Corrosion analysis of guyed rod used for 500 kV transmission tower

Tian Feng1,2,a, Chen Hao1,2,b*, Zhang Tao1,2,c, Guo Xinai1,2,d, Xianda Shi1,2,e

1Inner Mongolia Power Research Institute, Hohhot, Inner Mongolia, China
2Inner Mongolia Enterprise Key Laboratory of High Voltage and Insulation Technology, Hohhot, Inner Mongolia, China
aemail: tianfeng2@impc.com.cn, *bemail: chenhao3@impc.com.cn, cemail: zhangtao3@impc.com.cn, demail: guoxinai@impc.com.cn, eemail: shixianda@impc.com.cn

Abstract. As an important part of the guyed device of cable stayed tower, guyed rod plays a key role of preventing transmission tower from tilting and toppling. In this paper, the corroded guyed rod of 500kV transmission tower was investigated by means of macro-morphology inspection, chemical composition analysis, scanning electron micrograph analysis, microstructure analysis and energy spectrum analysis. The result showed that high content of corrosive sulfate in the soil near the leg of transmission tower was the main cause of corrosion of the guyed rod.

1. Introduction
Guyed tower is widely used in power grid because of its light weight and convenient construction. The guyed rod is usually set underground for a long time, thus its zinc coating would be prone to spalling failure under the influence of various factors in the soil. Without the protection of anticorrosive coating, the effective cross-sectional area would be reduced owing to rapid soil corrosion, resulting in decrease of bearing capacity and stability of the transmission tower. When encountering extreme weather such as storm, the guyed tower with severely corroded guyed rods would tilt or collapse, which would seriously threaten the safety and stability of the power grid.

During the inspection of transmission lines, it is found that some guyed rod of 500kV towers seriously corroded. The transmission line is located near a heavy industrial park and has been put into operation for 25 years. The corroded guyed rod is made of Q235B and hot dip galvanizing process is adopt for corrosion protection. In this paper, the corrosion reason of the guyed rod used for 500kV transmission tower was investigated by different physical and chemical test methods and effective anticorrosion suggestions were put forward in order to avoid the recurrence of similar failures.

2. Experiment results and analysis

2.1. Macroscopic observation
Figure 1 shows the macro-morphology of the corroded guyed rod used in 500kV transmission tower. It is clearly seen that the seriously corroded guyed rod is composed of rod part, U-shaped hanging ring and its connecting bolt, and its galvanized layer has completely fallen off. In addition, there are a large
mount of yellowish-brown corrosion products distributed on the surface of the guyed rod in pockmark form, without obvious mechanical damage and plastic deformation.

Figure 1. The macro morphology of the corroded guyed rod.

2.2. Metallographic structure Analysis

Figure 2 shows the metallographic microstructures of the corroded guyed rod. It could be seen that the metallographic structures of the U-shaped hanging ring and its connecting bolt and nut are mainly pearlite and ferrite, without abnormal microstructure. And the ones of the rod part are banded pearlite and ferrite with a large number of strip inclusions.

Figure 2. The metallographic microstructures of the corroded guyed rod.
2.3. Chemical composition analysis

The chemical compositions of the corroded guyed rod is determined by means of chemical composition analysis and the testing results (mass fraction) are shown in Table 1. The result illustrates that the contents of each element in the rod part and the U-shaped hanging ring meet the requirement of standard GB / T 700-2006 for Q235B steel.

| Chemical element                  | C    | Si   | Mn   | P     | S     |
|-----------------------------------|------|------|------|-------|-------|
| Rod part                          | 0.17 | 0.19 | 0.51 | 0.017 | 0.021 |
| U-shaped hanging ring             | 0.15 | 0.20 | 0.49 | 0.015 | 0.025 |
| Standard requirements             | ≤0.22| ≤0.35| ≤1.40| ≤0.045| ≤0.050|

2.3. Microstructure and energy spectrum analysis of corrosion products

Figure 3 shows the micro morphology of the corrosion products sampled from the corroded guyed rod and it is clearly seen that there are a large number of corrosion pits on the surface of the rod part and U-shaped hanging ring. Additionally, the corrosion products of the guyed rod are dense clusters of different sizes with a small amount of corrosion holes on the surface.
Figure 4 and Table 2. The result shows that the corrosion products of the guyed rod are mainly composed of iron oxide, sulfate and carbonate, which should be iron oxide and ferrous sulfate. And silicon and aluminum elements in the corrosion products of the guyed rod should exist in the form of oxide, which is mainly caused by the adsorption of sand on its surface.

![Figure 4](image)

**(a) Rod part**

**(b) U-shaped hanging ring**

**Figure 4.** The energy spectrum analysis result for corrosion products

| Chemical element | Fe    | O    | Si    | Na   | C    | K    | Ca    | Al    | S    |
|------------------|-------|------|-------|------|------|------|-------|-------|------|
| Rod part         | 55.34 | 19.62| 5.55  | 3.06 | 9.29 | 1.31 | 3.21  | 1.93  | 0.7  |
| U-shaped hanging ring | 36.97 | 27.72| 4.53  | 15.48| 12.6 | /    | /     | 1.51  | 1.19 |

### 2.5. Hardness testing

Hardness test was carried out on the corroded guyed rod samples, and the result shows that the Vickers hardness of the rod part and U-shaped hanging ring was 128 and 123 HV respectively, which basically meets the usage requirements.

### 3. Analysis and discussion

According to the energy spectrum analysis result, it is found that the corrosion products of the guyed rod and the U-shaped hanging ring contain sulfur element, which indicates that the content of corrosive sulfate in the soil near the guyed tower leg is high. Additionally, the higher content of sulfate anion and chloridion, the stronger corrosive the soil is. The sulfate anion and chloridion could accelerate soil corrosion of the guyed rod, which is concluded as followings. At first, in the soil with high sulfate content, the hot-dip galvanized layer is easy to be corroded into soluble zinc sulfate, resulting in the rapid consumption and corrosion failure of zinc coating. Secondly, the sulfate anion in the soil is strong electrolyte, which could make the electric resistance between anode and cathode decrease and the electric conductivity increase. Therefore, the electrochemical corrosion rate of the guyed rod would accelerate. Thus, the guyed rod of the transmission tower would suffer serious corrosion damage or even corrosion fracture under the combined action of chemical and electrochemical corrosion in the soil for a long time.

### 4. Conclusions

In this paper, the behavior and mechanism for corrosion of the guyed rod used for the 500kV transmission tower were systematically investigated and analyzed. Through comparing and analyzing the experimental results, the following conclusions are drawn.

1) The 500kV transmission line is located in the heavy industrial park with serious pollution. Many years of industrial production has made the guyed rod in the soil with high sulfate content for a long time. Under the comprehensive effect of chemical and electrochemical corrosion in the soil, the zinc
coating on the surface would constantly react with the sulfur in the soil to form soluble salt, which leads to continuous corrosion and consumption of zinc coating. Without the protection of the zinc coating, the base material of guyed rod would corrode rapidly.

2) In the heavy industrial pollution areas and saline alkali areas, more and more attention should be paid to the inspection of the guyed rod used for 500kV transmission tower, and the seriously corroded ones should be replaced in time to ensure the safety and stability of transmission lines.

3) The newly replaced guyed rod should adopt hot dip galvanizing anti-corrosion process. At the same time, the minimum thickness of the zinc coating is not less than 85μm, and the diameter is not less than 16mm, so as to ensure the corrosion resistance and strength of the guyed rod.

4) The application of concrete pouring sealing technology could not only improve the corrosion resistance of guyed rod for transmission tower, but also effectively prevent external force damage and theft of small tower angle steel, which could effectively prevents the recurrence of similar corrosion failure.

Acknowledgments
The authors would like to acknowledge the financial support from the Science and Technology Projects of Inner Mongolia Power Company (Grant No. 2019-102 and Grant No. 2021-46).

References
[1] Kandi, M.R.S., Shahrabi, T., Allahkaram, S.R., Geramian, M.J. (2004) An investigation on the atmospheric corrosion behaviour of coatings of electrical equipment in the coast of Persian Gulf – Bandar Abbas. Anti - Corrosion Methods and Materials, 51: 209–215.
[1] Shoji, M. (2019) Ultrasonic Guided Wave Inspection of Anchor Rods Embedded in Soil. Journal of Nondestructive Evaluation, 38: 1–12.
[2] Yun, C. (2014) Corrosion on the New Eastern Span of the San Francisco-Oakland Bay Bridge. Materials Performance, 53: 58-62.
[3] Du, J.Y., Han, J., Zhao, Y.J., Liu, W.H. (2014) A Model of Predicting Corrosion Rate for Substation Grounding Grid Based on the Similarity and Support Vector Regression. Applied Mechanics and Materials, 3335: 271–275.
[4] Song, C.F., Hou, Y.B., Du, J.Y. (2014) The Prediction of Grounding Grid Corrosion Rate Using Optimized RBF Network. Applied Mechanics and Materials, 3335: 245–250.
[5] Wei, B.X., Xu, J., Fu, Q., Qin, Q.Y., Bai, Y.L., Sun, C., Wang, C., Wang, Z.Y., Ke, W. (2021) Effect of sulfate-reducing bacteria on corrosion of X80 pipeline steel under disbonded coating in a red soil solution. Journal of Materials Science & Technology, 87: 1–17.
[6] Hirata, R., Yonemoto, W., Ooi, A., Tada, E., Nishikata, A. (2020) Influence of Soil Particle Size, Covering Thickness, and pH on Soil Corrosion of Carbon Steel:Surface Treatment and Corrosion. ISIJ International, 60: 2533–2540.
[7] Robert, B.P., Tony, W., Robert, E.M. (2020) Development of long-term localised corrosion of cast iron pipes in backfill soils based on time of wetness. Corrosion Engineering, Science and Technology, 55: 550–561.
[8] Wei, B.X., Xu, J., Qin, Q.Y., Fu, Q., Bai, Y.L., Yu, C.K., Sun, C., Ke Wei. (2020) Comparison of AC Corrosion of X80 Steel in Real Soil, Soil Extract Solution, and Simulated Solution. Journal of Materials Engineering and Performance, 29: 1–11.
[9] Liang, Z.P., Jiang, K.X., Zhang, T.G., Dou, Z.H. (2020) Effect of Cations on Protective Properties of Rust Layer Formed on Carbon Steel during Wet/Dry Cyclic CorrosionCorrosion behavior of Cu–Sn bronze alloys in simulated archeological soil media. Materials and Corrosion, 71: 617–627.
[10] Liu, H.W., Dai, Y.N., Cheng, Y.F. (2020) Corrosion of underground pipelines in clay soil with varied soil layer thicknesses and aerations. Arabian Journal of Chemistry, 13: 3601–3614.
[11] Karthick, S., Muralidharan, S., Saraswathi, V. (2020) Corrosion performance of mild steel and galvanized iron in clay soil environment. Arabian Journal of Chemistry, 13: 3301–3318.
[12] Liu, H.W., Cheng, Y.F. (2020) Corrosion of initial pits on abandoned X52 pipeline steel in a simulated soil solution containing sulfate-reducing bacteria. Journal of Materials Research and Technology, 9: 7180–7189.

[13] Zhu, M., Ma, J., Yuan, Y.F., Guo, S.Y. (2019) Effect of AC Interference on Corrosion Behavior of X100 Pipeline Steel with Different Microstructure in Alkaline Soil Environment. International Journal of Electrochemical Science, 14: 9711–9725.

[14] Wan, H.X., Song, D.D., Du, C.W., Liu, Z.Y., Li, X.G. (2019) Effect of alternating current and Bacillus cereus on the stress corrosion behavior and mechanism of X80 steel in a Beijing soil solution. Bioelectrochemistry, 127: 49–58.

[15] Ryakhovskikh, I.V., Bogdanov, R.I., Ignatenko, V.E. (2018) Intergranular stress corrosion cracking of steel gas pipelines in weak alkaline soil electrolytes. Engineering Failure Analysis, 94: 87–95.