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Research on Geoelectric Field of Metro Stray Current Based on ANSYS

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Abstract. The stray current generated by urban rail transit has become one of the major factors in the DC bias phenomenon of the main transformer of urban power grid. The electromagnetic field finite element method is used to theoretically calculate and analysed the geoelectric field of metro stray current. According to the mathematical model, the ANSYS finite element software is used to simulated and analysed the current under different stray currents. The results show that with the value of traction current increases, the stray current flowing into the ground increases, and the strength of the formed electric field increases.

1. Introduction

In the subway DC traction power supply system, the current flows back through the rail to the negative pole of the traction substation. Since the rail is not completely insulated from the ground, a small part of the current flows from the rail to the ground and flows back to the negative pole of the substation through a certain path. These currents are called stray currents[1]. Stray currents can cause corrosion hazards to tunnel structural reinforcement and surrounding buried metal pipelines, and even threaten personal safety in severe cases [2]. Therefore, the research on stray current has been paid attention to at home and abroad.

With the accelerated construction of urban subway projects, subway operations have had a certain impact on the urban power grid. The stray current generated by the subway operation may cause the neutral point of the main transformer of the urban power grid to exceed the DC component of the upper limit of the DC bearing capacity of the transformer. The magnetic flux generated by these DC may cause the transformer core to be severely saturated and the excitation current is highly distorted, generating a large number of harmonics, increasing the reactive power loss of the transformer, causing the system reactive power compensation device to overload or the system voltage to drop [3], at the same time the flux will cause transformer noise and vibration, transformer core, bolts, shells, etc. overheating, local temperature rise and damage, transformer metal structural parts increase the loss, reduce the service life, and may even cause damage to the transformer [4-5]. Therefore, studying the geoelectric field formed by the subway stray current into the ground has important practical significance for the safe and stable operation of the regional power grid.

In this paper, the electromagnetic field finite element method is used to theoretically calculate and analyze the electric field distribution of stray current. Then, the ANSYS software is used to establish a simple geoelectric field model for the ground electric field formed by the subway stray current in the



uniform soil environment. The transformer provides a theoretical basis for the effects of stray currents.

2. Mechanism of stray current formation

Most of the subways use DC power, and electric locomotives draw current from the contact rails. Theoretically, the contact rail and the return rail are insulated from ground, and all current flows back from the return rail to the traction substation. But in fact, due to the longitudinal resistance of the return rail itself and the transitional conductance to ground, a part of the current in the return rail leaks into the earth, some of which flow back to the substation through the drain network, and the other part is ground and buried metal. The path flows to form stray currents. A schematic diagram of the stray current distribution is shown in Figure 1.

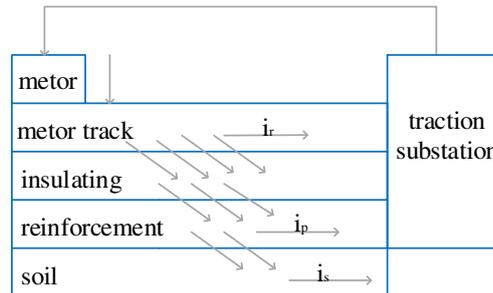


Figure 1. Schematic diagram of stray current distribution

3. Finite element analysis of geoelectric field of stray current

3.1. Overview of the finite element method

The principle of the finite element method is to use many subfields to represent the entire contiguous region. In a subfield, an unknown function is represented by a simple interpolation function with unknown coefficients. Therefore, the problem of the original boundary value of infinite degrees of freedom is transformed into a problem of a finite number of degrees of freedom. Then, a set of algebraic equations is obtained by the Ritz transform or the Galerkin method. Finally, the solution to the boundary value problem is obtained by solving the equation.

Taking a closed curved surface S in the space conductor with a bulk current density of j , the amount of electric charge flowing out per unit time according to the closed curved surface S is equal to the law of conservation of charge of the amount of charge reduced by the closed curved surface S per unit time, in a constant electric field, the electric field and charge do not change with time, then the differential form of the current continuity equation:

$$\nabla \cdot j = 0 \quad (1)$$

The basic equation of the electric field of the two-dimensional subway stray current electric field:

$$\frac{\partial}{\partial x} \left(\gamma_x \frac{\partial \varphi}{\partial x} \right) + \frac{\partial}{\partial y} \left(\gamma_y \frac{\partial \varphi}{\partial y} \right) = 0 \quad (2)$$

The corresponding boundary conditions are as follows:

(1) The second type of homogeneous Norman boundary conditions at the surface of the ground is:

$$\frac{\partial \varphi}{\partial n} = 0 \quad (3)$$

(2) The potential at infinity is 0, satisfying the first type of boundary condition, the Dirichlet condition:

$$\varphi = 0 \quad (4)$$

In order to apply the variational method to list the finite element equations, we first need to establish the required variational principle. The corresponding boundary value problem of the geoelectric field formed by the stray current into the ground is equivalent to the following variational problem:

$$\delta F(\phi) = 0 \quad (5)$$

In this paper, the two-dimensional finite element scalar potential method is used to analyze the variable geoelectric field. In the formula:

$$F(\phi) = \frac{1}{2} \iint \left[\gamma_x \left(\frac{\partial \phi}{\partial x} \right)^2 + \gamma_y \left(\frac{\partial \phi}{\partial y} \right)^2 \right] d\Omega \quad (6)$$

The meaning of the above formula is to find the stagnation point of the functional $F(\phi)$ given a Dirichlet boundary condition, where ϕ is an approximate solution in the functional or residual weighting equation.

In order to prove the above vibrational formula, take the first variation of $F(\phi)$ versus ϕ :

$$\delta F(\phi) = \iint \left[\gamma_x \left(\frac{\partial \phi}{\partial x} \right) \left(\frac{\partial \delta \phi}{\partial x} \right) + \gamma_y \left(\frac{\partial \phi}{\partial y} \right) \left(\frac{\partial \delta \phi}{\partial y} \right) \right] d\Omega \quad (7)$$

The imposed stagnation condition $\delta F(\phi) = 0$ can be obtained:

$$\delta F(\phi) = \iint \left[-\frac{\partial}{\partial x} \left(\gamma_x \frac{\partial \phi}{\partial x} \right) - \frac{\partial}{\partial y} \left(\gamma_y \frac{\partial \phi}{\partial y} \right) \right] \delta \phi d\Omega + \int \left[\frac{\partial}{\partial x} \left(\gamma_x \frac{\partial \phi}{\partial x} \right) + \frac{\partial}{\partial y} \left(\gamma_y \frac{\partial \phi}{\partial y} \right) \right] \delta \phi dS \quad (8)$$

Above the formula:

$$-\frac{\partial}{\partial x} \left(\gamma_x \frac{\partial \phi}{\partial x} \right) - \frac{\partial}{\partial y} \left(\gamma_y \frac{\partial \phi}{\partial y} \right) = 0 \quad (9)$$

$$\frac{\partial}{\partial x} \left(\gamma_x \frac{\partial \phi}{\partial x} \right) + \frac{\partial}{\partial y} \left(\gamma_y \frac{\partial \phi}{\partial y} \right) = 0 \quad (10)$$

It can be concluded that the solution of the vibrational formula (8) and the formula (9) is the solution of the boundary value problem of the defined formula (2-4). Equation (10) is the Euler equation of the functional $F(\phi)$ given by equation (6). The formula (9) is automatically satisfied in the process of finding the maximum or minimum of the functional, so this condition is considered Natural boundary conditions. Dirichlet's formula (4) must be imposed as a necessary boundary condition.

For the geoelectric field formed by stray current into the ground, the two-dimensional finite element scalar potential method is used in this paper. In the finite element analysis, the two-dimensional linear triangular element with discrete interpolation is used to describe the soil region. The Ritz method can be used to obtain the finite element equation.

3.2. Simulation of ANSYS of subway stray current geoelectric field

In order to more deeply and practically analyze the distribution law of the geoelectric field formed by the subway stray current into the ground, obtained the stray currents at various locations in the underground and determined the influence range of stray current of the main transformer in the city, the two-dimensional finite element model of the stray current geoelectric field of the subway was established. Therefore, this paper will use ANSYS finite element software to establish the electric field of subway stray current in the environment of uniform soil medium and layered soil medium, and simulate the calculation by loading stray currents of different sizes.

According to the actual subway tunnel size and depth, the design is shown in Figure 2 as a

cross-sectional view of the electric field calculation field of the subway stray current. The soil area in the figure is 100×60m. The dimensions of the various parts of the common tunnel structure of the subway are indicated in the figure. The thickness of the medium 1-4 in the figure is 6m, 14m, 10m and 30m respectively.

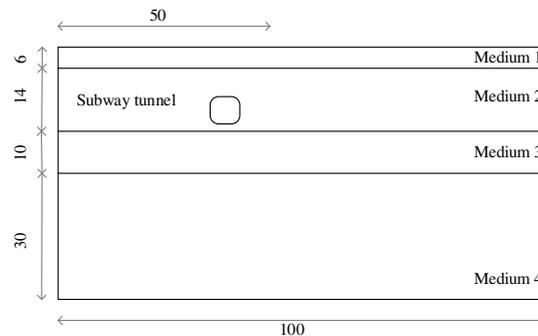


Figure 2. Cross-sectional view of the electric field calculation field of the subway stray current (unit: m)

The simulation parameters of each medium in uniform soil are shown in Table 1.

Table 1. Simulation parameters in uniform soil medium.

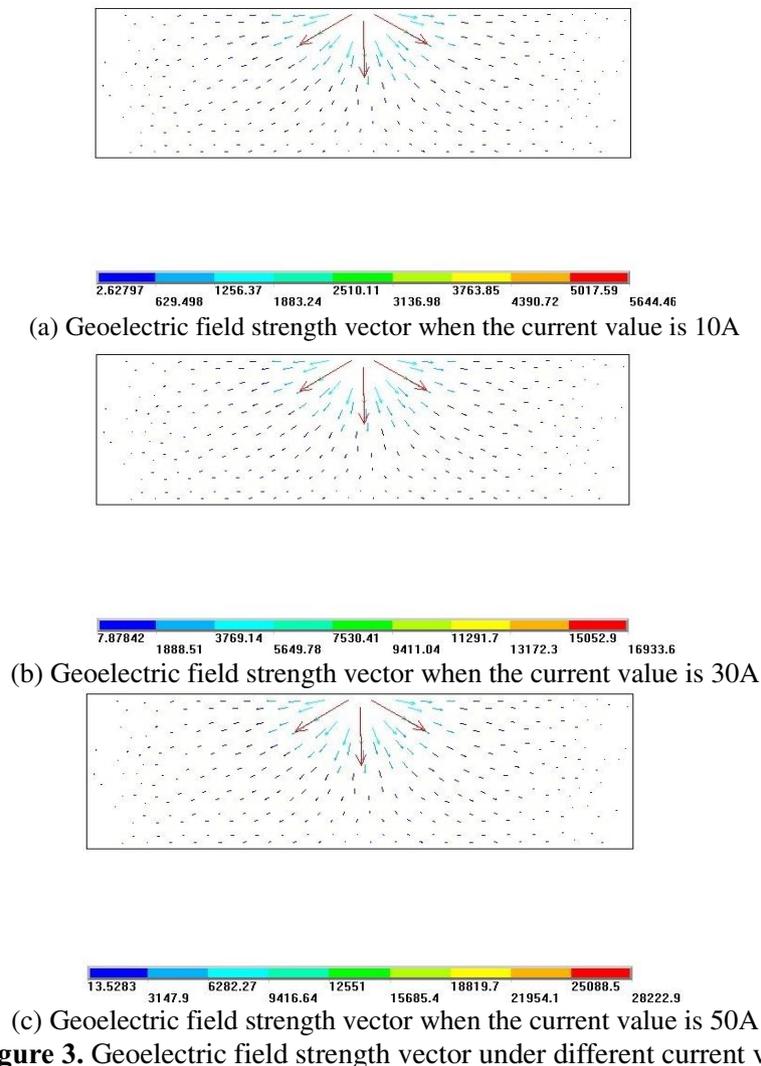
Material name	Relative permittivity	Resistivity ($\Omega \cdot m$)
Spray concrete	7	552.9
Reinforced concrete	6.4	150
Rail	1×10^7	2.1×10^{-7}
soil	30	100

The unit type selected in the ANSYS simulation calculation is the unit PLANE230, and the unit PLANE230 is a two-dimensional 8-node current-based planar unit type with node degrees of freedom as voltage. The results obtained by using this unit are more accurate.

In order to analyze the influence of different traction currents on the ground electric field caused by different traction currents, the load current is calculated as 5% of the traction current according to the stray current flowing into the ground. Therefore the current values at the loading are 10A, 20A and 50A. The boundary condition of the surface set under the calculation model is zero as shown by the formula (2-3).

In the finite element solution, the line current needs to be expressed in the form of current density, so the source current is first processed. The current density in the rectangular region of 100m×60m is equivalently expressed as the line current, and the stray current leakage is initially at the midpoint of the rectangle, and the current density amplitude is $1A/m^2$.

Used the ANSYS software for finite element analysis, it can be seen that the geoelectric field intensity vector of the stray current is obtained under the condition of loading different currents as shown in figure 3 . It can be seen from the figure that in the uniform soil medium, the potential increases with the increase of the load current at the same depth and direction.



4. Conclusion

In the operation of the subway, because the rail can not be completely insulated, stray current will flow into the ground to form a stray current electric field; as the traction current value increases, the stray current flowing into the ground will also increase, resulting in the formation. The strength of the geoelectric field also increases. Therefore, as the subway runs more and more, the insulation damage is greater, and the subway stray current will flow more into the geoelectric field formed by the earth, which will increase the impact on the urban main transformer. Therefore, the formation of the electric field by the stray current into the ground will provide a theoretical basis for the DC bias control analysis of the main transformer in the urban area. In the future research, the model should be combined with the time and the instantaneous moving distance of the subway to better solve the DC bias phenomenon of the main transformer in the urban area to improve the safe operation efficiency of the power system.

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