Case Analysis on the Abnormal Heating Defect of a 220kv XLPE Cable Intermediate Joint

Zhang Hao*, Li Pengfei, Ma Guoqing, Chen Zilong, Duan Yubing and Hu Xiaoli
State Grid Shandong Electric Power Research Institute, Jinan, China
Email: qinjiafeng@stu.xjtu.edu.cn

Abstract. In this paper, through the infrared temperature measurement and high frequency partial discharge detection, we found an abnormal heating defect in the intermediate joint of 220kV cable. After dissecting the intermediate joint and measure the insulation resistance of internal epoxy components in the laboratory, the causes of the defects were analyzed. The overall heating of the middle joint of the cable shall be caused by the damp insulation. Partial discharge detection can not detect the cable insulation moisture defects. The effect of The infrared temperature measurement is good.After that, the hidden danger of the equipment was dealt with in time and a serious power grid accident is avoided. This case verifies the practicability of infrared temperature measurement in abnormal heating diagnosis of the cable line, and also verifies the limitations of partial discharge detection for internal damp fault diagnosis. This paper also points out the design defect of intermediate joint of similar structure, which provides the basis and reference for the future work.

1. Introduction
In recent years, due to the rapid economic development, the power supply is very tight, which leads to a new round of power investment and construction climax. With the rapid expansion of power grid scale and the continuous improvement of voltage level, the security of power operation is increasingly prominent. In particular, cross-linked polyethylene (XLPE) high-voltage cables are widely used in urban underground power grid, resulting in new security issues [1-3].

The insulation structure of cable terminal and intermediate joint is complex, and the field installation is affected by the process level and environmental conditions, which is the fault prone part [4,5].

Infrared temperature measurement and high frequency PD detection do not affect the normal operation of the cable line, and the effect is obvious. So they are widely used in the fault analysis of high-voltage cable [6-8].

In this paper, infrared temperature measurement and high frequency partial discharge detection technology are used to detect an abnormal heating defect of high voltage cable line in time. The cause of abnormal fever was analyzed by anatomic examination. The hidden danger of the equipment was dealt with in time, which avoids a serious power grid accident.

2. Basic information of cable line
In the routine test, it is found that there is abnormal heating in the #4 intermediate joint of a 220kV cable line. The heating parts of the three phases are the same, which located in the middle of the joint.
The faulty line was put into operation in 2002, which connect two substations with XLPE cable of a cross-sectional area of 800 mm². And the line has seven intermediate joints. The total length of the line is 4.71 km, and the channel is a tunnel with humid environment. Figure 1 is the schematic diagram of the line.

![Schematic Diagram of Cable Line](image)

**Figure 1.** The Schematic Diagram of Cable Line

3. The results of on-site inspection

3.1 The results of high frequency partial discharge test

PD check partial discharge instrument is used to detect the partial discharge of the #4 intermediate joint. The detection results of phase-amplitude and time-frequency of three phases are shown in Figure 2~4.

![Diagram of Phase-Amplitude](image)

**Figure 2.** The high frequency partial discharge test of A Phase

![Diagram of Time-Frequency](image)

![Diagram of Phase-Amplitude](image)

**Figure 3.** The high frequency partial discharge test of B Phase
The diagram of phase-amplitude

The diagram of time-frequency

Figure 4. The high frequency partial discharge test of C Phase

Through the analysis of three-phase phase-amplitude diagram and time-frequency diagram of the #4 intermediate joint, we found that there was no obvious partial discharge signal in three phases. The collected signal is evenly distributed in all quadrants, which is judged as the noise interference from the outside.

3.2 The results of infrared temperature measurement

FLIR T660 infrared thermal imager is used to measure the temperature of the #4 intermediate joint. The results of infrared temperature measurement of three phases are as follows. The three-phase infrared temperature measurement results are as follows.

3.2.1. The A Phase of #4 intermediate joint. The infrared temperature measurement spectrum of A phase of the #4 intermediate joint is shown in Figure 5.

Figure 5. The infrared thermometric spectrum of A phase

It can be seen from the infrared spectrum that there is a heating phenomenon in the middle part of A phase. The maximum temperature of the heating part is 31.5°C, and the temperature of the normal part is 29.4°C, which the temperature difference is 2.1K.

3.2.2. The B Phase of #4 intermediate joint. The infrared temperature measurement spectrum of B phase of the #4 intermediate joint is shown in Figure 6.
Figure 6. The infrared thermometric spectrum of B phase

It can be seen from the infrared spectrum that there is a heating phenomenon in the middle part of B phase. The maximum temperature of the heating part is 35.2°C, and the temperature of the normal part is 29.0°C, which the temperature difference is 6.2K.

3.2.3. The C Phase of #4 intermediate joint. The infrared temperature measurement spectrum of C phase of the #4 intermediate joint is shown in Figure 7.

Figure 7. The infrared thermometric spectrum of C phase

It can be seen from the infrared spectrum that there is a heating phenomenon in the middle part of C phase. The maximum temperature of the heating part is 27.7°C, and the temperature of the normal part is 26.5°C, which the temperature difference is 1.2K.

The heating parts of the three-phase intermediate joint of the #4 intermediate joint are the same, which located in the middle part. The interphase temperature differences of three-phase heating parts are 3.7k, 7.5K and 3.8K, which are very serious.

4. The anatomy and test of intermediate joint

4.1 The anatomy in laboratory

The intermediate joint was dissected layer by layer according to the drawings in the laboratory. After cutting the outer heat shrinkable tube of the joint, it is found that the water in the inner side of the heat shrinkable pipe is serious, and the copper strip and lead strip wrapped on the outer side of the epoxy part are damped, as shown in Figure 8.
Figure 8. The drippy copper and lead strips on the outside of epoxy parts

After removing the protective copper shell of the cable joint, it was found that there was water in the epoxy part and there was water in the copper shell, as shown in Figure 9. There are water drops on the insulation gasket, as shown in Figure 10.

Figure 9. The drippy protective copper case

Figure 10. The drippy rubber gasket

After opening the stress cone stopper, it is found that there are water drops on the inner surface of the stress cone stopper, as shown in Figure 11. This indicates that the outer surface of the stress cone has been damped.

After the stress cone is opened, there is no obvious abnormality in the main insulation of the cable near the stress cone. The inner surface of the stress cone is located at the joint of the main insulation of the cable and the outer semiconducting, which has normal aging phenomenon during long-term operation, as shown in Figure 12. There is no abnormality at the crimping part of the connector core.

Figure 11. The water drops of the stress cone stopper

Figure 12. The aging trace of stress cone
4.2 Test results of resistance
It can be seen from the anatomy that the epoxy parts of the intermediate joint have been damped. In order to judge the moisture condition, the epoxy parts were heated for two hours with heating belt to remove the moisture. Test the resistance of epoxy parts before and after dehumidification. Before dehumidification of epoxy parts, the resistance of the epoxy parts is 37GΩ at 500V and 26GΩ at 2500V. After dehumidification, the resistance is 105GΩ at 500V and 130GΩ at 2500V respectively. The resistance of epoxy parts are shown in Table 1.

| Voltage (V) | Resistance (GΩ) |
|------------|-----------------|
| before dehumidification |           |
| 500        | 37              |
| 2500       | 26              |
| after dehumidification  |           |
| 500        | 105             |
| 2500       | 130             |

Table 1 The resistance of epoxy parts before and after dehumidification

5. The analysis of defect
According to the analysis of on-site inspection and laboratory anatomy, the heat of the #4 intermediate joint of a 220kV cable line is caused by the moisture of the epoxy resin parts caused by the water in the joint. After being damped, the resistance of epoxy part decreases and the dielectric loss increases. The highest voltage part in the middle of the intermediate joint is seriously heated. The middle joint of the cable adopts the structure of copper shell on both sides which butting the epoxy resin main body. The outer side is insulated by heat shrinkable sheath, without other waterproof filling layer, and the waterproof performance is poor.

Figure 13. The resistance measurement of epoxy parts before and after dehumidification

Figure 14. The schematic diagram of #4 cable joint
The operation environment of the cable tunnel where the joint is located is humid. When the joint operates in humid environment for a long time, the heat shrinkable sheath loses its elasticity. At the joint of copper shell and epoxy resin, voids are easy to be formed (Figure 14), and water vapor is easy to enter. The main body of the epoxy resin is damped by water absorption, and the resistance decreases. When the epoxy resin part is damped, its resistance decreases and dielectric loss increases. Finally, the temperature in the middle of the joint increases. In addition, the whole epoxy resin part is uniformly heated, which is consistent with the infrared temperature measurement image. This also confirms the conclusion.

6. Conclusion
The judgment of cable defects requires a variety of comprehensive methods. Partial discharge detection cannot detect the cable insulation moisture defects. The infrared temperature measurement can be used for the detection of cable insulation moisture, and the effect is good. The overall heating of the middle joint of the cable shall be caused by the damp insulation. For the structure of isolating metal sheath with insulating joint at both ends of intermediate joint, secondary protection measures such as waterproof shall be fully considered.

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