Study on Rail Potential of Metro Traction Power Supply System

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Abstract. Rail over-potential is one of the main problems of DC traction supply system. Firstly, based on the problem of rail over-potential, this paper introduces the comprehensive grounding system of metro substation and the structure of stray current returning ground network. Then, relative research methods and results of rail potential and its distribution are summarized, compared and evaluated. Meanwhile, various protective measures at present are summarized and evaluated according to the influence factors of rail potential. Finally, opinions about the ideas and methods of researching the rail potential of metro are put forward, and the research prospect is prospected.

Introduction

At present, most of urban rail transit lines adopt DC1500V or DC750V traction supply system in China. DC traction supply system adopts the path of running rail for returning current. The rail and the earth cannot be completely insulated in the actual project, so some of current will flow into the earth to form stray current, which corrodes underground metal pipelines.

In order to reduce stray current, the rail is not directly grounded. The returning current through the rail will produce rail potential. In order to solve the rail over-potential problem that may endanger the safety of passengers on the platform, the Over-Voltage Protection Device (OVPD) is installed between the rail and the grounded bus bar. However, when OVPD acts if the rail potential exceeds 90V to reduce the rail potential, a large amount of stray current will flow into the ground. In fact, the action of OVPD also fails to solve the problem of rail potential increase fundamentally.

Rail Potential Research Model

At present, rail potential model is mainly divided into mathematical model and simulation model, and some software are developed for traction power supply calculation such as ENS, URTPS, etc.

Mathematical Model

By establishing “π” resistance model for unilateral power supply and using current injection method and principle of superposition, Wang Meng analyzed rail potential of DC traction supply system and stray current theoretically [1].

According to the correlation between node current and loop voltage, the differential equations can be established to solve rail potential at x km distance from traction substation as follows:
Where \( I_t \) is traction current of train, \( R_s \) is longitudinal resistance of rail potential, \( L \) is distance from train to TPS, and \( R_m \) is the rail-to-earth conductivity.

Considering network structure of underground conductor, Mou Longhua established “double-π” resistance model with collection mat to deduce the analytical formulas of rail potential and stray current with the same method, and revise the original formula of stray current [2].

\[
U(x) = R_s I_t \frac{\cosh \gamma (L + x) - \cosh \gamma x}{\sinh \gamma L} \\
\gamma = \sqrt{\frac{R_s}{R_m}}
\]  

(1)

Influence Factors of Rail Potential Distribution

The influence on rail potential are compared between different grounding methods, and diode grounding method is recommended for metro traction power supply system in [5]. Since the voltage element of Frame Leakage Protection Device (FLPD) is also used to measure the potential of the rail to the ground, the action of FLPD may cause serious power failure impact on metro operation. Therefore, OVPD and FLPD should cooperate reasonably. In case of potential increase fault, OVPD should be guaranteed to perform protective action before the FLPD [6]. The structure diagram of the metro integrated grounding system is shown in Figure 4.
The factors influencing rail potential distribution can be divided into general and special cases. The general case includes the rail potential increase causes OVPD acting when the traction power supply system is in normal operation, while the special case is that the rail potential rise caused by certain fault happening or certain protection action.

Normal Cases
During normal operation, the influencing factors for rail potential include longitudinal resistance of rail, the space between TPSs, the rail-to-earth conductivity and the train’s operation mode, etc. [7]. The simulation of regenerative braking energy storage system of urban rail transit is studied to point out that regenerative braking has an impact on rail potential due to the change of current direction in [8]. In [9], physical model of distribution parameters between running track, tunnel wall and surrounding soil is established considering the influences of the length of the train, so as to establish the rail potential and stray current graphical analysis simulation software to prove that the train length has a significant effect on rail potential for two TPSs with short power supply distance.

Special Cases
The rail potential is significantly increased in some special cases, such as short-circuits between the contact net and the rail, short-circuits between contact network and the overhead ground line. When the short circuit current occurs in the DC equipment, the current will flow back to the rail through the ground network result in the rail potential raising in [10]. And the rail potential may rise when inputting the drainage cabinet is summarized in [11]. The permanent grounding of OVPD can limit the rail potential of the TPS, but it will increase the rail potential at the far end, and it does not solve the problem substantially is concluded in [12].

Rail Potential Suppression Method
At present, there are two main starting points to improve the frequent action of OVPD caused by the increase of rail potential: 1) to enhance returning path electrical conductivity and strength the parameters detection; 2) To optimize the control of OVPD and FLPD.

Enhance Electrical Conductivity and Strength Detection
Enhancing returning path electrical conductivity of return current is mainly achieved by reducing the loop resistance level and strengthening the insulation level, as follows specially:

(1) The return current jumper at the junction of the ballast and the rail fish-plate is replaced by the exothermic welding connection method [13];

(2) Regularly check the connection level of the return cable in the return current box, the negative cabinet, and the wiring bus bar, and apply conductive grease [12];

(3) Focus on checking whether the welding treatment at the welding point of the rail meets the relevant requirements [12];

(4) The connection of the cable to the rail is preferred to weld, and it is necessary to increase the anti-loose measures of the bolts [13];
(5) Regularly check the fish-plate and its bolts and short wires and confirm their contact surface is clean and smooth [12];

(6) In the part where the traction substation returns, 8-10 return cables should be connected in parallel to strengthen the return path. It is recommended to set more uplink and downlink current sharing cables for long lines [12];

(7) Strengthen the inspection and maintenance of rail insulation to achieve, and strengthen regularly test the integrated grounding system of the substation [14].

According to the voltage and current data of exhaust cabinet and the transmission data of locomotive load terminal, indirect measurement of transition resistance is carried out to realize on-line monitoring step by step in [15]. In [16], the automatic drainage cabinet based on the polarity drainage is designed, and the method of comprehensive evaluation of the multi-point monitoring data to evaluate whether the drainage cabinet is put into use is proposed.

**Optimization the Control of OVPD and FLPD**

Because the rail over-potential problem is a complex and comprehensive problem, which mainly causes a series of effects. When the rail potential cannot be reduced, the actions of OVPD should be optimized to reduce the impact on metro operation. Some suggestions on setting value and operation time adjustment of OVPD and DC frame protection are gave in [17]. Setting the FLPD component to alarm only and not trip is proposed in [18].

For the above improvement methods, this paper considers that the voltage components of FLPD cannot be canceled, because the voltage components of FLPD are used as backup protection of OVPD, but this protection can be improved by only alarming and constantly switching on and off. As for the way to introduce the signal of the train entering / leaving the station, this paper thinks that it is feasible but must be built on the condition that the platform screen door is well insulated, because the platform screen door and the rail are equipotential bonding.

**Summarize and Expectation**

This paper mainly lists the methodology aimed at the problem of rail over-potential in DC traction power supply system, some research results and some viewpoints have been summarized.

(1) At present, the rail potential model can estimate rail potential to a certain extent, which provides a reference for the solution of rail over-potential problem.

(2) This paper analyzes the integrated grounding system of DC traction power supply system of metro and summarizes the influence factors of rail potential under normal and special conditions.

(3) Based on the analysis, the suppression scheme of rail over-potential problem is summarized.

At present, most protection of metro stray current can generally meet the national standards but rail potential is too high. To solve this problem, some researches put forward to adopt the four-track power supply system which adds running rail and reflux rail. The running rail is only used for driving and the reflux rail is completely insulated from other facilities such as the track bed. Nowadays, it has adopted in 750V DC traction power supply system.

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**References**


