Design and research of temperature measurement system for intermediate joint of 10kV power cable

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Abstracts: Cable intermediate joint is the weak link of power cable. Its operation determines the quality of power transmission and distribution in power system. The temperature rise of the intermediate joint is the direct manifestation of a variety of faults. Therefore, monitoring the temperature of the intermediate joint of power cable and finding and eliminating cable faults in advance is of great significance to ensure the safe and reliable operation of power system. Based on the analysis of the temperature characteristics of the cable intermediate joint, the design scheme of the temperature measurement system of the power cable intermediate joint is given, and its hardware system and software system are designed. Finally, the temperature measuring device for the intermediate joint of power cable is obtained, tested on the spot, and the power consumption of the data is analyzed. The debugging results show that the system has good characteristics and meets the design requirements.

1. Introduction

The defect of cable accessories is an important cause of cable failure. For long-distance transmission cables, it is bound to need more intermediate joints to connect all parts of cables together [1]. The manufacturing process of the intermediate joint requires high requirements. Once it is unqualified, parasitic resistance, inductance and capacitance will be generated, and long-term operation will lead to the failure of the intermediate joint [2-3]. At present, the manifestation of most faults is the change of temperature. Therefore, it is very necessary to design the temperature measurement system of power cable intermediate joint. At the same time, because the output power of the intermediate joint of the power cable is not high, the low power consumption of the temperature measurement system is also a very important index. In order to solve the above problems, this paper intends to use the finite element method [4-6] to calculate the joint temperature field, and carry out preliminary simulation analysis on the design of the system. On this basis, the main system of low-power cable intermediate joint is designed [7-8]. According to the design idea, the main system complete of hardware system and software system, and finally make the physical device for testing [9]. The test results well meet the system design requirements.

Cable joint temperature change is a complex non-linear process, using the cable skin temperature to derive the core temperature is affected by the load current, ambient temperature, etc. The derivation of
the joint core temperature is a multivariate nonlinear regression problem.

2. Temperature characteristic analysis of power cable intermediate joint

The calculation of the intermediate joint temperature of power cable can determine the temperature measurement range of the temperature sensor of the temperature measurement system, estimate the conductor temperature and determine the high temperature alarm value. The temperature field of the intermediate joint will be solved by using the finite element calculation software COMSOL to calculate the temperature distribution of the intermediate joint under different operating conditions.

2.1 Calculation of temperature rise of power cable

The temperature characteristic of the intermediate joint of power cable determines the initial value setting of the subsequent system. The temperature measurement system needs to monitor the surface temperature of the intermediate joint, so it is necessary to study the variation range of the surface temperature under different operating conditions, so as to provide reference for the design of the temperature monitoring system. The surface temperature of the joint fluctuates in a certain range under different operating conditions. When the joint structure and material parameters are determined, the specific value is determined by the circulating current value of the joint and the ambient temperature. The higher the current, the higher the ambient temperature and the higher the surface temperature of the joint. For the temperature measurement system, two data are mainly needed: 1) the joint surface temperature of the cable under rated operation to determine the main working temperature range of the temperature sensor; 2) The maximum working temperature on the surface of the cable joint to determine the upper limit of the temperature measurement of the temperature sensor. After these two data are determined, the temperature measurement range of the temperature sensor is determined. The calculation of temperature rise of intermediate joint of power cable under two rated boundary conditions is analyzed below.

Set the boundary condition to 25 °C air, 415 A current, this calculation condition simulates the rated operation of the connector, and the results are shown in Fig. 1 and Fig. 2.

It can be seen from the figure that under this condition, the conductor temperature of the joint is about 68.1 °C. In the process of heat transfer from inside to outside, due to the different structural parameters of each layer, the temperature change rate of each layer is different, and the temperature finally transferred to the outer surface is 44.8 °C. And communicate with the outside world 25 °C natural convection of air occurs. Therefore, 45 °C can be considered as the main working temperature of the joint surface.

Set the boundary condition to 40 °C air, 250 °C conductor, which simulates the maximum allowable conductor temperature in case of power cable short-circuit fault. The calculation results are shown in
Fig. 3 and Fig. 4. Figure 3 steady state distribution figure 4 radial temperature change curve shows that in case of short circuit, the outer surface temperature is about 136.4 °C. This is the maximum value of the joint surface temperature. From the perspective of accommodating a certain margin, the upper temperature limit of the temperature sensor is 150 °C is better. Since the temperature sensor also needs to measure the ambient temperature, the lower limit of temperature measurement can be -30 °C. Based on the above analysis, the temperature measurement range of the temperature sensor is -30 ~ 150 °C. It can ensure the full section detection of the temperature of the intermediate joint of the power cable.

2.2 Relationship between internal and external temperature rise of power cable and alarm value

A perfect temperature measurement system needs to establish a set of fault judgment basis in order to alarm in case of joint failure. GB/T 12706.2-2008 standard stipulates that the maximum conductor temperature of XLPE cable under normal operation is 90 °C. So more than 90 °C can be regarded as a fault. Because the conductor temperature is not easy to detect, this paper uses the method of estimating the internal conductor temperature by the external temperature rise to determine the temperature alarm value.

The surface temperature and ambient temperature of the joint are easy to detect, so the conductor temperature can be set to 90 °C. The joint surface temperature at C is determined as the high temperature alarm value. When the measured surface temperature exceeds this value, the conductor temperature must be higher than 90 °C. This is the fault state. ninety ° The conductor of C can be obtained by adjusting the current. To 40 °C air as an example, conductor 90 °C can be obtained by adjusting the current. To 40 °C air as an example, conductor 90 °C can be obtained by adjusting the current. To 40 °C air as an example, conductor 90 °C can be obtained by adjusting the current. To 40 °C air as an example, conductor 90 °C can be obtained by adjusting the current. To 40 °C air as an example, conductor 90 °C can be obtained by adjusting the current. To 40 °C air as an example, conductor 90 °C can be obtained by adjusting the current. To 40 °C air as an example, conductor 90 °C can be obtained by adjusting the current. To 40 °C air as an example, conductor 90 °C can be obtained by adjusting the current. To 40 °C air as an example, conductor 90 °C can be obtained by adjusting the current. To 40 °C air as an example, conductor 90 °C can be obtained by adjusting the current. To 40 °C air as an example, conductor 90 °C can be obtained by adjusting the current.

As can be seen from the figure, at 40 °C in air environment, the surface temperature of the joint is about 62.94 °C. When the calculation method remains unchanged, different joint surface temperatures can be calculated only by changing the ambient temperature. The high temperature alarm value can be a little higher than the corresponding joint surface temperature.
It is difficult to measure the conductor temperature directly, so this paper uses the estimation method to estimate the temperature of the internal conductor by using the conductor surface temperature. This paper will solve the problem of conductor temperature estimation from the perspective of temperature field calculation. Let the current flowing through the conductor be $I$, the ambient temperature be $x$, the surface temperature be $y$, and the conductor temperature be $Z$. Both conductor temperature and surface temperature are determined by the internal heat source and ambient temperature, and the heat source is generated by the thermal effect of current. Therefore, when the current and ambient temperature are known, the conductor temperature and surface temperature are determined, and there must be a corresponding functional relationship between them, which is as follows:

$$ (z, y) = f_0(I, x)z = f(x, y) $$

(1)

If the corresponding conductor temperature and surface temperature can be obtained by selecting several sample values of current and ambient temperature, and then these data can be analyzed to fit the functional relationship:

$$ z = f(x, y) $$

(2)

Then the corresponding conductor temperature can be calculated according to the ambient temperature and surface temperature data detected by the sensor. The conductor temperature estimation process is shown in Fig 7.

### 3. System Design

According to IEC61850 standard of substation network and communication protocol (hereinafter referred to as IEC61850), this paper puts forward the concept of information layering in substation, and divides the communication system of substation into three parts: process layer, bay layer and station control layer. The designed temperature measurement system is mainly composed of temperature measurement terminal, aggregation terminal and monitoring station, which constitutes a hierarchical management communication system. Wireless data communication is adopted between temperature measurement terminal and aggregation terminal. Coordination between temperature measurement terminal and convergence terminal work, obey the unified dispatching of the monitoring station, so as
to realize the all-round monitoring of the intermediate joint temperature. The overall structure design of the system is shown in Fig. 8.

![Conductor temperature estimation process](image)

The temperature measurement terminal is located in the process layer and installed at the middle joint of the cable. Therefore, it is difficult to obtain power from the temperature measurement terminal, which is the part of the temperature measurement system that really needs to realize low-power design. The temperature measurement terminal needs to collect temperature data, then transmit the data to the aggregation terminal and receive the control signal of the aggregation terminal. According to this design, the temperature measurement terminal is mainly composed of controller, wireless communication circuit, temperature sensor and power supply.

The commissioning of the system is carried out in the substation of a power supply company of the State Grid. The commissioning objects are 5 temperature measurement terminals, 1 convergence terminal and 1 monitoring station. The temperature measurement terminal is installed at the middle joint of 10 kV cable, and the address is set to 0 ~ 4. The convergence terminal is installed in the weak current well, and the monitoring station is a computer. In terms of temperature measurement accuracy, due to the limitation of the operating environment, it is impossible to verify the precision temperature measurement equipment on site. Here, fluke infrared temperature measuring gun in the substation is used as the temperature measurement accuracy detection. The ambient temperature measured by infrared temperature measuring gun on site is 19 ℃. The temperature of each joint is mainly concentrated at 39 ℃ to 40 ℃. It is basically consistent with the temperature displayed by the aggregation terminal. In terms of communication distance, the field test results show that the wireless communication distance is about 230 m at 0 dBm transmission power and 360 m at 10 dBm transmission power, which meets the system design index.

4. Conclusion

By analyzing the temperature characteristics of the intermediate joint of power cable, this paper gives the approximate relationship between the internal and external temperature at the joint, and determines the alarm temperature and related data; the design scheme of low-power cable intermediate joint temperature measurement system is given, and the hardware and software design of the system are completed. Finally, the physical test device is completed and tested on the spot. The results show that the temperature measurement system can accurately measure the temperature of power cable intermediate joint, and can feed back the corresponding information in real time to meet the system design requirements.

References

[1] Harry Orton. Overview of power cable technology (English) [J]. High voltage technology, 2015, 41 (04): 1057-1067.

[2] Wang Yani, Zhang Hongliang, Wu Jiandong, et al. Simulation calculation of temperature field and electric field of HVDC cable under different laying methods [J]. Insulating materials, 2017, 50 (07): 71-78.
[3] Zhang Lei, Zhu Lixiang, Chen Qingyun. Simulation analysis of temperature field of single core cable with different frequency harmonics [J]. Hubei electric power, 2016, 40 (03): 45-51.

[4] Tang Ke, Wen Wu, Ruan Jiangjun, et al. Simulation of temperature field of single core cable based on finite element method [J]. Journal of Wuhan University (Engineering Edition), 2018, 51 (09): 811-816.

[5] Xie guangbin, Xie Wei. Study on ampacity of single core cable based on temperature field [J]. Sichuan electric power technology, 2010, 33 (01): 86-88.

[6] Xing Ya, Hou Zhe, Yang Yuqi, et al. Numerical calculation of transient temperature field of single core cable based on distributed optical fiber temperature measurement system [J]. Wire and cable, 2013 (06): 7-11.

[7] Jiang Hua, Li Xizhong, Qin Xiaolai, et al. Power cable temperature measurement device based on passive wireless sensing technology [J]. Instrument technology and sensors, 2018431 (12): 62-66.

[8] Gao Qiang, Wang Hongli, Liu Xin, et al. Design of wireless temperature measurement and early warning system for high voltage substation [J]. Instrument technology and sensors, 2009 (01): 105-107 + 110.

[9] Luo Junhua, Zhou zuochun, Li Huachun, et al. Application Research on on-line detection technology of operating temperature of power cable [J]. High voltage technology, 2007 (01): 169-172.