Breaking Cause Analysis on a 110 kV Overhead Grounding Wire (OGW)

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Abstract: An in-serviced 110kV overhead grounding wire (OGW) was found to be broken, and the fracture cause was then studied by means of macroscopic morphology and metallographic observations, fracture microanalysis and mechanical properties testing. The results revealed that the fracture of OGW was mainly resulted from the lightning stroke, which was mainly informed from the craters on the surface of the broken wire steel strand by fracture morphology observation results. The lightning currents led to a rapid temperature rise, which eventually caused the surface OGW to be broken by tension after fusing or partially fusing under high temperature. At last, it was advised that coarser steel strands should be used in areas with frequent lightning strikes to improve the thermal stability of OGW, and the metal technical supervision in the operation process of high voltage transmission lines should also be strengthened.

1. Introduction
Overhead grounding wire (OGW) plays an extremely important role in long-distance transmission system [1]. Therefore, the reliability of the OGW is very important. If the quality of the OGW is poor, broken faults may be caused and thereby impact the safe and stable operation of the transmission power system [2, 3]. In November 2019, several steel strands were found to be broken on the OGW surface of one 110kV transmission line, and the broken points was about 20 meters away from the tower. The model of the broken OGW is GJ-50 with the outer diameter of 9.0 mm, and the diameter of single steel wire is 1.80 mm. The transmission line was put into operation in 2004. In order to avoid similar failures happening again and ensure the safe operation of high voltage transmission power system, the broken cause of the OGW was thoroughly studied in this paper.

2. Experimental results and analysis

2.1. Geometric dimension measurement and analysis
GB/T 3428-2012 stand requires that the allowable diameter deviation is ± 0.03 mm for the galvanized steel strand with nominal diameter of 1.24 mm to 2.25 mm [4]. Therefore, the diameter of the broken steel strands was measured by micrometer. During measurement, three sections were selected for each single steel wire with each section measured twice, and the results were listed in Table 1. The results revealed that the diameter deviation of the single steel strands meet the standard requirements.
Table.1 Section diameter of the single steel strand (mm)

| Sample | Average value | Diameter deviation |
|--------|---------------|--------------------|
| #1     | 1.81          | +0.01              |
| #2     | 1.81          | +0.01              |
| #3     | 1.82          | +0.02              |

2.2. Macromorphology observation and analysis
As shown in Figure. 1(a), there are four single steel strands broken on the surface of OGW. Besides, some obvious high temperature fusing features can be found on the fracture surface of each single steel strand, and some carbon black spots and small metal tumors can also be easily seen on the fracture surface. In addition, no obvious mechanical damaged and plastic deformed characteristics are found on the fracture surface, as shown in Figure. 1(b).

![Figure 1](image1.png)

Figure.1 Macroscopic morphology of the broken OGW
(a) whole (b) locality

2.3. Fracture observation and analysis
The micro fracture morphology observation results indicate that the fracture surfaces as well as the regions near the fracture surface are all presented obvious high temperature melting morphology characteristics, as shown in Figure. 2(a).

![Figure 2](image2.png)

Figure.2 Micro fracture morphology of the broken OGW
(a) cross direction (b) longitudinal direction

In addition, no obvious transverse cracks are found on the outside of the steel strand fracture surface, and no other mechanical damage defects are found on the fracture surface of each broken steel strand as shown in Figure. 2(b).

2.4. Microstructure observation and analysis
The metallographic microstructure observation results are as shown in Figure. 3. It can be seen in Figure. 3(a), the microstructure of the fracture can be divided into two regions. In region I which is far away from the fracture, the matrix structure is mainly consisted of fibrous sorbites and a few ferrites. While the fracture tip matrix (region II) is mainly composed of the typical high-temperature quenching structures (acicular martensites), showing some intergranular cracking characteristics (Figure. 3(b)). Besides, the decarburization layer of the cross section of the broken steel strand is measured to be
about 66 microns deep (Figure. 3(c)). It can also be seen in Figure. 3(d) that there are obvious non-metallic inclusions in the matrix of the broken steel strand, which are mainly class C silicate inclusions with the coarse grade 2.5 according to rating criterion of GB/T 10561—2005 [5].

![Figure 3](image)

> **Figure.3** Metallographic structure of the broken single steel strand
> (a) longitudinal direction (whole) (b) longitudinal direction (locality) (c) decarburization layer (cross direction) (d) non-metallic inclusions-C (longitudinal direction)

### 2.5. Mechanical property test

Table 5 shows the mechanical properties of the broken OGW. It can be seen that the tensile strength of the single steel strand is 1573 MPa and the elongation is 5.3%, which all meet the minimum value requirements specified in GB/T 3428-2012 [4]. The winding test results show that no visible cracks are found on the surface of the single steel strand, which indicates that the toughness of the tested OGW is qualified.

| Items                     | Tensile strength/MPa | Elongation/% | Winding performance |
|---------------------------|----------------------|--------------|---------------------|
| Standard value (GB/T 3428-2012 [4] and GB/T 2976-2004 [6]) | $\geq 1310$          | $\geq 3$      | No cracks on the surface |
| Measured value            | 1573                 | 5.3          | No cracks           |

### 3. Conclusions and suggestions

From the above comprehensive analysis above, the main cause of the in-serviced 110 kV OGW breaking failure was that the OGW was hit by lightning during operation, and the temperature of the overhead ground wire rises rapidly due to the lightning current arcing, which eventually caused the surface OGW to be broken by tension after fusing or partially fusing under high temperature.

At last, it was advised to use coarser single wire steel strand to improve the thermal stability of the OGW in the area with frequent lightning stroke. Besides, according to metallographic structure observation results, there were obvious decarburization layer defects on the steel strand surface, which may be the cracking source under certain operation conditions. Therefore, it was also necessary to
strengthen the metal technical supervision and inspection during the operation of high voltage transmission line.

Acknowledgments
This research was financially supported by Science and technology project of Inner Mongolia Power Company (Grant No. 2019-37)

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