 20391                         | 20091                    | 20459   | NR      | 25.8824 | 117.6  |
|               | 58              | ABC         | 500                      | 20281                         | 20199                    | 20349   | NR      | 57.9412 | 58.8   |
| PR            | 10              | AG         | 10                       | 20581                         | 20513                    | 20037   | PR      | 10      | 0      |
|               | 29              | AB          | 50                       | 20517                         | 20449                    | 20101   | PR      | 28.8235 | 176.5  |
|               | 73              | ABG         | 200                      | 20367                         | 20299                    | 20251   | PR      | 72.9412 | 58.8   |
|               | 94              | ABC         | 500                      | 20295                         | 20227                    | 20323   | PR      | 94.1176 | 117.6  |

The simulation results show that the method proposed in this paper is error less than 200m under the different fault distances, different transition resistances and different fault types, which can better meet the needs of the project.

In order to compare the positioning effect of the method proposed in this paper, Hilbert-Huang transform is used to simulate the same fault conditions as above for the same system. Taking the fault occurs through 200 transition resistance at 40km away from the M-node as an example, the HHT and WT simulation results at the M-node, N-node and P-node are shown in Figure 3.

Figure 3. The results of HHT and WT of M-node, N-node, P-node

According to the Figure 3, it can be seen that the times for the initial fault traveling wave reach the three measuring points detected by Hilbert-Huang transform are respectively $t_M=0.020139s$, $t_N=0.020447s$ and $t_P=0.020477s$. $L^*=(39.17,100.83,140.83)$ and $D=(0.491,1.68,1.41)$ can be calculated. According to the identification rules of the fault section, it can be known that the fault occurs on MR section. Then, $L_{Md}=39.173km$ is calculated and the error is 827m. By using the same method, the
positioning result of wavelet transform is $L_{Md}=40\text{km}$, and the error is 0. Hilbert-Huang transform is used to simulate the same fault conditions for the same system. The results are shown in Table 2.

Table 2. Fault location results based on the HHT

| Fault section | Fault point (km) | Fault type | Transition resistance (Ω) | HHT TM(us) | HHT TN(us) | HHT TP(us) | Fault section identification | Fault point location (km) | Error (m) |
|---------------|-----------------|------------|---------------------------|------------|------------|------------|-----------------------------|--------------------------|-----------|
| MR            | 13              | AG         | 10                        | 20046      | 20435      | 20570      | MR                          | 12.3704                  | 629.6     |
|               | 34              | AB         | 50                        | 20118      | 20362      | 20500      | MR                          | 34.6377                  | 637.7     |
|               | 67              | ABG        | 200                       | 20231      | 20248      | 20386      | MR                          | 67.5362                  | 536.2     |
|               | 74              | ABC        | 500                       | 20256      | 20227      | 20364      | MR                          | 74.2336                  | 233.6     |
| NR            | 13              | AG         | 10                        | 20435      | 20047      | 20502      | NR                          | 12.0896                  | 910.4     |
|               | 26              | AB         | 50                        | 20391      | 20091      | 20460      | NR                          | 26.5217                  | 521.7     |
|               | 39              | ABG        | 200                       | 20346      | 20134      | 20416      | NR                          | 39.7143                  | 714.3     |
|               | 58              | ABC        | 500                       | 20282      | 20201      | 20351      | NR                          | 58.2609                  | 260.9     |
| PR            | 10              | AG         | 10                        | 20580      | 20512      | 20038      | PR                          | 10.2941                  | 294.1     |
|               | 29              | AB         | 50                        | 20516      | 20449      | 20101      | PR                          | 28.0597                  | 940.3     |
|               | 73              | ABG        | 200                       | 20200      | 20367      | 20298      | PR                          | 73.1884                  | 188.4     |
|               | 94              | ABC        | 500                       | 20295      | 20227      | 20321      | PR                          | 93.8235                  | 176.5     |

It is apparent from the Table 2 that the fault section identification matrix proposed in this paper can accurately identify the fault section. By comparing the positioning results of Table 1 and Table 2, it can be seen that the errors of Table 1 are less than the Table 4. The comparison results are shown in Figure 4.

Figure 4. The error of fault location by different methods

6. Conclusion

The fault location method proposed in this paper contains two main parts: the establishment of the identification matrix for the faulty section and fault point location. Both parts are independent of the traveling wave speed. The simulation results show that the arrival time of initial fault traveling wave can be detected accurately, and then the faulty section and the fault point can be located exactly by using the method proposed by this paper. And the method is unsusceptible to wave speed, fault type, transition resistance. Comparing with the simulation results based on Hilbert-Huang transform, the accuracy of the method proposed in this paper is higher.

References

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