Research on Fault Location for Direct Traction Network

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Abstract—In view of the low accuracy of existing fault location methods for traction networks with longer power supply lines, the equivalent model of the traction network for double-track electrified railways is calculated, and the power supply lines and contacts are introduced on the basis of traditional traction network fault location methods. The parameter of grid equivalent impedance ratio proposes a modified uplink and downlink current ratio ranging method, which effectively solves the problem of accurate fault location of the double-track electrified railway direct-supply traction network. The RT-plus smart grid real-time digital simulation instrument is used to establish the traction power supply dynamics. The simulation test system is simulated and tested, and the test results show that the proposed algorithm has good feasibility and accuracy, and fully meets the engineering requirements.

1. INTRODUCTION

The electrified railway currently in operation in China mainly adopts two forms of direct power supply and AT power supply, each of which can be divided into two modes, single-line and double-line\textsuperscript{1}. Regardless of the mode, the transmission line of the traction network is composed of two parts: the power supply line and the contact wire (catenary), and the parameters of the two lines are generally different\textsuperscript{2}. Since the length of the contact line is much longer than the length of the power supply line, the power supply line can be equivalent to a contact net to approximate the distance to the fault when the fault location accuracy requirements are not high. With the rapid development of electrified railways in China, the accuracy requirements for fault location of traction networks are becoming higher and higher. This has also become one of the urgent problems in the field of traction power supply systems.

At present, there are many solutions to the problem of fault location of electrified railway traction power supply system at home and abroad\textsuperscript{3~5}. In view of the large fault location error of direct supply traction network, the method of calculating fault distance by using two sets of traction network reactance setting tables is proposed in document \textsuperscript{6}, but the fault location device needs to automatically identify the operation mode of traction network. Literature \textsuperscript{7} adds the reactance setting table of the districts on the basis of the original reactance setting table. Cross-link current ratio ranging method, AT suction current ratio ranging method, and sub-section uplink and downlink current ratio ranging method \textsuperscript{8} are suitable for AT power supply mode. In the theoretical derivation of the above
methods, the influence of power supply line parameters on the distance measurement accuracy of the traction network is not considered. In order to reduce the error, some parameters need to be measured in advance through certain field tests to correct the distance measurement results in actual application.

Based on the above analysis, this article focuses on the problem of accurate fault location of the traction network of the double-track electrified railway direct power supply mode taking into account the parameters of the power supply line. After rigorous theoretical derivation, the corrected uplink and downlink current ratio ranging method is obtained. Finally, the traction network dynamic simulation test platform based on RT-plus real-time power grid intelligent simulation instrument verifies the effectiveness of the ranging algorithm.

2. TRADITIONAL RANGING METHOD

The direct power supply mode is a power supply mode in which the traction substation directly provides electric power to the electric locomotive via the catenary. It is mostly used for freight dedicated lines and early passenger dedicated lines.

2.1 Single-line direct supply ranging method

Theoretically, the equivalent unit impedance of the single-line direct-supply traction network is constant and proportional to the fault distance, which satisfies formula (1).

\[ Z_d = Z_0l \]  

In the formula: \( Z_d \) is the impedance measured at the time of failure; \( Z_0 \) is the equivalent impedance per unit length of the traction network; \( l \) is the distance from the exit of the traction substation to the point of failure.

If there is a transition resistance during a short circuit, it is necessary to replace the impedance in formula (1) with reactance. This method is called impedance or reactance ranging method.

2.2 Double-track direct supply ranging method

In the double-line direct supply mode, the upstream and downstream catenaries are connected in parallel in the districts. Due to the mutual inductance between the two catenaries and the rails, the equivalent impedance per unit length of the traction network is not constant, so from the substation to the short-circuit point The measured impedance and the fault distance are no longer a linear relationship, that is, equation (1) no longer holds.

In order to use the measured impedance to find the distance, the actual engineering adopts the idea of piecewise linearization to divide the impedance curve of the double-track traction network into several sections, and uses the formula (1) to carry out the fault location in each section. The impedance characteristic curve of single-line and double-line direct-supply traction network is shown in Figure 1.

![Impedance characteristic curve of single-line and double-line direct-supply traction network](image)

In addition to the impedance ranging method, in the double-line direct supply mode, the relationship between the upstream and downstream currents shown in equation (2) can also be used to calculate the fault distance. This method is called the upstream and downstream current ratio ranging method [7].
In the formula: $I_{t1}$ and $I_{t2}$ are the non-fault side current and the fault side current measured at the time of the fault, respectively, $L$ is the length of the power supply arm from the substation to the substation.

### 2.3 Shortcomings of traditional ranging methods

Through the discussion and analysis of the main power supply modes and ranging methods of the above traction network, it can be seen that each traction power supply mode has a corresponding ranging method and ranging formula, but these formulas ignore the length of the power supply line in the actual project. When the length of the power supply line is long, the accuracy of the distance measurement will inevitably be greatly affected. This article mainly analyzes the problem of accurate fault location when considering power supply line parameters in the form of double-line direct supply.

### 3. ACCURATE FAULT LOCATION OF DOUBLE-TRACK DIRECT-SUPPLY TRACTION NETWORK

#### 3.1 Equivalent of double-track traction network model

The layout of the single-chain suspension double-track traction net is shown in Figure 2(a). C1, J1 and C2, J2 represent the load-bearing cables and contact wires of lines I and II, and R11, R12 and R21, R22 represent the rails of lines I and II, respectively. The load-bearing cable and the contact wire are collectively referred to as the contact net.

In the double-track electrification section, the upper and lower line catenary is generally connected in parallel at the end, and the rails of the two lines must be connected in parallel at intervals. Therefore, the two catenaries should be equivalent to two circuits, and the two rails should be equal to each other. The effect is a loop, and the equivalent circuit is shown in Figure 2(b).

![Figure 2 Double-track traction network structure](image)

**Figure 2** Double-track traction network structure

#### 3.2 Modified uplink and downlink current ratio ranging method

From the analysis in the previous section, we can see that when the parameters of the uplink and downlink are the same, $z1 = z2$ in Figure 2(b), the equivalent model of the double-line direct-supply traction network can be obtained as shown in Figure 3.

![Figure 3 Equivalent model of double-track direct-supply traction network](image)

**Figure 3** Equivalent model of double-track direct-supply traction network

The meaning of the variables in the figure: $z_s$, $z_{gm}$ are the equivalent self-impedance and mutual
The short circuit voltage equation in the figure is

\[
(z_{gm}l_1 + z_{m}x)I_{t1} + (z_{g}l_1 + zx)I_{t2} = U
\]  

The long loop voltage equation is

\[
\left[ z_{g}l_1 + z(2D_1 - x) - 2z_{m}(D_1 - x) \right]I_{t1} + 2L_2 \left[ z_{g} - z_{gm} \right]I_{t1} + \left( z_{gm}l_1 + z_{m}x \right)I_{t2} = U
\]

Current relationship is satisfied

\[
I_{t1} + I_{t2} - I = 0
\]

It can be solved that the ratios of the up and down currents to the total current are:

\[
\begin{align*}
I_{t1} &= \frac{x + kL_1}{2(D_1 + k(L_1 + L_2))} \\
I_{t2} &= \frac{-x + 2D_1 + k(L_1 + 2L_2)}{2(D_1 + k(L_1 + L_2))}
\end{align*}
\]  

In the formula, \( k = \frac{z_{g} - z_{gm}}{z - z_{m}} \) is called the equivalent impedance ratio of the power supply line and the catenary.

The relationship between the ratio coefficient of the upstream and downstream currents and the distance to the fault is shown in Figure 4.

![Figure 4 Relationship between current ratio coefficient and the distance from the fault point to the substation](image)

From equation (6) and Figure 4, it can be seen that the current ratio coefficient of the faulty line and the fault distance satisfy a linear decreasing relationship, and the non-faulty line is the opposite. This equation can be used to accurately calculate the fault distance. This method is called the uplink and downlink current ratio ranging method.

4. **DYNAMIC SIMULATION TEST SYSTEM SIMULATION**

The traction power supply dynamic simulation test system based on the RT-plus smart grid real-time digital simulation instrument can simulate various operating conditions and failure scenarios of the traction power supply system, comprehensively assess the functions and performance of the relay protection and safety automatic devices. The structure of the test system is shown in Figure 5. The
main hardware equipment includes RT-plus real-time digital simulator, fault location protection device prototype (KF6571), clock synchronization device, background system, switch and Ethernet.

![Figure 5 Traction power supply dynamic simulation test system](image)

The RT-plus traction power supply real-time digital simulator is used to simulate the real traction power supply system, and the background system control is used to control the simulation model. The electrical quantity of the traction network can be transmitted to the fault location device through direct transmission or Ethernet transmission.

Build a full-parallel AT power supply traction network model based on RT-plus, and control the position of the circuit breaker of the AT and the district to make the system run in the double-line direct supply mode.

The calculation process of the relevant parameters of the traction power supply system can be found in literature [9,10] and so on. The main parameters in the model: the length of the power supply line of the substation \(L_1=3\) km, the length of the power supply line of the substation \(L_2=0.5\) km, the length of the catenary from the substation to the substation \(D_1=25\) km, the reactance ratio coefficient of the power supply line and the catenary \(k\) is 1.4.

A metallic instantaneous short-circuit grounding fault is set 8 km away from the substation. The fault waveform recorded by the prototype KF6571 of the fault location device is shown in Figure 6. The effective value of voltage \(U=14791\) V, the effective value of current \(I_{t2}=3114\) A, \(I_{t1}=566\) A. When considering the influence of the power supply line parameters, the calculated fault distance is 8.0004 km, and the error is only 0.4 m, which meets the accuracy requirements of the standard requirement of ranging error not greater than 500 m. When ignoring the influence of power supply line parameters, the calculated fault distance is 8.7696 km with an error of 770 m, which cannot meet the accuracy requirements.

![Figure 6 Voltage waveform of substation](image)
Perform simulation analysis in other locations of the line, and summarize some results as shown in Table 1.

Table 1 Fault location results of uplink and downlink current ratio

| U/V | Iu/A | It/A | Fault Distance /km | Absolute Error /m |
|-----|------|------|--------------------|-------------------|
|     |      |      | Actual Distance    | k=1.4             | k=1              |
| 12347 | 3984 | 379  | 4                  | 4.0008            | 4.95703          |
| 14791 | 3114 | 566  | 8                  | 8.0004            | 8.7696           |
| 16364 | 2521 | 714  | 12                 | 12.0000           | 12.5819          |
| 17428 | 2090 | 844  | 16                 | 15.9995           | 16.3942          |
| 18164 | 1757 | 965  | 20                 | 19.9991           | 20.2065          |
| 18673 | 1491 | 1086 | 24                 | 23.9986           | 24.0187          |
| 19011 | 1268 | 1210 | 28                 | 27.9981           | 27.8310          |

It can be obtained by analyzing the data in the table that when the influence of power supply line parameters is considered, the ranging result of the modified uplink and downlink current ratio ranging method is very close to the actual value. Its ranging error is almost zero, and all are within the allowable range of error specified by the national standard. However, the traditional uplink and downlink current is very unstable compared with the ranging method, that is, when k=1, a large error may occur.

5. CONCLUSION
After discussing and analyzing the main operation modes and ranging methods of traction power supply, this article concludes that the traditional traction network fault location method does not consider the influence of power supply line parameters. When the power supply line is long, the ranging error is large and the accuracy is large. Not high; A modified uplink and downlink current ratio ranging method is proposed for the accurate fault location of the double-line direct-supply traction network with power supply line parameters. The simulation test results of the traction power supply dynamic simulation test system show that after introducing the equivalent impedance ratio coefficient of the power supply line and the catenary, the method proposed in this paper greatly improves the accuracy of the fault location of the traction network in the double-line direct supply mode.

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