Research on the Electromagnetic Interference of Yanmenguan DC Grounding Electrode on West-East Transmission Gas Pipeline

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Abstract. There was a west-east gas transmission pipeline nearby the Yanmenguan DC grounding electrode. In order to assess the electromagnetic interference of Yanmenguan DC grounding electrode on the pipeline, an electromagnetic simulation model was established. The pipeline to earth potential was analyzed. The effects of insulation layers and insulation joints on the pipeline to earth potential were investigated. It can provide theoretical support for the practical operation of gas pipelines.

1. Introduction
With the advancement of China’s energy strategy, it is inevitable to share construction lands for HVDC transmission system and oil or gas pipelines. However, when HVDC transmission system operates in unipolar earth or bipolar unbalanced mode, there is a large grounding current flowed through the soil, and a potential gradient in the soil is generated [1]. The potential gradient will accelerate the corrosion of buried metal pipelines or abnormal operation of cathodic protection equipments. So it is necessary to study the electromagnetic interference of HVDC transmission systems on the pipelines.

Haubrich et al proved that transmission lines or electrified railways have electromagnetic interference to the gas pipelines [2]. Compared to HVDC transmission systems, these interferences are much smaller. Bo et al have studied the electromagnetic influence of HVDC transmission systems on AC power grid [3]. Xiaobo et al have measured the pipeline to earth potential using small-scale pipeline [4].

In section 2 the theoretical basis of the electromagnetic interference calculation are described. In section 3 the pipeline to earth potential of west-east gas pipeline are analyzed. The effects of insulation layers and insulation joints on the pipeline to earth potential were investigated. We conclude this paper in section 4.

2. Theory of the Electromagnetic Interference Calculation
The electrical characteristics of pipelines buried in uniform soil can be equivalent by one transmission line [5]. Suppose that the resistance per unit length of pipeline is R and the conductance per unit length of pipeline is G, the current along the pipeline is
\[ I(x) = \frac{1}{2\sqrt{RG}} \int_0^e E(y) \left[ e^{-\sqrt{RG} |x - y|} - e^{-\sqrt{RG}(x+y)} \right] dy \]  
\[ U(x) = \frac{\sqrt{RG}}{2} \int_0^e V(y) \left[ e^{-\sqrt{RG} |x - y|} + e^{-\sqrt{RG}(x+y)} \right] dy \]  
\[ J(x) = -\frac{G}{2} \int_0^e \left[ \text{sign}(x - y)e^{-\sqrt{RG} |x - y|} - e^{-\sqrt{RG}(x+y)} \right] dy \]

where \( E(y) \) is the potential at each point of the pipeline.

The pipeline to earth potential is

\[ U(x) = \frac{\sqrt{RG}}{2} \int_0^e V(y) \left[ e^{-\sqrt{RG} |x - y|} + e^{-\sqrt{RG}(x+y)} \right] dy \]

where \( V(y) \) is potential generated outside the anticorrosive coating by the leakage current.

The leakage current is

\[ J(x) = -\frac{G}{2} \int_0^e \left[ \text{sign}(x - y)e^{-\sqrt{RG} |x - y|} - e^{-\sqrt{RG}(x+y)} \right] dy \]

where \( \text{sign}(\cdot) \) is the signum function.

3. Results and Discussions

3.1. Pipe to Ground Potential

Based on the experimental data, it can be obtained that the number of soil layer of Yanmenguan converter station is 3. The first layer is from the surface to the depth of 400m with the thickness \( h_1 = 400 \) m, and the soil resistivity is \( \rho_1 = 101.72 \ \Omega \cdot m \). The second layer is from 400m to 5000m with thickness \( h_2 = 4600 \) m, and the soil resistivity \( \rho_2 = 1037.5 \ \Omega \cdot m \). The third layer is from 5000m to infinity, with the soil resistivity \( \rho_3 = 76.4 \ \Omega \cdot m \).

Yanmenguan DC grounding electrode has double ring structure. The outer ring diameter is 350m, and pipe diameter of outer ring is 70mm. The inner ring diameter is 150m, and pipe diameter of inner ring is 60mm. The buried depth of inner and outer diameter is 2.5m and 3m, respectively.

The diameter of the pipeline is 700mm, and wall thickness is 50mm. The length is 60km, and the Yanmenguan converter station is at the midpoint of pipeline. The buried depth of the pipeline is 2m. The relative resistivity of the pipeline is 17, the relative magnetoresistance is 300. The thickness of the insulation layer is 3mm, and the resistivity of the insulation layer is \( 10^5 \ \Omega \cdot m \).

Suppose that Yanmenguan converter station operates in the anode mode, and the injected current is 5000A. Ground, pipe and pipe to ground potential versus distance is shown in Figure 1. It can be seen that the pipe potential relative to the potential at infinity is constant. The reason is that the metal pipe is approximately equipotential. The ground potential decreases with the increase of the distance from the midpoint of the pipeline. The pipe to ground potential at 12km away from the midpoint is negative, and the pipe to ground potential at the endpoint of pipeline is positive. It is indicated that when Yanmenguan converter station operates in the anode mode, the midpoint of the pipeline is prone to oxygen absorption reaction or hydrolysis reaction, so hydrogen embrittlement may occur in midpoint. However, the endpoint is prone to electric corrosion.

![Figure 1. Ground, pipe and pipe to ground potential versus distance.](image-url)
3.2. Influencing Factors

3.2.1 Operation modes. The pipe to ground potential under different operation modes is shown in Figure 2. It can be seen that when the grounding electrode operates as anode mode, the pipe to ground potential at the midpoint is negative, and the pipe to ground potential at the endpoint is positive. However, when the grounding electrode operates as cathode mode, the pipe to ground potential at the midpoint is positive, and the pipe to ground potential at the endpoint is negative. The distribution of the pipe to ground potential in the anode mode is opposite to that in the cathode mode.

![Figure 2. Pipe to ground potential under different operation modes.](image)

3.2.2 Thickness of insulation layer. The pipe to ground potential at different thickness of insulation layer is shown in Figure 3. It can be seen that pipe to ground potential is basically the same when the thickness of the insulation layer is 3mm, 5mm and 7mm. The reason is that although increasing the thickness of the insulation layer can reduce the leakage current of the pipeline, the equivalent resistance of the anti-corrosion coating increases. So pipe to ground potential changed little.

![Figure 3. Pipe to ground potential at different thickness of insulation layer.](image)

3.2.3 Resistivity of Insulation Layer. The pipe to ground potential at different thickness of insulation layer is shown in Figure 4. It can be seen from Figure 4 that pipe to ground potential is approximately the same when the resistivity of the insulation layer is $10^5 \Omega \cdot m$, $10^7 \Omega \cdot m$ and $10^9 \Omega \cdot m$. The reason is that
increasing the resistivity of the insulation layer can reduce the leakage current of the pipeline, but the equivalent resistance of the anti-corrosion coating increases.

3.2.4 Insulation Joints. Ground, pipe and pipe to ground potential with two insulated joints 5km away from the midpoint of the pipeline is shown in Figure 5. It can be seen that the pipe potential between two insulated joints is 13.1V, and the pipe potential beyond the joints is 7.2V. Compared to Figure 1, there is no change with the ground potential with and without two insulated joints. The pipe to line potential between two insulated joints decreases dramatically.

Figure 4. Pipe to ground potential at different resistivity of insulation layer.

Figure 5. Ground, pipe and pipe to ground potential with two insulated joints 5km away from the midpoint of the pipeline.

Figure 6. Comparison of pipe to ground potential with and without insulation joints.
Comparison of pipe to ground potential with and without insulation joints is shown in Figure 6. It can be seen that the pipe to ground potential between two insulation joints decrease significantly by installing insulation joints. However, the pipe to ground potential away from the insulation joints changes little. It is indicated that installing insulation joints can only reduce the electromagnetic interference of part of the pipeline.

4. Conclusions
(1) When DC current is injected from DC grounding electrode, the pipe potential is approximately equipotential, the pipe to line, the ground potential decreases with the increase of the distance from the midpoint of the pipeline, and the pipe to ground potential at the midpoint is opposite to that at the endpoint.
(2) The insulation layer characteristics have little effect on the pipe to ground potential.
(3) Installing insulation joints can only reduce the electromagnetic interference of part of the pipeline, but the joints have little effect on that of other parts of the pipeline.

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