Advanced Detecting Technologies for Aging Performances of Composite Insulators

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Abstract. As common electrical equipment, composite insulator played an important role on the safe and stable operation of transmission lines. Hence, it was meaningful to explore effective methods to detect the service performances of operated composite insulators. In this paper, several advanced technologies were introduced to check the performances of in-service composite insulators. The macroscopic properties were mainly detected by means of X-ray digital imaging system, ultrasonic phased array (UPA) and hydrophobicity measurement. In addition, the microscopic properties were analysed by the way of scanning electron microscope (SEM) observation, microscopic infrared spectral imaging system and thermogravimetric (TG) analysis. It was believed that defects such as micro-cracks, gaps etc. could be earlier and quickly found by using these detection techniques, thereby avoiding power failure accidents of the transmission lines.

Keywords: Composite insulator; Transmission line; Aging; Technology.

1. Introduction

Composite insulators play an important role in supporting and isolating the transmission line, ensuring power system run safely. Since first successfully developed in 1950s, the performance of composite insulator has been improved by leaps and bounds. Nowadays, composite insulator has been widely applied in transmission lines all over the world for its limited volume, light weight, superior mechanical properties, excellent anti-pollution properties and easily installed and maintained [1, 3]. As the common electrical insulation equipment, composite insulator is composed of high strength fiber reinforced plastic (FRP) core, high temperature vulcanized silicone rubber sheath and metal fittings [4, 5]. In China composite insulators were firstly introduced in heavily polluted areas in early 1990s [6].

With the increase of operating time of composite insulator, the shed and sheath silicone rubber materials will be gradually affected by environmental factors (such as ultraviolet, ozone, temperature, humidity and contamination, etc.) and electrical stress factors (such as arc discharge, corona and leakage current, etc.). With long-term effect of high fields, electrical discharges will be induced in insulator shed, sheath and end fittings, especially in EHV and UHV transmission lines [7, 8]. Thereby, the electromechanical performance and pollution flashover resistance of composite insulator will be gradually deteriorated, even leading to the line disconnection. In 1994, CIGRE and IEEE launched an investigation of in-service composite insulator failures, and the findings revealed that aging, mechanical properties and electrical properties problems are the main causes, in which 64% of the failures are caused by shed
aging. According to the CIGRE statistical data in 1999, the failure rate of composite insulators is nearly 0.035%, in which the fracture and falling off of fiber accounts for 57%, interface breakdown accounts for 28%, shed deterioration accounts for 14% and the metal fittings damage is only accounting for 1% [9].

Therefore, in order to secure a reliable service performance of composite insulators, key technologies for aged performances detecting of composite insulators have important sense. In this paper, several advanced methods for detecting the macroscopic and microscopic performances of in-serviced composite insulators are introduced, which is in order to provide technical supports for the operation and maintenance of the domestic composite insulators.

2. Macroscopic performance testing

2.1. X-ray digital imaging system

X-ray digital imaging system (Fig. 1a) is a new method of nondestructive testing technology, by which can quickly detect the internal structure and defects inside the composite insulator interface according to gray distribution in the captured image [10, 11]. The nondestructive test methods appear suitable for detecting voids, cracks inside the composite insulator. During the measurement, the composite insulator sample is placed in lead shield room and exposed to X-ray photons. The X-ray photons are subsequently received by the detector and transformed into digital signals through a series of transformations. Then the digital signals are amplified and processed by computer processing in digital images, such as shown in Fig. 1b.

![X-ray digital imaging system](image1)

2.2. Ultrasonic phased array detection (UPA)

UPA technique (Fig. 2) has continuously been developed on the basis of ultrasound technology in recent years [12]. With the fast development of computer and electronic control technology, UPA has gradually been used in many industrial fields [13, 14], by using which the location of defects at different depths and identifying different types of defects can be quickly solved, even the objects having complex shapes. Yuan [15] has investigated the composite insulators with various types of detects by UPA technology, the obtained results shown that void defects in the bulk of the insulator housing can be easily detected. Holes under insulator sheds can also be detected by the edge of scanning range. However, it is difficult to detect defects near the interface between the sheath and core.
2.3. Hydrophobicity measurement
Hydrophobicity of materials is a property of resistance to flow of water on the surface. If the material is highly hydrophobic, the contact angle of the drop will be large when the water is dropped on its surface. The hydrophobicity of silicone rubber materials is one of the most important factors related to anti-pollution flashover performance of composite insulators. The contact angle is generally measured by drop shape analyzer (Fig. 3a), during the test, a water drop is placed on the surface of composite insulator shed then measured automatically using a calculation program in an image, as shown in Fig. 3b. Rowland studied the hydrophobicity of a 400 kV silicone rubber composite insulator [16]. It revealed that the hydrophobicity was change varied from the low voltage shed to the high voltage shed, and the lowest contact angle was found in the middle shed.

![Figure 2. Photograph of Ultrasonic phased array (UPA) equipment.](image)

(a) Drop shape analyze (b) static contact angle of one water drop on the surface of composite insulator shed

Figure 3. Image of drop shape analyzer and its application.

3. Microscopic performance test

3.1. Scanning electron microscope (SEM) observation
SEM is a common device usually applied to observe the micromorphology of the materials surface by secondary electronic signal imaging. Therefore a micro magnified image showing the surface information of composite insulator can be obtained by the SEM observation. As shown in Fig.4, the surface micromorphology of a operated composite insulator shed was observed by SEM after gold coating [17]. It can be seen that the composite insulator shed had been deteriorated due to the effect of electrical discharges or corona discharges, and several micro-cracks were obviously found in the shed surface.
3.2. Microscopic infrared spectral imaging system

Microscopic infrared spectral imaging system is composed of a fourier transform infrared (FTIR) spectrometer and an infrared microscope [18]. During measurement, the interference infrared light from the host enters the microscope system, then deflecting a certain angle and focusing on the surface of tested sample by elliptical paraboloid focusing mirror. As shown in Fig. 5, different colors represent the area sizes of methyl peak in the longitudinal section of composite insulator shed. The leftmost blue region represents the blank area, indicating that the methyl concentration is close to 0. The rightmost blue region represents that the methyl concentration is nearly not changed, revealing that the silicone rubber material is not aged. Therefore, it can be informed the depth of aging layer of the sample shown in Fig. 5 is 41.43 μm [19].

3.3. Thermogravimetric (TG) analysis

TG is a kind of instrument that uses thermogravimetry to measure the relationship between temperature and mass change of various materials. The composite insulator silicone rubber material is mainly composed of PDMS, SiO₂ and ATH. According to the characteristics of different thermal decomposition behaviors and non-overlapping of thermal decomposition temperature range, the aging properties of composite insulator silicone rubber material can be studied through the thermal decomposition test by TG analysis. It can be seen in Fig. 6 that the decomposition process of silicone rubber material is mainly divided into two stages. It can be seen that the ATH is completely burned out in stage I, and the PDMS is mainly decomposed at the second stage. Due to that the hydrophobicity of composite insulator is mainly related to the content of PDMS, therefore, the aging degree of composite insulator can be evaluated according to PDMS content changes [19].
4. Inclusion
As known, composite insulators play an important role in anti-pollution flashover of high voltage and ultrahigh voltage transmission lines, the running state of which impose a great effect on the safe and stable operation of power system. Therefore, in order to ensure the safe and stable running of transmission lines, it is necessary to explore highly-efficient and fast detecting methods to carry out regular inspections on the service performance of composite insulators. Thereby, several faults such as sheath cracking, shed hydrophobicity losing, gaps forming inside the sheath and mandrel interface, etc. can be earlier detected, avoiding occurrence of blackout accidents on the transmission line, furthermore, effectively prevent the damages of composite insulator failures, ensuring for safe and stable operation of transmission lines.

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