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Comparison on ac icing flashover performance of porcelain, glass, and composite insulators

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ABSTRACT

The electrical performance of insulators under the comprehensive conditions of low air pressure, pollution and icing, is an important basis for the selection of external insulation of transmission lines and substations in icing regions. However, little research has been dedicated to the comparison on ac icing flashover performance of composite, porcelain and glass insulators in this environment. Based on the investigations carried out in the artificial climate chamber on three types of iced insulators, the ac flashover performances of insulators were researched in this paper. In addition, the paper analyzed and compared the effects of various factors, including ice thickness, pollution and air pressure on the flashover performance of three types of iced insulators. The experimental results show that the flashover voltage of three types of insulators decreased with the increase of ice thickness, pollution, and the altitude. The characteristic exponent characterizing the influence of the ice thickness, pollution and atmospheric pressure on the flashover voltage were related with the insulator types. The effect of ice thickness and atmospheric pressure on icing flashover voltage was more apparent for composite insulator than porcelain and glass insulator. The characteristic exponent characterizing the influence of pollution on the flashover voltage was small for composite insulators. Under the same condition, the flashover voltage gradients of ice-covered composite insulators are slightly greater than porcelain and glass insulators.

1. Introduction

China is one of the countries that have severe icing problems of transmission lines in the world. Current research and operational experience show that singly or in combinations, pollution, icing, low air pressure on insulators may cause a drastic decrease in the electrical insulation strength that can lead to flashover and power outages at normal service voltage. Most parts of Southern China encountered the most serious ice and snow disaster in the meteorological record history in January and February 2008. The power grid suffered severe damage in East China, Central China, South China, and Southwest China. In addition to a lot of mechanical damage, icing flashover was also an important reason for the large-scale power outage. The disaster brought greater concerns about icing problems of the power grid to Chinese power departments.

The electrical performance of insulators in freezing conditions is an important basis for the selection of external insulation of transmission lines and substations in icing regions, and it has been extensively investigated by researchers in recent decades in the world. It is proved that the flashover voltage decreases with the increase of freezing water conductivity, with voltage decreasing at a decreasing rate (Hu et al., 2007; Meghnefi et al., 2008; Yunpeng et al., 2010). References (Farzaneh et al., 2003a, 2003b; Hemmatjou et al., 2005; Zhang and Farzaneh, 2000) indicate that the flashover voltage of iced insulators is much lower in ice-melting period than that in ice accretion period. It is considered that *m*, characteristic index of the influence of air pressure on ice-covered insulators' flashover voltage, is related to insulator' material quality, structure type, pollution level and ice thickness (Farzaneh et al., 2006; Jiang et al., 2005a, 2005b; Sima et al., 2004; Sun et al., 2002; Tian et al., 2002; Zhang et al., 1993). Usually, some researchers measured the ice thickness of the ice accumulated on a monitoring cylinder to describe the icing degree of insulators (Cheng et al., 2009; Farzaneh and Kiernicki, 1997). And the relationship between flashover voltage and ice thickness can be described as a negative exponent function (Hu et al., 2007; Jiang et al., 2002, 2008, 2009a, 2009b; Shu et al., 2001; Zhang et al., 2008).

To date, little research has been dedicated to the comparison of ac icing flashover performance of composite, porcelain and glass insulators covered with ice, especially under the comprehensive conditions of low air pressure, pollution and icing. Based on the investigations carried out in the multi-function artificial climate chamber in the High Voltage and Insulation Technological Laboratory of Chongqing University, China, this paper investigates the ac flashover performance of three types of iced insulators. Then, the paper analyzed and compared the effects of various factors, including ice thickness, pollution and air pressure on the flashover performance of three types of iced insulators.

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2. Test equipment, specimens and methods

2.1. Test equipment

The experimental investigations were carried out in the multi-function artificial climate chamber (Hu et al., 2007), with a diameter of 7.8 m and a height of 11.6 m, is shown in Fig. 1. It mainly consists of refrigeration system, vacuum-pumping system, spraying system and wind velocity regulating system. The minimum temperature in the chamber can be adjusted to −45 °C; the air pressure in the chamber can be as low as 30 kPa, which can simulate the atmospheric conditions at an altitude of 9000 m. According to the previous studies, the most dangerous type of ice for the insulators in power system is wet-grown ice. Therefore, this paper mainly focused on wet-grown ice.

The power was supplied by a 500 kV/2000 kVA test transformer. The major technical parameters are as follows: rated capacity 2000 kVA, rated current 4 A, input voltage 0–10.5 kV, output voltage 0–500 kV, and short-circuit impedance less than 6% under a rated voltage of 500 kV. The test power supply satisfies the requirements recommended by IEEE publication (Farzaneh et al., 2003a, 2003b). The test circuit of the ice-covered flashover experiment is shown in reference (Jiang et al., 2002).

2.2. Test specimens

This study, takes seven-unit porcelain, glass insulator strings and 110 kV composite insulators as objects whose structure and parameters are described in Fig. 2 and Table 1, and uses the same test procedures and strictly controls environment parameters for each. In Table 1, *D* is the diameter, *H* is the height, *h* is the minimum dry arcing distance, and *L* is the leakage distance.

2.3. Test procedures and methods

(1) Preparation: Before tests, all samples were carefully cleaned to ensure the removal of all traces of dirt and grease and then dried naturally.

(2) Artificial polluting: The solid-layer method (SLM) and the icing-water-conductivity method (IWCM) are widely used in the insulator icing tests. In (Xingliang Jiang et al., 2010), the equivalent relation of influence of the two methods on ice flashover stress was analyzed and studied. In this paper, the IWCM was used to form the pollution layer on the samples. The conductivities of freezing water (corrected to the values at 20 °C, and the conductivities that will be mentioned are corrected to the values at 20 °C) in this investigation were 300, 450, 630, and 1000 μS/cm, respectively.

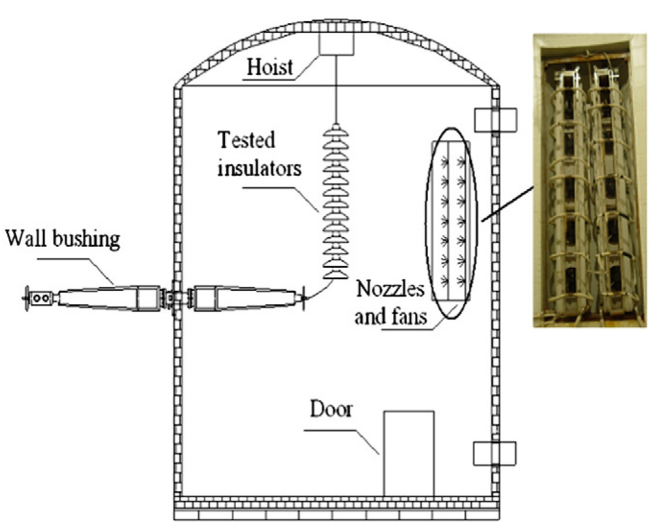

Fig. 1. The schematic diagram of the artificial climate chamber in Chongqing University.

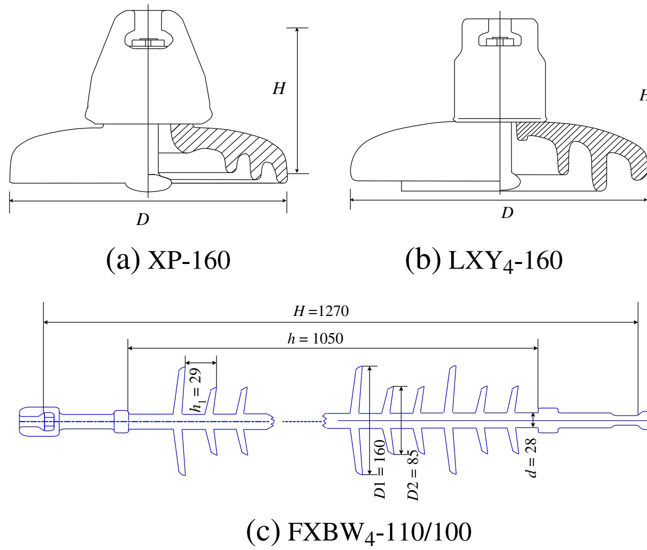

Fig. 2. Profiles of test insulators. (a) XP-160, (b) LXY_4-160 and (c) $FXBW_4$-110/100.

(3) Ice deposit: the specimens were suspended vertically from the hoist at the center of the chamber, rotating at 1 r.p.m. Then the spraying system was used to form wet-grown ice on insulators without service voltage in this paper. The minimum clearances between any part of the specimens and the spraying system were larger than 3.8 m, the droplets size was 80–100 μm, the spray flux was about 60–80 L h^{-1} m^{-2}, the wind speed was 3.0–5.0 m/s, the temperature in the climate chamber was −10.0 °C to −7.0 °C. The densities of glaze on the samples were about 0.80–0.90 g/cm^3.

(4) Characteristics defining the icing degree: As the amount of ice accretion on the insulators is one of the major parameters in evaluating flashover performance, the average thickness of ice on the insulators was checked by measuring the thickness d of the ice accumulated on a monitoring cylinder with a diameter of 28 mm and rotating at 1 r.p.m. (Cheng et al., 2009; Hu et al., 2007).

(5) Simulation of high altitude: The low atmospheric pressure in the chamber was used to simulate the high altitude conditions. The atmospheric pressure *P* (in kPa) is the synthetical reflection of the atmospheric temperature t (in °C), the relative density δ_d of dry air and absolute humidity h_a (in g/cm^3) of air (Jiang et al., 2004, 2005a, 2005b). References (Jiang et al., 2004, 2005a, 2005b) indicate that the relationship between the atmospheric pressure and the altitude *H* (in km) can be expressed as follows:

$$H = 45.1 \times \left(1-(P/P_0)^{0.1866}\right). \quad (1)$$

Where P_0 is the standard atmospheric pressure (101.3 kPa). In this paper, the altitudes of 232 m, 1000 m, 2500 m, and 4000 m were simulated in the chamber, with atmospheric pressures of 98.6 kPa, 89.8 kPa, 74.6 kPa and 61.6 kPa, respectively.

Table 1
Parameters of test insulators.

Type	*D* (mm)	*H* (mm)	*h* (mm)	*L* (mm)
XP-160	255	155	–	305
LXY_4-160	280	155	–	380
$FXBW_4$-110/100	150/115	1270	1050	3350