ESP Simulation Study on the DC Grounding Electrode in Chinese Shanbei Converter Station Based on ANSYS

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Abstract. When the UHVDC project was put into operation, the grounding current of DC grounding electrode may have a great influence on the transformer near the pole. The calculation of earth surface potential (ESP) distribution was a problem to be considered in the planning and design stage. In this paper, the calculation method of the current field of DC transmission grounding electrode was deduced. The grounding electrode project of Chinese North Shaanxi converter station was referred, and the layered model of 6 layers of ground soil was established. The potential distribution in the range of 0-100 km of the earth electrode was calculated by using ANSYS. The calculation results show that the distance between the ground electrode and the ground electrode decreases faster than that of the ground electrode. The distribution of earth surface potential within the range of 2 km of the earth electrode should be studied emphatically, and the potential distribution of the substations and power plants that have been built and planned has been calculated. The method presented in this paper could provide reference for the debugging of HVDC transmission monopole.

1. Introduction

The development of ultra-high voltage AC/DC power transmission is an important measure to meet the state's national conditions of air pollution prevention and control. On June 23, 2017, the Jiu Lake DC ±800 kV UHVDC transmission project was put into operation across the whole line after the commissioning of the receiving end power grid at the low end and the high end. The project is of far-reaching significance for air pollution prevention and control in Central China.

The UHVDC project is completed and put into operation early and system monopolar locking maintenance phase, and earth current will run into the ground by DC grounding electrode [1]. Powerful and long-lasting time in earth current may make the transformer near the DC grounding electrode DC bias magnetic saturation and then excessive temperature rise, increased reactive power consumption and high-order harmonics [2].

This paper provides a certain auxiliary reference for the calculation of the ground potential distribution of the HVDC grounding electrode in the relevant design unit. Shaanxi Fugu Village Station Daliushu-Yan grounding with the construction of the project, the actual measurement data of the geodetic resistivity of the magnetotelluric sounding are applied. It is used to check the design, planning and measurement of the design institute by ANSYS for modeling and simulation calculation. Through the
simulation calculation, the design staff can better grasp the influence of the earth electric potential rise distribution around the earth resistivity.

2. Theoretical Basis of Ground Current Field
The starting point of the DC power transmission line is the Northern Shaanxi converter station in Yulin, Shaanxi. The grounding pole of the converter station in Northern Shaanxi is located in the Fugu County of Yulin. When UHVDC transmission works in a single pole mode, the ground potential near the ground pole will be greatly improved. The ground and underground artificial technical system and the earth form the loop. It will inevitably lead to the increase of its DC current, electrochemical corrosion in the underground, and the ground AC transformer occurs DC bias. The damage of railway signal electromagnetic interference is increasing, which affects the safe operation [3-4].

2.1. Basic Equation of Ground Current Field
In the way of the monopole earth line, the ground pole to the earth is inflow into the earth from the end of the power grid to the earth, and the current is infinitely deep into the earth. Then, the current flows from the receiving power grid to the ground pole. In this process, the direct current is deep down from the ground to the ground. Flowing from the upper soil to the depths of the earth, the flow of current in the soil is continuous, through soil with different resistivity. Basic Equations are as follow:

\[ \nabla \times E = 0 \tag{1} \]
\[ \nabla \cdot J = -\frac{\partial \rho}{\partial t} \tag{2} \]
\[ J = \sigma \dot{E} \tag{3} \]
\[ \ddot{E} = -\nabla V \tag{4} \]
\[ \nabla^2 V = 0 \tag{5} \]

where, \( E \) is the ground induced electric field intensity (V/m) excited by the current of the earth, \( J \) is current density (A/m²), \( \rho \) is body charge density (C/m³), \( \sigma \) is electrical conductivity (S/m) and \( V \) is potential (V).

2.2. Boundary Condition of Ground Current Field
The DC transmission project is thousands of kilometers long. The geodetic potential distribution of the earth pole is widely analyzed. The DC grounding current can be considered as a point current source. The field equation of the underground region containing the point current source is the Poisson equation, and the region that does not contain a point current source is the Laplace equation. The above is satisfied with the relation of field equation (5).

Assuming that a DC grounding current \( I \) nearby the grounding electrode. In the ground 5 meters underground within the scope of the regional point current source is \( I \), the unit point charge density function is defined as a formula (6).

\[ \rho(x) = \delta(x - x') \tag{6} \]

Where, \( \delta(x - x') \) is defined as the unit point charge density, at the point \( x' \).

\[
\begin{cases} 
\delta(x) = 0 & x \neq 0 \\
\int \delta(x) \, dx = 1 & \text{else}
\end{cases}
\tag{7}
\]

It can be seen that the point charge is the limit of a charged ball with a small volume and a large charge density, distributed within a small volume \( \Delta V \). When \( \Delta V \to 0 \), \( \rho \to \infty \). The values of \( \nabla \cdot \vec{J} \) with current source are derived by formula (8) and formula (9).
The first layer of underground soil region with point current source field equation is as follows:

\[ \nabla \cdot \vec{J} = I \delta(x) \]  

The boundary conditions are as follows: \( V = 0 \). At boundary between the air and the air, \( \frac{dV}{dn} = 0 \). And \( n \) is directed to the air side in the direction of the outer normal. At boundary between \( i \) and \( j \) in adjacent soils with different conductivities, there is

\[ \frac{1}{\rho_i} \frac{dV_i}{dn} = \frac{1}{\rho_j} \frac{dV_j}{dn} \]

### 3. MT Measurement of Earth Resistivity of DC Grounding Electrode in North Shaanxi Converter Station

In this project, the resistivity of shallow soil has been surveyed in the research stage. In addition to conventional resistivity measurements, the MT measurement is also used to detect the deep electrical structure characteristics of the recommended polar site [5]. After the systematic analysis and processing of the interpretation results of magneto telluric sounding data, the electrical parameters have been obtained about Yan site of Daliushu village. The soil stratified soil model is shown in figure 1. The results of specific electrical delamination are shown in Table 1.

**Table 1. Daliushu Yan village site of earth layering results.**

| Serial number | Upper interface electric layer depth /km | Lower interface electric layer depth /km | Electric layer thickness/km | Resistivity equivalent value/ (Ω•m) |
|---------------|------------------------------------------|------------------------------------------|-----------------------------|------------------------------------|
| 1             | The surface                              | 0.3                                      | 0.3                         | 30.047                             |
| 2             | 0.3                                      | 1.5                                      | 1.2                         | 10.707                             |
| 3             | 1.5                                      | 16.0                                     | 14.5                        | 385.36                             |
| 4             | 16.0                                     | 36.0                                     | 20.0                        | 7.150                              |
| 5             | 36.0                                     | 90.0                                     | 54.0                        | 15.000                             |
| 6             | 90.0                                     | \( \infty \)                               | \( \infty \)                 | 15.000                             |
4. ANSYS Simulation Calculation of Earth Electrode Geodetic Potential

4.1. Main Parameters of Built Substations Engineering
The data shown in table 2 are the main parameters of built transformer substation and the power plant around the North Shaanxi converter station.

Table 2. Main parameters of built substations engineering.

| Substation and Power Plant | Distance/km | Grounding Resistance/Ω | Transformer (Type)/MVA | Voltage/kV |
|---------------------------|-------------|-------------------------|------------------------|------------|
| Haojia                    | 16.0        | 0.5                     | 2×240                  | 330        |
| Fuguer                    | 25.0        | 0.5                     | 3×360                  | 330        |
| Yangsihai                 | 45.0        | 0.5                     | 3×180                  | 220        |
| Chuanzhang                | 24.0        | 0.5                     | 2×240                  | 220        |
| Gudu                      | 26.0        | 0.3                     | 2×90                   | 220        |
| Baode                     | 33.0        | 0.3                     | 2×150                  | 220        |
| Qingshui Power Plant      | 18.0        | 0.5                     | 2×370                  | 330        |
| Guojiawan Power Plant     | 45.5        | 0.5                     | 2×370                  | 330        |
| Hequ Power Plant          | 24.4        | 0.5                     | 2×420                  | 220        |
| Linzhou                   | 55.0        | 0.2                     | 2×360                  | 330        |
| Shenmu330                 | 71.0        | 0.2                     | 2×360                  | 330        |

4.2. Simulation and Analysis of ANSYS
Due to the earth model is more complex, this paper uses magnetotelluric sounding to model geodetic stratified resistivity data. A large amount of formula derivation should be carried out under the complex structure model of the earth. If the traditional method is used for calculation, the formula is tedious and the calculation is inefficient. The method of field analysis proposed in this paper is one of the most suitable methods. The method of numerical calculation is used. Although the terrain is different, the field equation is constant [6-13]. The earth potential rise data curve in the 0~10 km range of the ground electrode in figure 2, and the 0~50 km range earth potential rise curve is shown in figure 3. The 0~10 km range earth potential rise data curve is calculated by ANSYS as shown in figure 4, and the 0~5 km range earth potential rise curve is shown in figure 5.

Figure 2. Earth potential rise data curve in the 0~100 km range of the ground electrode.

Figure 3. Earth potential rise data curve in the 0~50 km range of the ground electrode.

Figure 4. Earth potential rise data curve in the 0~10 km range of the ground electrode.

Figure 5. Earth potential rise data curve in the 0~5 km range of the ground electrode.
Through ANSYS calculation and analysis, in conjunction with figure 2, figure 3, figure 4, figure 5, the geodetic potential rise curve within the range of 100 km of the polar address of the ground pole is connected to the range of the polar address of the ground pole. It can be seen that the trend of the geodetic potential rise is decreasing. The fastest range of reduction is 2 km of the earth's polar square. The problem of ground potential distribution in the 2 km range of the earth's polar square should be taken into consideration. The effect of the ground potential is faster and the ground potential gradient is larger, and the effect on the ground artificial system is greater. The land into the earth is deep in the depths of the earth. The current density on the surface gradually decreases as it is far away from the ground pole.

5. Conclusion
For the surface potential distribution, the 6 level soil resistivity model is measured with MT method to calculate by ANSYS. The calculation results show that the farther the earth potential is, the slower it decreases from the ground electrode, and the first 2 km deceleration is faster. The effect of the ground potential is faster and the ground potential gradient is large, and the effect on the ground artificial system is greater. And the observation of the DC bias current of the transformer should be strengthened by the station near the ground pole.

6. References
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**Appendices**

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