A New Fault Location Algorithm for T-type Transmission Lines Based on Phase Recognition

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Abstract. In view of the traditional method for fault location of T-type transmission lines is not able to realize fault location correctly when the fault occurs near the T-type node, a new algorithm based on phase recognition is proposed about fault location of T-type transmission lines in this article. The algorithm constructs a range function by using the phase property of hyperbolic tangent function, regard the fault position parameter as a given condition, and the phase of function equals to zero when the reference point matches the fault position. Finally, the PSCAD/EMTDC simulation results verify the effectiveness of the algorithm.

1. Introduction

High voltage transmission line is an important component of power system. It not only undertakes the important task of power transmission, but also undertakes the interconnection of regional power grid. Its security and stability are really important. However, due to the long transmission distance and adverse external environment, it is easy to be affected by natural disasters such as wind, icing, lightning and so on, thus causing the line fault. For the long distance power transmission, the fault patrol has many difficulties, so searching a fast and accurate algorithm of fault location has very important significance to security, stability and economic operation of the power system[1].

With the rapid development of power system and national economy, T-type transmission lines are widely used in power systems because of their high transmission capacity and low cost of transmission construction. However, due to its large transmission power, the fast and accurate fault location of it is more and more important. Because of the complex structure of the T-type transmission lines, the conventional method of two-terminal fault location[2-3] can not be well applied to it. At present, T-type transmission lines are mainly based on traveling wave [4-5] and fault analysis[6-7]. The traveling wave method needs to be put into special equipment, the technology is more complex, the application cost is higher, and the difficult problem of wave-head identification exists. The method of fault analysis is of low requirement for equipment and small investment, so as to obtain wider application. However, the traditional method for fault location of T-type transmission lines is not able to realize fault location correctly when a high impedance fault occurs near the T-type node.

A new algorithm based on phase recognition is proposed about fault location of T-type transmission lines in this article. The algorithm regards the fault position parameter as a given condition, and the phase of function equals to zero when the reference point matches the fault position. The method does not need to judge fault types in advance, and has good applicability to nonlinear resistance faults and various fault types, and solves the problem of measuring dead zone near the T-type node in traditional method.
2. Fault analysis of double terminal line based on phase identification

According to figure 1, when there is an unbalanced fault at the f point on the line, there is:

\[
\dot{U}_{f1} = \dot{U}_{a1} \cosh \dot{I}_{af} - \dot{I}_{af} Z_{c1} \sinh \dot{I}_{af} \tag{1-1}
\]

\[
\dot{I}_{af1} = \dot{I}_{a1} \cosh \dot{I}_{af} - \frac{\dot{U}_{a1}}{Z_{c1}} \sinh \dot{I}_{af} \tag{1-2}
\]

\[
\begin{cases}
\dot{I}_{fe1} = \dot{I}_{af1} - \dot{I}_{f1} \\
\dot{U}_{e} = \dot{U}_{be1} \\
\dot{I}_{e} = -\dot{I}_{be1}
\end{cases} \tag{1-3}
\]

\[
\dot{U}_{e} = \dot{U}_{f1} \cosh \dot{I}_{fe} - \dot{I}_{fe1} Z_{c1} \sinh \dot{I}_{fe} \tag{1-4}
\]

\[
\dot{I}_{e} = \dot{I}_{f1} \cosh \dot{I}_{fe} - \frac{\dot{U}_{f1}}{Z_{c1}} \sinh \dot{I}_{fe} \tag{1-5}
\]

Taking (1-1) , (1-2) , (1-3) into (1-4) ,we can get:

\[
\dot{U}_{e} = \dot{U}_{a1} \cosh (\dot{I}_{af} + \dot{I}_{f1}) - \dot{I}_{af} Z_{c1} \sinh (\dot{I}_{af} + \dot{I}_{f1}) + \dot{I}_{f1} Z_{c1} \sinh \dot{I}_{fe} = \dot{U}_{ae1} + \dot{I}_{f1} Z_{c1} \sinh \dot{I}_{fe} \tag{1-6}
\]

\[
\dot{U}_{ae1} - \dot{U}_{be1} = \dot{U}_{e} - \dot{I}_{f1} Z_{c1} \sinh \dot{I}_{fe} - \dot{I}_{be1} = \dot{I}_{f1} Z_{c1} \sinh (\dot{I}_{f} - \dot{I}_{e}) \tag{1-7}
\]

Taking (1-1) , (1-2) , (1-3) into (1-5) ,we can get:

\[
\frac{\dot{I}_{ae1} + \dot{I}_{f1} \cosh \dot{I}_{fe}}{Z_{c1}} + \frac{\dot{I}_{a1} \cosh \dot{I}_{af} - \dot{U}_{a1}}{Z_{c1}} \sinh \dot{I}_{af} = \dot{I}_{ae1} - \dot{I}_{f1} \cosh \dot{I}_{fe} \tag{1-8}
\]

\[
\dot{I}_{ae1} + \dot{I}_{f1} \cosh \dot{I}_{fe} + \dot{I}_{be1} = \dot{I}_{f1} \cosh \dot{I}_{fe} \tag{1-9}
\]

where $\dot{U}_{a1}$, $\dot{U}_{b1}$ are positive sequence voltage of point A and point B; $\dot{I}_{a1}$, $\dot{I}_{b1}$ are positive sequence current of A and B; $\dot{U}_{f1}$, $\dot{I}_{f1}$ is positive sequence voltage and current of fault point f; $\dot{U}_{ae1}$, $\dot{U}_{be1}$ is the positive sequence voltage of reference point e from A and B by calculation; $\dot{U}_{e}$, $\dot{I}_{e}$ is positive sequence voltage and current of reference point e; $\gamma$ is positive sequence propagation coefficient of transmission line; $Z_{c1}$ is wave impedance.

According to (1-7) and (1-9) distance function can be constructed:

\[
f(\dot{I}_{e}) = \frac{\dot{U}_{ae1} - \dot{U}_{be1}}{\dot{I}_{ae1} + \dot{I}_{be1}} = Z_{c1} \tanh (\dot{I}_{f} - \dot{I}_{e}) \tag{1-10}
\]

The hyperbolic tangent function is a singular function, so $f(\dot{I}_{e})$ phase properties is similar to the odd functions, when $\dot{I}_{e} < \dot{I}_{f}$, arg $f(\dot{I}_{e})$ located near 90 degrees; when $\dot{I}_{e} > \dot{I}_{f}$, arg $f(\dot{I}_{e})$ located near -90 degrees, the phase is zero degree only when the reference point coincides with the fault point, so it has better phase recognition characteristics.

According to the phase characteristic, using the dichotomy or secant method to make the reference point E approaching the fault point F. Only when the reference point E coincides with the fault point F, the phase of the ranging function is zero, so we get the fault location.

3. Fault analysis of T-type transmission line based on phase identification
According to the second chapter, referencing the double terminal fault location, a new algorithm for fault location of T-type transmission lines is proposed.

![Positive sequence circuit diagram of T-type transmission lines](image)

**Figure 2.** Positive sequence circuit diagram of T-type transmission lines

Figure 2 is positive sequence circuit diagram of T-type transmission lines when taking the AT line fault as an example. \( \dot{U}_{at1}, \dot{U}_{bt1}, \dot{U}_{ct1} \) are positive sequence voltage of point A, point B and point C; \( \dot{I}_{at1}, \dot{I}_{bt1}, \dot{I}_{ct1} \) are positive sequence current of point A, point B and point C; \( \ddot{U}_{t1} \) is positive sequence voltage of T node; \( \ddot{I}_{at1}, \ddot{I}_{bt1}, \ddot{I}_{ct1} \) are positive sequence current form each branch.

\[
\begin{align*}
\dot{U}_{at1} &= \dot{U}_{at1}\cosh\dot{y}_{at} - \dot{I}_{ct1}\sinh\dot{y}_{at} \\
\dot{U}_{bt1} &= \dot{U}_{bt1}\cosh\dot{y}_{bt} - \dot{I}_{at1}\sinh\dot{y}_{bt} \\
\dot{U}_{ct1} &= \dot{U}_{ct1}\cosh\dot{y}_{ct} - \dot{I}_{bt1}\sinh\dot{y}_{ct}
\end{align*}
\]

\[
\begin{align*}
\dot{I}_{at1} &= \dot{I}_{at1}\cosh\dot{y}_{at} - \frac{\dot{U}_{at1}}{Z_{ct1}}
\dot{I}_{bt1} &= \dot{I}_{bt1}\cosh\dot{y}_{bt} - \frac{\dot{U}_{bt1}}{Z_{ct1}}
\dot{I}_{ct1} &= \dot{I}_{ct1}\cosh\dot{y}_{ct} - \frac{\dot{U}_{ct1}}{Z_{ct1}}
\end{align*}
\]

When located at branch AT, we can get the voltage and current of T node by parameter of point B and point C, \( \ddot{I}_{t1} = \frac{\dot{U}_{bt1} + \dot{U}_{ct1}}{2}, \dot{I}_{t1} = \dot{I}_{bt1} + \dot{I}_{ct1} \); according to (1-7) and (1-9), we can get:

\[
\begin{align*}
\dot{U}_{atk1} - \dot{U}_{tk1} &= \dot{I}_{f1}Z_{ct1}\sinh(\dot{r} - \dot{l}) (2-3) \\
\dot{l}_{atk1} + \dot{l}_{tk1} &= \dot{I}_{f1}\cosh(\dot{r} - \dot{l}) (2-4) \\
f(l_{ak}) &= \dot{U}_{atk1} - \dot{U}_{tk1} = Z_{ct1}\tanh(\dot{r} - \dot{l}) (2-5)
\end{align*}
\]

Similarly, the ranging function of branch BT and branch CT is:

\[
\begin{align*}
f(l_{bk}) &= \dot{U}_{btk1} - \dot{U}_{atk1} = Z_{ct1}\tanh(\dot{r} - \dot{l}) (2-6) \\
f(l_{ck}) &= \dot{U}_{ctk1} - \dot{U}_{ctk1} = Z_{ct1}\tanh(\dot{r} - \dot{l}) (2-7)
\end{align*}
\]

Based on the above analysis and the conclusion of the second chapter, a new T-type fault analysis algorithm based on phase identification is proposed:

1) determine the fault branch

Choosing the reference point K at the node T, according to the formula (2-5), (2-6), (2-7) separately calculate \( \text{argf}(l_{ak}), \text{argf}(l_{bk}), \text{argf}(l_{ck}) \). If there is only one branch, the phase is near -90 degrees, the phase of other branches are near 90 degree, it can be judged that this branch is the fault branch; if more than one branch judge as fault branch, the fault occurred at the T node.

2) fault distance measurement
Assuming that the branch AT fails, we divide branch AT into n equal to the right length, and calculate \( \arg \left( \frac{h}{n} \cdot l_{ak} \right) \) at each equal point. There must be a point of h let \( \arg \left( \frac{h}{n} \cdot l_{ak} \right) > 0 \) and \( \arg \left( \frac{h+1}{n} \cdot l_{ak} \right) < 0 \). Dichotomy is used within the interval \( \left[ \frac{h}{n} \cdot l_{ak}, \frac{h+1}{n} \cdot l_{ak} \right] \), the point whose \( \arg \left( l_{ak} \right) = 0 \) is the fault location.

3. Simulation and results
Simulation model of T-type transmission line as shown in the following figure, using PSCAD/EMTDC for simulation calculation.

![Simulation model of T-type transmission line](image)

Figure 3. simulation model of T-type transmission line

| Fault Type | Transition resistance | Actual Fault Distance /km | Maximum Deviation |
|------------|-----------------------|---------------------------|-------------------|
| Single     | 50+25i                | 49.865 99.905 149.945     | 0.068%            |
|            | 100+50i               | 49.845 99.875 149.905     | 0.078%            |
|            | 150+100i              | 49.805 99.865 149.915     | 0.098%            |
| Two-phase  | 50+25i                | 50.075 100.115 150.075    | 0.058%            |
|            | 100+50i               | 49.123 99.865 149.905     | 0.068%            |
|            | 150+100i              | 49.785 99.895 149.945     | 0.108%            |
| Three-phase| 50+25i                | 49.665 99.755 149.885     | 0.168%            |
|            | 100+50i               | 50.025 99.975 150.025     | 0.013%            |
|            | 150+100i              | 50.025 100.075 150.015    | 0.038%            |

Table 1. influence of different fault types and transition resistance on distance measurement results.
Table 2 gives the result when the single phase grounding occurs near the T nodes, we can see that the fault location can still be judged well through the algorithm, and solves the problem of measuring dead zone near the T-type node in traditional method.

| Fault branch | Fault distance/km | arg($f_{at}$) /° | arg($f_{bt}$) /° | arg($f_{ct}$) /° | Fault branch judgment | Result |
|--------------|-------------------|------------------|------------------|------------------|-----------------------|--------|
| AT           | 199               | -85.726          | 81.365           | 94.534           | AT                    | +      |
| AT           | 199.5             | -85.175          | 82.152           | 95.372           | AT                    | +      |
| AT           | 199.8             | -84.332          | 90.564           | 89.879           | AT                    | +      |
| AT           | 199.9             | -84.233          | 86.665           | 92.862           | AT                    | +      |
| BT           | 99                | 90.766           | -103.31          | 89.751           | BT                    | +      |
| BT           | 99.5              | 90.717           | -103.26          | 89.754           | BT                    | +      |
| BT           | 99.8              | 90.655           | -103.38          | 89.816           | BT                    | +      |
| BT           | 99.9              | 90.614           | -103.39          | 89.687           | BT                    | +      |
| CT           | 149               | 96.226           | 82.125           | -84.299          | CT                    | +      |
| CT           | 149.5             | 97.158           | 83.142           | -83.387          | CT                    | +      |
| CT           | 149.8             | 90.767           | 90.877           | -82.642          | CT                    | +      |
| CT           | 149.9             | 90.859           | 91.065           | -82.231          | CT                    | +      |

4. Conclusion
This paper presents a new fault location method of T-type fault location based on phase identification. The algorithm constructs a range function by using the phase property of hyperbolic tangent function, using the phase difference to judge the fault branch, and using the phase of function equals to zero when the reference point matches the fault position to realize fault location.

The method firstly judges the fault branch line, and then makes precise location of the fault, which reduces the scale of operation and improves the efficiency of fault location. Compared with the traditional T-type transmission line fault location algorithm, the algorithm is not affected by the load current, no need to know fault types in advance, has good applicability for nonlinear resistance fault. At the same time, it solves the problem of measuring dead zone near the T-type node in traditional method.

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