

Discussion on infrared accurate temperature-measuring technology of composite insulators for overhead lines

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Abstract: Through analysing the infrared temperature measurement data obtained from composite insulators for overhead lines in actual operation state and atmospheric environment, detection requirements of infrared accurate temperature-measuring technology of composite insulators for overhead lines were discussed, such as the detector, detection environment, and position. According to the local detection, two kinds of insulators' local heating, caused by insulation deterioration and damp contamination on the surface, were researched. A judgment method was proposed, and overheat of the electric equipment, which was caused by voltage effect, should be judged from both the contrast of similar equipment and the thermal image characteristic. This method can greatly reduce the insulators overheat error rate, improve the detection efficiency of composite insulators, and enhance the accuracy of composite insulators' insulation defects judgment.

1 Introduction

In recent years, the fracture accident of overhead line composite insulators was happened many times, because internal insulation defects existed in the wire side of insulators. Most fault insulators' break is basically the same, there are different degrees of crack and perforation in the sheath, and the mandrel fracture surface is not uniform, like a broom, ordinary mandrel fracture state. In order to ensure the safe operation of overhead lines, it is an urgent problem to take simple and effective detection methods to find out the internal insulation defects of composite insulators [1].

When there were insulation defects in the composite insulator, such as internal insulation defects, aging damage of sheath, and so on, there would be partial discharge in this part, which would lead to the local temperature of insulators rise [2, 3]. Therefore, the partial damage and discharge defects of composite insulators can be found according to the heating phenomenon. Making use of this mechanism, infrared temperature-measuring technology can determine whether insulators in service have insulation defects, according to the heating situation of different parts [4, 5]. A great deal of practice has proved that infrared temperature-measuring technology is an effective means to find out the internal defects of composite insulators [6].

At present, the popularity of domestic composite insulators infrared temperature-measuring technology is not very high in the operation and maintenance department. The local detection requirements for composite insulators on overhead lines are very imperfect, and there is no unified standard for infrared detection of composite insulators. Sometimes, the composite insulator was overheated at site, but there was no internal defect in laboratory inspection and later broken due to insulation defects. It happened due to the operation conditions, weather, and other factors. At present, there is a certain proportion of miscarriage of justice and

leakage in the local detection, and the requirements and judgment method of local detection should be further improved.

The heating of composite insulators is caused by voltage effect, and the voltage heating equipment should be accurately detected. This paper studied the problems encountered in the infrared temperature measurement of composite insulators, the detection images and data were analysed, and testing requirements were discussed from the device requirements, environment, and detection position. The judgment method of insulation defects in composite insulators through infrared temperature measurement was supplemented and consummated.

2 Discussion on local detection requirements

2.1 Device requirements

Requirements of infrared accurate temperature measurement of composite insulators on the device are mainly reflected in the spatial resolution. In the current local detection, two kinds of commonly used camera lens are 40 mm lens (0.65 mrad, view angle of 24×18 degrees) and 131 mm lens (0.2 mrad, view angle of 7×5.3 degrees). In order to compare the two kinds of lenses, they have been used to detect the same insulator which has overheated defects. The detection distance is 53 m, and the thermal image is shown in Fig. 1. As can be seen from the image, 40 and 131 mm lenses have little difference in temperature measurement, but the latter one's image is much clearer than the former, and the outline of the large umbrella skirts is clear and the hot spot can be learned from the image. The two kinds of lenses can be used to detect insulator insulation faults when the detection distance meets the requirements, but to determine the location of the hot spots, the use of 131 mm lens is better.

2.2 Environmental requirements

The ambient temperature of accurate detection is generally not less than 5°C , and relative humidity is less than 85%. The detection should be carried out in cloudy weather, on night or 2 h after sunset, but should not be in the thunder, rain, fog, snow, and other bad weather conditions. The image quality of night detection is better. The wind speed should be less than 0.5 m/s. The device should be balanced around the background radiation, and try to avoid interference near the heat radiation source, the human heat source, and strong electromagnetic field, to prevent the strong



Fig. 1 Thermal images of overhead insulator using different lens

(a) Using 40 mm lens, (b) Using 131 mm lens

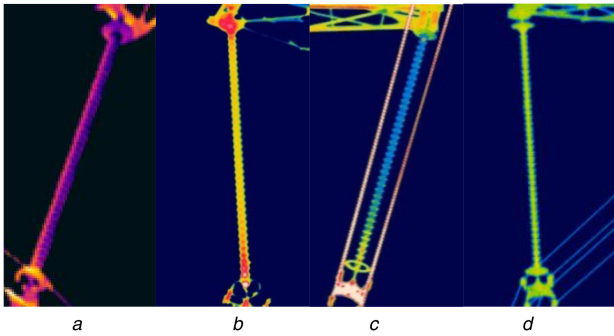


Fig. 2 Thermal images with different detected distances
(a) 32 m, (b) 40 m, (c) 80 m, (d) 125 m

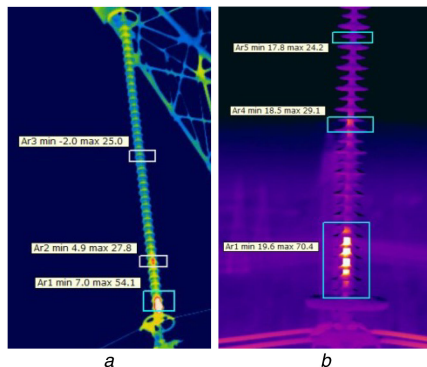


Fig. 3 Thermal images of the insulator on 500 kV line
(a) Ground temperature measurement, (b) On-tower temperature measurement



Fig. 4 Overheat insulator inspection
(a) Punch holes and cracks, (b) Sheath peeling

magnetic field from affecting the normal work of infrared thermal imager [7].

When the weather is cloudy, the sun cannot shine directly on the insulator, but at close to noon, due to the atmospheric temperature, the insulator surface temperature will rise up. When the surface temperature is close to or higher than the ground temperature, temperature measurement results cannot reflect actual heating of insulators. Therefore, this article considers that even on cloudy days, it is not appropriate to detect from noon to sunset.

2.3 Detection position

On account of composite insulators hung on the steel tower, in order to choose the best detection position based on the terrain of the tower, we should do the following: (1) to avoid the obstacles in the visual field, try to make the insulator not overlapped with the tower, the wire, and the ring; (2) to make full screen and make sure that the insulator's thermal image is located in the centre of screen; and (3) to maintain a certain distance with the location below the insulator to minimise the umbrella skirts overlap.

The detection range shall be determined by the identification distance of the thermal imager. Generally speaking, accurately measuring the target temperature, for an infrared thermal imager, usually requires nine pixels, while recognition requires only four pixels, so the approximate distance can be calculated. The concrete formula is as follows:

$$\text{Identification distance} = \frac{\text{target length or height}}{(\text{spatial resolution} \times \text{pixels})} \quad (1)$$

Take 500 kV composite insulators as an example, the structure height is generally 4360 mm, umbrella structure, the distance between the two big umbrella skirts is about 100 mm, and the distance between the adjacent big umbrella skirt and the small umbrella skirt is about 50 mm. Local detection should be able to identify at least the insulator umbrella skirts that is two large umbrella skirts. According to formula (1), identification distances of 40 and 131 mm lens are 38.5 and 125 m, respectively.

As shown in Fig. 2a, when the 40 mm lens was used to detect with the distance of 32 m, it was difficult to distinguish the insulator's umbrella skirts in the thermal image. At the same time, by using a 131 mm lens, the image detected with three different distances was compared, as shown in Figs. 2b–d. When distance was 40 m, umbrella skirts overlapped seriously, the image was better when distance was 80 m, but when distance was 125 m, it could barely distinguish umbrella skirts.

Considering the height of 500 kV towers mostly about 50 m, the height of insulator is about 20–50 m. Combined analysis of the local detection image and infrared accurate temperature measurement should use 131 mm or larger focal length lenses, and detection distance should be in 50–100 m range.

3 Overheat of insulators caused by several different reasons

Internal partial discharge, dielectric loss caused by water infiltration defects, and resistance loss caused by sheath insulation aging and resistance decline are the main reasons of the composite insulator overheat [8].

The insulation resistance of a good composite insulator is very large, and the leakage current through the insulator is only microampere level. When insulation degrades and insulation resistance drops to a certain extent, the leakage current will increase, resistance loss will increase too, and the local overheat will occur. When the insulators are polluted heavily, and contamination on the surface becomes damp to a certain extent, it will form a low resistance area and the leakage current will increase, which will cause the surface temperature to rise, but the heat will not last too long time, in good weather, under dry conditions, and overheat will not appear. Based on the results of local detection, this paper analyses three kinds of conditions, such as overheat caused by insulation deterioration, surface contamination, and coexistence of the two above.

3.1 Overheat due to insulation deterioration

In the test on ground, one insulator on 500 kV line was found overheat serious, the wire side temperature of the insulator was 28 K higher than the adjacent phase insulator at the same position, thermal image as shown in Fig. 3. Fig. 3a shows the ground temperature measurement result, and the maximum temperature of the insulator was 54.1°C, which was 29.1 K higher than the normal position. Fig. 3b shows the on-tower temperature measurement result, and the maximum temperature of the insulator was 70.4°C, which was 46.2 K higher than the normal position. The temperature between the second and the sixth umbrella skirt was the highest, and there is also a hot spot between the sixteenth and seventeenth umbrella skirt.

After found the defect, professional personnel replaced the insulator immediately. It was found the sheath of the insulator heating part damaged, and mandrel exposed. The insulator has been degraded seriously because of the internal insulation defect, as shown in Fig. 4. It can be seen that infrared temperature measurement is very effective for detecting the insulation degradation defects and preventing the insulators from break, which may cause the wire dropping on the ground.

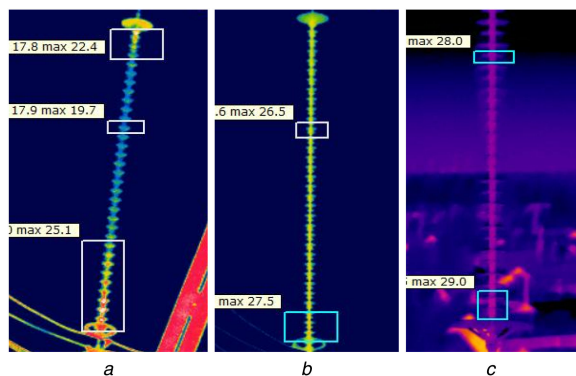


Fig. 5 Thermal images of normal insulator detected after rain
(a) Detected 4 h after rain, (b) Retested on ground under sunny weather, (c) Retested on tower under sunny weather

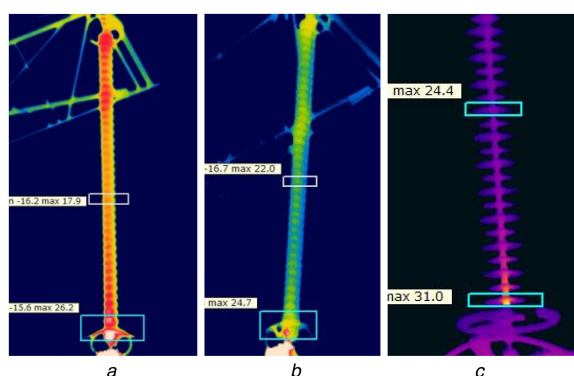


Fig. 6 Thermal images of overheated insulator detected after rain
(a) Detected 13 h after rain, (b) Retested on ground under sunny weather, (c) Retested on tower under sunny weather

3.2 Overheat caused by surface contamination

Many insulators were found overheat when detected not too long after rain stopped and atmospheric humidity was lower than 85%, but the retest results were normal when detected in a sunny day or after sunset. This instance has appeared many times, which resulted in repeated local detection, and even replacing the insulators. This kind of unnecessary work may make a greater risk and affect the safety of power grid.

Fig. 5 shows thermal images of one insulator detected after rain. The maximum temperature of the insulator was 25.1°C when detected 4 h after rain, which was 5.4 K higher than the normal position, as shown in Fig. 5a. The maximum temperature of the insulator was 27.5°C when retested on ground under sunny weather, which was 1 K higher than the normal position, as shown in Fig. 5b. The maximum temperature of the insulator was 29°C when retested on tower under sunny weather, which was 1 K higher than the normal position, as shown in Fig. 5c.

The temperature difference was 5.4 K when the insulator was measured in cloudy day after rain. After one sunny day, the temperature difference was only 1 K when measured after sunset. The contamination on surface of the insulator has been accumulated for 10 years. In damp condition, partial insulation resistance on wire side of insulator was reduced, the leakage current increased, so the surface temperature rose. When the surface was dry, the surface heating phenomenon disappeared. It can be concluded that the insulation was in good condition, and the high temperature difference measured after rain was caused by damp contamination on the surface. This kind of heating can easily lead to the misjudgement of whether the insulator has an internal insulation defect.

In the detection after rain, more than half of the insulators on the line were still normal. This paper argues that the damp contamination on the surface of insulators does not always cause the surface temperature rise. Only when the accumulated degree and the damp degree of the surface contamination reach to a certain level, the overheating of insulators will occur.

Through the above analysis, it is considered that the infrared accurate temperature measurement of composite insulators shall not be carried out after rain, at least ensuring that the insulators have been exposed to the sun for one day and the surface of insulators has been dry.

3.3 Deterioration of insulation coexists with the damp contamination on the surface

Some insulators were found overheat when detected not too long after rain stopped, and the retest results were certainly abnormal when detected in a sunny day. Take insulator images in Fig. 6 as an example, when detected 13 h after rain, and the temperatures of insulator's wire side and normal position were 26.2°C and 17.9°C, respectively, while the temperature difference reached 8.3 K, but when detected in the second day under sunny weather, the temperatures of insulator's wire side and normal position were 24.7°C and 22°C, respectively, while the temperature difference was 2.7 K. Although the temperature difference was not too high, it can be seen from the thermal image that there was a hot spot at the end of wire side. Then power crews climbed up the tower and retested the insulator. The result showed that the temperature difference was 6.6 K, while the maximum temperature of the insulator's wire side was 31°C. Judging from the thermal image, it was obviously overheated, and the wire side mandrel of the insulator was defective. This paper suggests that the insulators' surface damp contamination aggravates the overheat caused by insulation defects, which lead to the high temperature difference when detected after rain.

4 Judgment method

The most used method of infrared temperature measurement of composite insulators is to judge the temperature difference between the highest temperature point and normal point in thermal images. The method is effective to judge some serious overheating insulators, but there is no unified standard about how high the judgment value should be taken yet.

In a large number of local detection, though temperature differences among three-phase insulators were greater than 1 K, the temperature distribution along the insulator was uniform, only 1–2 K between the highest temperature point and the lowest temperature point. In laboratory tests, it was found that a certain number of normal composite insulators overheat about 2 K at high voltage side. A large amount of insulators with temperature difference of 3–4 K at local detection were found that there was no overheat in the retest in the laboratory, and there was no defect in the dissection. This paper believed that these insulators were normal and the overheat was caused by different spatial positions on tower and the different detecting distance in local detection. The thermal image of insulators should be carefully analysed and compared to reduce the misjudgement.

Usually, due to the electric field distribution along the composite insulator, the temperature distribution along the whole string should be a smooth approximation of 'U' type, with two high ends and a low middle part. Temperature distribution along composite insulators will appear peak value, where exist insulation defects, and there will be obviously different colours between the adjacent umbrella skirts in the thermal image.

Fig. 7 shows thermal images of three-phase composite insulators on a 500 kV line tower designed with double strings.

Seen from the thermal images, all of the six composite insulators' wire side had abnormal hot spots, and the temperature difference between the highest temperature point and the ambient temperature was 2.6 K. Now make a similar comparison, the maximum temperatures were 20.1°C and 20.9°C on the two top-phase composite insulators, 21.5°C and 21.9°C on the two middle-phase insulators, and 21.2°C and 22°C on the two bottom-phase insulators. The temperature difference was 1.8 K between top phase and middle phase, and 0.5 K between bottom phase and middle phase, but compared with the two insulators on the same phase, the maximum temperature difference was only 0.8 K. In this case, it cannot be considered the composite insulators of bottom phase and middle phase were overheat, and the on-tower detection

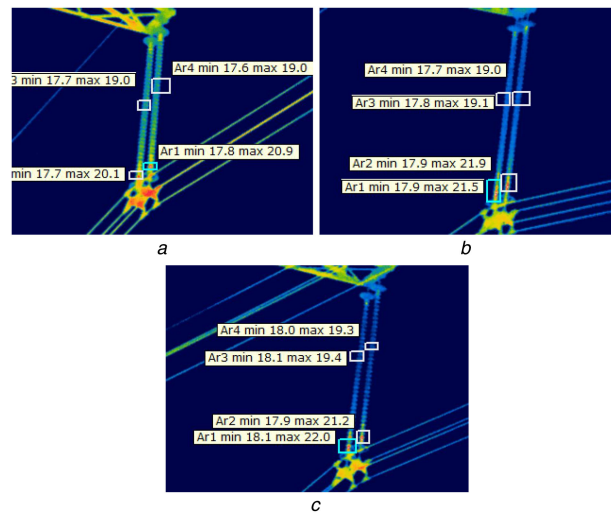


Fig. 7 Thermal images of three-phase composite insulators
(a) Top phase, (b) Middle phase, (c) Bottom phase

result is necessary to confirm that. The different position of the composite insulators, the difference of the three-phase current, and the weather condition during the temperature measurement may cause this phenomenon, which may lead to miscarriage of justice.

Through the above analysis, this paper proposed a method of insulation defect detection of composite insulators based on infrared accurate temperature measurement.

First, according to the different temperatures displayed as different colours in thermal images, if no abnormal heating part exists, the equipment is normal. If there is abnormal heating, then we need to compare the temperature between the hottest point and lowest temperature point along the insulator. When the temperature difference is greater than 5 K, we can firmly believe that the insulator has insulation deficiencies. Otherwise, we have to make a similar temperature comparison between the corresponding parts of the three-phase insulators on the same tower, or the double insulators string on one phase. If the similar temperature difference is less than 1 K, the higher temperature insulator is normal, or we need to climb up the tower to confirm whether the insulator has insulation deficiencies.

Specially, when there is only one composite insulator on the tower, it can only be judged based on whether thermal image has obvious hot spots and the temperature distribution along the insulator string is uniform.

5 Conclusion

Based on the analysis of large amount of infrared temperature measurement data and images of composite insulators, the following conclusions were obtained:

(i) It is better to use the telephoto lens for the ground infrared accurate temperature measurement of the insulators on overhead lines. The best location should be selected according to the topography of the tower, and the obstacles in the visual field should be avoided. The instrument should be kept at a certain distance with the insulators, and the detection distance is better in the range of 50–100 m, so as to minimise the overlap of the umbrella skirts.

(ii) Infrared accurate temperature measurement should be carried out under clear weather or after sunset. The insulators should not be detected from noon to sunset, even on cloudy days. After the rain, the insulators should be exposed to the sun for at least one day, to make sure the surface of insulators has been dry, when detected.

(iii) The damp moisture on the surface of insulators may cause the surface temperature rise, which will aggravate the heating caused by insulation deterioration of insulators, and lead to misjudgement of the insulation condition.

(iv) The composite insulators, as a kind of voltage heating equipment, should be judged from both the contrast of similar equipment and thermal image characteristic. The temperature difference between the corresponding part of the three-phase insulators on the same tower, or the double insulators string on one phase, should be compared, and the temperature distribution should be analysed.

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