THE Study on the Polar Potential Distribution of DC Grounding in Earth Structures

Chenglian Ma¹, Shujian Zhao¹, Li Sun¹*, Letian Wang² and Tao Wang²

¹ School of Electrical Engineering, Northeast Electric Power University, Jilin, Jilin 132012, China
² ShanDong Electric Power Engineering Consulting Institute CORP.,LTD. Jinan, Shandong 250013, China

* Li Sun: sunlinedu@163.com

Abstract. This paper introduced the boundary conditions of the complex soil potential. Then the simulation is carried out with the ANSYS software. And effect of the ground potential distribution in rivers and mountains of the complex geological conditions are analyzed. It is pointed out that rivers can change the potential distribution, and mountains can hardly change the potential. The rational use of these characteristics can effectively alleviate the effect of the grounding electrode potential on the power system and the environment. At last, the importance of establishing a three-dimensional geoelectric field model is put forward, and the geodetic structure is more accurately understood by considering the transversal difference of the earth. Then the current field distribution around the DC ground electrode is calculated accurately. It is better to serve the construction of UHVDC power transmission project in China.

1. Introduction

The initial and maintenance stages of the UHVDC power transmission project in China are completed. It is usually temporarily operated in a monopole circuit, there will be a strong DC current (3000A, 5000A, and 6250A) at this time. For a long time into the earth, potential distortion is caused in a wide range of ground. It will be around the environment, the adverse effects of oil gas pipeline network and power grid communication system are harmful. The key to solve the above problems lies in exploring the flow law of current in the soil and the distribution of the ground potential [1]. There have been many scholars in the field of geodetic potential analysis. In most previous analyses of the geodetic potential, the commonly used soil model is the horizontal homogeneous multi-layer soil structure [2-4]. There is no analysis of the influence of geodetic structure on the surface potential distribution. Therefore, the influence of the structure of the soil on the neutral current of the transformer can not be obtained from the results of the analysis. The soil structure is actually uneven. On the macro level, there are horizontal and vertical partitioning. As a mountain area, the soil structure will be more complex in the near sea or lake area [5].

In this paper, the finite element method is applied to the calculation of the ground current field. The calculation formula of the DC ground potential under the complex geodetic structure is derived. Then the simulation analysis is carried out by using ANSYS. The distribution of surface potential in the presence of rivers and mountains is simulated. The influence of geodetic structure on the distribution of ground potential is analyzed. The distribution of surface potential in the unipolar operation of DC
grounding electrode with different influence factors is summarized. It provides reference for the design and construction of the later UHVDC transmission project.

2. The Influence of Geodetic Structure on the Distribution of Ground Potential

The current of the rated operating ±800 kV UHVDC power transmission projects, which have been put into operation, is 3000 A or 4000 A. The current of the ZhunDong - Wannan ±1100 kV UHVDC in the construction is 5000 A. And the construction scale of the transmission terminal of the Hubei ±800 kV UHVDC transmission project as follow: the transmission capacity of the DC system is 10000 MW, and the rated DC current is 6250 A.

A single phase transformer of ZZDFPZ-321000/500 model is adopted for the change and rheology of ±800 kV. Through the calculation of the nameplate parameters, the DC resistance of the windings is 0.704, and the grounding resistance of the converter station is 0.1. ±500 kV AC substations usually use single-phase autotransformer. The DC resistance of high voltage and medium voltage windings is 0.238 and 0.097, respectively. The grounding resistance of 500 kV substations is 0.2. The AC lines use four split wires. The resistance of single phase line is 0.0187 /km.

It can be seen that the DC resistance of HVDC transmission lines is small. For an AC grid, if there is a potential difference between two points on the ground, and there is an electrical connection between the ground and the ground system, the grounding of the ground pole to the ground will flow into the power grid, which has a serious impact on the power grid system, resulting the DC bias of the AC transformer, vibration and noise, and the load increased.

However, the vast majority of the currents flow through the earth. Therefore, it is necessary to analyze the impact of the direct current on the power system or the environment. The key problem is to analyze the distribution of the geodetic soil in the earth and the potential distribution on the ground. From some of the existing DC projects that have been put into operation, the influence of DC transmission to the polar potential is often underestimated, even the wrong estimate. The distribution of the ground potential is not only determined by the distance from the grounding electrode. It is related to the stratification of the soil and the distribution of the surrounding rivers, lakes, seas and mountains, especially for the study of large range potential distribution.

Considering the effect of geodetic structure on the distribution of ground potential is not only used in HVDC. It can also provide reference for the study of the phenomenon of high current to ground such as lightning. On the other hand, it has value for the study of the distribution of magnetic induction current GICs on the earth, ESP and so on.

3. Analysis Method and Boundary Condition Setting

3.1. Analysis Method

With the help of ANSYS, the simulation of the ground potential under different geodetic conditions is completed. Under the complex geodetic structure, if the traditional mirror method or the complex image method is used to calculate, it is inevitable that a large number of formula derivation should be carried out. The earth is not always horizontal or vertically homogeneous. The derivation of different ground potential formulas for various complex terrains is not only tedious but also inefficient. The most suitable method is the method of field analysis. The equation of different topographic field is constant. As long as the corresponding boundary conditions are set for the interface between different terrain, it is possible to use the method of numerical calculation to solve the problem quickly. At the same time, the application of the theory and research method to the finite element calculation of the three dimensional electromagnetic field of the transformer is also a subject worthy of study.

3.2. Boundary Condition Setting

The distribution of ground potential and the striding voltage and grounding resistance in the vicinity of the ground electrode are analyzed. Then a model of soil and grounding electrode near the pole site is established. An axisymmetric model is established in ANSYS. Using current field calculation module, the unknown field is the potential value V in the area of the 0 reference point at infinity. At the same time, the soil resistivity of each layer is defined. The vertical external method of the surface potential
is 0. The underlying potential is set to 0. The choice of excitation is determined by the method of defining the potential value at the ground pole. First, the voltage on the grounding electrode is defined. Then the finite element calculation is carried out. Calculate the electric field strength of each side of the grounding electrode \( E \),

\[
E = 2\pi R \int E_x dx
\]

\[
E = 2\pi R \int E_y dx
\]  

(1)

Then the grounding electrode current \( I \) is obtained.

\[
I = E / \rho
\]  

(2)

where, \( R \) is ground pole radius, \( E_x \) is The electric field intensity (V/M) in the radial direction of the electrode, \( E_y \) is the electric field intensity (V/M) in the vertical direction of the electrode profile, \( \rho \) is the soil surface (\( \Omega \cdot M \)) of electrical resistivity.

4. Simulation Results and Analysis

The distribution of the ground potential is calculated in the following parts of the sea and the high mountain. The point current source is used. The range is from a radius of 50 to 100 km. The soil model is illustrated by the typical tectonic model of the earth, as shown in Table 1. The effect of geodetic structure on the ground potential is analyzed in the light of the calculation results.

| Thickness of layer (km) | Resistivity (\( \Omega \cdot m \)) |
|-------------------------|-------------------------------|
| \( \rho_0 \)            | 0.1                           | 10                           |
| \( \rho_1 \)            | 2                             | 200                          |
| \( \rho_2 \)            | 30                            | 10000                        |
| \( \rho_3 \)            | 100                           | 0                            |

4.1. The Influence of Rivers

In this study, two river models are established. One is perpendicular to the radius of the earth's polar radius, and the other is along the radius of the earth's pole. For the first case, a soil model with long and wide 100 km and 100 km long rectangles is established. The river model is a small rectangular body with a vertical distance of 20 km, a width of 1 km, a depth of 1 km, and a long 100 km on the surface of the soil. The conductivity of the river is \( 1 \ \mu \text{S/cm} \). For the second case, the same soil model was established to solve the lake. The river model is taken from 5 km to 40 km from the central point, 1 km in width and 1 km in depth on the surface of the soil.
Figure 1. The distribution of the potential of the lateral rivers.

Figure 2. The distribution of potential distribution of longitudinal rivers.

Figure 1 is the distribution of the equipotential line of the earth when the lateral river exists in the vertical direction of the earth's radius. As shown in Figure 1, the direction of the river is parallel to the direction of the equipotential line. Therefore, the lateral river has little effect on the geodetic potential. The entire surface of the river is equipotential, and the decrease of the geodetic potential of the river at the ground pole is slightly quicker. On the outside of the river, the decrease of the potential of the earth slightly slows down. In general, the impact is not very big.

Figure 2 is the direction of the flow of a river along the radius of the earth's electrode. That is, the distribution of the geodetic potential in the presence of a longitudinal river. As shown in Figure 2, the change of potential in the area flowing through the river is obvious. Firstly, in the extreme part of the river near the ground, the potential changes sharply. The partial potential change in the river far away from the ground pole is slow. Secondly, the river at this time is similar to a wire that flows through the current, and the resistance is small, and the potential is small. The whole river spans tens of kilometers in the direction of the radius. The whole river spans tens of kilometers in the direction of the radius. But the whole potential drop is less than 5 V. It also affects the whole river area, and the rate of potential decline also slows.
In the presence of a river that flows along a radius in the vicinity of the DC ground, one is to consider the problem of the large current distribution density of the earth’s surface near the extreme near the ground. In addition, if the conditions are available, the average potential action of the river can be used to reduce the effect of the ground potential difference on the power system and the environment.

4.2. The Influence of Mountains
In this chapter, the surface potential is simulated with the distribution of mountain ranges around the ground pole. The soil model uses the typical soil model of Table 1. The alpine model uses a cone. The surface diameter of the upper surface is 1 km, the lower surface diameter is 20 km, and the height is 10 km. The center of the mountain is located at 70 km from the ground to the ground. The mountains are basically composed of rocks. In this paper, 1000 Omega m is taken.

Figure 3. The earth surface potential top view in the presence of high mountains.

Figure 4. Lateral view of the earth potential distribution when Alpine exists.
Figure 3 is a view of the potential distribution of the earth’s surface potential in the presence of Alpine. It can be seen that the geodetic potential of the region in which the mountain is located is distorted. But in the area outside the mountains, the potential is distributed according to the normal concentric circle. It’s basically unaffected by the mountains.

Figure 4 is a view of the side potential distribution in the presence of a high mountain. Because the resistivity of the mountain is higher than that of the ordinary soil, in theory, when the current flows through the mountains, the potential drops rapidly. However, in figure 4, after the current flows through the mountains, the absolute value of the potential at the other end of the mountain is not the same as that in the normal condition. And the potential distribution on the mountain is thinner, and the potential drop is slower than that in the normal condition. This is due to the high resistivity of the high mountain and the low flow of current. On the other hand, the height of the mountains is large, the surface area is large, and the area of the current flows is larger. These two aspects work together, and the flow of current is just parallel to the surface of the potential line on the surface of the surrounding ground. In the rear of the mountain, the distribution of potential is the same as that under normal conditions.

According to the above situation, when there is a high mountain near the ground pole, it is unnecessary to think about the impact of high mountains. At the time of calculation, the mountain can be ignored and the calculation can be simplified.

5. Conclusion
(1) The earth potential equation and boundary condition are derived under the condition of complex soil structure. The finite element method is applied to solve the problem. A suitable model can be set up, and the boundary conditions and the source of the field are set up scientifically. With the help of the finite element ANSYS, the distribution of the ground potential is obtained.
(2) Because the structure of the earth is complex, the range of geodetic measurements in the site of the grounding electrode is limited. There is a great deviation between the actual situation of the grounding current distribution of the grounding electrode and the theoretical analysis and calculation. The necessity of establishing three-dimensional geodetic resistivity model in large area is becoming more and more important.

6. References
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