Research on Corrosion Causes of Common Metal Material in Power Grid

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Abstract. The power grid equipment has been serving in the harsh environment for a long term, if reasonable differential design is not adopted, and the operation process is not effectively supervised, the safe and stable operation of power grid system would have greater threats. Aiming at the corrosion problem of common metal material in power transmission and transformation facilities of Inner Mongolia power grid, the corrosion failure factors of carbon steel, stainless steel and copper alloy were studied by methods of energy spectrum analysis, morphology observation and metallographic examination. Then, suggestions and measures have been put forward in adopting differentiated applications, strengthening quality control and improving installation process.

1. Introduction
At present, with the continuous growth of power transmission capacity and the extended power grid, our requirements have become higher and higher, such as power grid system security and steadiness, power quality, ability to respond to incidents and disasters[1]. The environment of transmission line and substation is in great difference, so the metal components have been facing various environmental corrosion. If there were no effective supervision in the operation process, the reliability of power grid system would have greater potential safety hazard[2]. In this paper, the corrosion of common metal material in power transmission and transformation facilities of Inner Mongolia power grid is comprehensively evaluated through the analysis of quality test results. In addition, puts forward the corresponding corrosion protection measures, and improves the service life of the metal components in power grid.

2. Carbon Steel
Transmission line towers and metal structures in substation are usually made of carbon steel. But the corrosion resistance of carbon steel has been performing poorly in the coastal city and heavy industry polluted area. Corrosion products are α-FeOOH, γ-FeOOH and Fe₃O₄[3]. Galvanizing is the main corrosion protection technology for carbon steel. On the one hand, the galvanized coating has stable chemical properties, which can effectively isolate carbon steel from corrosive media. On the other hand, the voltage of zinc electrode is low, and it is corroded first as sacrificial anode, which protects the basal body. If the process is appropriate, the quality of galvanized coating met the requirements, the protection effect shall be good and also economical. However, judging from the corrosion statistics of carbon steel components in Inner Mongolia region, there are still some problems. The corrosive situation of steel tower on a 220kV overhead line is not optimistic. The surfaces of tower foot steel plate, tower leg angle steel and inclined angle steel are covered by pockmarked sharp pits, where
locally form large areas of tawny rust fouling and the inclined angle steel is bent and deformed, as shown in Figure 1.

![Figure 1. Macroscopic morphology of steel tower.](image)

The results of dimension measurements are shown in Table 1. It reflects that the thinning rate of tower foot steel plate, tower leg angle steel and inclined angle steel all exceed 20%, with the thinning rate of inclined angle steel reaching 34%. The loss of cross section reduces the structural performance of steel tower, damages the overall stress balance and severely weakens the bearing capacity of steel tower.

| Tower foot steel plate | Tower leg angle steel | Inclined angle steel |
|------------------------|----------------------|----------------------|
| Original size (mm)     | 7.5                  | ∠125×10.0            | ∠70×5.0            |
| Measured thickness (mm)| 5.8                  | 8.0                  | 3.3                |
| Thinning rate (%)      | 23%                  | 20%                  | 34%                |

Galvanized thickness of not corroded steel tower was tested by coating thickness gauge. The experimental results indicated that the coatings on the surface were not uniform and the thickness at local location did not meet the minimum requirements specified in GB/T 2694—2010. Sulfur dioxide is an effective cathodic depolarizing chemical, its presence will accelerate the corrosion rate. With the exposure to sunlight and rain, the galvanized coating that does not meet the standard will become thinner and thinner, eventually losing all of it and the steel base will lose protection. According to the actual situation of the service site environment, adjusting the thickness of the galvanized coating, removing the fault parts in time and carrying out reinforcement treatment can ensure the effectiveness of corrosion protection work. Apart from this, composite coating with good hydrophobic and weather ability can also be considered for protection[4].

3. Stainless Steel
In general, outdoor mechanism boxes and terminal boxes equipped with precision instruments and electronic components in substation are made of austenitic stainless steel, which has good processing property and low temperature toughness during working process. The dense oxide layer formed on the surface raises the electrode voltage, produces deactivation reaction and has strong corrosion resistance[5]. Some outdoor sealed boxes in a 110kV substation are rusted, with orange spots, small and deep pits, discontinuous and solid floating rust, as shown in Figure 2.
Figure 2. Macroscopic morphology of outdoor sealed box.

The X-ray fluorescence was used to carry out random inspection on the chemical compositions of seven outdoor sealed boxes, as shown in Table 2. The concentrations of Mn in four outdoor sealed boxes are between 8.94–9.51%, which do not up to the DL/T 1424—2015 that the concentration of Mn in the austenitic stainless steel box should not exceed 2%. In addition, the Cr contents in these four are between 14.6–15.0%, and the Ni contents in these four are between 0.69–1.17%. As to austenitic stainless steel, the main function of Cr is to prevent the matrix from being eroded, and the concentration of Cr should be controlled from 17% to 19%. Ni as an element expanding austenite rage, can ensure that structure of stainless steel is austenite when its content reaches more than 8%, thus achieving the purpose of improving corrosion resistance, plasticity and toughness of the material.

Table 2. Chemical compositions of outdoor sealed boxes (wt%).

| Section                       | Cr | Mn  | Ni  |
|-------------------------------|----|-----|-----|
| #1 Section bus voltage transformer terminal box | 15.0 | 9.11 | 0.91 |
| #1 Main transformer high voltage earthing switchmechanism box | 17.9 | 1.08 | 8.07 |
| #1 Main transformer terminal box | 14.9 | 9.13 | 1.08 |
| #1 Main transformer online oil filter | 14.7 | 9.51 | 0.69 |
| #2 Main transformer terminal box | 18.2 | 1.15 | 8.45 |
| #3 Main transformer high voltage earthing switchmechanism box | 14.6 | 8.94 | 1.17 |
| #3 Main transformer high voltage isolation switch mechanism box | 17.3 | 1.21 | 8.21 |

The energy dispersive spectrometer was used to analyse and evaluate chemical compositions in the corrosion products of the voltage transformer terminal box and the isolating switch mechanism box. The mass fraction of each element is shown in Table 3. It is noticeable that two corrosion products are mainly Fe oxides with high Cl content of 1.20% and 2.31% respectively.

Table 3. Mass fractions of elements in corrosion products (wt%).

| O    | Si  | Al | Fe | Ca | Mn | Mg | Cr | Cl | S   |
|------|-----|----|----|----|----|----|----|----|-----|
| Voltage transformer terminal box | 30.08 | 10.82 | 3.64 | 43.97 | 1.62 | 1.94 | 1.04 | 5.69 | 1.20 |
| Isolation switch mechanism box | 19.25 | 1.34 | — | 60.07 | — | 5.01 | — | 10.04 | 2.31 | 1.98 |

The passive metal still has certain reaction ability, the dissolution and repair of the deactivation layer keep dynamic equilibrium. The ability of activating chloride ion is strong. When there is high chloride ion in the environment, the equilibrium is destroyed and the dissolution is faster than the deactivation. The reason is that chloride ions can preferentially adsorb on the deactivation layer, squeeze out oxygen atoms, and combine with cations in the deactivation layer to produce chloride, forming small corrosion pits[6]. When the surface structure of stainless steel is uneven, such as surface scars, inclusions and other defects, spot corrosion is easy to occur. Therefore, the working life of stainless steel components can be effectively prolonged by doing a good stainless steel quality identification for outdoor sealed boxes and creating an archive of inspection documents.
4. Cooper Alloy

Copper alloy is a kind of diamagnetic nonferrous metal, which is widely used in electric power industry. The brass connecting nut of operating mechanism for tank circuit breaker in a 500kV substation cracked many times, causing air leakage in the pipeline and the operating mechanism could not be used normally. The crack part of that brass connecting nut mainly appears at the transition angle from the hexagonal nut to the externally threaded pipe and the end surface part of the hexagonal nut. The transition angle is 90 degrees with no round corner treatment, so that the brass connecting nut belongs to a part which is easy to form larger stress. The scanning electron microscope and energy dispersive spectrometer were used to detect the microcosmic morphology and chemical compositions in the fracture surface of brass connecting nut. The results display that entire fracture had the characteristic of cracking along grains, accompanied by the formation of secondary cracks, as shown in Figure 3. It is found that there are as much as 1.64% S and 7.81% Pb in the initial cracking part of brass connecting nut. Sulphur-containing medium dissolved in the thin liquid layer on the copper surface will cause considerable corrosion damage[7]. The higher content of Pb impurity element would increase the brittleness of the material.

Taking samples of brass connecting nut for metallographic examination, as shown in Figure 4. The longitudinal section of brass connecting nut is a two-phase structure of α+β, and the α phase is distributed along grain boundary in block or feather shape. According to YS/T 347—2004, the average diameter of grain is 0.11mm, and the grain fineness number is 3.5, which indicates that the brass connecting nut is under high temperature during forging process, resulting in coarse grain size. In addition, the distribution of α phase weakens the bonding force between grain boundaries, which causes cracking of material strength and toughness.

Stress concentrations can lead to initiation of cracking by fatigue. When copper alloy is in a specific corrosion medium and there is stress exceeding a certain critical value, then stress corrosion cracking occurs[8]. Under the comprehensive action of inner pressure, micro-cracks generation and
propagation. Once cracks are formed, their expansion speed is much faster than other types of partial corrosion. The damage caused by stress corrosion cracking often occurs suddenly without obvious warning. As a rule, stress corrosion cracking is a kind of corrosion with great destructiveness and harmfulness. It is particularly important to optimize the installation process of connecting parts and improve the management of the installation process. Be prepared for having spare parts storage, and select products with good stress corrosion resistance when necessary, which can further improve the trusty of equipment operation.

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