Corrosion analysis on grounding grid used for 220kV electrical equipment

Zefeng Li[1,2], Hao Chen[1,2,*], Tao Zhang[1,2], Xin Qiao[1,2], Xianda Shi[1,2]

[1]Inner Mongolia Power (Group) Co., Ltd., Inner Mongolia Power Research Institute Branch, Hohhot, Inner Mongolia, China
[2]Inner Mongolia Enterprise Key Laboratory of High Voltage and Insulation Technology, Hohhot, Inner Mongolia, China

*chenhao1984223@163.com

Abstract. With the rapid development of the power grid, the soil corrosion problem of buried metallic components used for electrical equipments is increasing, which brings huge safety hazards to the power grid and leads to a significant increase in operation and maintenance costs. In this paper, the corroded grounding electrode used for electrical equipment in 220kV substation was investigated by means of microstructure analysis, macro-morphology inspection, soil physicochemical properties testing and energy spectrum analysis. The results show that insufficient anti-corrosion performance and alkaline service environment with high salt were the main causes for corrosion of grounding electrode. Additionally, effective suggestions were put forward in order to improve the corrosion resistance of the grounding electrode in order to ensure the safety and stability of the power grid.

Keywords: 220kV Electrical equipment; Grounding grid; Soil corrosion; Failure analysis.

1 Introduction

The grounding device of power transmission and transformation equipment is the unity of lightning protection grounding, working grounding, and protective grounding. If the grounding device of a substation is corroded and damaged, it would not only shorten its service life, but also cause an increase in the grounding resistance value, reducing the current dissipation capacity of the grounding body. Once the electrical equipment is struck by lightning, it could not timely discharge the lightning current to the ground, leading to the occurrence of power safety accidents and causing great harm to the safe operation of the power system. Considering both cost and anti-corrosion effect, the commonly used surface treatment for grounding grids mainly adopts hot-dip galvanizing anti-corrosion technology. However, the galvanized layer has poor corrosion resistance in soil with high chloride ions, which is prone to premature corrosion failure. Therefore, corrosion and rusting of grounding devices in power systems is an issue that cannot be ignored [1-4].

© The Author(s) 2024
P. Liu et al. (eds.), *Proceedings of the 2024 5th International Conference on Civil, Architecture and Disaster Prevention and Control (CADPC 2024)*, Atlantis Highlights in Engineering 31,
https://doi.org/10.2991/978-94-6463-435-8_2

During the inspection process, maintenance personnel at a certain 220kV substation discovered extensive corrosion damage to the grounding body of electrical equipment, with some copper clad steel strands and grounding flat steel corroded and fractured. The substation has been in operation for 10 years and there are no heavily polluting enterprises nearby. In order to identify the cause of corrosion damage to the grounding body and prevent similar failures from happening again, the author conducted a systematic inspection and analysis of the corroded grounding electrode.

2 Physical and chemical performance testing and analysis

2.1 Macroscopic morphology observation

Figure 1 shows the macro morphology of the corroded grounding electrode and it was found that the grounding electrode was severely corroded and damaged. The galvanized layer on the surface of the buried part of the grounding flat steel has completely peeled off and undergone obvious corrosion and fracture, and some areas of the grounding flat steel have been severely softened and perforated. The yellow brown corrosion products are distributed layer by layer on the surface of the grounding electrode, and some of the corrosion products have fallen off without obvious mechanical damage or plastic deformation. Most copper clad steel strands have completely peeled off the copper layer from the steel core, causing severe corrosion of the steel core without copper layer protection. The corrosion products are yellow brown, and some steel cores have completely corroded. In addition, some steel strands with well preserved copper layers have not found obvious corrosion.

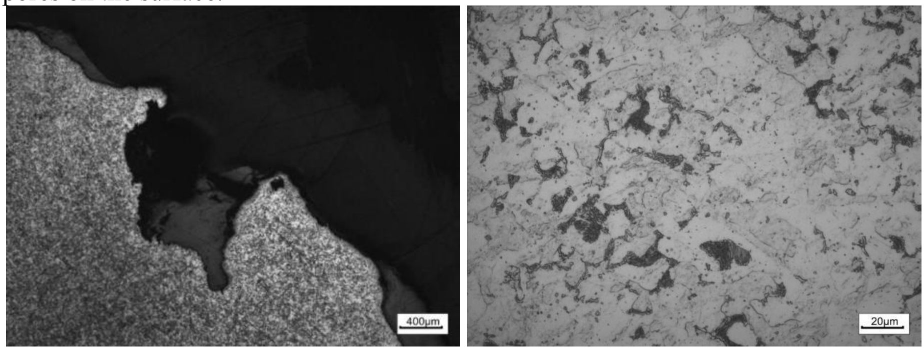
(a) Grounding flat steel (b) Copper clad steel stranded wire

Fig. 1. The macro morphology of the corroded grounding electrode.

2.2 Metallographic examination

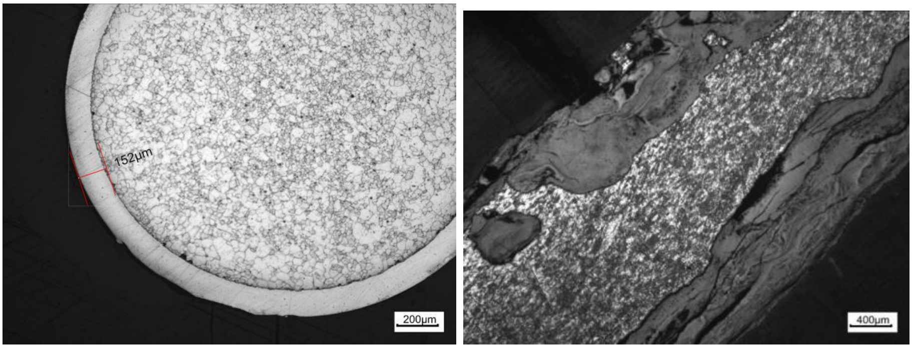
Figure 2 shows the metallographic structure of the corroded grounding flat steel, and it could be clearly seen that the matrix structure of the corroded grounding flat steel was a small amount of banded pearlite and block shaped ferrite, with varying depths of corrosion pits on the surface. And some of the corrosion holes have penetrated the entire grounding flat steel.

Figure 3 shows the metallographic structure of the corroded copper clad steel stranded wire, and it could be found that the thickness of the copper layer on the corroded copper clad steel stranded wire is about 0.15mm, which is much lower than the standard requirement that the copper layer thickness of stranded wire should not be less than 0.25mm. In addition, the matrix structure of the stranded wire is fibrous martensite with a small amount of ferrite, with a large number of corrosion pits and pores on the surface.



(a) Corrosion pits (b)Matrix

Fig. 2. The metallographic structure of the corroded grounding flat steel.



(a) Copper layer thickness (b) Corrosion pits and holes

Fig. 3. The metallographic structure of the corroded copper clad steel stranded wire.

2.3 Morphology and energy spectrum analysis of corrosion products

The microstructure and chemical composition of the corrosion products of corroded copper clad steel strands were detected and analyzed using scanning electron microscopy (SEM) and energy dispersive spectroscopy (EDS). Figure 4 shows the SEM morphology of the corrosion product and it could be seen that the corrosion products on the surface of the stranded wire are relatively dense and accompanied by block like particles of different sizes. Figure 5 and Table 1 show the energy spectrum analysis chart and results for corrosion products, and the results indicate that the corrosion products are mainly iron oxides and chlorides. Through analysis, the copper element should be caused by the mixing of corrosion products after the copper layer falls off.

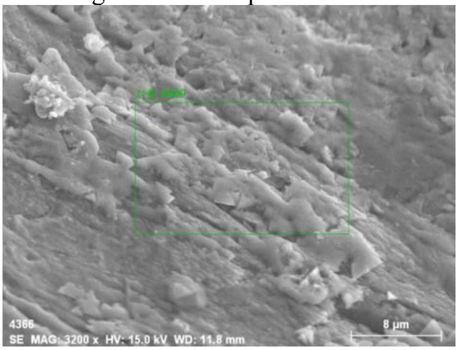


Fig. 4. The SEM morphology of the corrosion product.

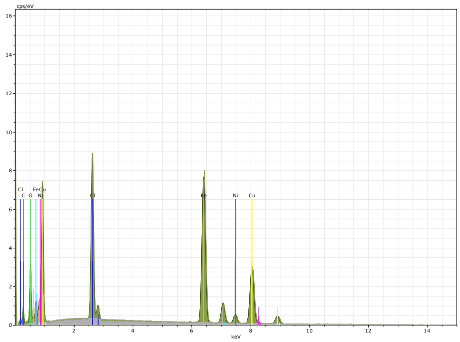


Fig. 5. Energy spectrum analysis chart for corrosion products.

Table 1. Energy spectrum analysis result of corrosion products(wt%).

Test elements	Fe	O	C	Cu	Cl	Ni
Test value	28.67	21.04	16.43	19.99	11.36	2.50

2.4 Detection and analysis of soil physical and chemical properties

Table 2 shows the test result of physical property and ion content of soil sample for buried grounding electrode of corroded electrical equipment. And it could be found that the soil near the grounding grid of electrical equipment is high salt alkaline soil, with chloride ion and sulfur content as high as 0.38g/kg and 0.17g/kg, respectively. At the same time, the soil conductivity is 1220 μS/cm, with a pH of 8.95.

Table 2. The test result of physical property and ion content for soil sample.

Testing items	Cl^-(g/kg)	Sulphur content (g/kg)	Conductivity (μs/cm)	pH
Test value	0.38	0.17	1220	8.95

3 Analysis and Discussion

The substation is located in the irrigated farmland of the Yellow River, and the soil inside the station is alkaline and high salt soil. After testing, it was found that the soil contains high levels of sulfate and chloride salts, which are soluble in water and could be decomposed into chloride ions and sulfate ions. Both ions have a promoting effect on soil corrosion, and the higher their content, the stronger their corrosiveness [5,6]. When the content of chloride ions and sulfate ions in the soil reaches a certain value, they would penetrate the passivation film of the grounding electrode. Subsequently, it would react to produce soluble chlorides or sulfates, causing rapid consumption and ultimately failure of hot-dip galvanized and copper coated layers. In addition, the thickness of the copper layer on copper-clad steel stranded wire was much lower than the standard requirements. Due to weak bonding between the copper layer and the steel stranded wire, a large area of copper layer detachment occurs, resulting in insufficient anti-corrosion performance and exacerbating the corrosion rate of the grounding electrode to a certain extent [7-10]. Finally, galvanized flat steel and copper coated steel stranded wire form a primary battery due to significant differences in electrode potential, and galvanized flat steel as the negative electrode of the battery is more susceptible to corrosion.

4 Conclusion

Based on the above analysis, the main reason for the corrosion of the grounding electrode used for the electrical equipment in the 220kV power station is the insufficient anti-corrosion performance of copper clad steel strands and grounding flat steel. Due to the long-term burial of the grounding electrode in alkaline and high salt soil with high chloride ion and sulfate ion content, the grounding grid ultimately undergoes severe corrosion under the combined effects of soil chemical, electrochemical corrosion, and stray current corrosion.

Firstly, it is necessary to strengthen the inspection of the electrical equipment grounding grid in the substation nearby the irrigated farmland of the Yellow River, and corroded or broken grounding flat steel and copper clad steel stranded wires should be replaced in a timely manner. The newly replaced grounding flat steel should be coated with hot-dip galvanizing technology for corrosion prevention, and the minimum thickness of the galvanized layer should not be less than 70 μm and the average thickness is not less than 85 μm. The substation located in the desert and irrigated areas could increase the thickness of the galvanized layer of the grounding body to 120 μm due to the strong corrosiveness of the soil. The thickness of the newly replaced stranded wire copper layer shou'l'd not be less than 0.25mm and the copper layer should not be separated from the steel core, without defects such as cracks, fragments, holes, etc [11,12].

Secondly, due to the severe oxygen concentration corrosion of grounding bodies buried within a depth of 1.5m in highly saline alkaline soil, it is recommended to use casing or coating protection for the grounding electrode in this section for dual anti-corrosion. When using dissimilar metal grounding materials in the same area, additional protection should be given to the connection parts [13,14].

Thirdly, the corrosion status of the grounding grid cloud only be determined through excavation inspection at present. Given the rapid development of non-destructive technology in pipeline corrosion detection in recent years, it is necessary to use guided wave or phased array detection technology to evaluate the corrosion status and predict the corrosion life of the grounding grid [15].

Finally, considering the serious corrosion damage of galvanized steel and copper clad steel grounding materials in high salt alkaline soil, it is recommended to explore the feasibility of using new grounding materials such as aluminum alloy, stainless steel, and graphene in non critical electrical equipment. If there is no serious corrosion damage and no significant decrease in conductivity after one year of trial operation, it could be promoted and applied to grounding devices of other electrical equipment [16,17].

Acknowledgments

This study was funded by the Science and Technology Projects of Inner Mongolia Power Company (Grant No. 2024-4-20).

References

1. S. Wang, H. Luo, Z. Li, K. Xiao, H. Ji and C. Dong. (2011) Corrosion analysis on galvanized flat steel grounding electrode of power system. Science & Technology Review, 30: 37-42.
2. G. Li. (2012) Discussion on setting of earth-termination system in corrosive soil areas. Building Electricity, 31: 58-59.
3. F. C. Chen,A. Katayam, M. Oyamada, et al. (2024) Effects of soil environmental changes accompanying soil erosion on the soil prokaryotes and fungi of cool temperate forests in Southern Japan. Journal of Forest Research, 29: 89-102.
4. B. Hou and D. Lu. (2018) Corrosion cost and preventive strategies in china. Strategy & Policy Decision Research, 33: 601-609.
5. X. Pan, H. Jiang, H. Fu, et al. (2017) Investigation on initial-stage corrosion behavior of lowalloy high-strength weathering resistant steel in regional climates. Corrosion Science and Protection Technology, 29: 356-362.

6. K. Kaffas, G. R. Pisaturo, G. Premstaller, et al. (2024) Event-based soil erosion and sediment yield modelling for calculating long-term reservoir sedimentation in the Alps. Hydrological Sciences Journal, 69: 321-336.
7. H. Xu,and S. Yin. (2018) Prediction model of pipeline corrosion rate based on improved BP neural network. Surface Technology, 47: 177-181.
8. S. Wang, X. Xia, Z. Li, et al. (2016) The application of Krijing method in the national soil corrosion distribution map. Total corrosion control, 30: 38-42.
9. Y. Li, X. Xiong, S. Liu, et al. (2020) Drawing of atmospheric corrosion grade distribution map for metal materials in Zhejiang province. Corrosion & Protection, 41: 48-51.
10. W. Zhan and X. Sui. (2019) Analysis of Tianjin substation soil corrosion. Journal of Northeast Electric Power University, 39: 56-61.
11. W. Zhuang, L. Chu and H. Shao. (2011) Acid corrosion mechanism of the sulfate-reducing bacteria and protecting studies in oil field. Special Equipment Safety Technology, 31: 575-582.
12. Y. Wang, L. Xu, H. He, et al. (2018) Evaluation of grounding material life based on soil corrosivity classification. Smart Power, 46: 8-12.
13. Y. Wang, G. Zhang, Z. Lu, et al. (2007) Regularity of soil corrosion of Pb, Al, Cu with climate. Journal of Chinese Society for corrosion and Protection, 20: 326-328.
14. J. Liao, J. Liu, J. Sun, et al. (2001) A study on corrosion behavior of carbon steel in South China acidic soil. Journal of South China University of Technology (Natural Science Edition), 29: 70-74.
15. Z. Zhu, X. Ma, L. Jing, et al. (2009) Soil corrosion evaluation of substation and metal corrosion characteristics analysis for grounding grid. Insulators and Surge Arresters, 52: 18-26.
16. A. Mohsenzadeh, T. Ebadi, S. M. Fattahi, et al. (2024) Soil erosion control of Urmia Lake using indigenous ureolytic calcifying bacteria. International Journal of Environmental Science and Technology, 21: 5981-5996.
17. G. Yin, L. Zhang, S. Chang, et al. (2004) A brief introduction of methods used in soil corrosion researches. Corrosion Science and Protection Technology, 16: 367-374.

Open Access This chapter is licensed under the terms of the Creative Commons Attribution-NonCommercial 4.0 International License (http://creativecommons.org/licenses/by-nc/4.0/), which permits any noncommercial use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license and indicate if changes were made.

The images or other third party material in this chapter are included in the chapter's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the chapter's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder.