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Protection Schemes for Uniline Zone in Bilateral AT Traction Power Supply System

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ABSTRACT

With the rapid development of the construction of high-speed railway in china, higher levels of power quality and reliability of traction power supply systems are required. The combination of bilateral power supply technology with AT traction power supply technology can better meet the needs of development of high-speed railways, which will require new protection approaches to be proposed. Thus, corresponding protection schemes will be of great significance for the application and promotion of bilateral power supply technology.

Keywords: High-speed Railway; Bilateral Power Supply; AT Power Supply; Protection Schemes

1. Introduction

In the past, due to the restrictions of management modes of power grid and limitations of protection schemes, unilateral power supply systems have been used while bilateral power supply technology has not been used in practical railway projects [1]. Thus, researches on protection schemes of bilateral power supply system have decreased.

With the improvement of power systems, the voltage class of major network has been generally increased to 220 kV or above 220 kV level, thus, the load capability of local power systems is enhanced, and the safety and stability of electric networks are increasingly improved, which makes the application of bilateral power supply systems possible. Current calculations, protection schemes and the advantages of bilateral power supply are concluded briefly in reference [2], meanwhile, trial run is conducted, which demonstrates the feasibility and technical advantages of a bilateral power supply system. Protection schemes of bilateral power supply systems under direct power supply mode are analyzed in reference [3]. Electrical characteristics of the bilateral power supply system and T-R short-circuit current and impedance parameters of traction electric network are analyzed in this article, through which protection schemes of bilateral power supply systems in uniline zone are put forward.

2. Introduction of Bilateral Power Supply System

The contact line system is separate at substations and section posts, and thus, the contact line between two substations is divided into two independent power supply sections, called as feeding sections[4]. Each feeding section respectively gains power from one substation, which is defined as a unilateral power supply. If power is gained from both substations at the same time, it is called a bi- lateral power supply mode. Under bilateral power supply mode, section posts are set up between two substations, those two feeding sections are connected by a circuit breaker, and electric locomotives and motor train units can gain power from the two substations at the same time.

Unlined zone in bilateral AT traction power supply system is shown in **Figure 1**.

3. Short Circuit Characteristics of Bilateral Power Supply System

Equivalent circuit of unlined zone in bilateral power supply system is shown in **Figure 2.**

The equivalent circuit can be further simplified into **Figure 3**.

In **Figure 3**, $z'_A = \frac{z_2 z_3}{z_2 + z_3}$, I'_1 , I'_2 and I'_3 are equivalent currents respectively, $U_{SSA} = U_{SSB} = 27.5kV$.

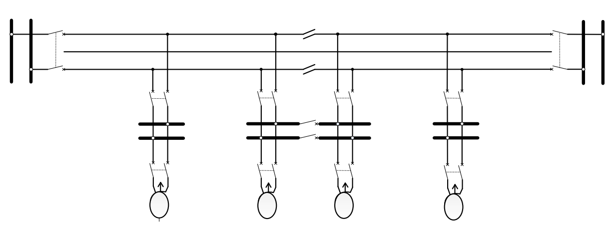

Figure 1. Unlined zone in bilateral AT power supply system.

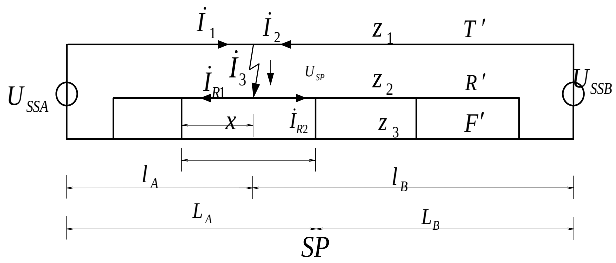

Figure 2. Equivalent circuit of unlined zone in bilateral traction power supply system.

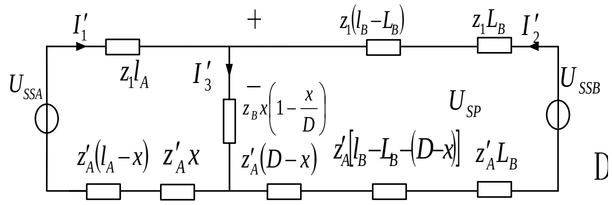

Figure 3. Simplified equivalent circuit.

According to **Figure 3**, using voltage equation, the short circuit impedance and current of the two substation A and B are:

$$\begin{cases} Z_{SSA} = \dfrac{U_{SSA}}{I'_1} = z_A l_A + z_B x\left(1-\dfrac{x}{D}\right)\cdot\dfrac{l_B+l_A}{l_B} \\ Z_{SSB} = \dfrac{U_{SSB}}{I'_2} = z_A l_B + z_B x\left(1-\dfrac{x}{D}\right)\cdot\dfrac{l_B+l_A}{l_A} \\ I'_1 = \dfrac{l_B}{l_A+l_B} I'_3 \\ I'_2 = \dfrac{l_A}{l_A+l_B} I'_3 \end{cases} \quad (1)$$

In equation (1), l_A and l_B are distance from substation A and B to fault point. Measuring the short circuit impedance of feeding section L_A at section post feeder:

$$Z_{SP} = \frac{U_{SP}}{I'_2} = z_A\left(l_B - L_B\right) + z_B x\left(1-\frac{x}{D}\right)\cdot\frac{l_B+l_A}{l_A} \quad (2)$$

when T-R short circuit takes place in feeding section L_B, the measured value of impedance at section post feeder:

$$Z_{SP} = \frac{U_{SP}}{I'_1} = z_A\left(l_A - L_A\right) + z_B x\left(1-\frac{x}{D}\right)\cdot\frac{l_B+l_A}{l_B} \quad (3)$$

4. Simulation of Short Circuit Characteristics

The simplified circuit is illustrated above by ignoring the self-impedance of auto-transformer and the rail-earth leakage reactance. The equations of short circuit impedance are concluded. Characteristic curves of short circuit impedance are gained by simulating with MATLAB / SIMULINK models.

4.1. Simulation of Short-circuit Fault Current

When T-R fault occurs in unlined zones, the measured currents of two substation and relationship between currents of fault points and distance are shown as follows:

From **Figure 4,** the ratio of substation (A and B) feeder fault current to fault point current is gained and shown in **Figure 5**. I_1 (I_2) is the value of fault current of substation A (B) multiplies 0.5, and I_3 is the value of fault point current multiplies 0.5. l_A (l_B) is the distance from substation A (B) to the fault point and the distance between substation A and B is *L*.

4.2. Simulation of Short-circuit Impedance

When the T-R short circuit fault takes place in unlined zone in the system, based on equation (1), using MATLAB, the curve of short-circuit impedance ($|Z|$) of substation A can be drawn and illustrated in **Figure 6**.

It can be seen from **Figure 6** that the simulation results are quite close to calculated values, which demonstrates that it is feasible to ignore the self-impedance of auto-transformers and leakage reactance of rails to earth.

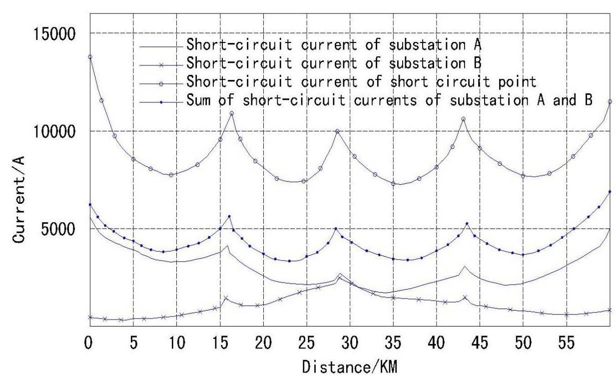

Figure 4. Relationship between T-R fault current of substation A (B) and distance.

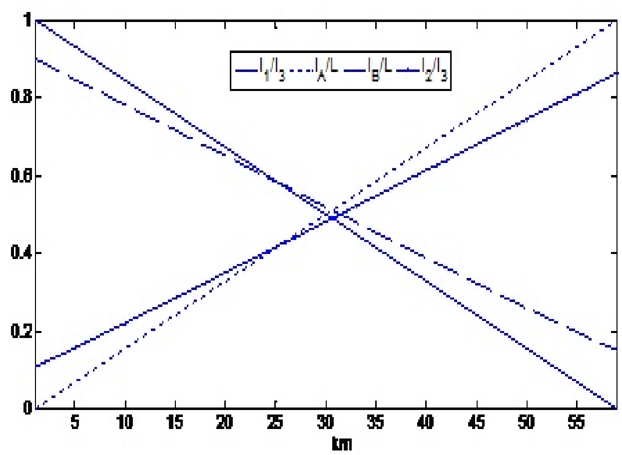

Figure 5. Ratio of feeder fault current to fault point current.

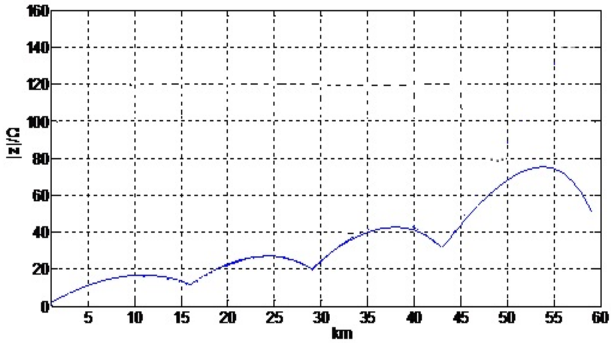

Figure 6. T-R short-circuit impedance simulation of uniline zone.

5. Protection Schemes for Bilateral at Power Supply system

5.1. Requirements Analysis

From **Figure 1**, it can be seen that when feeding sections are short-circuited, the feeder protection of the two substations and section posts working together can isolate the fault. For example, when feeding section A (feeding section which is connected with substation A(B) is defined as feeding section A(B)) is faulted, the operating procedures of circuit breakers are described as follows:

- Substation circuit breaker 101 and section post circuit breaker 301 trip, there is no voltage at feeding section A, feeding section B operates normally, and the system is transformed into unilateral power supply system;
- It will go to next step below, if the circuit breaker recloses successfully**.** If re-closure is unsuccessful, the auto-reclose relay locks out the circuit breaker, and the feeding section is powered off;
- Circuit breaker 301 at section post recloses, and the bilateral power supply system is regained.

5.2. Protection Schemes

Zone 1 setting: Up to 85% of the protected line from substation to section post is for zone 1 protection [5]. The reactance boundary is set according to the minimum short-circuit reactance. When T-R short circuit occurs for instance, replace the distance variable in equation (1) with x, and then differentiate x:

$$Z'_{SSA} = x^2 - 2K\cdot x + A = 0$$

where, $A = \dfrac{z_A K^2 + z_B \cdot KL}{z_A + z_B \cdot \dfrac{L}{D}}$; $L = l_A + l_B$; $K = L - l_N$;

$l_A = l_N + x$; l_N is the sum of distances of the first n AT sections located between the substation and fault point, in the N+1 AT section, the short-circuit impedance is minimum at location x, and the minimum value is $Z_{SSA}|_{x=x_{\min}}$, so the setting value of reactance boundary is:

$$X_{set} = K_{rel}\cdot X|_{x=x_{\min}} \tag{4}$$

The resistance boundary is set based on load impedance.

$$R_{set} = \frac{0.9U_N}{K_{rel}\cdot I_{L\cdot\max}}\left(\cos\phi_L - \frac{\sin\phi_L}{tg\phi_{line}}\right) \tag{5}$$

where K_{rel} is the coefficient of reliability, U_N is the rated voltage of the traction electric network, $I_{L\cdot\max}$ is the maximum load current of traction electric network. The maximum load current is gained when both the left and right feeding sections are under full load [6]. ϕ_L is load angle, and ϕ_{line} is the impedance angle of the circuit line.

Zone 2 setting: Zone 2 reach, as the remote backup protection of section post, is set to be equal to 85% of the overall length of the two feeding sections. The setting value is gained according to the maximum shorted resistance value in AT sections. Reactance and resistance boundary are set based on equation (4) and equation (5). Because the measured impedance value of the last AT section is large, the protection reach can be reduced to the first AT station which is right behind the section post if zone 2 setting value is too large[7].

Low voltage startup overcorrect protection: The current is set as follows:

$$I_{set} = \frac{K_{rel}\cdot\left(I_{L\cdot\max} + I_{CY-\max}\right)}{K_f} \tag{6}$$

where, $I_{CY-\max}$ is the maximum through-fault current, K_f is resetting ratio and voltage is set according to equation below:

$$U_{set} = \frac{U_{L\cdot\min}}{K_{ref}\cdot K_f} \tag{7}$$

where, $U_{L\cdot\min}$ is the minimum operating value of feeder line under the peak load condition.

To avoid mal-operation caused by magnetizing inrush, harmonic blocking elements should be added, and when the second harmonic content exceeds setting value, blocking operates.

6. Conclusions

The simplified method of ignoring the self-impedance of auto-transformers and leakage reactance of rails to earth to obtain short circuit impedance is effective. When T-R fault occurs, the current flowing through the rails is small, and thus, auto-transformers can be considered as ideal transformers when analyzing and calculating. Meanwhile, the lengths of left and right feeding sections are different, which means the distance from power supply to the two substation are different, so the measured current values of substation A and substation B are different. When the short-circuited fault occurs, the breaker trips, which will change the bilateral power supply system into unilateral power supply system. The fault can be isolated by auto-reclosing and then the protection resets to keep the fault in the faulted line, while other parts can operate normally.

7. Acknowledgements

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