Research on metal corrosion mechanism and inhibition measures of transmission and distribution equipment in Hunan

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Abstract. Through the analysis of the different mechanisms of corrosion of metal materials in AC and DC power transmission and transformation equipment and the factors affecting the corrosion rate, the impact of metal corrosion on the mechanical and electrical performance of electrical equipment was deeply studied. The selection of electrical equipment, material inspection and on-site anti-corrosion treatment were proposed. It was an effective measure to prevent corrosion failure of power transmission and transformation equipment.

1. Introduction

Metal materials are widely used as engineering materials and equipment materials in power systems, which support the safe and stable operation of power systems. However, metal material defects, improper protection, corrosion fatigue, wear and deformation, etc., may bring greater hidden dangers to power operation. The most common forms of damage are fracture, deformation, wear and corrosion [1].

Fracture or deformation is the damage that occurs when the load on the metal material exceeds its load-bearing limit; wear is the gradual damage of the metal material due to mechanical friction; corrosion is the damage that occurs gradually under the action of the surrounding environmental media. Among the many forms of damage, corrosion damage is particularly important. Since all metal structural parts of electrical equipment are in contact with the surrounding medium, not only high temperature, high pressure, and industrial gas can corrode the metal, but also the metal flow parts will accelerate the galvanic corrosion due to the action of current. There are also humid air, industrial dust, acid rain, etc. in Hunan, making the corrosion rate and degree of electrical equipment in this area more serious than other areas.

2. Corrosion mechanism

From the thermodynamic point of view, metal corrosion is essentially the process of transforming metal materials into low-energy oxides. AC equipment is mainly corroded by primary batteries. The corrosion of most metal materials or structural parts of electrical equipment at near room temperature occurs in an environment with water and is electrochemical in nature.
The oxidation reaction is generally called the anode reaction, and the reduction reaction is generally called the cathode reaction. Two electrochemical reactions are essential to the occurrence of corrosion. The oxidation reaction causes the actual loss of metal, but the reduction reaction must consume the electrons released by the oxidation reaction to maintain the neutrality of the charge. Otherwise, a large amount of negative charges will quickly form between the metal and the electrolyte and stop the corrosion process.

![Figure 1. Corrosion morphology of DC terminal.](image1)

![Figure 2. Corrosion morphology of DC insulator.](image2)

The oxidation reaction and the reduction reaction are sometimes called half-cell reactions, and they can occur locally at the same point of the metal or separately. When these electrochemical reactions are separated, the process is called a differential corrosion cell. The point where the metal is oxidized is called the anode or anode zone. In this area, when metal ions leave the metal surface, a direct current (defined as the flow of positive charges) flows from the metal surface into the electrolyte. The current flows through the electrolyte to another point where the oxygen, water, or some other substances are reduced. This point is called the cathode or the cathode zone.

Underground corrosion of grid grounding metals is often due to the existence of different types of differential corrosion batteries. These include gas-filled differential batteries, where different parts of the grounding material are exposed to different oxygen concentrations in the soil, and the batteries are generated due to the surface properties of the grounding material or the chemical substance of the soil. Galvanic corrosion is a form of differential battery corrosion in which two different metals are electrically paired and placed in a corrosive environment.

The main cause of DC equipment corrosion is electrolytic corrosion. The chemical reaction formula of electrolytic corrosion is the same as that of galvanic corrosion. But its corrosion rate is much faster than that of galvanic cells. After moisture between the positive and negative metals, a corrosion electrolytic cell is formed. The anode metal loses electrons and an oxidation reaction occurs.

When the metal secondary components are under the positive and negative power supply, the positive side will make the terminals more susceptible to corrosion in a humid environment. As shown in Figure 1, the terminals connected to the wires will corrode significantly faster than other unconnected terminals under the action of the DC power supply. The first ±800kV Chusui DC and Fufeng DC put into operation in my country, insulator corrosion appeared in less than a year [2-3], as shown in Figure 2.

3. Corrosion influence factors

3.1 Atmospheric environment in Hunan

The average annual precipitation is between 1200-1700 mm, with abundant rainfall and high air humidity in Hunan. It is one of the areas with serious acid rain pollution. Acid rain is widely distributed, mainly in the Xiangjiang River basin centered on Changsha and Northwestern Hunan represented by Huaihua. The pH value of precipitation is low and the frequency of acid rain is high. The Hunan Provincial Environmental Bulletin in 2017 showed that the average average PH value of the province was 5.04 (range 3.02-8.63), and the frequency of acid rain was 54.5%. Among the 14 prefecture-level cities in the province, Yongzhou, Zhuzhou, Hengyang, and Xiangtan belonged to
areas with heavy acid rain pollution. Chenzhou, Huaihua, Changsha, Loudi, Shaoyang, and Yiyang belong to acid rain areas, and only Changde, Jishou, Yueyang, and Zhangjiajie belong to non-acid rain.

High-frequency acid rain can directly corrode most metals, such as copper, iron, zinc, aluminum, etc., while the anti-corrosion coating of power equipment is mainly zinc. Under the acidic effect of acid rain, the zinc layer directly reacts and corrodes away, and then the metal surface is destroyed by acidic substances. After a clear day, the metal will rapidly oxidize under the action of air with a certain humidity. In areas with more acid rain and harsh atmospheric environment, equipment corrosion is generally more serious, such as leaf erosion in Zhuzhou. Areas with large air humidity all year round are prone to corrosion. The severely corroded areas of Chusui DC and Fufeng DC are all areas with high humidity and perennial clouds and fog.

3.2 Metal material of the equipment

The mismatch between the metal material of the equipment and the environment is also a major reason. According to statistics on the corrosion defects of metal materials of power transmission and transformation equipment in the past 5 years, this factor accounts for a large proportion. For example, high-strength stainless steel replaces austenitic stainless steel, and high-strength aluminum alloy replaces rust-proof aluminum alloy. For example, a 220kV transformer substation was overhauled and found that the stainless steel bolts of the aluminum row were corroded, as shown in Figure 3, which is a high-strength stainless steel instead of austenitic stainless steel. At the same time, the aluminum tube of the isolating switch in the station has spalling corrosion, which is a high-strength aluminum alloy instead of rust-proof aluminum alloy, as shown in Figure 4.

3.3 Surface anticorrosion process

The anti-corrosion treatment of electrical equipment metal mainly includes coating and paint. The anti-corrosion of non-stainless steel parts mainly adopts hot-dip galvanizing, and paint is mainly used to protect the surface of steel components in the actual installation process. The quality of the surface anti-corrosion process is directly related to the anti-corrosion effect.

For example, during the overhaul construction of a 220kV substation, it was found that the primer coating of the isolating switch base had holes, as shown in Figure 5. The reason was that the primer thinner was added in a high proportion. At the same time, the newly applied anti-corrosion coating of the secondary cable protection tube peeled off, which is incompatible with the galvanized layer, as shown in Figure 6.
The on-site adhesion test shows that the bonding force between the coating and the steel parts is less than 2MPa. In addition, the galvanized layers of porcelain and glass insulator iron caps on the ±800kV Chusui and Fufeng UHV DC projects are all considered in accordance with AC equipment, which is far from meeting the thickness requirements for electrolytic corrosion of DC equipment.

4. The effect of corrosion on the electromechanical characteristics of equipment

Corrosion of the metal parts of electrical equipment will adversely affect its operating characteristics, which mainly include electrical characteristics and mechanical characteristics. The following uses insulators as an example to illustrate the harm of metal accessories corrosion.

After the iron cap of the insulator is corroded, an obvious rust channel will be formed on the surface of the insulator, which is difficult to clean by itself under natural conditions. The results of the study indicate that the rusty channel will lead to the accelerated accumulation of nearby dirt. The pollution degree of the corrosion product accumulation area is much heavier than that of the clean area, and the difference in salt density is 16 times in the worst case.

The early research results of Wuhan High Voltage Research Institute also showed that the leakage current of rusted insulators in a humid state is 2-3 times larger than that of non-rusted insulators, and most of the creepage phenomenon first occurs in rusted insulator strings. The pollution flashover voltage of the iron cap corroded insulators with ±800kV Chusui DC put into operation for two years has decreased by 18%~21% compared with the uncorroded insulators [3-5].

After the steel feet are corroded, the diameter of the feet becomes thinner, as shown in Figure 7. The corrosion products expand in volume, resulting in a greater stress between the steel feet and the cement, resulting in a decrease in the mechanical strength of the insulator, and a broken string accident may occur [4,7].
5. Prevention measures
The anti-corrosion work of metal parts of power transmission and transformation equipment in Hunan can be carried out from the aspects of material inspection, acceptance check, and anti-corrosion measures to reduce the corrosion rate. In view of the four types of typical failures and reasons of unreasonable design, inadequate corrosion protection, improper assembly and inadequate fastening, corresponding improvement measures had been proposed.

1) For electrical equipment in Grade IV pollution areas in Changsha, Zhuzhou, Changde, Jishou, Zhangjiajie, Huaihua and other areas where acid rain corrosion is more serious, explore the method of sealing polyurethane topcoats on metal surfaces to isolate acid rain; at the same time, new stations will give prity to GIS or indoor layout, the outdoor equipment metal accessories prefer stainless steel.

2) Select metal materials that meet the environment and carry out inspections of metal parts entering the network.

3) It is strictly forbidden to use alkyd paint with weak adhesion for the galvanized layer. It is recommended to use epoxy iron red primer + silver powder topcoat. For heavy anti-corrosion treatment, use epoxy primer + epoxy mica intermediate paint + polyurethane topcoat. The anticorrosion of the zinc layer can also consider the epoxy phosphate zinc-rich primer to improve the adhesion on the galvanized layer.

4) Strict anti-corrosion treatment process standards, and the visual evaluation of the degree of corrosion on the steel surface and the quality of rust removal before painting shall be implemented in accordance with the requirements of GB8923 "Surface corrosion grade and rust removal level of steel before painting". The surface to be coated must be thoroughly cleaned to ensure that the surface to be coated is free of rust, oil, water, and dust.

5) When coating the surface with blending paint, enamel paint or other various coatings, it should be as thin and even as possible. If the covering power of the paint is poor, the thickness should not be increased arbitrarily, and the paint should be applied several times. The thickness of each layer of paint film should be carried out according to the design requirements. After each layer is applied, there should be a sufficient drying time, and the next layer can be applied after the previous layer is completely dry.

6) The grid metal components that have been corroded very seriously and have no anti-corrosion significance should be replaced as soon as possible. For example, a corroded ground wire with a diameter change of more than 8%, Rusty iron tower angle steel, and rusty ground flat iron.

6. Conclusion
The Primary battery corrosion and electrolytic corrosion are the main causes of corrosion of metal accessories in AC electrical equipment and DC electrical equipment, respectively. Metal material, anti-corrosion technology and atmospheric environment are the main factors affecting the corrosion of electrical equipment.

The impact of corrosion of metal accessories on electrical equipment mainly includes electrical and mechanical properties. The electrical characteristics are reflected in reducing the pollution flashover voltage of the equipment, and the mechanical characteristics are mainly reflected in reducing the mechanical strength of the equipment.

Strict checks should be made in terms of metal material, network inspection, anti-corrosion paint coating method and technology, etc., to improve the corrosion resistance of metal accessories of electrical equipment and reduce the impact of corrosion on the electromechanical characteristics of the equipment.

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