Failure Analysis on Galvanized Steel-tube Pole Used for Supporting Electrical Equipment in 500 kV Substation

Hao Chen*, Feng Tian, Xiaochun Zhao and Weiwei Gong

Inner Mongolia Electric Power Science & Research Institute Hohhot, Inner Mongolia, China

*chenhao3@impc.com.cn
chenhao1984223@163.com

Abstract—Electrical equipment in substation plays a key role in power transmission and distribution, which is usually supported by the steel-tube pole. In recent years, more and more crack defects were found in steel-tube pole used for supporting electrical equipment in substations, thus the safety and stability of power grids is severely affected. In this paper, the cracked steel-tube support of electrical equipment in a 500kV substation was investigated by means of macro-morphology inspection, chemical composition analysis, mechanical properties test, microstructure analysis, water sample analysis and fireworks experiment. The result showed that there was a grouting hole with poor sealing in the top of the steel-tube pole, so the rainwater and snowmelt could flow into the tube through the gaps. Once the temperature dropped abruptly, the water inside the tube would freeze and expand, led to the bursting of the steel-tube pole. Finally, effective suggestions were put forward, which could ensure the electrical equipment operating safely and stably.

1. INTRODUCTION

In substation, electrical equipment such as insulator, circuit breaker and disconnector are mainly supported by steel-tube pole or concrete pole. Once the support fails, it would cause damage to the electrical equipment and affect the safety and stability of the power system. At present, scholars at home and abroad have done a lot of research on the structural stability of electrical equipment support. Wen [1] analyzed the seismic damage of structure and electrical equipment and reviewed seismic performance of substation. Xie [2] studied the seismic behavior of the equipment by shake table test on a full-scale disconnecting switch and estimated the influence of the supporting frame and blades on seismic responses of insulators. You [3] calculated the seismic responses of circuit-breaker for uninstalling and installing lead alloy absorber at the bottom of the support respectively by means of numerical simulation.

In the winter of 2008, eight steel-tube poles used for supporting electrical equipment in a 500kV substation were found cracked by inspector. The crack was located on the longitudinal weld of steel-tube pole and extended along the axial direction. The maximum length and width of the crack was 2500mm and 30mm, respectively. Additionally, other tubes without cracks were found in the substation frozen by of slapping method. The cracked steel-tube pole is made of Q235B with the diameter of 400mm and the thickness of 6mm, and hot dip galvanizing process is adopted for the pole as anticorrosive coating. In order to find out the reason leading to the steel-tube pole crack and ensure the
stability and security of other similar equipment, the cracked steel-tube support was investigated by means of different test methods.

2. EXPERIMENTAL RESULTS AND ANALYSIS

2.1. Macroscopic observation

Figure 1 shows the macro morphology of the cracked steel-tube pole. And it is clearly observed that the tube expands in local area and the edge of the crack is sharp, which illustrates that the tube undergoes plastic deformation before cracking. Meanwhile, the weld is straight and even with a good appearance, and the height and width of the longitudinal weld are 7mm and 20mm respectively. Additionally, no welding defects such as undercut and surface crack are found in the pole.

Through consulting related drawings, it is found that there is a grouting hole with a diameter of 90mm in the top of the cracked steel-tube support. After grouting, the top grouting hole would be welded with a round steel plate, which forms a round weld. Because the gap between the electrical equipment and steel-tube support is too small, it is difficult to evaluate the weld quality, as shown in Figure 2. While for the steel-tube pole adopted root grouting, the weld of the grouting hole could be observed and the welding process is the same as that of the top grouting hole. Therefore, the weld quality of the top grouting hole could be reflected by detecting that of the root grouting hole. Figure 3 shows the macro morphology of the weld for the root grouting hole, and it could be found that the weld quality of the root grouting hole is extremely poor and some areas are not even welded. As a result, it could be considered that the sealing of the top grouting hole is poor, so that the rainwater and snowmelt could flow into the tube through the gaps.
2.2. Metallographic structure analysis

Figure 4 shows the metallographic microstructure of the cracked steel-tube pole. In the cross section, the metallographic structure of the pole is mainly polygonal ferrite and equiaxed pearlite, without abnormal microstructure.

2.3. Chemical composition analysis

The chemical compositions of the substrate material (Q235) and the welding material (E43) of the cracked steel-tube pole are determined by means of chemical composition analysis and the testing results (mass fraction) are shown in Table 1 and Table 2, respectively. The results show that the contents of each element for the substrate material and the welding material used in the tube meet the standard requirement.

| TABLE 1. CHEMICAL ANALYSIS RESULT OF THE SUBSTRATE MATERIAL IN THE STEEL-TUBE POLE (wt%) |
|---------------------------------|-----|-----|-----|-----|-----|
| Chemical element | C   | Si  | Mn  | P   | S   |
| Standard requirements | ≤0.22 | ≤0.35 | ≤1.40 | ≤0.045 | ≤0.045 |
| Test values         | 0.12 | 0.20 | 0.39 | 0.018 | 0.017 |

| TABLE 2. CHEMICAL ANALYSIS RESULT OF THE WELDING MATERIAL IN THE STEEL-TUBE POLE (wt%) |
|---------------------------------|-----|-----|-----|-----|-----|
| Chemical element | C   | Si  | Mn  | P   | S   |
| Standard requirements | ≤0.12 | ≤0.25 | 0.35–0.60 | ≤0.050 | ≤0.035 |
| Test values         | 0.09 | 0.24 | 0.59 | 0.024 | 0.017 |
2.4. Fireworks experiment
Fireworks experiment is adopted to examine the tightness of the grouting hole at the top of the steel-tube support, as shown in Figure 5. Before the fireworks experiment, a small hole should be drilled on the tube, and then the lit fireworks would be put into it for observing diffusion of smoke. The result shows that the smoke could be emitted from gaps between the electrical equipment and cracked steel-tube support, while there is no leakage of smoke for the unfrozen tubes. Thus, it illustrates that the top grouting hole in the cracked tube is not well welded, resulting in poor sealing.

![Fireworks experiment site.](image)

2.5. Water sample analysis
Table 3 shows the result of water sample analysis for the water inside the steel-tube pole. The result shows that the inner water of the tube is similar to the condenser water, and its quality is obviously better than that of ambient water. This is because the water in the tube is purified during long-term evaporation and condensation due to the seasonal change of weather.

| Test item                               | Test values |
|-----------------------------------------|-------------|
| Phenolphthalein alkalinity (mmol/L)     | 0           |
| Methyl orange alkalinity (mmol/L)       | 0.26        |
| Calcium ion concentration (mmol/L)      | 0           |
| Magnesium ion concentration (mmol/L)    | 0           |
| Water hardness (mmol/L)                 | 0           |
| Chloride concentration (mg/L)           | 5.36        |
| Sulfate concentration (mg/L)            | 11.29       |
| Aluminum ion concentration (mg/L)       | 0           |
| Iron ion concentration (mg/L)           | 1.73×10⁻³   |
| Conductivity (µs/cm)                    | 129         |

2.6. Mechanical properties testing
The mechanical properties of the cracked steel-tube pole are tested by universal tensile testing machine at room temperature and the testing result is shown in Table 4. The result shows that the yield strength,
tensile strength and percentage elongation after fracture of the steel-tube support meet the requirement of standard GB/T 700-2006.

### TABLE 4. The Test Result of Mechanical Properties of the Cracked Steel-Tube Pole (20°C)

| Test item                      | Yield strength /MPa | Tensile strength /MPa | Percentage elongation after fracture /% |
|--------------------------------|---------------------|-----------------------|----------------------------------------|
| Standard requirements          | ≥225                | 370~500               | ≥26                                    |
| Test values                    | 293                 | 416                   | 30                                     |

### 3. ANALYSIS AND DISCUSSION

The longitudinal weld of the steel-tube pole is welded by means of automatic submerged arc welding, and its shape (including weld height and width) meets the design requirement. Additionally, there is no surface and interior defect in the weld, and the contents of each element for the substrate material and the welding material used in the tube meet the standard requirement. Therefore, the longitudinal weld strength of the steel-tube pole is sufficient for supporting equipment and bearing wind pressure [4].

Under the 500kV substation, there is a basalt layer, and two deep wells of more than 100 meters have been drilled, but no water source has been found. The water supply of substation staff is transmitted from remote areas, so the water in the tube could not come from the groundwater. After the concrete foundation is cured for twenty-eight days, the steel-tube pole was installed and fixed by grouting, and the grouting hole was not welded and sealed until ten days later. Therefore, the possibility of water accumulation in the tube caused by grouting is excluded.

There is a concrete layer with the thickness of 1.2m at the bottom of the steel-tube pole, so that the water inside the tube could not penetrate downward. In recent two years, the precipitation in this area has increased significantly. Due to the small gap on the top of the support, the water inflow is far greater than its evaporation, so the water volume in the tube gradually increases. After a long time of distillation, the water inside the tube is purified to make the upper water clear and the lower water turbid.

The results of fireworks experiment and weld inspection of root grouting hole illustrate that the sealing of the top grouting hole is poor. According to statistical result, it could be found that top grouting is adopted for the frost-cracked tubes, while there is no frost crack in the ones without top grouting holes. Thus, it could be concluded that the water inside the tube comes from the rainwater and snowmelt, which flows into the steel-tube pole through the gaps of the top grouting hole.

When the temperature drops suddenly, the water inside the tube would freeze and expand. As a result, the tube would bear a considerable internal pressure, which makes the tube undergo a two-dimensional stress state [5]. When the local stress exceeds the yield stress of Q235, plastic deformation would occur. Additionally, the tangential stress in the tube is twice of the longitudinal one and the weld is the weak point of the whole tube. Therefore, with the increase of stress, the steel-tube pole would burst along the longitudinal weld.

### 4. CONCLUSIONS

In this paper, the cracking reason for the steel-tube pole was systematically investigated and analyzed. Through comparing and analyzing the experimental results, the following conclusions are drawn.

1) The cracked steel-tube support adopts top grouting and the grouting hole is not tightly sealed. In this way, rainwater and snowmelt could flow into the steel-tube support through the gaps. When the temperature drops abruptly, the water inside the tube would freeze and expand, which makes the steel tube burst.
2) Considering that the steel-tube poles of the electrical equipment have cracked many times in the power grid, the supports used in other similar equipment should be comprehensively inspected and the cracked ones should be replaced in time.

3) In order to avoid water accumulation in the steel-tube pole, drainage hole should be set at the root of the tube. Meanwhile, the frozen but not cracked steel-tube pole should be heated to melt the ice inside the tube, which would be discharged from the drainage hole.

ACKNOWLEDGMENT
The authors would like to acknowledge the financial support from the Science and Technology Project of Inner Mongolia Power Company (Grant No. 2019-102).

REFERENCES
[1] B. Wen, D. T. Niu and P. Zhao, “Review of substation seismic performance research,” Earthquake Resistant Engineering and Retrofitting, vol. 29, pp. 73–77, 2007.
[2] Q. Xie, R. Y. Zhu, Y. Zhou, W. Yang and Y. F. Wang, “Shake table test on 220kV disconnecting switch,” Power System Technology vol. 36, pp. 262–267, 2012.
[3] H. B. You and F. X. Zhao, “The anti-seismic performance analysis of the porcelain knob type SF6 high-voltage circuit-breaker,” Technology for Earthquake Disaster Prevention, vol. 5, pp. 418–427, 2010.
[4] X. Wang, “Failure cause analysis of aluminium alloy trestle,” Corrosion & Protection in Petrochemical Industry, vol. 34, pp. 44–47, 2017.
[5] Y. T. Han, K. J. Liu and Y. H. Zhang, “Vibration characteristics and failure analysis of a heavy-duty truck exhaust brake bracket using finite element technique,” Failure Analysis and Prevention, vol. 8, pp. 145–150, 2013.