Research on transformer fire alarm threshold based on multi-sensor data analysis

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Abstract. Based on literature, on-site investigation and accident case analysis, this paper selects multi-sensor for transformer fire alarm, builds the transformer fire test platform, and carries out the transformer fire test and interference test to obtain the training and test data of neural network data fusion. This paper determines the fire alarm threshold of multi-sensor signal. It provides a benchmark for comparing the alarm results of multi-sensor data simulation fusion with those of single sensor. This paper studies the preprocessing multi-sensor data, compiles the corresponding algorithm, and obtains the multi-sensor preprocessed data after dimension reduction and noise reduction. It provides data support for multi-sensor data fusion.

Keywords: Transformer fire; Multi sensor; Data analysis; Alarm threshold.

1. Introduction

Oil-filled equipment fires in substations are characterized by transient high energy [1-3], and it is difficult to apply a fixed fusion algorithm for the unified study of multi-sensor data fusion of different fire types. Therefore, it is necessary to build corresponding fire testbeds to carry out research according to different fire types. In order to study multi-sensor data fusion algorithms for different fire types, various simulation experimental platforms have been built by domestic and foreign scholars. Yang Bo [4] used a mixture of kerosene and gasoline (ratio 1:10) as fuel to conduct system functionality tests using 5 m, 25 m, and 50 m combustion pans to track and locate the suspected fire source area and verify the function of image-based fire detection and identification system. Wang Xuegui [5] built the ISO9705 combustion experimental platform with the dimensions of 3.6*2.4*2.4m, and carried out the corresponding multi-sensor data fusion study using polypropylene and polyethylene as fuels, and verified the effectiveness of the multi-sensor data fusion fire identification algorithm by measuring parameters such as temperature, smoke and heat release rate. Zhang Chuanbin [6] built a simulated ship fire test platform to collect fire data from multi-sensors under open fire, shaded combustion and no fire conditions, and compared the results obtained from the simulation fusion of these data with the actual results to study the effectiveness of multi-sensor data fusion algorithm for ship fire warning. Qiao Gaolin [7] carried out experiments in different time periods, designed fire tests using different combustibles, including alcohol and gasoline, and designed interference tests such as headlights, etc. The RS-SVM fire classifier developed to study the accuracy of fire recognition and obtained more satisfactory results. Meng Lin [8] built a ship model and carried out a study on the performance of the ship fire smoke detection model in the experimental monitoring environment, analyzed the influence of fire parameters such as light intensity, smoke concentration and smoke diffusion size on the fire recognition algorithm, and concluded that the performance of the recognition algorithm studied was good. Zhong Ming [9] built an experimental platform for testing their developed intelligent fire detection system in a closed indoor experimental environment and conducted anti-interference and simulated fire response time experiments using five flammable materials to verify the anti-interference capability and timeliness of the intelligent fire detection system. Rachman et al [10] built a test system for multi-sensor fires in a confined space, conducted fire tests and fused multi-sensor data by fuzzy logic algorithm for multi-sensor data fusion, and it was found to be effective in identifying fires.

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The study of multi-source data fusion technology contains many aspects of theory and technology, and there is no unified algorithm that can be applied in all fire scenarios [11], so the corresponding fusion algorithms need to be studied for different fire contexts. Jesus et al [12] divided the algorithms for fire detection and identification into threshold method, statistical method, etc.; Javadi et al [13] divided the intelligent algorithms for fire detection and identification into neural network, fuzzy inference and other algorithms.

This paper studies the development of fire and fire characteristics parameters, selects fire multi-sensors and builds a transformer fire test platform, carries out transformer fire tests and cigarette ignition interference tests and collects data, pre-processes the collected multi-sensor data, and then simulates and calculates these data through the design of two data fusion algorithms to obtain the corresponding fire alarm signal.

2. Experimental system

Transformer fire multi-sensor test platform is shown in Figure 1. The use of high-speed camera to monitor the environment around the transformer in real time, when the transformer fire occurs when the open flame, the camera according to the fire image signal alarm, its arrangement is 2 m away from the transformer oil pool; environmental temperature sensor, the use of K-type thermocouple to monitor the environment around the transformer in real time, to detect whether the temperature of its environment occurs abnormal sudden changes in the situation, its specific arrangement from the center of the oil pool 30 cm above the center of the oil pool; cable-type linear temperature-sensitive cable, the temperature-sensitive cable around the transformer oil pool a circle, real-time judgment of the transformer oil pool wall temperature, when its temperature exceeds the threshold value of the fuse and alarm; CO_2, CO gas sensor, the application of the smoke analyzer for real-time monitoring of environmental gas data around the transformer, to determine whether the collected CO_2, CO data appear abnormal, specifically arranged at a distance of 40cm above the center of the oil pool.

The test device, transformer oil pool, holds about 80% of the overall capacity of the pool; the ignition device, a lighter gun, is used to ignite the transformer oil; the ignition material, n-heptane, is added to the pool containing transformer oil, 5 ml of n-heptane, to facilitate the ignition device for ignition. In the transformer fire test study, a typical transformer oil pool fire was sampled using multi-sensors, and the sampling frequency of the multi-sensor data was adjusted to 1 s. A total of six sets of typical transformer fire tests were conducted in this paper, of which five sets of multi-sensor data from transformer fire tests were used as the training set for neural network data fusion, and the remaining one set was used as the test set for data fusion to test the neural network. Two sets of cigarette ignition tests were conducted to use the collected data as anti-interference research data, with one set as the training set and one set as the test set for anti-interference research.

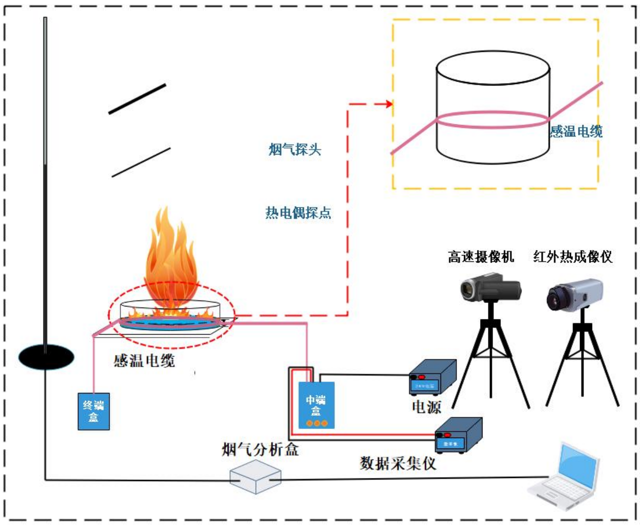


Fig.1 Schematic diagram of fire multi-sensor test platform

3. Results and Discussion

3.1 Temperature sensitive cable data fire alarm threshold analysis to determine

In this paper, the specific role of the cable-type wire-type temperature-sensitive cable in the test platform for monitoring the temperature of the transformer oil pool wall, as can be seen above cable-type wire-type temperature-sensitive cable can be approximated as monitoring the transformer oil temperature. Its working principle is that the entire detector is connected to the power supply, where there is a large resistance in the terminal box so that there is a weak current in the circuit, when the surrounding environment of the temperature-sensitive cable reaches the threshold temperature, the internal circuit of the thermal insulation material fuses short circuit, the current drops to 0 V. The cable-type wire-type temperature-sensitive cable is arranged in a circle around the transformer oil pool from the bottom of about 40% of the liquid level line. Transformer oil deterioration temperature of 104.4 ℃, so this paper will transformer fire test temperature threshold of the temperature-sensitive cable is set to 105 ℃, when the transformer oil temperature exceeds 105 ℃ when the early warning alarm signal, then the transformer can be known to be in abnormal working condition. Figure 2 shows the infrared image of the transformer oil pool, from the figure can be learned at this time the transformer oil pool wall temperature exceeds 105 ℃, the line type temperature-sensing cable issued a fire warning alarm signal.

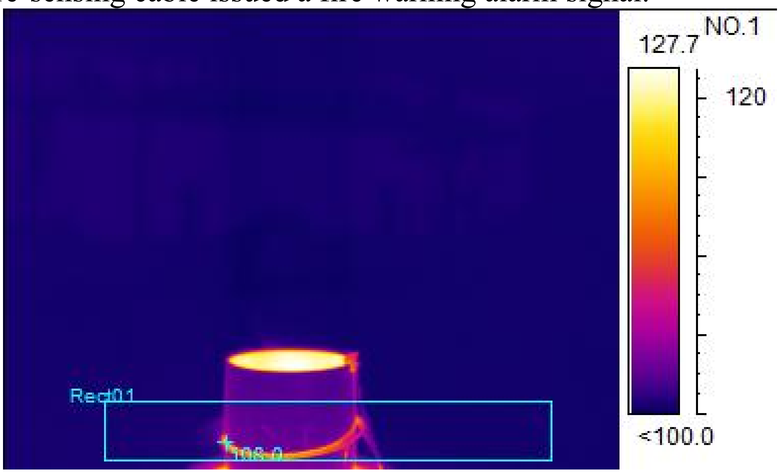


Fig.2 Infrared image of transformer oil pool

Transformer fire test to obtain the corresponding temperature-sensitive cable data signal, the normal inspection of the temperature-sensitive cable working signal and abnormal working signal to make a graph for comparison, as shown in Figure 3. From the figure can be seen cable-type line temperature-sensitive cable in a non-fire state when its signal shows regular periodic fluctuations.

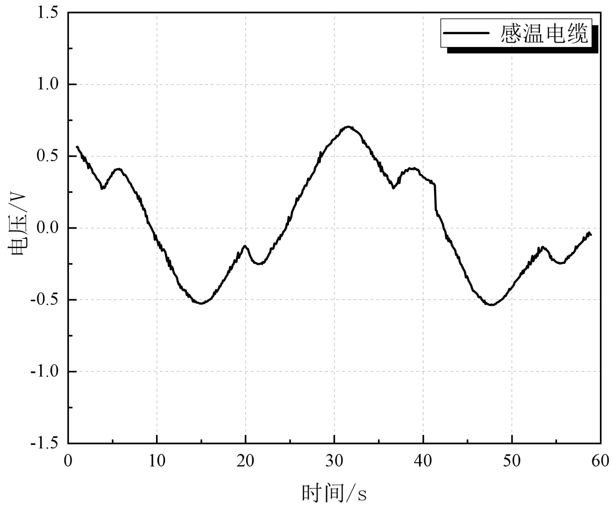


Fig.3 Inspection signal diagram of temperature sensing cable under normal working condition

Figure 4 shows the signal curve of the alarm state of the temperature-sensitive cable, from the figure can be seen when the temperature around the cable type temperature-sensitive cable exceeds 105 ℃ in the alarm state, the signal is about 0 V, and the signal continues to be about 0 V in the following time. Cable-type wire temperature-sensitive cable is in a non-fire state between 0-31 s, the signal is a regular periodic fluctuation, 32 s and after the time signal continuous about 0 V, when the temperature around the cable-type wire temperature-sensitive cable exceeds the threshold value of 105 ℃ and in the alarm state.

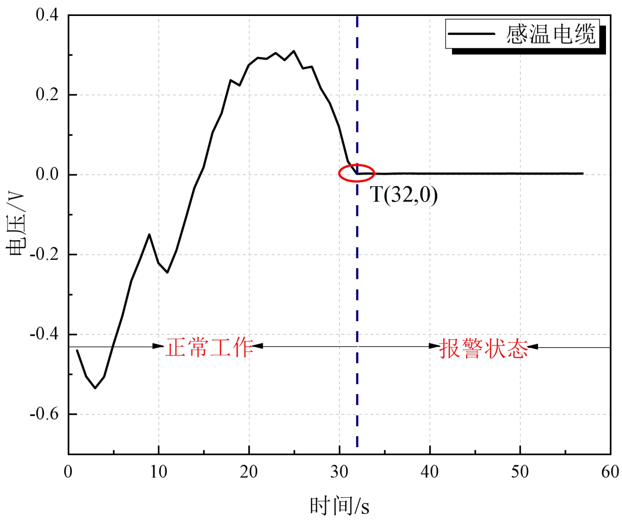


Fig.4 Temperature sensing cable alarm status signal curve

3.2 Gas sensor data fire alarm threshold analysis to determine

The gas sensor is a German Detu 350 flue gas analyzer, which allows real-time monitoring of CO, CO_2 and O_2 gas parameters via a built-in module. The smoke analyzer probe is positioned 40 cm above the center of the transformer oil pool and automatically stores the measured gas data and generates an EXCEL file. The CO, CO_2 and O_2 signals when the fire does not occur are compared with the time variation of the three gases when the fire occurs, and the fire alarm thresholds of the three gases are analyzed.

Figure 5 shows the CO_2 signal in the non-fire condition, and it can be seen from the figure that the CO_2 data in samples one to four fluctuate in a certain range, specifically between 0.12 and 0.17 mg/m^3 during the non-fire condition.

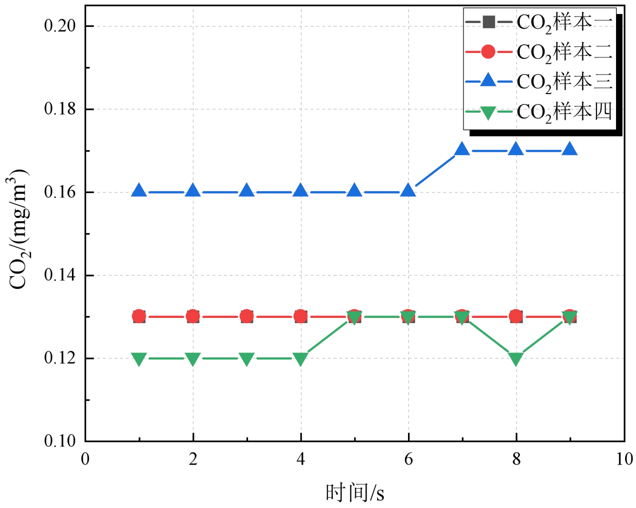


Fig.5 CO_2 signal diagram under normal working condition

Figure 6 shows the non-fire state CO signal graph, from the graph it can be seen that in the non-fire state CO data is 0 mg/m3, no fluctuation occurred.

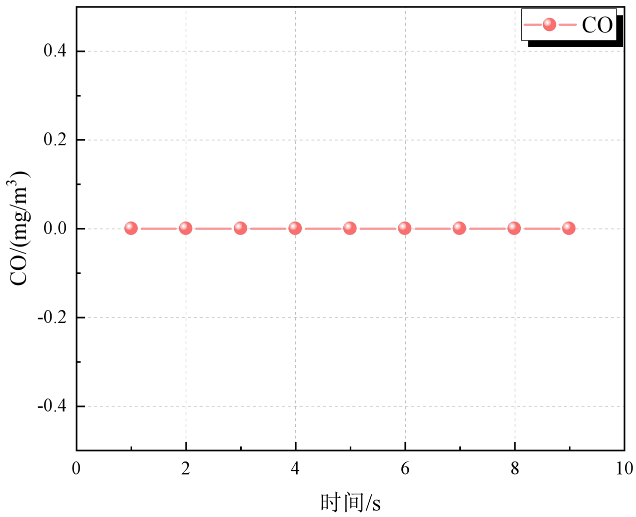


Fig.6 CO signal diagram under normal working condition

Figure 7 shows the non-fire O2 signal graph, from the graph it can be seen that the non-fire O2 data is about 21.03%, which fluctuates within a certain degree and the fluctuation range is small.

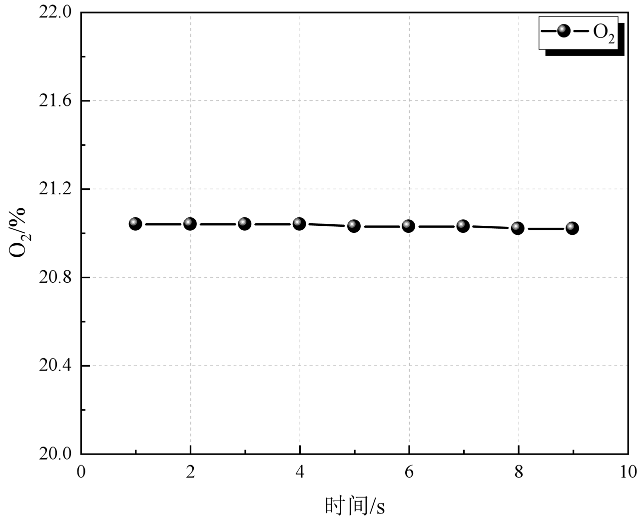


Fig.7 O_2 signal diagram under normal working condition

Figure 8 shows the signal curve of the gas sensor alarm status. From the figure, it can be seen that the oxygen content at 26 s tends to decrease with the occurrence of fire to a certain extent, while the CO_2 and CO content exceed their non-fire values and tend to increase with the occurrence of fire, and the CO_2 in the figure is less sensitive and slower to respond to fire than the CO. The upward peaks of O_2 and downward peaks of CO_2 and CO were observed between 27-45 s. Based on the combustion principle of fire, it can be inferred that the pulsation of the flame during the combustion process leads to the absorption of oxygen from the environment, which causes the surrounding oxygen content to increase and then decrease, and the CO_2 and CO to decrease and then increase.

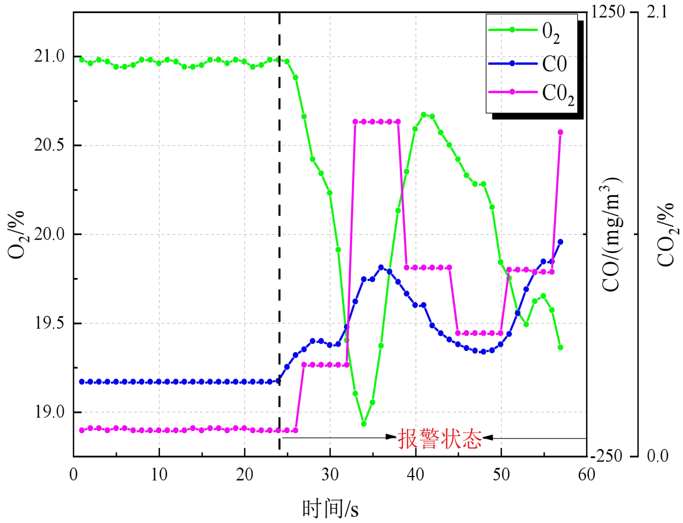


Fig.8 Gas sensor alarm status signal curve

Comparing the CO_2, CO and O_2 data in normal condition and the CO_2, CO and O_2 data in fire condition, it can be seen that the CO_2 sensor fluctuates around 0.17 mg/m^3 in non-fire condition and the CO sensor is basically 0 mg/m^3 in non-fire condition, when the fire occurs, a large amount of CO_2 and CO will be produced and the data of the two gas sensors will rise. When a fire occurs, the CO_2 and CO data will rise rapidly and a fire alarm signal will be issued; as for the O_2 data, the change of the data signal before and after the fire is not significant and is not used as the basis for fire alarm.

3.3 Temperature sensor data fire alarm threshold analysis to determine

The temperature sensor is a K-type thermocouple, whose role is mainly to monitor the ambient temperature around the transformer in real time and issue an alarm signal when the ambient temperature exceeds the fire alarm threshold. Ambient temperature sensor arrangement is located 30 cm above the center of the transformer oil pool, monitoring the ambient temperature around the transformer test platform. According to GB4716-2005, the minimum temperature of the action of the temperature sensor is 54 ℃, the action of the upper limit of 160 ℃, in order to improve the sensitivity of the transformer fire temperature sensor, this paper will be determined in the transformer fire multi-sensor test ambient temperature threshold of 54 ℃.

Because the ambient temperature and temperature-sensing cable are temperature sensors, according to the transformer fire multi-sensor test data from the ambient temperature and temperature-sensing cable to make a graph for analysis, as shown in Figure 9. When the transformer oil fire, the temperature in its surrounding environment will be in a certain degree with the occurrence of fire in the rising trend, when the time is 27 s when the ambient temperature exceeds the threshold value of 54 ℃ for the first time, at this time to judge the occurrence of fire; temperature-sensing cable in the fire before the occurrence of non-fire patrol state, when the time reaches 32 s when the temperature of the temperature-sensing cable reaches 105 ℃ fuse and signal to zero, at this time the ambient thermocouple temperature is higher than 200 ℃, this is because the ambient thermocouple fire alarm threshold temperature is lower, the temperature-sensing cable only more than 105 ℃ will send a fire alarm. Fire does not occur when the thermocouple shows the surrounding ambient temperature of about 30 ℃, when the ambient temperature sensor for the first time over the threshold value of 54 ℃ when its fire alarm; cable type linear temperature-sensing cable when the fire occurs when the temperature around the temperature-sensing cable reaches 105 ℃ fuse its signal continuous 0 V, when the fire alarm signal.

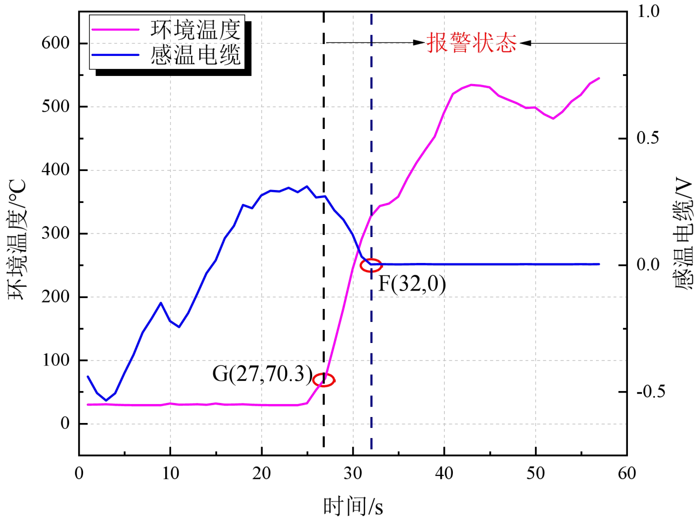


Fig.9 Data diagram of temperature and temperature sensing cable

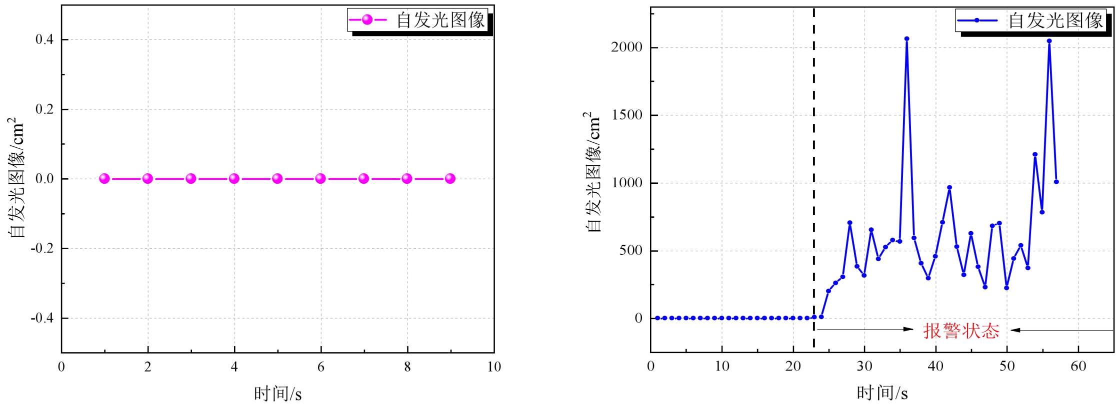
3.4 Image sensor data fire alarm threshold analysis to determine

The image sensor used by the high-speed camera, its role is to monitor the transformer oil pool in real time, when the flame appears to capture and fire alarm. Figure 10 is the flame pulsation diagram, in which (a-d) is the initial growth phase of the pool fire, the flame height as well as the area is increasing, while the flame continues to radiate the surrounding environment resulting in an increase in temperature, transformer fire alarm should be in the initial stage of the pool fire to ensure that the fire does not become a disaster; (e-f) pool fire into a stable combustion phase, this stage of the burning rate tends to stabilize, the flame size tends to stabilize, this stage of the fire alarm Later to take control measures are more difficult; (e) Figure indicates that the pool fire into the extinguishing stage.


(a) (b) (c) (d) (e) (f) (g)

Fig10 Flame pulsation diagram

Figure 11 image sensor state signal diagram, from Figure 11 (a) can be seen in the non-fire state self-luminous image data is 0cm2, at this time that the video image sensor did not capture the flame image; from Figure 11 (b) can be seen in the 0-22 s in the non-fire state, and 23 s after the self-luminous image appears rising trend, at this time that there is an abnormal signal, that the image sensor captured the flame image and the alarm signal needs to be issued. Therefore, the threshold value of the image sensor is 0 cm2, and when its signal value exceeds 0 cm2, it should send a fire alarm signal.



(a) Image sensor normal state operating signal diagram

(b) Image sensor fire status signal diagram

Fig.11 Image sensor status signal diagram

3.5 Multi sensor fire signal recognition algorithm determination

The above analysis shows that the fire alarm threshold of temperature-sensitive cable is 105℃, and its signal is periodic in the non-fire state, when the temperature exceeds its threshold, the cable melts and the data signal is 0 V continuously; the data threshold of CO_2 sensor is 0.17 mg/m3, which fluctuates around 0.12-0.17 mg/m3 in the non-fire state in the transformer fire test, and when its fire occurs and the concentration exceeds the threshold, its signal is rapidly increasing; the CO sensor is 0 mg/m3 in the non-fire state, and the temperature sensor is 0 mg/m3 in the ambient temperature when the fire occurs. When the fire occurs and the concentration exceeds the threshold value, its signal has a rapid rising trend; CO sensor is 0 mg/m3 in the non-fire state and has a rapid rising trend when the fire occurs; temperature sensor is ambient temperature in the non-fire state, while GB4716-2005 stipulates that the minimum temperature of the temperature sensor is 54℃ and the upper limit of the action is 160℃, in this paper, the ambient temperature threshold value is determined to be 54℃ in order to improve the sensitivity. 54 ℃; image sensor in the non-fire state data signal is 0 cm2, when the fire occurs is rapidly rising trend. This leads to the alarm data discrimination criteria, as shown in Table 1.

Table 1. Alarm data discrimination criteria

Data	No fire	Fire Alarm Threshold	Recognition algorithm
Environmental Thermocouples	30℃	54℃	Intuitive Threshold Method
Temperature sensitive cable	Periodic fluctuation	105℃	Intuitive Threshold Method
CO_2	0.12-0.17 mg/m^3	0.17 mg/m^3	Intuitive Threshold Method
CO	0 mg/m^3	0 mg/m^3	Intuitive Threshold Method
Image	0 cm^2	0 cm^2	Intuitive Threshold Method

4. Conclusion

This paper conducts a study on the determination of fire alarm thresholds for transformer multi-sensor data signals:

(1) Based on thermogravimetric tests the fire alarm threshold of 105°C was derived for transformer temperature-sensitive cables with a continuous 0 V data signal, and the fire alarm threshold of 54°C was derived for ambient temperature data according to the national standard.

(2) The data plots of the transformer fire test for the gas sensor and the image sensor in the non-fire state as well as the fire state were analyzed, and the alarm thresholds for the corresponding fire characteristic parameters were derived, including 0.17 mg/m3 for the CO_2 fire alarm, 0 cm2 for the fire alarm threshold of the image sensor flame area data, and 0 mg/m3 for the CO fire alarm threshold.

(3) The principles of the fire signal recognition algorithm were obtained, and the discrimination methods and sensor alarm thresholds for the five sensor data fire alarms were determined.

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