Analysis and Treatment of the Cause of Heating of Single-core XLPE Cable GIS Terminal

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Abstract. In this paper, the heat generation of 110kV cable GIS terminal discovered by infrared thermal imager is briefly described. The causes of heat generation are discussed by means of sheath current detection and circulation calculation, and further analysed by high frequency partial discharge monitoring system, timely handling of equipment hidden dangers, to avoid the occurrence of vicious accidents. Through the analysis and judgment of this accident, the significance of infrared temperature measurement, sheath current detection technology and high frequency partial discharge detection technology for the discovery of cable defects is proved, which provides a basis and reference for future work.

1. Introduction

With the deepening of urban power grid reconstruction work, power cables have become the meridians of the distribution network. Therefore, ensuring the safety and stability of cable lines is directly related to the reliability of the entire power supply system. In this paper, the sheath current test, infrared temperature measurement technology and high-frequency partial discharge detection technology are used to detect a high-voltage cable line current abnormal event in time. Through analysis and demonstration, the cause of excessive current and terminal heat is found out, and the equipment hidden danger is dealt with in time. This will avoid the occurrence of a vicious accident.

2. Shelter grounding method of high voltage cable

AC single-core cable usage is getting higher and higher. When it is subjected to overvoltage or asymmetric short-circuit fault, a high induced voltage is formed on the metal sheath, which causes breakdown of the sheath insulation, so special grounding is required. In this way, the insulation of the cable sheath is prevented from being broken down. Common grounding methods for high-voltage single-core cables are as follows [1].

2.1. Grounding at both ends of metal sheath

Grounding the two ends of the sheath means that the two ends of the metal sheath are directly grounded. This kind of grounding method can reduce the workload, but there is a circulation on the metal sheath, the applicable conditions are harsh, the cable line is required to be short, the transmission power is small, the transmission capacity has a large margin, etc., so it is generally inappropriate to adopt this way.
2.2. *One end of the metal sheath is grounding, and the other end is protective grounding*  
When the cable line is short (within 500m), the metal sheath is usually grounded directly at one end. And the other end is grounded through the protector. The ground insulation does not form a loop, which can reduce and eliminate the circulation, which is beneficial to improve the transmission capacity of the cable and the safety of the cable run.

2.3. *Metal sheath midpoint grounding, protective grounding at both ends*  
When the cable line is long (within 1000m), if the cable line is grounded at one end, the induced voltage of the metal sheath will not meet the design specifications, and the metal sheath of the cable can be grounded at a single point at the midpoint of the cable line. The two terminals of the cable metal sheath are grounded through the protector. Therefore, the cable line using this grounding method can be regarded as a connection method in which two cable lines of directly grounded at one end and protected at one end are connected together.

2.4. *Metal sheath cross interconnection*  
The cross-connection of the sheath means that the cable line is divided into several large sections. Each section is divided into three sections of equal length in principle. Each small section is connected by an insulated joint, and the metal sheath of the insulated joint is connected by a coaxial cable. Box (also known as transposition box) for transposition connection, a set of sheath protectors are installed in the transposition box at the insulation joint, and the sheaths at both ends of each section are interconnected and grounded. When the cable line is > 500m, the connection of the sheath cross-connection can be used.

3. Analysis of temperature abnormality of 110kV cable sheath  

3.1. *Cable terminal temperature is too high*  
![Infrared imaging map of GIS terminal in station](image)

During the infrared temperature measurement of the high-voltage cable, the operation and maintenance personnel found that the temperature of phase B of the GIS terminal of a certain cable of 110kV was too high, as shown in Figure 1, the temperature difference between the phases was 20°. The cable is from the GIS in the station to the gantry outside the station, with a total length of 60m and cable type YJLV-1*400. It was put into operation in 2003, and the normal load current is 250~400A. The grounding mode of the metal sheath is grounded by the protector in the station and directly grounded outside the station.

3.2. *Cause analysis*  
According to the infrared thermo gram analysis, the hot spot is located at the junction of the cable end tube and the cable sheath. The initial reason for the heat is that the lead is not strong and the contact resistance is too large. In order to further determine whether the cause of heat generation is voltage heating or circulation heating, we use a clamp-type ammeter to clamp the sheath current at the grounding
box at both ends of the cable and the connection between the GIS switch bottom plate and the sealing base (as shown in Fig.2). The current was tested and the test results are shown in Table 1.

![Image of test position](image)

**Fig. 2** GIS terminal current test position in the station

| Sheath current test position                     | Capacitance current measured value |
|--------------------------------------------------|-----------------------------------|
| Outer station cable protection grounding box      | A: 240A, B: 240A, C: 220A, Zero sequence: 20mA |
| GIS terminal cable directly at the grounding box  | A: 11.9mA, B: 7.6mA, C: 6.1mA, Zero sequence: 3.4mA |
| GIS sealing base connection line                  | A: 6*38A, B: 6*35A, C: 6*35A, Zero sequence: — |

According to the structural characteristics of the GIS terminal, the switch bottom plate and the seal base of each phase are connected by 6 bare copper wires. As shown in the test results of Table 1, the current of each copper wire is about 35A, and the current and station after six parallel connections the current at the external direct grounding box is equivalent. Therefore, in the manufacturing process of the cable terminal, due to the direct connection of the sheath grounding wire to the metal base of the GIS, the sheath is grounded through the metal casing of the GIS, so that the grounding protector is short-circuited and loses protection. Thus, the grounding method of the sheath at the time of design is changed, and one end is protected from grounding, and one end is directly grounded to become directly grounded at both ends of the sheath. The induced voltage forms a circulation between the sheath and the ground, causing heat to be generated at a large contact resistance. To verify our analysis, we calculated the cable sheath current that was directly grounded at both ends.

### 3.3. Cable sheath circulation calculation of direct grounding at both ends

The current flowing through the conductor of a high-voltage single-core cable under operating conditions generates an induced voltage in the metal sheath of the cable. When the two sections of the sheath are directly grounded, the induced voltage will form a large circulation between the sheath and the ground due to the small enough resistance, which will endanger the stable operation of the cable.

The cable line is laid in a triangular arrangement, and the calculation formula of the sheath induced voltage is as follows [2].

\[
\hat{U}_{SA} = \hat{U}_{SC} = \frac{jXI_B(-1+\sqrt{3})}{2} 
\]  

\[
jXI_B = \hat{U}_B 
\]

\[
X = 2w\ln\left(\frac{S}{r_i}\right) \times 10^{-9} (\Omega/cm)
\]
Where \( U_{SA} \), \( U_B \), and \( U_{sc} \) are the induced voltages of the A, B, and C three-phase metal sheaths respectively. \( I_B \) is the B-phase current; \( S \) is the distance between the axes; and \( r_s \) is the average radius of the metal sheath.

Taking the B phase as an example, according to the above formula, when the load current is 300A and the distance between the shafts is 220m, the induced voltage of the B-phase sheath is 18.75V, which satisfies the induction of GB50217-94 on the metal sheath of the single-core cable. The voltage does not exceed 50V.

However, due to the particularity of the GIS terminal structure in the station to which the cable is connected, the cable sheath is grounded at both ends, and a circulation is formed between the grounding point and the ground, as shown in Fig. 3. The circulating current formed by the induced voltage in the sheath is calculated according to the formulas (4) and (5), and the sheath circulation \( I_{SB} = 288A \) is obtained. The sheath circulation of the other two phases is equal to the phase B, and the phase difference is 120° [3].

\[
\dot{I}_{SB} = \frac{jX I_B}{R_S + jX} \tag{4}
\]

\[
R_S = \frac{40 \rho_S}{\pi (d_{s2}^2 - d_{s1}^2)} \times 10^{-5} (\Omega/cm) \tag{5}
\]

Where \( R_S \) is the metal sheath resistance; the resistivity of the \( \rho_S \) metal sheath; \( d_{s1}, d_{s2} \) are the inner and outer diameters of the sheath.

Since the calculation of the grounding resistance and the influence of the ambient temperature on the resistivity is not taken into account in the calculation process, the calculated value is slightly larger than the measured value, but it can still be proved by comparison that the circulation of the cable is too large because of the sheath direct grounding at both ends.

![Fig. 3 Schematic diagram of the metal sheath of a single core cable](image)

3.4. High frequency partial discharge detection

3.4.1. The test data of Phase A. The operation and maintenance personnel use the high-frequency cable PD monitoring system to test the cable lines. The detection signal and the characteristic maps of phase A are shown in Fig. 4.

It can be seen from Fig. 4 that there is a significant pulse signal in the test of 110kV I line’ phase A, the signal amplitude is low, and the signal exhibits a relatively obvious phase distribution characteristic.

The cable test of 110kV I line’ phase A was continuously monitored for 24 hours, and the obtained signal change trend is shown in Fig. 5.
It can be seen from Fig. 5 that the signal change trend measured in the phase A of the cable is not stable, exhibits abnormal fluctuation, and should be followed by attention.

3.4.2. The test data of phase B. The real-time detection signal and feature maps of phase B are shown in Figure 6.

As can be seen from Fig. 6, there is a significant pulse signal in the cable test of phase B. The signal amplitude is high and the signal exhibits a distinct phase distribution characteristic.

The phase B was continuously monitored for 24 hours, and the signal change trend obtained is shown in Fig. 7.
It can be seen from Fig.7 that the signal change trend measured in the phase B is not stable, showing obvious abnormal fluctuations, and the subsequent attention should be paid attention.

3.4.3. The test data of phase C. The real-time detection signal and feature maps of phase C are shown in Figure 8.

It can be seen from Fig. 8 that there is continuous monitoring of the cable test phase C for 24 hours in the C-phase grounding line of the cable test, and the obtained signal change trend is as shown in Fig. 9.
It can be seen from Fig. 9 that the signal change trend measured in the cable C phase is not stable, showing obvious abnormal fluctuations, and subsequent attention should be paid.

The three-phase high-frequency partial discharge signal at the joint has obvious pulse characteristics, and both exhibit obvious phase distribution characteristics. The amplitude of phase B is larger than the other two, and the results of infrared temperature measurement, sheath current detection and high frequency partial discharge detection are combined to determine that the joint defect is located in phase B.

4. Defect processing
Under normal circumstances, the cable connected to the overhead line is normally grounded at the overhead line and the protector is installed at the other end. However, due to the particularity of this line, such installation will cause the protector in the station to lose its protective effect, resulting in a large circulation on the cable jacket. Therefore, after analysis and demonstration, we changed the grounding method of the cable sheath, and replaced the protective grounding box in the station with the direct grounding box outside the station, so that the protection outside the station was grounded and the station was directly grounded. After one day of resuming power transmission, we tested the cable termination temperature and sheath current again, and the test results returned to normal.

5. Conclusion
The cable terminal heating defect was caused by the wrong cable jacket grounding method, which caused a large circulation. Therefore, several precautions were proposed according to the defect handling.

(1) When selecting the single-core cable sheath grounding method, careful analysis and detailed demonstration should be carried out, and combined with the structural characteristics of the electrical equipment, the sheath circulation should be reduced and eliminated to ensure the stable operation of the cable.

(2) The temperature measurement of the cable through infrared temperature measurement technology can effectively monitor the operation status of the equipment. The online real-time temperature monitoring system can be used to monitor the cable temperature for key lines and key parts.

(3) Strengthen the sheath current test for the running cable, and find and deal with the abnormality of the current abnormality in time to avoid the occurrence of malignant accidents.

(4) The PD detection technology can effectively judge the position of the cable defect, but the actual situation should be combined with the infrared temperature measurement result and the sheath current detection result to comprehensively judge the cable defect.

References
[1] Jiang Rihong. XLPE power cable line, China Electric Power Press, Vol.11(2009) No.21, p.27-29.
[2] Chen Chuanting, Zhang Guosheng, Zhou Zhicheng et al. Circumfluence Method for Monitoring Multi-point Grounding of XLPE Cable Metal Sheath. High Voltage Technology, Vol.5(2002) No.3, p.122-125.
[3] Zhang Lilin. Research on on-line detection system for 110~220kV single-core high-voltage cross-linked cable sheath insulation. China Electrical Engineering Society High Voltage Committee 2007 Annual Conference, Vol.8(2007) No.21, p.225-228.