Cause Analysis for a Corroded 220kV Transmission Tower Legs

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Abstract. In this paper, the corrosion cause of a 220 kV iron tower was analyzed by macroscopic examination, chemical composition analysis, microstructure observation and finite element analysis. The results showed that the tower was located in a heavy chemical industry park, the sulfur dioxides and other waste gases discharging from the nearby factories resulted in a high content of sulfate in the foundation of the iron tower. Besides, the drainage of the iron tower was very poor, causing the tower legs immersed in highly corrosive sewage. In addition, the thickness of the galvanized layer on the surface of the tower materials was uneven and the thickness and local zinc content did not meet the standard requirements, finally resulting in poor resistance and accelerating the corrosion of the tower materials. At last, it was advised to replace a new tower with zinc aluminum alloy layer for the better sulfur corrosion resistance and connected by high-strength bolts.

Keywords: Corrosion; Iron tower; Tower leg; Decarburized layer.

1. Introduction
Transmission line plays an important role in the process of power conveying and distribution [1, 2]. However, as the important part of the transmission line, the reliability of iron tower is also an important guarantee for the safe and stable operation of power transmission systems [3, 4]. In 2019, the leg angle steel, the fastening bolts and the connecting plates of a 220 kV iron tower were found to be extensive corrosion damaged. The corroded iron tower was located in a heavy chemical industrial park, being put into operation for 24 years. The materials of the leg angle steel and connecting plate are all Q235, which surfaces are treated by hot-dip galvanizing anti-corrosion process. In order to avoid similar failures happening again and ensure the safe operation of high voltage transmission power system, the corrosion cause of the iron tower was thoroughly studied in this paper.

2. Experimental results and analysis
2.1. Site observation and analysis
After the site inspection, it can be found that there were many high pollution enterprises around the iron tower, besides there was a pungent smell in the around air, which all proved that the operation condition of the tower was very bad, as shown in Figure. 1(a). It can be seen in Figure. 1(b) that the whole iron tower legs were severely corroded, as well as the connecting bolts and grounding wire. In addition, the
tower leg of the other side was obviously crooked and cracked as shown in Figure. 1(c) and Figure. 1(d), which indicates that the overall force balance of the iron tower had changed and the bearing capacity of the tower leg had been seriously insufficient, posing a serious threat.

![Figure 1. Scene photos of the corroded iron tower](image)

(a) general view  (b) corroded tower legs  (c) crooked tower leg  (d) cracked tower leg

2.2. Tower material size and galvanized layer thickness measurement

The measurement results of the material size and galvanized layer thickness for the corroded iron tower are listed in Table. 1. It can be informed that the thickness of all the tower materials is seriously reduced, and the galvanized layer of the connecting plate is nearly disappeared, which reveals that the bearing capacity of the iron tower is greatly decreased, existing potential safety hazard.

| Types            | Design thickness/mm | Measured thickness/mm | Thinning rate/% | Measured thickness of zinc coating/μm | Minimum thickness of zinc coating required by the standard/μm |
|------------------|---------------------|-----------------------|-----------------|--------------------------------------|-------------------------------------------------------------|
| Leg steel        | 11                  | 8.1                   | 26              | 75~140                               | ≥70                                                         |
| Oblique steel    | 5.5                 | 0                     | 100             | 60~120                               | ≥70                                                         |
| Connecting plate | 7.5                 | 4.3                   | 43              | 0                                    | ≥70                                                         |

2.3. Chemical composition analysis

The Chemical composition test results of the tower leg steel are listed in Table.2. It can be seen that the content of each element in the chemical composition meets the requirements of GB/T 700-2006 for Q235B steel [5].

| Tested elements | C     | Si    | Mn    | P     | S     |
|-----------------|-------|-------|-------|-------|-------|
| GB/T 700-2006   | ≤0.20 | ≤0.35 | ≤1.40 | ≤0.045| ≤0.045|
| Tested value    | 0.13  | 0.15  | 0.34  | 0.011 | 0.017 |
2.4. Metallographic microstructure analysis

It can be found in Figure 2 that the matrix structure of the tower leg steel is mainly uniform distributed ferrites and a few pearlitic, indicating the number of the pearlitic are obviously decreased. Besides there are amount of sharp corrosive holes existed in the matrix, under the action of shear stress, stress concentration is easily to be formed along the sharp corner of these holes, resulting in the cracking of the iron material.

![Figure 2. Metallographic structure of the tower leg steel (100×)](image)

2.5. Stress distribution diagram of the iron tower leg

In order to calculate the stress distribution level of the tower legs before and after corrosion, the geometric model is then built according to the design drawings and the actual measurement data, as shown in Figure 3(a). In the process of modeling, the tower materials are calculated according to the main materials thickness reduction due to the angle steels of iron tower has the lightest corrosion thinning rate. Besides, only one single tower leg is selected as the analysis object to improve the calculation speed considering the symmetry of tower leg structure and stress conditions. According to the design manual and considering the operation conditions of the tower under the extreme icing and strong wind conditions, the equivalent load of 19.6 kN is applied to the tower leg and the bottom of the tower foot connecting plate is set as a fixed constraint with tetrahedral mesh elements.

The stress distribution level of the tower legs before and after corrosion is shown in Figure 3(b) and Figure 3(c) respectively. It can be found that the maximum stress appears at the connecting part of connecting plate and main material in both cases. The maximum stress of the tower without corrosion is 180 MPa, however the maximum stress of tower leg with corrosion is up to 280 MPa, exceeding the yield stress of Q235 steel. In the limit case, the corroded tower leg will lead to the plastic bending deformation of the tower legs and even causes tower collapse.

![Figure 3. Geometric model and the stress distribution diagram of the iron tower leg](image)

(a) geometric model (b) before corrosion (c) after corrosion

2.6. Morphology and energy spectrum analysis of corrosion products

Scanning electron microscope (SEM) is then used to detect the tower leg angle steel with corrosion damage. It can be found that there are a large number of corrosion pits on leg angle steel surface, and the corrosion products in the pits are dense and irregular distributed, as shown in Figure 4(a) and Figure 4(b). The corrosion products composition analysis results of the of the leg angle steel surface are listed...
in Table 3. It can be informed that the corrosion products are mainly iron oxides, and the S content is very high, according with the characteristics of acid corrosion. Besides, no Zn is detected in the corrosion products, indicating that the galvanized layer has been consumed.

![Figure 4. SEM morphology of corrosion products](image)

(a) Low magnification (b) local magnified

Table 3. Chemical analysis result of corrosion products (wt%)

| Element | Measured value |
|---------|----------------|
| Fe      | 49.48          |
| O       | 33.08          |
| Si      | 12.64          |
| S       | 3.48           |
| K       | 1.32           |

3. Conclusions and suggestions

It was reported that the zinc coating will form a protective oxide layer and protect the iron matrix from oxygen in the atmospheric environment [6-8]. When the galvanized layer is damaged, the zinc element can also sacrifice as anode thereby protecting the steel substrate. In this paper, the tower was located in a heavy chemical industry park, the sulfur dioxides and other waste gases discharging from the nearby factories resulted in a high content of sulfate in the foundation of the iron tower, which was very acidic and highly corrosive to the concrete foundation and tower materials of the iron tower. Besides, the drainage of the iron tower was very poor, causing the tower legs immersed in highly corrosive sewage for a long time in the rainy season. Therefore, the galvanizing layer had not been able to play an effective anti-corrosion role as used in normal conditions. In addition, the thickness of the galvanized layer on the surface of the tower materials was uneven and the thickness and local zinc content did not meet the standard requirements, resulting in poor resistance and accelerating the corrosion of the tower materials to some extent. The finite element analysis results also revealed that the actual carrying capacity of the tower would be further reduced after the corrosion of iron tower angle steel. Therefore, it was advised to replace this corroded tower, and the new tower material surfaces should be coated with zinc aluminum alloy for the better sulfur corrosion resistance and connected by high-strength bolts. At last, it was better to improve the drainage environment of the tower, avoiding corrosion damage caused by long-term soaking in sewage and sludge.

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