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Regular article

Interface defect detection for composite insulators based on infrared thermography axial temperature method☆

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ABSTRACT

Interface quality is one of the most important properties of composite insulators, and is hard to be effectively detected. Poor interface quality may lead to interface discharge or insulator fracture and hence threatens the safety of power systems. In order to detect interface defects of in-service composite insulators, 15 samples were collected from transmission lines in this paper. The dry power frequency voltage test and the steep-front impulse voltage test were conducted. The surface temperature after dry power frequency voltage test was recorded by infrared thermography. Then a method for quantitative characterization of composite insulator interface defects based on infrared thermal image axial temperature was proposed. By defining heating section according to temperature level of each sample, we summarized temperature distribution characteristics, including characteristics on location, length and maximum temperature point of heating sections. Our results show that the connection zone of composite insulators is prone to generate interface defects. Temperature analysis together with steep-front impulse voltage test results indicate that interface defects of test samples can be judged by the following three features of heating sections, namely, temperature rise (ΔT) above 80 K, ΔT above 20 K with 10 cm in length, and ΔT above 10 K with 40 cm in length.

1. Introduction

It is unavoidable for composite insulators in service to be exposed to natural stresses. For a composite insulator, there are many interfaces which can be divided into two kinds: macroscopic ones and microscopic ones [1]. The interface among the glass fiber reinforced (GFR) core, the fitting and the housing is the most delicate point, so degradation may initially develop from there when a composite insulator operates in a complex environment that contains electrical, mechanical and chemical factors. Besides, poor adhesion of the interface may result in inner deterioration [1]. A lab research indicates that deterioration process may be caused by hydrolysis reactions and electrical discharges [2]. Moisture together with contaminants might immerse into voids, gaps or cracks on the interface, leading to brittle fracture under mechanical stress [3–5].

In addition, another abnormal fracture known as "decay-like" fracture has been brought forward recently [6]. Current research demonstrates that degradation might start from weak adhesion points of the interface between core and housing, and will be exacerbated by partial discharges and surface micro current, which always accompany local heating and hydrolysis [6,7]. Therefore, abnormal heating of a composite insulator in service probably suggests degradation inside. The research mentioned above indicates that the quality of interface is of great importance for a composite insulator. Poor interface connection may lead to fracture and some other severe accidents. Thus, regular sampling tests on interfaces are very necessary.

Despite the existence of many other intelligent methods and techniques proposed or developed to monitor the safety of electrical equipment [8–13], infrared thermography (IRT) is widely applied in numerous areas thanks to its advantages of being non-contact and non-destructive [8,14]. It is one of the most common techniques for measuring the temperature of composite insulators [1]. In China, this technique was first brought into service systematically in 2001 by Foshan Power Supply Bureau when abnormal heating was found in composite insulators in transmission lines of AC 220 kV and above [15]. After that, it has become increasingly popular in power systems, capable of detecting faulty insulators effectively [6,7]. In addition, IRT is also utilized in laboratories together with the other techniques to investigate heating mechanism of composite insulators [16–20]. Papers [17–19] indicate that surface conditions such as humidity and

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Table 1
Parameters of test samples.

Voltage (kV)	Sample	Manufacturer	Shed type (large/ small)	Number of shed (large/ small)	Large shed diameter (mm)	Small shed diameter (mm)	Shed spacing (mm)	Assembly length (mm)	Arcing distance (mm)	Creepage distance (mm)	In-service time(year)
110	H02	B	1L2S	10L20S	160	85	94	1275	1070	3310	7.5
	H06	B	1L2S	10L20S	162	85	96	1270	1082	3297	12.5
	H07	B	1L1S	13L12S	135	100	76	1210	1032	3180	9.5
	H10	B	1L2S	10L20S	163	85	95	1274	1060	3287	11.5
	H17	B	1L2S	10L20S	160	85	93	1350	1115	3332	8
	H21	B	1L2S	10L20S	162	85	95	1300	1120	3341	11.5
	ZH05	A	1L1S	12L11S	150	110	87	1400	1205	3279	10.5
	ZH07	B	1L2S	10L20S	161	85	94	1360	1162	3396	10
	ZH08	C	1L2S	12L22S	160	98	95	1360	1150	3852	10
	ZH11	C	1L2S	12L22S	161	98	93	1360	1154	3864	10
	ZH24	A	1L1S	13L12S	151	110	79	1256	1020	3223	12
	ZH27	B	1L2S	10L20S	162	85	96	1270	1082	3297	11.5
	ZH28	B	1L2S	10L20S	162	85	96	1270	1083	3292	11.5
	ZH33	A	1L1S	12L11S	149	115	88	1392	1020	3227	10
	ZH34	A	1L1S	12L11S	149	115	88	1392	1020	3227	10

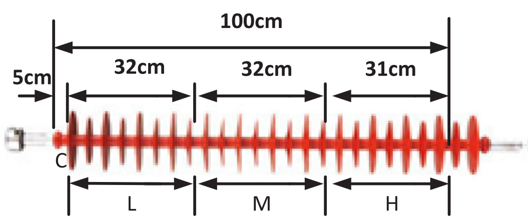

Fig. 1. Definition of each section. C is connection zone. L, M and H represent low voltage section, middle section and high voltage section respectively.

contamination near the high voltage end of composite insulators can lead to abnormal local heating. This may explain why abnormal heating is detected on a composite insulator in service but not in the laboratory. Hence errors may occur when adopting IRT to diagnose interface problems of insulators in operation.

According to IEC 62217 [21], many methods can be applied to test the quality of interfaces of composite insulators in a laboratory, including water immersion pre-stressing, steep-front impulse voltage test and dry power frequency voltage test. However, these are all designed for newly manufactured samples. There is no specific standard targeting samples in service. Besides, research done before mainly focused on the highest temperature rise of a whole specimen; much other information about temperature distribution was ignored in infrared images.

In this paper, fifteen composite insulators of AC 110 kV in service in Guangdong Province for roughly 10 years were taken as samples for reliability testing. Dry power frequency voltage test and steep-front impulse voltage test were conducted after all the samples were boiled. The appearance of each sample was inspected visually before and after boiling. IRT was applied to record the temperature of each sample after the dry power frequency voltage test. Then the axial temperature distribution in the infrared images was analyzed. The distribution characteristics of heating sections as well as temperature features were also studied. After that, the steep-front impulse voltage test was conducted to find out how temperature rise in the dry power frequency voltage test correlated with damage in the steep-front impulse voltage test. Work done in this paper can help improve the current acceptance criteria of in-service composite insulators by interface defect detecting.

2. Test samples and methods

The in-service time of the above fifteen typical composite insulators ranges from 7.5 years to 12.5 years. Detailed information is shown in Table 1.

In order to describe the distribution characteristics of heating sections in power frequency voltage tests and the sections energized with steep-front impulse voltage, each sample is divided into four sections from the low voltage end: 0–5 cm, 5–37 cm, 37–69 cm, 69–100 cm, as shown in Fig. 1. The first two parts are defined as connection zone (C) and low voltage section (L). The remaining two parts are middle section (M) and high voltage section (H) respectively. An experiment was conducted referring to IEC 62217, 9.2 Tests on Interfaces and Connections of Metal Fittings. The whole process is shown in Fig. 2. Visual inspection was firstly conducted. Then the samples were washed by deionized water before being put into boiling water with conductivity of 1650 μS/cm ± 50 μS/cm at 20 °C. After 42 h of boiling, visual inspection was conducted again. Then dry power frequency voltage test was conducted prior to steep-front impulse voltage test to avoid possible pre-mature damage to the samples. High voltage was applied on all samples at the same time for 30 min. After temperature measurement by infrared imaging, data was analyzed and the steep-front impulse voltage test was conducted.

Fig. 3(a) shows the samples being boiled. Fig. 3(b) shows the samples during dry power frequency voltage experiment. Fig. 4 illustrates the infrared image. The dry power frequency voltage test circuit is illustrated in Fig. 5. On the left side of Fig. 5 is the Regulator-Transformer system with capacity of 2400 kVA. The ratio of transformer is constant, so adjustment of test voltage is realized by the regulator (the one with tap). The input voltage of the regulator is 10 kV (stable), while its output voltage can be adjusted. Then the output voltage of the regulator becomes input voltage of the transformer, which turns lower voltage into higher voltage through its constant ratio.

Test voltage was decided referring to the IEC 62217 criterion, which states that the test specimens shall be continuously subjected to 80% of the flashover voltage gained by previous flashover test for 30 min. However, the criterion aims at new insulators on the production line. In order to avoid possible damage caused by flashover test for in-service samples, the operation experience of Grid Company was adopted. That is, the flashover voltage of a 1-meter-long insulator is around 375 kV. In this experiment high voltage of AC 300 kV was energized to a 1-meter-