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The Application of a Novel Infrared Temperature Measurement System in HVDC Converter Valve Equipment Connector Overheat Failure Prevention

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Abstract

Converter valve is the most important equipment in HVDC transmission system, but during the operation and maintenance of HVDC projects, electrical connectors overheat failures in converter valve equipments caused several unexpected trip events, which affects the safe and reliable operation of HVDC projects. Portable infrared temperature instrument is effective to surpervise the temperature of eletrical equipments in valve hall and prevent the overheat failure, but it is carried out manually. The electric company arranges oeprators to inspect the temperature of certain important equipments, which requires a lot of labor and has inspection blind aera. Therefore, on line temperature measurement system based on infrared radiation thermometer is proposed. The infrared temperature instrument performance is affected by ambient temperature seriously, in order to improve the accuracy of the measurement, this paper designs a novel infrared temperature measurement system with a silicon temperature sensor device embedde to provide valve hall temperature. This paper introduces the situation of converter valve equipments overheat failure and infrared temperature measurement technology, then a novel infared temperature measurement system applied in converter valve hall is proposed, both hardware and software design are addressed. At last, experiments are carried out to test the performance, which shows the embedded temperature measurement has high accuracy.

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*Keywords:*temperature sensor; infrared temperature measurement system; HVDC; converter valve; connectors overheat failure

1. Introduction

From 2009 to 2018, 690 converter valve defects occurred in the converter stations under the jurisdiction of China Southern Power Grid UHV Company, of which 255 were overheat defects, accounting for 36.96%. The main overheat sites are connectors overheat, 233 items, and anode reactor overheat 10 items. From 2014 to 2015, 114 connectors overheat abnormalities occurred in the Fufeng, Jinsu, Tianzhong and Binjin converter stations under the jurisdiction of State Grid in China, of which 10 overheat cases caused temporary shutdown events. According to the statistics of the overheat parts, 44 were the converter valve reactor and parallel arrester connectors, accounting for 38.6%. The main reasons for the overheat problem are insufficient design margin, inadequate installation process quality and unqualified fittings quality. Since 2011, the number of overheat failures in the connectors of converter valve has been increasing year by year. Affected by ambient temperature and long-term full-load operation, June-October is the peak period of overheat failure generation of converter valve connectors. The overheat failures in converter valve connectors affect the safe and reliable operation of HVDC transmission seriously, which needs a method to pridct the overheat failure beforehead. Portable infrared temperature instrument is effective to surpervise the temperature of eletrical equipments in valve hall and predict the overheat failure, but it is carried out manually. The electric power company arranges oeprators to inspect the temperature of certain important equipments, which requires a lot of labor and has inspection blind aera. And the inspection quality depends a lot on personal skills. Therefore, on line temperature measurement system based on infrared radiation thermometer is proposed.

Infrared thermal imaging technology is a science and technology to acquire and analyze thermal information from non-contact thermal imaging devices.[1] Infrared thermal imager can convert invisible infrared radiation into visible images. The infrared radiation of the object is detected by the detector, ahe detector will generate electrical signals, which are amplified and digitized into the electronic processing part of the thermal imager, and then converted into infrared images that can be seen on the display. Infrared diagnostic method is a remote sensing diagnostic method, which is non-contact and can realize fast scanning and imaging of charged equipment.[4,5] It is not necessary to carry out the disintegration test of the equipment like the preventive test, and it is able to keep the running state of the equipment unchanged without power failure, and to know the current situation of the power equipment in time.[6]

The temperature measurement belongs to the narrowband spectral radiation temperature measurement system, it must be clear that the measured surface temperature of the object is not measured directly, but calculated by the measured radiation energy. Therefore, the measurement accuracy is affected by the ambient temperature a lot. When the temperature of the measured object is close to the ambient temperature, the error caused by the ambient temperature is larger.[7] Therefore, this paper proposes a novel on line infrared temperature measurement system applied in HVDC converter valve hall with a silicon temperature sensor device embedde to provide ambient valve hall temperature. This paper introduces the situation of converter valve equipments overheat failure and infrared temperature measurement technology, then a novel infared temperature measurement system applied in converter valve hall is proposed, both hardware and software design are addressed. At last, experiments are carried out to test the performance, which shows the embedded temperature measurement has high accuracy.

2. The design of the infared temperature measurement system

1.1. System hardware structure

The hardware structure of the on-line infrared temperature measurement system for HVDC converter valve equipments is shown in Fig. 1. It adopts a fully digital, star-shaped network topology structure and has high anti-interference ability. It connects the computer with the inspection device in the substation through serial server. The system adopts hierarchical and distributed structure, which is divided into device layer, network layer and station layer. The device layer mainly includes temperature sensors, embedded temperature measurement device and alarm, which is designed for the collection and data conversion of original data. The temperature sensors and embedded temperature measurement device collect the original data of equipments temperature and ambient temperature of

valve hall respectively. Part of the temperature sensors are placed according to the list of equipments that have high risks of overheat failure, and the rest is placed to supervise the overall temperature of the vale hall. The network layer mainly consists of serial server and network link, serial server is for the conversion of network interface, and if there is more than one host computer, the network should be expanded. The station level mainly includes the main temperature monitoring station. Its main function is to do the data processing and recording, screen display, and printing. The valve hall ambient temperature obtained by embedded temperature measurement device is input as the ambient temperature in infrared temperature measurement system to improve the accuracy.

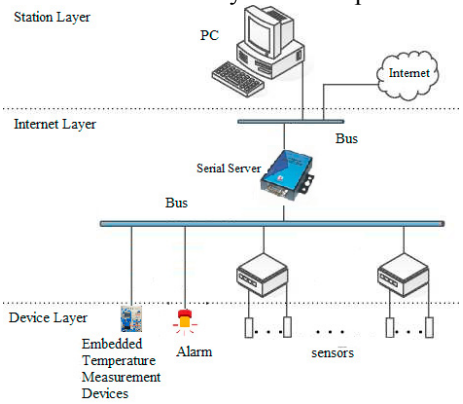

Fig. 1. Hardware structure of infrared temperature measurement system.

1.2. System software design

The software of on-line infrared temperature measurement system for HVDC converter valve equipments applies module design. It is mainly consisted of infrared temperature measurement module, embedded temperature measurement device module, alarm module, interface module, sampling and AD converter module, data processing module and display module. The signals from temperature sensors are sampled and converted to electrical signals by sampling and AD converter module, the electrical signals are processed by data processing module to elimate the wrong data. The data of data processing module and embedded temperature measurement device module are transmitted to infrared temperature measurement modle, which outputs the objective equipment temperature in valve hall. The alarm module applies relative temperature difference method to determine whether the equipment has overheat trend and failure. The interface module provides the human machine interface. And the display module displays the real time temperature and temperature trend map. The software design block diagram is shown in Fig. 2.

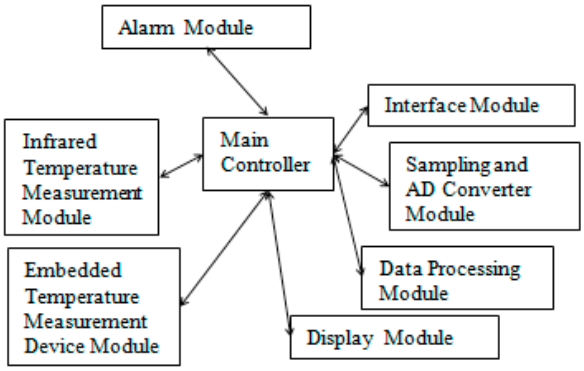

Fig. 2. Software structure of infrared temperature measurement system.

The main program module mainly realizes system initialization, temperature detection, serial port communication, and display functions [3]. The system initialization includes serial communication interruption, liquid crystal display and wireless transmission initialization; infrared temperature measurement module obtains temperature data and calculates temperature value; display module obtains and processes corresponding temperature data; wireless transmission module transmits the measured temperature from the controller to the management station; data display module displays data; system settings module sets system parameters according to user needs.

1.3. The design of embedded temperature measurement device

The dual-integral AD converter chip 7106 is used to realize the conversion from analog signal to digital signal. The main circuit diagram is shown in Fig. 3. The AD 7106 chip pin 1 and pin 26 are connected by 9V DC power supply. The external resistor and capacitor are connected to pin 38, 39 and 40 to generate the oscillation frequency. Pin 35 and pin 36 are connected to reference high voltage and reference low voltage by changing the variable resistance. The LCD display is driven by 7106's driver. With the digital voltmeter head, the measurement of voltage, current, resistance and temperature can be realized.

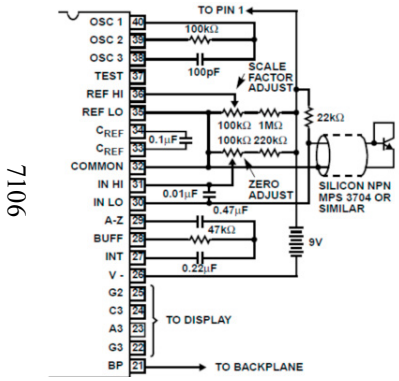

Fig. 3. Circuit diagram of embedded temperature measurement device.

1.4. The high risked overheat equipments

In order to determine where to place the infrared temperature measurement cameras and sensors, the cause of overheat defects are studied. The main causes of joint heating are improper installation, bolt loosening, uneven contact surface, broken lead strands, improper application of conductive paste, surface oxidation of connector or clamp, and design defects leading to current density exceeding the limit value.

Bolt Loosening

The loosening of bolts is due to insufficient contact pressure and moment of force does not meet the standard, resulting in larger contact resistance. Through experiments and calculations, it is known that the contact resistance R is inversely proportional to the total applied contact pressure F, as shown in Fig. 4.

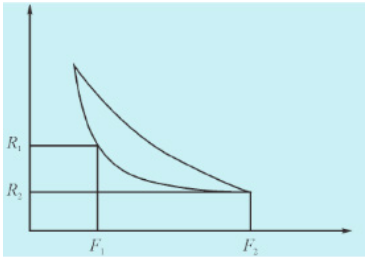

Fig. 4. The inversely proportional relationship between contact force F and contact resistance R.

Uneven Contact Surface

In the processing of the contact surface of the connector material, no matter how to deal with it, the surface of the connector material is always uneven, so the contact surface is not completely even. When two metal surfaces are in contact with each other, only a few protruding points have been contacted, and only a small number of metal contact or quasi-metal contact spots can conduct electricity. When the current passes through these very small conductive spots, the current line will inevitably shrink. As the current line shrinks, the current path near the conductive spot increases and the effective conductive area decreases, so the resistance value increases correspondingly, as shown in Fig. 5.

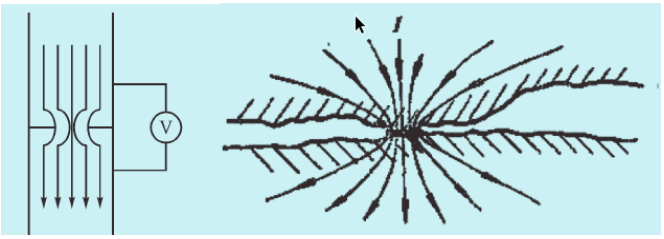

Fig. 5. The contact resistance increase due to the uneven contact surface.

- Surface Oxidation of Connectors or Clamps

Bolt connection is commonly used in electrical equipment connectors. When the connectors are overheated due to climate change in summer or too high current density, it will lead to expansion, while the expansion coefficient of aluminum and copper is larger than steel. Due to the limitation of steel washers, bus connectors can not expand freely. When the bus current decreases, the shrinkage of bus is larger than that of steel wahsers, so the contact pressure decreases. At this time, the position of the contact surface is staggered, and forming a gap between the contact surface and surface oxidation will accelerate. Thus the contact pressure decreases, and the contact resistance increases.

From the above analysis, the equipments that have high risks of overheat failure are connectors, bolt and clamps. And the infared cameras and sensors will be distributed in proper position in valve hall to collect the original signals of these equipments.

3. Experiment

The embedded temperature measurement device prototype is built according to the circuit diagram in Fig. 3. The temperature sensor is silicon temperature sensitive triode 9013, the AD converter 7106 is installed in lower part of the device, as shown in Fig. 6. The temperature data is ambient temperature, and is transmitted to the on line infrared temperature system to improve the infrared temperature calculation accuracy.

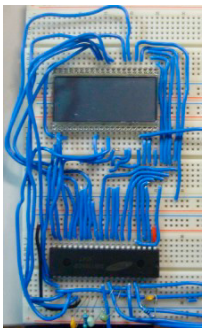

Fig. 6. The prototype of embedded temperature measurement device.

In order to test the performance of the embedded temperature measurement device, an experiment is carried out. As the temperature signal is transformed to voltage signal, so the test is carried out to measure temperature based voltage, the measured voltage is compared with standard voltmeter measured value. By adjusting the potentiometer of 100KΩ in Fig. 3 connected to 7106 pin 36, the mesured voltage value of the prototype is in good consisitance to the voltage shown in the standard voltmeter, as shown in Table 1. The error is less than 1%, which verifies the accuracy of the embedded temperature measurement device.

Table 1.An example of a table.

Measured value/mV	0	100	180	190
Standard value/mV	0	99.9	179.8	189.8

The infrared temperature measurement equipment experiment is carried out to test the performance. An reactor applied in HVDC transmission project station is selected to be the temperature measured object. The reactor is turned on for about 3 hours, and then turned off. The infrared temperature measurement device measures the temperature and record the temperature map, as shown in Fig. 7(a). According to the high risks of overheat failure position, 8 spots are selected to record the temperature. And the temperature trend of a 4 hour time span is shown in Fig. 7(b). The temperature of spot 1 rises when the reactor is turned on from the begining, when it's on for 3 hours, the temperature reaches about 180 ℃, then the reactor is turned off, and the temperature decreases. The experiment results show the good performance of the infrared temperature measurement system.

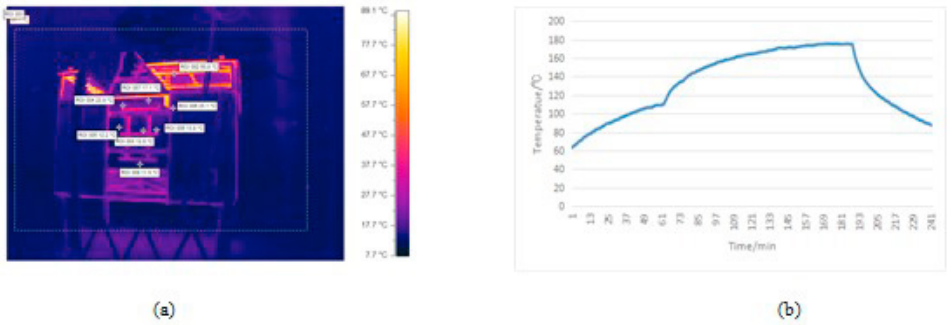

Fig. 7. (a)The temperature map of the reactor created by infrared temperature measurement device

(b)The temperature trend of the reactor.

4. Conclusions

A novel on line temperature measurement system based on infrared radiation thermometer is proposed. The infrared temperature instrument performance is affected by ambient temperature seriously, in order to improve the accuracy of the measurement, this paper designes a novel infrared temperature measurement system with a silicon temperature sensor device embedde to provide valve hall temperature. This paper introduces the situation of converter valve equipments overheat failure and infrared temperature measurement technology, then a novel infared temperature measurement system applied in converter valve hall is proposed, both hardware and software design are addressed. At last, experiments are carried out to test the performance, which shows the embedded temperature measurement has high accuracy.

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