Research on the Effects of DC Grounding Electrode of Yanmenguan Converter Station on the Earthing Network of Substation and Windfarm Based on CDEGS Software

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Abstract. It is of importance to assess the electromagnetic influence of HVDC converter station on buried metal facilities of AC substations, fossil-fuel plants, windfarms and pipelines. Electromagnetic interference model was established based on the experimental measurement of soil resistivity and actual physical location. It was shown that the grounding potential rise (GPR) of Yijing 220kV substation, Banjing wind farm, Nanhuashan wind farm, Jiyangshan wind farm, Liugou wind farm and Limin wind farm exceeded the standard. The effects of distance, soil resistivity and injected current on GPR were also investigated. The results can provide reference significance for design and maintance of HVDC transmission engineering.

1. Introduction
When the HVDC transmission operates in the trail run mode, or in the planned or forced outage mode, a large direct current will flow through the soil, and buried metal facilities of AC substations, fossil-fuel plants, windfarms and pipelines nearby will generate the grounding potential rise (GPR). GPR will not only affect the normal operation of power equipment, but also accelerate electric corrosion. So it is of importance to assess the electromagnetic influence of HVDC converter station on neighbouring buried metal facilities [1].

In recent years, some preliminary studies on the electromagnetic influence of HVDC converter station have been made. Li et al proposed an equivalent complex image method to calculate the GPR [2]. Ma et al used ANSYS software to calculate the GPR near the north Shaanxi converter station [3]. Geng et al have studied the influence factors of the GPR [4]. However, the electromagnetic influence of Yanmenguan converter station cannot be infered directly based on the above research results because of the different distance and soil structure.

In section 2 the theory to calculate the GPR is introduced. The GPR of AC substations, fossil-fuel plants, windfarms and pipelines nearby Yanmenguan converter station is studied in section 3. The effects of distance, soil resistivity and injected current on GPR were obtained in section 4. We conclude this paper with a discussion in section 5.

2. Theory of GPR Calculation
The potential distribution in soil around DC grounding electrode can be described by Laplace equation in cylindrical coordinate system

\[
\frac{\partial^2 V}{\partial r^2} + \frac{1}{r} \frac{\partial V}{\partial r} + \frac{\partial^2 V}{\partial z^2} = 0 \tag{1}
\]

The solution of Laplace equation (1) is obtained as follows [5-7]

\[
V = \theta(\lambda)J_0(\lambda r)e^{-\lambda z} + \phi(\lambda)J_0(\lambda r)e^{\lambda z} \tag{2}
\]

where \(J_0\) is the first kind of zero order Bessel function.

The potential function in uniform soil is

\[
V = \frac{\rho I}{4\pi} \frac{1}{\sqrt{r^2 + z^2}} \tag{3}
\]

The potential function of the three layers of soil is

\[
V_1 = \frac{\rho_1 I}{2\pi} \left[ \int_0^h \theta_1(\lambda)J_0(\lambda r)e^{-\lambda z}d\lambda + \int_0^h \phi_1(\lambda)J_0(\lambda r)e^{\lambda z}d\lambda \right] \tag{4}
\]

\[
V_2 = \frac{\rho_2 I}{2\pi} \left[ \int_h^{h_2} \theta_2(\lambda)J_0(\lambda r)e^{-\lambda z}d\lambda + \int_h^{h_2} \phi_2(\lambda)J_0(\lambda r)e^{\lambda z}d\lambda \right] \tag{5}
\]

\[
V_3 = \frac{\rho_3 I}{2\pi} \left[ \int_{h_2}^{\infty} \theta_3(\lambda)J_0(\lambda r)e^{-\lambda z}d\lambda + \int_{h_2}^{\infty} \phi_3(\lambda)J_0(\lambda r)e^{\lambda z}d\lambda \right] \tag{6}
\]

The undetermined coefficients in equations (4)-(6) are determined by the following boundary conditions:

\[
z \to \infty, \quad V = 0 \tag{7}
\]

\[
z = h_1 + h_2, \quad V_2 = V_3, \quad \frac{1}{\rho_2} \frac{dV_2}{dz} = \frac{1}{\rho_3} \frac{dV_3}{dz} \tag{8}
\]

\[
z = h_1, \quad V_1 = V_2, \quad \frac{1}{\rho_1} \frac{dV_1}{dz} = \frac{1}{\rho_1} \frac{dV_2}{dz} \tag{9}
\]

\[
z = 0, \quad \frac{dV_1}{dz} = 0 \tag{10}
\]

3. GPR of Buried Metal Faciliteis Nearby Yanmenguan Converter Station

3.1. Calculation Model

The GPR calculation model is established in the Malz module of CDEGS software. Based on the experimental results of soil resistivity, the number of soil layer of Yanmenguan converter station is 3. The first layer is from the surface to the depth of 400m, the thickness is \(h_1 = 400\)m, the soil resistivity is \(\rho_1 = 101.72\) \(\Omega\)·m. The second layer is from 400m to 5000m with thickness \(h_2 = 4600\)m, and the soil resistivity \(\rho_2 = 1037.5\) \(\Omega\)·m. The third layer is from 5000m to infinity, with the soil resistivity \(\rho_3 = 76.4\) \(\Omega\)·m. The resistivity, thickness, relative permeability and dielectric constant of air, top soil layer, middle soil layer and bottom soil layer are input into the editbox of “soil characteristics”. The layout of Yanmenguan DC grounding electrode and buried metal facilities is shown in Figure 1. The distance between DC grounding electrode and buried metal facilities are set according to the physical loacations as shown in the second column of Table 1.

The inner ring diameter of Yanmenguan DC grounding electrode is 60mm, the ring diameter is 150m, and the buried depth is 2.5m. The outer ring diameter is 70mm, the ring diameter is 350m, and the buried depth is 3.0m. The resistivity of inner and outer ring is \(2.1 \times 10^7\) \(\Omega\)·m. When Yanmenguan converter station operates in the monopole-earthe model, The current injected is 3000A, and the corresponding monopole transmission power is about 2400MW.
3.2. GPR of Buried Metal Facilities

The GPR of AC substations, fossil-fuel power plants and wind farms nearby Yanmenguan converter station is shown in Table 1. It can be seen that the maximum GPR occurs in the Yijing 220kV substation, and the GPR is 8.1450 V. The minimum GPR occurs in the Kelan 220kV substation, and the GPR is 1.1642 V.

According to the standard DL/T 5224-2014 titled “technical code for design of HVDC earth return system”, the GPR limit of substation, power plant and wind farm is 3 V. The GPR of Yijing 220kV substation, Banjing wind farm, Nanhuashan wind farm, Jiyangshan wind farm, Liugou wind farm and Limin wind farm exceeds the GPR limit. The GPR of Wuzhai 500kV substation is near the limit value. The GPR of other substations, fossil-fuel power plants and wind farms meets the requirements of the technical specification.

Table 1. Calculation results for GPR nearby Yanmenguan converter station.

| Name                  | Distance (km) | GPR (V)  | Whether it exceed the standard |
|-----------------------|---------------|----------|-------------------------------|
| Wuzhai 500kV substation | 28            | 2.9080   | No                            |
| Suzhou 500kV substation | 33            | 2.4668   | No                            |
| Shenquan fossil-fuel plant | 49            | 1.6613   | No                            |
| Yijing 220kV substation | 10            | 8.1450   | Yes                           |
| Fenghuang 220kV substation | 31            | 2.6266   | No                            |
| Kelang 220kV substation | 70            | 1.1642   | No                            |
| Fangcheng 220kV substation | 34            | 2.3935   | No                            |
| Shuitou 220kV substation | 36            | 2.2609   | No                            |
| Xiangyangpu 220kV substation | 45            | 1.8077   | No                            |
| Pushang 220kV substation | 39            | 2.0893   | No                            |
There is a gas transmission pipeline (Shenchi–Sancha–Pianguan) in the southwest of Yanmenguan converter station. The pipeline extending from west to east is about 60km long. Yanmenguan DC grounding electrode is located in the north of the pipeline, and roughly in the middle of the pipeline. The nearest distance to the pipeline is about 10km. The GPR of the middle point of the pipeline is 5.3288V.

The nearest railway to Yanmenguan DC grounding electrode is the railway located at the west of Xiaodongwan village, Hezhi Township, Shencheng County, Xinzhou City. The distance from the DC grounding electrode to the railway is 10.851 km. The maximum GPR on the railway is 7.5479V. It is necessary to pay attention to the influence of DC grounding electrode on rail corrosion and magnetic saturation of power supply transformers.

4. Influencing Factors Analysis
4.1. Distance
When the injected current is 5000A and the uniform soil resistivity is 100 Ω·m, the relationship of the earth potential with distance is shown in Figure 2. It can be seen from Figure 2 that with the increase of the distance between the DC grounding electrode and the buried metal facilities, the voltage on the buried metal facilities shows a downward trend, which is consistent with the conclusion of formula (3). When the distance is less than 10 km, the voltage drops rapidly. When the distance is greater than 10 km, the voltage drop trend becomes slower. The maximum GPR is 981.58V, which locate at the outer ring of the DC grounding electrode. When the distance between DC grounding electrode and buried metal facilities is 100km, the GPR is only 1.35V.

![Figure 2. The curve of the earth potential versus distance.](image)

4.2. Soil Resistivity
When the injected current is 5000A, the earth potential of buried metal facilities under different soil resistivity is shown in Figure 3. It can be seen from Figure 3 that the earth potential of buried metal facilities decreases with the increase of distance under different resistivity. When the resistivity is 100 Ω·m, the earth potential of buried metal facilities decreases rapidly with distance. When the resistivity is 900 Ω·m, the earth potential decreases slowly with the distance. The reason is that when the soil resistivity is small, the current is more likely to flow in the soil around the DC grounding electrode. When the resistivity is 100 Ω·m, the maximum GPR is 981.58 V. When the resistivity is 900 Ω·m, the maximum GPR is 5560 V. The maximum GPR is located at the outer ring of DC grounding electrode.

![Figure 3. The curve of the earth potential under different soil resistivity.](image)
4.3. Injected Current
When the soil resistivity is 100 Ω·m, the earth potential of buried metal facilities under different injected current is shown in Figure 4. It can be seen from Figure 4 that the potential variation trend of buried metal facilities is basically the same under different injected current. The smaller the injection current is, the smaller the maximum GPR is. This is because in the same soil, the distribution of electric current field is the same. The smaller the injected current, the smaller the current value at a certain point.

![Figure 4](image)

**Figure 4.** The curve of the earth potential under different injected current.

5. Conclusions
(1) The GPR of Yijing 220kV substation, Banjing wind farm, Nanhuashan wind farm, Jiyangshan wind farm, Liugou wind farm and Limin wind farm exceeds the GPR limit. So it is necessary to strength monitoring the corrosion status of the grounding grid.

(2) The GPR decreases with the increase of distance, the decrease of soil resistivity and injected current.

(3) The effects of long pipeline on the GPR are not considered in this paper. The electromagnetic inference of DC grounding on long pipeline is worth further study.

Acknowledgments
The work is supported from project of Shanxi Electric Power Company under the Grant SGSXJXOOFYMJS1900155.

References
[1] Machczyński W 2007 *Eur. Trans. Electr. Power* **12** 329
[2] Li L and Jiezhong S 1998 *High Voltage Eng.* **26** 49
[3] Chenglian M, Letian W, Bo L, Yingjin L, Hongzhen H, Shujian Z and Gan G 2018 *Electr. Power* **51** 52
[4] Shan G, Yanfang F, Xiaoling G and Xuefeng F 2019 *High Voltage Appar.* **55** 163
[5] Slaoui F H, Georges S, Lagace P J and Mohanna Y M 2009 *Int. Rev. Electr. Eng.* **4** 284
[6] Pereira W R, M G and Neto L M 2015 *IEEE Trans. Power Del.* **31** 622
[7] Isiam S T, Chik Z, Mustafa M and Sanusi H 2012 *Math. Probl. Eng.* **18** 472457