

PAPER • OPEN ACCESS

The corrosion analysis and prevention of secondary cable joints used in outdoor terminal boxes of substation in humid environment

To cite this article: Yujing Hu *et al* 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **621** 012031

View the [article online](#) for updates and enhancements.

You may also like

- [Transient Simulation Model for Electric Field Distribution in Cable Joint](#)
Lei Liao, Ruxin Zhang, Gang Du et al.
- [Research on live detection technology of cable joint defects based on high-speed light sensing and pressure wave method](#)
Wu Zhaoguo, He Weisheng, Zhang Haibing et al.
- [Three-dimensional defects detection of high-voltage cable joint based on iterative residual fitting](#)
Zhihao Zheng, Jiayin Bian, Yuqun Gao et al.



ECS
The
Electrochemical
Society
Advancing solid state &
electrochemical science & technology

DISCOVER
how sustainability
intersects with
electrochemistry & solid
state science research

The corrosion analysis and prevention of secondary cable joints used in outdoor terminal boxes of substation in humid environment

Yujing Hu¹, Wei Hu², Wen Yang², Junjie Wu¹, Yan Chang¹, Fucheng Yin³ and Yi Xie^{1,*}

¹ State Grid Hunan Electric Power Company Limited Research Institute, Changsha 410007, China

² State Grid Hunan Electric Power Corporation Yueyang Power Supply Company, Yueyang 414000, China

³ Key Laboratory of Materials Design and Preparation Technology of Hunan Province, School of Materials Science and Engineering, Xiangtan University, Xiangtan 411105, China

*Corresponding author's e-mail: chao.feng@tju.edu.cn

Abstract. The reasons for corrosion cracking of secondary cable joints used in outdoor terminal boxes of a 220 kV substation in humid environment were investigated by scanning electron microscopy (SEM), X-ray diffractometer (XRD), infrared spectroscopy (IR) and ion dissolution test. According to the results of ion dissolution test, polyvinyl chlorid (PVC) insulated and sheathed cable material would precipitate chloride (Cl) ions under humid environment and at a certain temperature, which leads to accelerated corrosion cracking of the exposed copper core wires of secondary cable. In addition, the newly supplied PVC and cross-linked polyethylene (XLPE) materials without Cl precipitation under the same experimental conditions, indicating that PVC materials would precipitate Cl after reaching a service time threshold. Therefore, it is recommended that XLPE used for the insulation materials and accessories of secondary cable in outdoor terminal box of substation, as well as humidity in the terminal box should be controlled.

1. Introduction

The secondary control cable in terminal boxes of substation act as the main control loop of the power grid and electric equipment, and it is generally used for the control signal transmission^[1]. Copper (Cu) is usually used as the core wire material of secondary cable. PVC and XLPE are widely used for insulation as well as the number cylinder (used to circuit auxiliary mark) materials. Among them, secondary cable are arranged by a centralized manner in terminal box, and copper core wires of them should be exposed to plug without insulated layer. Though copper is a good conductor, it will occur electrochemical corrosion under humid atmosphere or environment. And it is a great disadvantage to control signals transmission of secondary cable. Especially when serious corrosion cracking happens, the signal will miss or the wrong signal will be sent due to control circuit broken.

There are many reports on corrosion of Cu under atmospheric environment. According to the related reports, due to the industrial pollution of oxysulfides, it will commonly generate brochantite



($\text{Cu}_4\text{SO}_4(\text{OH})_6$), antlerite ($\text{Cu}_3\text{SO}_4(\text{OH})_4$) and posnjakite ($\text{Cu}_4\text{SO}_4(\text{OH})_6 \cdot \text{H}_2\text{O}$) in usual humid environment. Then, due to higher chloride concentration in the marine atmosphere, the corrosion product of Cu is generally dicopper chloride trihydroxide ($\text{Cu}_2(\text{OH})_3\text{Cl}$)^[2-3].

This work investigated a 220 kV substation near some inland lake where the environmental humidity is relatively high. During a routine inspection, it was found that number cylinder of secondary cable in the 610 terminal box of the No. 1 main transformer turned green. Meanwhile, copper core wires near the terminal were corroded, and even there was a copper core wire of secondary cable joint rust broken. In view of these circumstance, our study investigated the reasons for corrosion cracking on copper core wires of secondary cable joints, and proposed relevant preventive measures to provide a reference for operation and maintenance stage.

2. Methods

Conducting on-site inspections on terminal boxes and secondary cable, and failure or fracture appearance of secondary cable were recorded by camera. In the meantime, pollutants and other factors affecting corrosion at the substation site and near were investigated.

The surface corrosion morphology and element composition of the copper core wires were obtained by scanning electron microscopy (SEM) and energy disperse spectroscopy (EDS).

The types of functional groups composition of insulation and number cylinder materials were identified by infrared spectroscopy (IR).

The composition of corrosion product on the surface of copper core wire was investigated by X-ray diffractometer (XRD).

To determine the causes of Cl element appearing in corrosion product of copper core wires, the ion dissolution test at different temperatures was carried out on insulation of secondary cable and number cylinder materials. The secondary cable insulation and number cylinder materials were respectively cut to 8 cm length, and three samples of them were separately putted into beaker with 50 ml deionized water. Followed by the samples dissolved for 48 h, at a constant temperature condition (40 °C, 50 °C and 60 °C respectively). After that, ion chromatograph was used to measure the Cl concentration in solution. Meanwhile, ion dissolution test was carried out on the newly supplied PVC and XLPE insulation materials in the same conditions.

3. Results

3.1. On-site inspections

According to the local investigation of this 220 kV substation, the surface of terminal near terminal block was green in the 610 terminal box of the No. 1 main transformer, especially the white number cylinder. As can be seen from Figure 1, one of the black secondary cable has been broken and its fracture has been covered by green corrosion product.

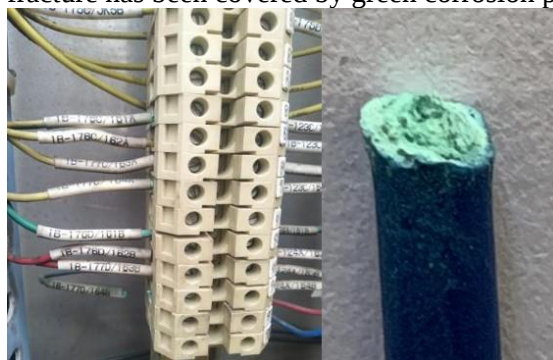


Figure 1. Corrosion morphology of secondary control cable joint in terminal box.



Figure 2. Corrosion morphology of the external wall of terminal box.

Moreover, two of terminal boxes, far away from the exhaust gas window of high-power heater, were found corrosion on external wall, as shown in Figure 2. While, there was no corrosion on external wall of the remaining boxes, including boxes in the nearby high-power heater. The terminal boxes are manufactured by 304 austenitic stainless steels, and corrosion will occur only in the presence of Cl under humid conditions.

3.2. SEM

SEM with EDS was used to analyse element of corrosion product on copper core wires. As shown in Figure 3, we can find that Cu and Cl are the main elements of corrosion product, and the atomic percentage of Cl is 38.16%. Therefore, it could be considered that corrosion product is copper chloride

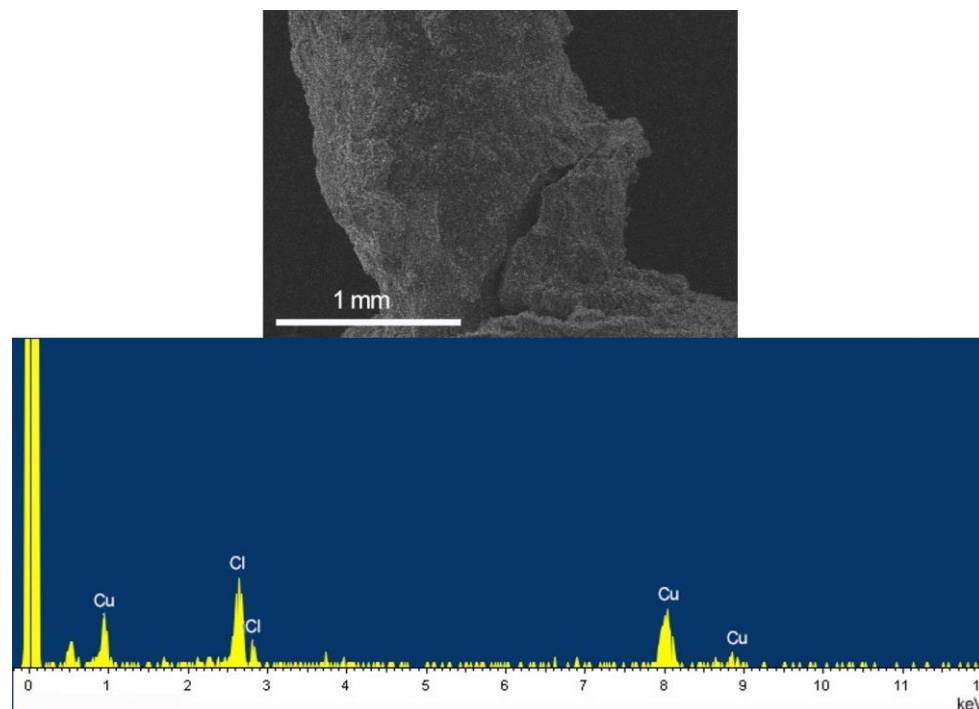


Figure 3. Morphology and EDS spectra of corrosion product on secondary cable

3.3. XRD

The components of corrosion product on copper core wires of secondary cable joints were studied by XRD analysis, and the results are presented in Figure 4. There are only Cu and $\text{Cu}_2\text{Cl}(\text{OH})_3$ can be observed in the characteristic lines of XRD spectrum. Cu stem from the copper core wires. And $\text{Cu}_2\text{Cl}(\text{OH})_3$ can be inferred as corrosion product, combining on the results of the analysis.

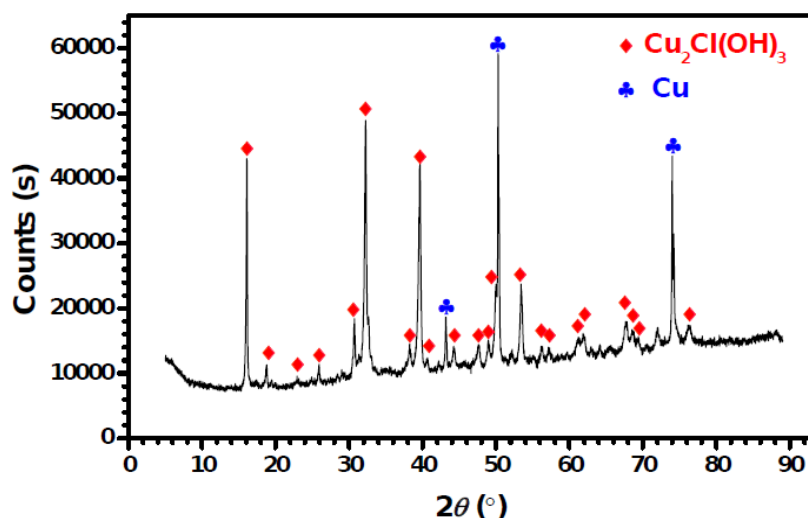


Figure 4. XRD spectrum of corrosion product on copper core wire of secondary cable joint

3.4. IR analysis

The chemical structure of secondary cable insulation and number cylinder materials were characterized by IR analysis, and the IR spectra are shown in Figure 5. It can be obviously distinguished two different characteristic lines on spectra. Among them, the blue line is PVC material which belongs to insulation of secondary cable, and the other red line is XLPE material which is owned by number cylinder.

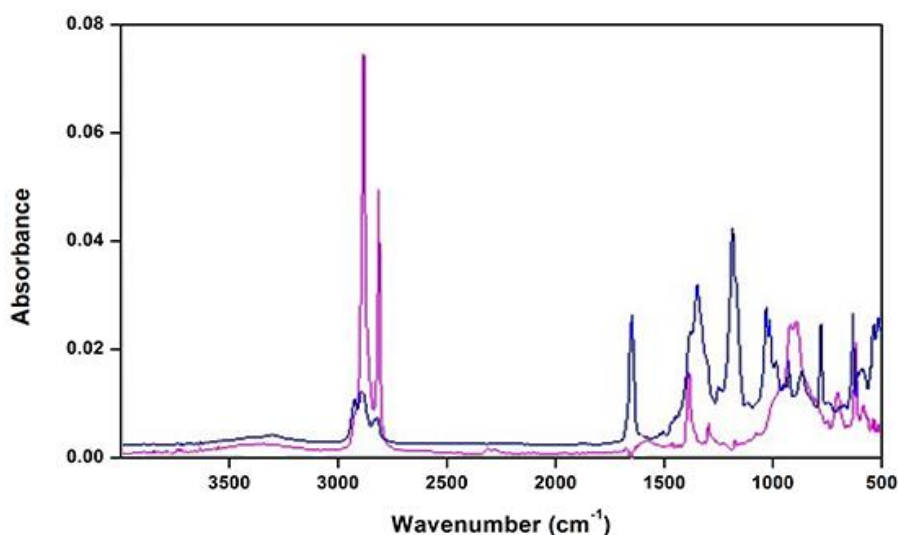


Figure 5. IR spectra of insulation of secondary cable and number cylinder materials.

3.5. Ion dissolution test of insulation of secondary cable and number cylinder materials

To figure out the source of Cl in the corrosion product on the copper core wires, ion dissolution test was carried out on the on-site secondary cable and number cylinder materials. The test results are listed in Table 1. It serves to show that the Cl ions content of secondary cable insulation material is obviously an order of magnitude higher than that of number cylinder. For secondary cable insulation material, the amount of Cl ions dissolved at 60 °C is more than that at 40 °C. Although the dissolved Cl ions content of the number cylinder also follows the same temperature trend, their respective absolute value have a few difference.

Table.1. The results of the Cl ion dissolution test of insulation and number cylinder materials of secondary cable.

Sample	Length (cm)	Dissolved time (h)	Dissolved temperature (°C)	Water volume (ml)	Cl content (µg/L)	Other
Insulation materials	8	48	40	50	213.3	Removal of copper core wires
	8	48	50	50	380.6	
	8	48	60	50	610.0	
Number cylinder	8	48	40	50	9.5	
	8	48	50	50	12.1	
	8	48	60	50	17.4	

3.6. Ion dissolution test of newly supplied PVC and XLPE materials

In order to evaluate the difference in the ion dissolution test between newly supplied materials and the long-term used materials, the newly supplied insulation materials of secondary cable and number cylinder (made of PVC and XLPE respectively) were tested under the same conditions. The test results are shown in Table 2. For these materials made of PVC or XLPE, the dissolved Cl ions content also increases with increasing temperature, while the numerical difference is quite slight. Considering some influence factors during the test, it can be considered that there is approximately no difference.

Table.2. The results of Cl ion dissolution test of new supplied insulation materials for secondary cable and number cylinder.

Sample	Length (cm)	Dissolved time (h)	Dissolved temperature (°C)	Water volume (ml)	Cl content (µg/L)	Other
Insulation materials (PVC)	8	48	40	50	4.6	Removal of copper core wires
	8	48	50	50	7.6	
	8	48	60	50	8.4	
Insulation materials (XLPE)	8	48	40	50	7.1	Removal of copper core wires
	8	48	50	50	11.2	
	8	48	60	50	13.1	
Number cylinder (PVC)	8	48	40	50	12.6	
	8	48	50	50	13.8	
	8	48	60	50	18.9	
Number cylinder (XLPE)	8	48	40	50	6.0	
	8	48	50	50	7.0	
	8	48	60	50	8.6	

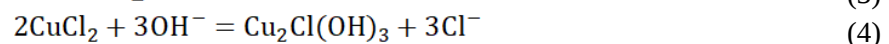
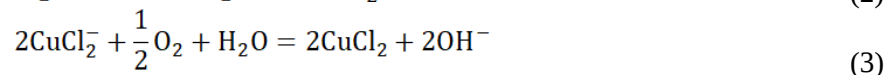
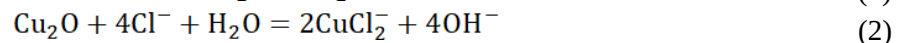
4. Discussion

The No. 1 main transformer of this substation was put into operation in 2008, and the 610 terminal box has been running for 12 years. This substation is located in the inland lake area with high humidity. To reduce humidity, the 610 terminal box is equipped with two heaters of 100 W and 50 W, and there are a row of three exhaust moisture windows are designed at the bottom of wall back the box. Nevertheless, the sealing property of box is poor, and internal moisture is relatively high. Thus the small heater cannot heat and dry the moisture in the box.

According to analysis results of corrosion product on copper core wires of secondary cable, the existence of Cl ions in corrosion product was verified. And XRD results identifies it is $\text{Cu}_2\text{Cl}(\text{OH})_3$.

Corrosion on external wall of stainless steel terminal box near exhaust moisture window is also caused by Cl ions, in accordance with the corrosion theory of austenitic stainless steel ^[4].

IR analysis results illustrate that secondary cable insulation is made from PVC, and number cylinder is made by XLPE. On the basis of ion dissolution test of secondary cable insulation material and number cylinder, it is confirmed that secondary cable insulation material made from PVC will continuously release Cl ions under a certain temperature and humidity environment. Then, Cl ions participate in corrosion of copper core wires at terminal block. It is a typical electrochemical corrosion, and the detailed reactions (equation 1-4) are as follows:



Therefore, the main corrosion product should be $\text{Cu}_2\text{Cl}(\text{OH})_3$ which is a green crystal or crystalline powder, insoluble in water, soluble in acid and ammonia ^[5]. And this result shows that Cl ions and H_2O in environment participate in the reaction during corrosion failure process of copper core wires, and dominate composition and structure of corrosion product.

Based on above analysis, combined with electrochemical corrosion theory and related reports, it can be concluded that environmental humidity and Cl ions content are two key factors in the process of electrochemical corrosion of copper core wires.

According to corrosion product and its morphology, the cable corrosion failure process belongs to electrochemical corrosion. (1) Water is a necessary condition for the formation of electrochemical corrosion of copper wires, serving as an ionic conductor. (2) The corrosion position of secondary cable is mainly distributed away from the heating device in terminal box. (3) Some number cylinder are also green, and corrosion product has spread to the position far away from the corrosion point. It is unreasonable if corrosion product reaches the far end of number cylinder only by solid diffusion. The phenomenon can only be explained by water assisting the diffusion of corrosion product.

Above three reasons all show that environmental humidity is the most critical factor for electrochemical corrosion of copper wires. The more serious electrochemical corrosion occur when the higher humidity refer to related literature.

Cl ions released by secondary cable insulation material in the terminal box continuously will accelerate the electrochemical corrosion of the secondary cable copper core wires. Thus Cl ions content is an important factor affecting cable corrosion process.

In addition, the results of ion dissolution test of newly supplied PVC and XLPE insulation materials and number cylinder shows a few difference, and nearly is negligible. Although Cl functional groups exist in the newly supplied PVC materials, the dissolving Cl ions content of PVC materials is no different from the XLPE materials without Cl. The results indicate that there are time effect on Cl ions of PVC materials precipitating, and a large amount of Cl ions can only be released when a certain service time threshold is reached.

5. Conclusion and suggestion

Corrosion on copper core wires of secondary cable in 610 terminal box for this substation is caused by that Cl ions precipitating from PVC insulation materials accelerate electrochemical corrosion. And high humidity in terminal box will give rise to lots of Cl ions precipitation.

Firstly, it is recommended to apply for a power outage as soon as possible, check the secondary cable terminal of each terminal box in this substation, and replace or reinstall all corroded secondary cable joints. At the same time, the sealing design of terminal boxes should be optimized, the moisture removal device in boxes should be improved, and the operation and maintenance management for terminal boxes should be strengthen.

Secondly, the Cl ions precipitating time threshold of PVC materials in working environment need further study. Considering the safety of power grid long-term operation, for the newly renovated and expanded substation terminal boxes, secondary cable insulation materials and number cylinder should give priority to use XLPE materials.

References

- [1] Yamaguchi, H., Alauddin, M. (2003) Control of cable vibrations using secondary cable with special reference to nonlinearity and interaction. *Engineering Structures*, 25, 6: 801-816.
- [2] Mcneil, M.B., Mohr, D.W. (1992) Sulfate formation during corrosion of copper alloy objects. *Mater. Res. Soc. Symp. Proc*, 267: 1047.
- [3] Kong, D.C., Dong, C.F., Fang, Y.H., Xiao, K., Guo, C.Y, He, G., Li, X.G. (2016) Copper corrosion in hot and dry atmosphere environment in Turpan, China. *Transactions of Nonferrous Metals Society of China*, 26, 6: 1721-1728.
- [4] Costa-Mattos, H.S.D., Bastos, I.N., Gomes, J.A.C.P. (2008) A simple model for slow strain rate and constant load corrosion tests of austenitic stainless steel in acid aqueous solution containing sodium chloride. *Corros. Sci.*, 50, 10: 2858-2866.
- [5] Malvault, J.Y., Lopitaux, J., Delahaye, D., Lenglet, M. (1995) Cathodic reduction and infrared reflectance spectroscopy of basic copper (II) salts on copper substrate. *J. Appl. Electrochem.*, 25, 9: 841-845.