Calculation of Corrosion Depth of Wind Power Generators and AC Substations Induced by HVDC Grounding Electrode

Lijun Feng¹, Chenglong Hao¹, Yuting Zhao¹, Dongqing Guo¹, and Xinjing Cai²*

¹Matianence Division, Shanxi Electrical Power Company, 9 Jiahua Street, Taiyuan, China.
²Department of Electrical Engineering, Shenyang University of Technology, 111 Shenliao West Road, Shenyang, China

Email: 81252546@qq.com

Abstract. At present, grounding potential rise is often used as the evaluation index to assess the electromagnetic interference induced by HVDC grounding electrodes. It will lead to too stringent standards, because HVDC grounding electrodes are considered as long-term operation. Actually, HVDC grounding electrodes operates only in the test run stage, planned maintenance and forced outage. In this paper corrosion depth is adopted as the evaluation index to assess the electromagnetic interference. The method to calculate the corrosion depth of wind power generators and AC substation is described. The corrosion depth of windfarms and AC substation nearby Yanmenguan converter station is derived. The effects of material properties, distance and soil resistivity on corrosion depth are also studied.

1. Introduction

With the development of HVDC transmission system, there are many AC substations, windfarms and pipelines inevitably nearby the converter station [1]. For example, there are two substations (Wuzhai and Yijing), five wind farms (Banjing, Nanhua, Jiyangshan, Liugou and Limin), and a gas transmission pipeline (Shenchi-Pianguan) within 30km of Yanmenguan converter station.

Presently, in order to assess the electromagnetic interference induced by HVDC grounding electrodes, grounding potential rise is often used as the evaluation index [2-4]. However, grounding potential rise leads to too stringent standards, because HVDC grounding electrodes are considered as long-term operation. Actually, HVDC grounding electrodes operates only in the test run stage, planned maintenance and forced outage. So we propose corrosion depth as the evaluation index to adapt the short-term characteristics of HVDC grounding electrodes.

In section 2 the method to calculate the corrosion depth of windfarms and AC substation is described. In section 3 the corrosion depth of windfarms and AC substation nearby Yanmenguan converter station is obtained. The effects of material properties, distance and soil resistivity on corrosion depth are studied. We conclude this paper with a discussion in section 4.

2. Calculation Method of Corrosion Depth

According to Faraday’s first theorem, in electrolysis the corrosion of the electrode is directly proportional to the quantity of electric charge passing through the medium [5]

\[ m = \frac{ItM}{nF} \]

(1)
where \( m_t \) is the corrosion quality, \( I \) is the current, \( t \) is the operation time, \( M \) is the molar mass, \( n \) is the electron number of gain and loss, \( F \) is the Faraday’s constant.

The grounding equipment of wind power generators is small compared to the distance of HVDC grounding electrodes and the grounding equipment. So it is assumed that the grounding equipment has no effect on the current distribution of HVDC grounding electrode. If the distance of HVDC grounding electrodes and the grounding equipment is \( L \), the corrosion depth can be obtained by

\[
h = \frac{IM}{nF \pi L^2 \rho_m}
\]

where \( h \) is corrosion depth, \( \rho_m \) is the density of grounding equipment.

The ground grid of AC substations is relatively large as shown in Figure 1, so the effect of the grounding grid on the current distribution. Subscript 1 and 2 denote the soil and iron, respectively. According to the condition of interface connection, the current density \( J \) and the electric field \( E \) satisfy [6]

\[
\begin{align*}
E_t &= E_{2t} \\
J_n &= J_{2n}
\end{align*}
\]

where subscript \( t \) and \( n \) denote the tangential and vertical components, respectively.

The tangential current density is

\[
J_{2t} = \frac{E_{2t}}{\rho_{iron}} = \frac{I}{2\pi L^2} \sqrt{\frac{L^2 - h_0^2}{L}} \frac{\rho_{soil}}{\rho_{iron}}
\]

where \( h_0 \) is the depth of the grounding grid of substations, \( \rho_{soil} \) and \( \rho_{iron} \) is the resistivity of the soil and grounding grid.

By approxiamte calculation, the corrosion depth is

\[
h = \frac{J_{2t}IM}{\rho_{iron}nF} \frac{L^2 - h_0^2}{L^2} \frac{\rho_{soil}}{\rho_{iron}S \rho_m}
\]

where \( R_{iron} \) is the resistance per unit length of grounding bar, \( S \) is the area of the grounding grid.

![Diagram of HVDC grounding electrode and grounding grid of AC substation](image)

**Figure 1.** Configuration of HVDC grounding electrode and grounding grid of AC substation.

### 3. Results and Discussions

#### 3.1. Corrosion Depth of Wind Power Generators and Substations

Calculation results for corrosion depth nearby Yanmenguan converter station is shown in Table 1. Values in brackets is the grounding potential rise calculated by CDEGS software. It can be seen that
although grounding potential rise of Banjing, Nanhuashan, Jiyangshan, Liugou and Limin windfarm exceeds the standard, but the corrosion depth is relatively small. So the grounding potential rise as the

Table 1. Calculation results for corrosion depth nearby Yanmenguan converter station.

| Name                        | Distance (km) | Corrosion Depth (mm) | Whether it exceed the standard |
|-----------------------------|---------------|----------------------|--------------------------------|
| Wuzhai 500kV substation     | 28            | 2.000×10⁻³ (2.9080)  | No                             |
| Yijing 220kV substation     | 10            | 1.550×10⁻² (8.1450)  | Yes                            |
| Banjing windfarm           | 17            | 3.211×10⁻⁶ (4.7885)  | Yes                            |
| Nanhuashan windfarm        | 12            | 6.444×10⁻⁶ (6.7896)  | Yes                            |
| Jiyangshan windfarm        | 11            | 7.699×10⁻⁶ (7.3986)  | Yes                            |
| Liugou windfarm            | 11            | 7.699×10⁻⁶ (7.3986)  | Yes                            |
| Limin windfarm             | 17            | 3.211×10⁻⁶ (4.7885)  | Yes                            |
| Wuzhai 110kV substation     | 29            | 1.800×10⁻³ (2.8097)  | No                             |

Table 2. Corrosion depth of wind power generators by different materials.

| Distance /km | Iron /mm | Copper /mm |
|--------------|----------|------------|
| 0.4          | 0.005 797| 0.011612   |
| 0.8          | 0.001 449| 0.002 904  |
| 1.2          | 0.000 644| 0.001 290  |
| 1.6          | 0.000 362| 0.000 726  |
| 2.0          | 0.000 232| 0.000 464  |
| 2.4          | 0.000 161| 0.000 322  |
| 2.8          | 0.000 118| 0.000 236  |
| 3.2          | 0.000 091| 0.000 181  |
| 3.6          | 0.000 072| 0.000 143  |
| 4.0          | 0.000 058| 0.000 116  |

evaluation index is too stringent. The grounding potential rise of Yijing 220kV substation is 8.1450V, and it exceeds the standard. The corrosion depth per year of Yijing 220kV substation is 1.550×10⁻²mm,
approximately 0.39% of the depth of flat steel. It is indicated that grounding potential rise as the evaluation index is more suitable for substation.

3.2. Analysis of Influencing Factors

When the injected current is 5000A, the corrosion depth of grounding electrode of wind power generators made by iron and copper is shown in Table 2. It can be seen that corrosion depth of grounding electrode of wind power generators made by iron is smaller than that by copper. When the distance is 0.4km, corrosion depth of grounding electrode of wind power generators made by iron is 0.005 797mm. Compared to the natural corrosion 0.36~0.4mm, corrosion of grounding electrode of wind power generators induced by HVDC grounding electrode is negligible.

The substation grounding grid is made of flat steel with a size of 4×40mm². The resistance of flat steel is 0.75Ω/km. When the injected current is 5000A, the corrosion depth of AC substation under different soil resistivity is shown in Table 3. It can be seen from Table 3 that the corrosion depth increases with the increase of soil resistivity. The corrosion depth increases with the decrease of distance.

| Distance /km | ρSoil=100Ω·m/m | ρSoil=300Ω·m/m | ρSoil=500Ω·m/m | ρSoil=1000Ω·m/m |
|--------------|-----------------|-----------------|-----------------|-----------------|
| 0.5          | 6.183 780       | 18.551 340      | 30.918 900      | 61.837 800      |
| 1.0          | 1.545 945       | 4.637 835       | 7.729 725       | 15.459 450      |
| 1.5          | 0.687 087       | 2.061 260       | 3.435 433       | 6.870 867       |
| 2.0          | 0.386 486       | 1.159 459       | 1.932 431       | 3.864 863       |
| 2.5          | 0.247 351       | 0.742 054       | 1.236 756       | 2.473 512       |
| 3.0          | 0.171 772       | 0.515 315       | 0.858 858       | 1.717 717       |
| 3.5          | 0.126 200       | 0.378 599       | 0.630 998       | 1.261 996       |
| 4.0          | 0.096 622       | 0.289 865       | 0.483 108       | 0.966 216       |
| 4.5          | 0.076 343       | 0.229 029       | 0.381 715       | 0.763 430       |
| 5.0          | 0.061 838       | 0.185 513       | 0.309 189       | 0.618 378       |

4. Conclusions
(1) The grounding potential rise of windfarms exceeds the standard, but the corrosion depth is relatively small. The grounding potential rise as the evaluation index is more suitable for AC substation.
(2) Corrosion depth of grounding electrode of wind power generators made by iron is smaller than that by copper.
(3) The corrosion depth increases with the increase of soil resistivity, and corrosion depth increases with the decrease of the distance.

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