IOP Conference Series: Materials
Science and Engineering

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To cite this article: Hao Chen *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **892** 012026

Analysis on corrosion of flat steel used in grounding grid for 220 kV substation

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Abstract. Grounding grid plays an important role in protection of main device for power system. With the increase of power capacity and voltage level, the safety of grounding grid is particularly important. In this paper, the seriously corroded flat steel of grounding grid in 220kV substation was investigated by means of different test methods. The result showed that electrode potentials difference existed between different locations on the surface of the buried grounding electrode was the major reason to cause electrochemical corrosion. Meanwhile, higher sulphur and chlorine content of the soil around the substation caused by long-term industrial pollution, led to rapid depletion of zinc coating and acceleration of corrosion process of grounding material. Additionally, effective suggestions were presented in order to reduce the grounding resistance and improve the anti-corrosion performance.

1. Introduction

The grounding grid of power system is used for ensuring power equipment operate safely and economically. With the rapid improvement of power capacity and voltage level, the reliability and stability of grounding grid becomes more and more important for power system. Considering that the grounding grid laid underground, the chemical and electrochemical corrosion of grounding material in the soil is inevitable, and the influence of stray current corrosion could not be ignored [1]. Once the grounding material corroded, the effective area of the grounding electrode would decrease, which made its electric conductivity decrease and electric resistance increase. In case of lightning stroke or short circuit, it would cause damage to electrical equipment owing to poor current drainage.

As corrosion medium of grounding grid material, the soil is heterogeneous and inhomogeneous. Meanwhile, the corrosion behavior of grounding grid is very complex, which is influenced by climate conditions, water content, pH value, various anions and cations, salt content, porosity, redox potential, electrical resistivity, stray current, microbiological species and power system characteristics [2]. Thus, it becomes very difficult to study the corrosion mechanism of grounding grid material.

In recent years, a number of research efforts have been made on soil corrosion of metal material, and great progresses have been made in this field. Shao [3] investigated the effects of iron-aluminum oxides on the corrosion behavior of the cross section of copper-clad steel in the red soil and concluded that the iron-aluminum oxides could promote the corrosion of copper-clad steel in the red soil. Li [4] studied the corrosion behavior of Q235 steel in actual Yingtan soil and two simulated acidic soils with different water contents, and found that the diatomite soil could simulate the corrosion in actual soil veritably. Karthick [5] investigated the corrosion performance of mild steel and galvanized iron in clay soil environment and thought that in the soil enriched with acidic clay periodic replacement of pipes was necessary. Muhammad [6] summarized the factors causing corrosion of buried pipes in soils and found that corrosion rate of pipes increase with moisture contents up to the critical moisture value.

With rapid development of power system, accidents caused by corrosion of grounding grid occurred frequently, thus more and more attention has been paid to corrosion and protection of grounding electrode. In this paper, the corrosion cause of flat steel of grounding grid for a 220kV substation was investigated by means of macro-morphology inspection, chemical composition analysis, microstructure analysis, soil physicochemical properties testing, scanning electron microscope, hardness testing and energy spectrum analysis. Meanwhile, the corrosion mechanism and corrosion behavior were systematically studied and effective suggestions were put forward to prevent the soil corrosion of the grounding grid.

2. Experiment results and analysis

2.1. Macroscopic observation

The 220kV substation is located in a chemical industrial park, around which there is a pungent smell in the air and the industrial pollution is very serious. The flat steel made of Q235B is used for the grounding grid, with the width of 40mm and the thickness of 4mm. Furthermore, hot dip galvanizing process is adopted for the flat steel as anticorrosive coating. Through excavation inspection, it is found that the grounding grid has suffered from severe corrosion without obvious mechanical damage and plastic deformation, as shown in Figure 1. Moreover, the zinc coating of the grounding electrode has totally depleted and the corrosion products in some areas have fallen off. The corrosion products are distributed on the surface of the flat steel in lamellar or bark form, among which the surface corrosion products are yellowish brown, and the inner ones are reddish brown.

(a) The front morphology (b) The side morphology

Figure 1. The macro morphology of the corroded flat steel of grounding grid.

2.2. Chemical composition analysis and hardness testing

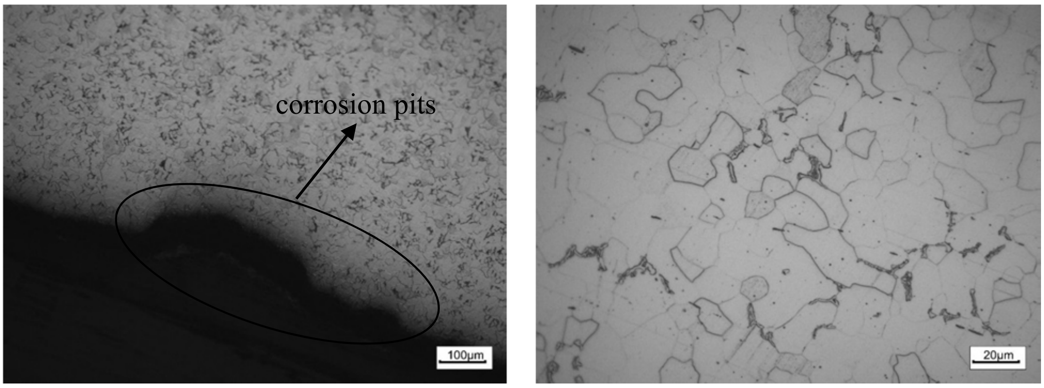
The chemical compositions of the corroded flat steel of grounding grid are determined by means of chemical composition analysis and the testing results (mass fraction) are shown in Table 1. The result shows that the contents of each element meet the requirement of standard GB / T 700-2006 for Q235B steel. In addition, the Vickers hardness of the grounding material is determined in the range of 105～110HV by fully automatic Vickers hardness tester.

Table 1. Chemical analysis result of the corroded flat steel of grounding grid (wt%).

Chemical element	C	Si	Mn	P	S
Standard requirements	⩽0.22	⩽0.35	⩽1.40	⩽0.045	⩽0.050
Test values	0.14	0.27	0.47	0.011	0.016

2.3. Metallographic structure Analysis

Figure 2 shows the metallographic microstructure of the corroded flat steel of grounding grid. In the cross section of the flat steel, the metallographic structure is mainly polygonal ferrite, little pearlite and tertiary cementite, and the tertiary cementite is distributed along the grain boundary. Additionally, there are many corrosion pits in different sizes and depths on the surface of the grounding electrode.



(a) The corrosion pits (b) The matrix

Figure 2. The metallographic structure of the corroded flat steel of grounding grid.

2.4. Microstructure and energy spectrum analysis of corrosion products

The micro morphology of the corrosion products sampled from the corroded grounding electrode is investigated by means of scanning electron microscope (SEM) and the result is shown in Figure 3. It is clearly seen that there are a large number of cluster particles with different sizes accompanied by a few corrosion holes on the surface of the corrosion products.

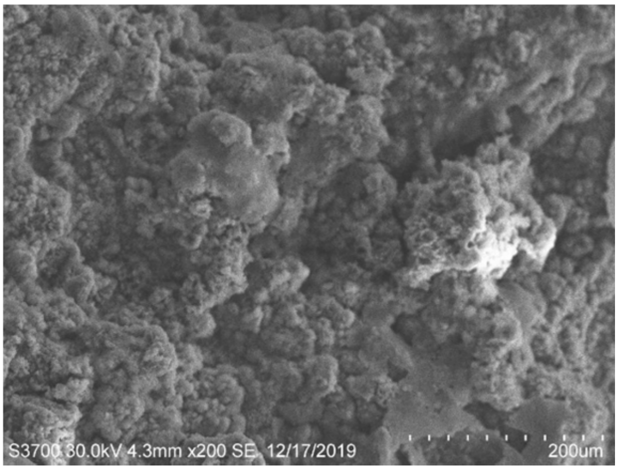


Figure 3. The SEM morphology of corrosion products.

The chemical compositions of the corrosion product on the surface of the corroded flat steel are analyzed by energy spectrum analyzer, and the testing results are shown in Figure 4 and Table 2. The result illustrates that the corrosion product is mainly composed of iron oxide, silica, chloride and sulphate, and the silica should originate in the sand adsorbed on the surface of the flat steel [7, 8].

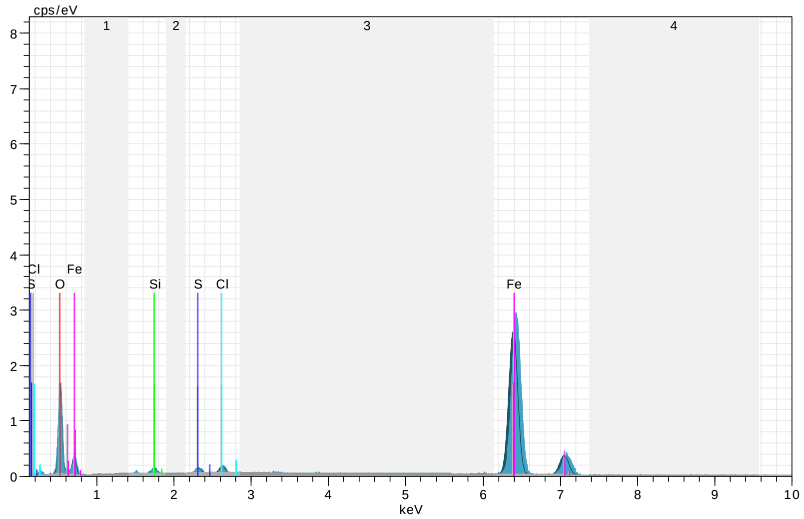


Figure 4. Energy spectrum analysis chart for corrosion products.

Table 2. Energy spectrum analysis result of corrosion products (wt%).

Chemical element	Fe	Si	O	S	Cl
Test values	67.78	1.78	27.74	1.17	1.53

2.5. Physicochemical properties testing of soil sample
Table 3 shows the test results of physical and chemical properties and ion content of the soil samples in the substation. The result shows that the sulfate anion and chloridion contents of the soil are 4.64g/kg and 1.63g/kg respectively, with the salinity being 1.52%. In addition, the soil water content is 7.48%, and its pH value is 6.15. As a result of industrial pollution, the weakly acid soil sample presents strong corrosiveness with high sulfur and chlorine content.

Table 3. The test result of physical property and ion content for soil sample.

Test item	SO42-/(g/kg)	Cl-/(g/kg)	NO3-/(g/kg)	pH	Water content/%	Salinity/%
Test values	4.64	1.63	0.015	6.15	7.48	1.52

3. Analysis and discussion
Generally, the zinc coating could form a protective oxide film with oxygen in the soil environment to inhibit further corrosion, which effectively prevents the steel substrate from the external corrosive medium. Once the zinc coating is damaged, it could be used as a sacrificial anode to protect the exposed steel substrate from corrosion. Therefore, the hot-dip galvanized layer has good corrosion resistance in general soil.

The 220kV substation is located in the chemical industrial park, and the smoke and dust such as sulfur dioxide, hydrogen sulfide and hydrogen chloride have been discharged by industrial production for many years. As a result, the content of sulfate anion and chloridion of the soil around the substation is relatively high, which makes the soil highly corrosive. Additionally, the higher content of sulfate anion and chloridion, the stronger the soil corrosion. The sulfate anion and chloridion could accelerate soil corrosion of the grounding grid, which is concluded as followings. At first, due to smaller radius, chloridion is easily adsorbed on metal surface and has a strong penetration to the zinc coating or passivation film, which makes protective film easy to be damaged [9, 10]. Secondly, in the soil with high sulfate content, the zinc coating is easy to be corroded into soluble zinc sulfate, leading to the rapid depletion of the hot-dip galvanizing layer [11, 12]. Moreover, when the generated ferrous ions could not diffuse to the soil in time and accumulate on the anode surface, the anode reaction would be inhibited. As a catalyst, chloridion plays a key role in anode depolarization. Under the action of electric field, the free chloridion could migrate and gather to the anode, and could react with the ferrous ion to produce ferrous chloride. Then the soluble ferrous chloride would diffuse to the soil and react with hydrogen peroxide to produce ferrous hydroxide and release chloridion. Thus, the above reaction process repeats consistently, causing the corrosion rate of the anode material accelerate [13]. Finally, electrolyte is extremely important for corrosion battery, bearing the responsibility of transportation of conductive ions. The sulfate anion and chloridion 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 grounding material would accelerate [14, 15]. In conclusion, as corrosive medium, the soil is heterogeneous and inhomogeneous, which caused an electrode potentials difference of the buried grounding flat steel between different locations. Under the action of electrochemical corrosion, the grounding material is continuously corroded. In addition, higher content of sulfate anion and chloridion in the soil caused by industrial pollution, results in the rapid depletion of the hot-dip galvanizing layer and the acceleration of electrochemical corrosion of the grounding material.

4. Conclusions

In this paper, the reason of corrosion of the grounding grid was systematically investigated and analysed. Through comparing and analysing the experimental results, the following conclusions are drawn.

1) Industrial pollution by years has resulted in high content of sulfate anion and chloridion in the soil around the 220kV substation, which made the soil highly corrosive. Therefore, in the corrosive soil, the zinc coating of the grounding flat steel was continuously corroded until it was exhausted. Without the protection of the zinc coating, the grounding material rapidly eroded and the corrosion product gradually covered the surface of the grounding electrode. Additionally, tertiary cementite that distributed along the grain boundary leads to a serious decrease in the plasticity of the flat steel， and brittle fracture is easy to occur under the effect of shear stress.

2) In view of heavy industrial pollution, more and more attention should be paid to the inspection of the grounding grid used for the electrical equipment in the 220kV substation, and the seriously corroded grounding electrode should be replaced in time to ensure safety operation of electrical equipment.

3) Generally, increasing cross-sectional area of the flat steel or introducing copper and copper-clad steel instead of carbon steel as the grounding material could effectively improve the corrosion resistance and extend the service life of the grounding grid. In addition, adopting bentonite-based resistance-reducing agent could also reduce the grounding resistance and improve the anti-corrosion performance during the overhaul and transformation of the grounding grid.

Acknowledgments

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

References

[1] Changjun Ding, Huanxin Yang, Jiangdong Wang, Biao Ma, Chang Song, Xuegui Xu, Likun Cui, Kedong Bi 2019 Corrosion and protection of materials for grounding grid *Corrosion Science and Protection Technology,* **31** 109-113.

[2] Wangyan Lv, Shinian Liu, Wei Su, Zengfu Wei 2013 Research Progresses in the corrosion and protection of grounding grid at substation *Total Corrosion Control,* **27** 26-30.

[3] Yupei Shao, Miaomiao Mu, Bing Zhang, Kaibin Nie, Qiangqiang Liao 2017 Corrosion behavior of copper-clad steel bars with unclad two-end faces for grounding grids in the red clay soil

Journal of Materials Engineering and Performance, **26** 1751-1757.
[4] Jian Li, Hang Su, Feng Chai, Xiao-ping Chen, Xiang-yang Li, Hui-min Meng 2015 Simulated corrosion test of Q235 steel in diatomite soil *Journal of Iron and Steel Research International* **22** 352-360.
[5] Subbiah Karthick, Srinivasan Muralidharan, Velu Saraswathy 2020 Corrosion performance of mild steel and galvanized iron in clay soil environment, *Arabian Journal of Chemistry*, , **13** 3301-3318.
[6] Muhammad Wasim, Shahrukh Shoaib, N. M. Mubarak, Inamuddin, Abdullah M. Asiri 2018 Factors influencing corrosion of metal pipes in soils *Environmental Chemistry Letters* **16** 861-879.
[7] S. A. Ganiyu, O. T. Olurin, K. A. Ajibodu, B. S. Badmus, A. O. Ajayi 2018 Assessment of the degree of external corrosion of buried water pipelines and source identification of heavy metals due to surrounding soil conditions in humid environment *Environmental Earth Science* **77** 1-18.
[8] Jun Wang, Jie Liu, Ping Cao, Qiao Liang, Jian Duan 2017 Coupled creep characteristics of anchor structures and soils under chemical corrosion *Indian Geotechnical Journal* **47** 521-528.
[9] K. Tronner, A. G. Nord, G. Ch. Borg 1995 Corrosion of archaeological bronze artefacts in acidic soil *Water, Air, & Soil Pollution* **85** 2725-2730.
[10] Youngmin Hyun, Heesan Kim, Young-Ho Kim 2014 Effects of chloride and crevice on corrosion resistance of stainless steels buried in soil within seoul metropolitan *Metals and Materials International* **20** 249-260.
[11] W. Schimmack, U. Gerstmann, W. Schultz, G. Geipel 2007 Long-term corrosion and leaching of depleted uranium (DU) in soil *Radiation and Environmental Biophysics* **46** 221-227.
[12] O. E. Andreikiv, O. V. Hembara 2013 Influence of Soil Corrosion and transported products on the service life of welded joints of oil and gas pipelines *Materials Science* **49** 189-198.
[13] Xin Su, Zhenxing Yin, Y. Frank Cheng 2013 Corrosion of 16Mn line pipe steel in a simulated soil solution and the implication on its long-term corrosion behavior *Journal of Materials Engineering and Performance* **22** 498-504.
[14] Zhiping Zhu, Chun Shi, Yu Zhang, Zhifeng Liu 2020 The effects of Cl− and direct stray current on soil corrosion of three grounding grid materials *Anti - Corrosion Methods and Materials* **67** 73-82
[15] A. M. El-Shamy, M. F. Shehata, H. I. M. Metwally, A. Melegy 2018 Corrosion and corrosion inhibition of steel pipelines in montmorillonitic soil filling material *Silicon* **10** 2809-2815