Corrosion and Protection of Galvanized Steel in Power Grid

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Abstract. Galvanized steel is widely used in power grid, the failure of these steel components will seriously threaten the safe operation of the grid. In this paper, transmission tower angle steel and connecting bolts were investigated by means of macro-inspection, zinc coating measurement, energy dispersive spectrometer(EDS). Then the corrosion mechanism and behavior of galvanized steel have been investigated and the protection measures were proposed. The results show that the zinc coating is corroded quickly in the high sulfur environment; corrosion failure of zinc coating on the aluminum-steel dissimilar metal connecting bolt can accelerate the corrosion of the aluminum connecting plate.

1. Introduction
Steel materials are widely used in the transmission and distribution equipment of the power grid, and because many of them are used in industrial pollution environments or humid harsh environments, the corrosion rate of these steels will be accelerated. And once these components are corroded and failure, they will affect the normal use of power grid equipment and endanger the safe operation of the power grid. Therefore, the corrosion and protection of steel materials are particularly important to ensure the safe, stable and economical operation of the power grid. At present, galvanizing is still the main anti-corrosion technology for steel components of electricity grid equipment[1], since they often run in difficult conditions, corrosion failure of these components will inevitably occur. Therefore, this paper analyzed the corrosion failure of galvanized steel components and puts forward protective measures, which can provide a basis for the operation and maintenance of galvanized steel components in power grid equipment.

2. Corrosion failure analysis of 220kV transmission tower
The tower feet of the transmission towers I-21 and III-21 of a 220kV line are immersed in corrosive mediators, the tower legs and feet are severely corroded, and the concrete foundation protective cap was also severely damaged. This line is located in the heavy chemical industry park, close to heavy pollution-emitting enterprises, and the nearby soil, water sources and air had been polluted.

2.1. Macro inspection
According to the macroscopic inspection, the visible parts of the corrosion damage of I-21 tower are mainly the foundation protection cap and the tower feet materials within 600mm above it. The concrete protective caps of four tower feet are cracked, crumbled and partially peeled off in varying degrees. The steel plate of tower feet, the angle steel of tower leg, cable-stayed steel, connecting bolt...
and grounding wire are all damaged by corrosion, and the corrosion extends to the form of pitted sharp pits connected to each other, forming a large area of corrosion thinning.

The visible parts of the corrosion damage of III-21 tower are mainly the foundation protection cap and the tower feet materials within 300mm above it. The steel plate of the tower feet, the angle steel of tower leg, the cable-stayed steel, the connecting bolt and the grounding wire within 300mm above the foundation protection cap are severely damaged by corrosion. The steel plate of the tower feet and the angle steel of tower leg had been severely corroded and thinned, the cable-stayed steel had been corroded to partial loss, and the grounding flat iron had been corroded to fracture. The serious local deformation of the cable-stayed steel indicates that the tower had been inclined to a certain extent.

In order to evaluate the corrosion damage of steel tower steel, the vernier caliper was used to measure the size of the tower's angle steel. The results are shown in Table 1.

Table 1. Comparison of dimensions of I-21 and III-21 steel towers before and after corrosion

| Design thickness (mm) | Thickness (mm) | Thinning rate (%) |
|-----------------------|----------------|-------------------|
| angle steel of tower leg | 10 | 8.0 | 20 |
| cable-stayed steel | 5 | 3.3 | 34 |
| steel plate of tower feet | 7.5 | 5.8 | 23 |
| angle steel of tower leg | 11 | 8.1 | 26 |
| cable-stayed steel | 5.5 | 0 | 100 |
| steel plate of tower feet | 7.5 | 4.3 | 43 |

2.2. Galvanized coating inspection
The MiniTest 740 coating thickness gauge (probe FN1.5) was used to measure the thickness of the surface galvanized coating of the most severely corroded tower (III-21). The results are shown in Table 2. It can be seen that the minimum thickness of the galvanized coating of the main transmission tower angle steel meets the requirements, but the thickness is not uniform; the minimum thickness of galvanized coating of cable-stayed steel is lower than the standard and the thickness is uneven; the galvanized coating on the surface of the steel plate has all fallen off due to the serious corrosion damage, so it is impossible to measure the galvanized coating.

2.3. Analysis of corrosion medium
The Energy Dispersive Spectrometer (EDS) was used to analyze the soil medium taken from the base parts of I-21 and III-21 transmission tower. The result shows that the content of S in the soil media at the base of I-21 and III-21 transmission tower is as high as 8%~11%, and contains other heavy metal elements such as Pb, Pd, Ge and K.
The analysis result of the sewage sampled from the I-21 and III-21 transmission tower is shown that the waste water at the feet of the tower has strong acidity (pH=2) and high sulfate concentration (2.64×10^5 mg/L).

Table 2. III-21 steel tower angle steel galvanized coating thickness

| Measured value (mm) | Standard (mm) |
|---------------------|---------------|
| angle steel of tower leg | 75~140 | ≥70 |
| cable-stayed steel | 60~120 | ≥70 |
| steel plate of tower feet | — | ≥70 |

Table 3. Content of soil in the foundation of I-21 and III-21 towers

| Element(wt.%) | O | Si | S | Pb | Pd | Ge | K |
|---------------|---|----|---|----|----|----|---|
| I-21          | 44.00 | 16.60 | 7.89 | — | 1.78 | 1.22 | 0.92 |
| III-21        | 44.00 | 4.63 | 10.80 | 6.31 | — | 0.93 | 0.79 |

2.4. Failure analysis and suggestion

I-21 and III-21 transmission tower are located in the heavy chemical industrial park, and the mass fraction of S element in the surrounding soil and atmosphere is relatively high. The dissolution process of SO2 will produce H+, H+ as depolarizer to participate in the cathodic reaction, so as to accelerate the corrosion rate of zinc coating. In the atmospheric corrosion environment, the zinc coating corrosion will produce the basic zinc carbonate compact film, which can prevent the water infiltration, so as to slow down the subsequent corrosion. However, in the environment with high S content, the basic zinc carbonate film will react with SO2 to produce ZnSO4, unlike the basic zinc carbonate, ZnSO4 is a soluble salt, which can be washed away by rain water, resulting in zinc layer exposure and accelerating the corrosion rate of zinc coating[2]. When the galvanizing coating is completely destroyed by corrosion, the tower steel begins to corrode. Under the high sulfur atmosphere, the steel tower material will corrode and fail soon.

Hot dip galvanizing is suitable for corrosion protection in general atmospheric environment, but in high sulfur soil and sewage environment, hot dip galvanizing coating cannot play an effective role in corrosion protection. In sulfur atmosphere, the corrosion rate of zinc coating can reach 6-7 times of that in general atmosphere.

In order to solve the problem of corrosion failure of I-21 and III-21 transmission tower, it is suggested that the original I-21 and III-21 transmission tower be relocated to the area with low S mass fraction, and the new hot-dip galvanized transmission tower shall be coated with anti-corrosion coating. The system should adopt 30μm epoxy zinc phosphate primer, 80μm epoxy micaceous iron intermediate paint and 50μm acrylic polyurethane finish[3]. Hot dip aluminizing has better ability to resist sulphide corrosion. If it is unable to move, it is recommended to replace the original tower with hot dip aluminizing tower. The thickness of aluminizing layer shall not be less than 86μm, and the new tower shall be coated with anti-corrosion coating.

3. Corrosion failure analysis of connecting bolts in 220 kV Substation

During the patrol inspection of 220 kV Substation in an electric power bureau, it was found that the connecting bolts of several electrical equipment in the substation were rusted, especially the connecting bolts of 2016 disconnector and 201 circuit breaker terminal block.

3.1. Macro inspection

Take down the corroded connecting bolts of 2016 disconnector and 201 circuit breaker terminal block for observation. It can be seen from Figure 2 that the galvanized coating on the surface of most of the bolts has completely fallen off and corroded, and the corroded parts are reddish brown. In addition, there are white powdery corrosion products in some areas on the external surface of the bolts.
3.2. Galvanized coating inspection
In order to evaluate the quality of galvanized coating of connecting bolts, MiniTest 740 coating thickness gauge (probe FN1.5) was used to measure the thickness of galvanized coating of connecting bolts of 2016 disconnector and 201 circuit breaker terminal block with relatively intact galvanized coating, and the test results are shown in Table 4. The results showed that the average thickness of zinc coating of connecting bolts is 10~20μm, and the minimum thickness of zinc coating is only 3.6μm, far away 45μm[3] lower than the standard.

| Table 4. Results of connecting bolt zinc coating |
|-----------------------------------------------|
| Minimum value (mm) | Average value (mm) |
| 2016 disconnector connecting bolts |
| 1 | 3.9 | 10.2 |
| 2 | 6.6 | 11.6 |
| 201 circuit breaker terminal block connecting bolts |
| 1 | 3.6 | 9.6 |
| 2 | 6.9 | 10.8 |

3.3. Analysis of corrosion products
SEM and EDS were used to analyze the white corrosion products on the surface of connecting bolts of 2016 disconnector. As shown in Figure 3, the white corrosion products are dispersed on the bolt base in granular form. The results show that the percentage of Al and O atoms in the white corrosion products is 41.78% and 58.22%, respectively. It can be seen that the white corrosion product is aluminum oxide, which should be caused by the corrosion of aluminum alloy terminal block.

3.4. Failure analysis and suggestion
3.4.1. Failure analysis. In the process of using the aluminum terminal block, rainwater and snow water penetrate into the gap between the bolt and the terminal block to form an electrolyte environment. Because the aluminum terminal block contacts with different metals of the bolt zinc coating, corrosion couple is formed and galvanic corrosion occurs. In the case of galvanic corrosion of dissimilar metals, two metals form a macrocell, which produces galvanic current. The dissolution rate of metal (anode) with lower corrosion potential is faster, and that of metal (cathode) with higher corrosion potential is slower. It has been reported that the corrosion potential of Zn, Al and Fe increases in turn in salt water and snow water[4]. At the beginning of the service of the connecting bolt of the terminal block, the galvanized coating of the bolt is intact, and the zinc coating acts as the anode, which can protect the aluminum terminal block and the bolt body. However, because the thickness of bolt zinc coating (3~20μm) is far less than the standard requirement (45μm), the zinc coating will lose its protective effect due to corrosion. The exposed steel bolt body is in direct contact...
with the aluminum terminal block, which becomes the anode to provide protection for the bolt, accelerating the corrosion rate of the aluminum terminal block, thus forming a large number of silver white aluminum oxide products on the bolt surface. Under the condition of dissimilar metal contact, the corrosion failure of zinc coating of bolt will not only lead to bolt corrosion, but also accelerate the corrosion of aluminum terminal block due to the effect of primary battery.

Figure 3. Macroscopic appearance of (a) 2016 disconnector (b) 201 circuit breaker terminal block connecting bolts.

3.4.2. Prevent the infiltration of corrosive medium. The application of anti-corrosion grease can effectively prevent the infiltration of rain and snow water, and can extend the service life of connecting bolts and terminal blocks. Therefore, the anti-corrosion grease can be applied in the steel core aluminum strand to prevent the corrosion of the aluminum strand caused by the failure of the zinc coating on the steel core[5].

3.4.3. Increase the thickness and adhesion of zinc coating. Zinc as anode can effectively protect the aluminum terminal block and steel bolt. When the zinc coating is intact, the zinc coating can be corroded before the aluminum terminal block and steel bolt. The thickness and adhesion of the zinc coating are directly proportional to its service life. Through research[6], the corrosion rate of zinc coating in heavy industry area is about 6.4μm/a, and the zinc coating below 20μm can only effectively protect 3~4a. Generally speaking, galvanized metal components in power grid equipment require hot-dip galvanizing. Compared with cold galvanizing, hot-dip galvanizing can form a thicker galvanizing coating, so it can play a role of anti-corrosion for metal components in a longer period of time. However, the connecting bolts of the terminal board are all anticorrosive by cold galvanizing technology, and the thickness is less than 20μm, the galvanizing coating will be corroded and consumed soon, which will not play its due anticorrosive role. Therefore, before installation, the quality and thickness of the galvanized coating of the connecting bolt of the terminal board of the power grid equipment should be tested and controlled to extend its protection time and improve its service life.

4. Conclusion

The galvanizing layer corrodes rapidly in the corrosive medium with high S mass fraction, which cannot protect the substrate. Therefore, in the industrial atmosphere or near the industrial park with high S mass fraction, the coating of surrounding galvanized metal components should be checked regularly, and the thickness of the coating should be increased appropriately, or the aluminum coating or aluminum zinc alloy coating should be replaced.
The metal components of power grid equipment shall generally be hot-dip galvanized, because hot-dip galvanizing can provide a thicker coating; before installation, the quality and thickness of the galvanized coating of galvanized components shall be tested and controlled to prevent corrosion failure caused by the quality and thickness of the galvanized coating do not meet the standards.

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