Cold Regions Science and Technology 128 (2016) 47–56

Contents lists available at ScienceDirect

Cold Regions Science and Technology

journal homepage: www.elsevier.com/locate/coldregions

Effects of icing degree on ice growth characteristics and flashover performance of 220 kV composite insulators

Qin Hu [a,*], Shijing Wang [b], Hongjun Yang [c], Lichun Shu [a], Xingliang Jiang [a], Hantao Li [a], Jiahao Qi [a], Yanqing Liu [a]

[a] State Key Laboratory of Power Transmission Equipment and System Safety and New Technology, School of Electrical Engineering, Chongqing University, Chongqing 400030, China
[b] State Grid Wuhu Power Supply Company, Wuhu, Anhui Province 241027, China
[c] Xiangfan Guowang Composite Insulator Co.,Ltd., Xiangfan, Hubei Province 445000,China

ARTICLE INFO

Article history:
Received 12 May 2015
Received in revised form 21 March 2016
Accepted 20 April 2016
Available online 22 April 2016

Keywords:
Icing degree
Composite insulator
Electric field distribution
Leakage current
Icing flashover voltage
Flashover arc path

ABSTRACT

Icing degree is one of the important factors influencing insulator's icing flashover performance. But there may be differences between the effects of icing degree under non-energized and energized icing conditions. For this purpose, the comparative tests of non-energized and energized glaze ice accumulation are conducted on 2 types of typical 220 kV composite insulators under different icing degrees in this paper. Combining with the numerical calculation of electric field distribution, the monitoring of leakage current, the measurement of the ice-melting water conductivity and the observation of flashover arc paths, the influences of icing degree on ice growth characteristics and flashover voltages of composite insulators are deeply analyzed. Results indicate that with the increase of icing degree, all relevant ice parameters gradually increase but their regularities are related to the shed configuration and the position of sheds as well as whether the ice deposits on non-energized or energized insulators. These variations lead to differences of the quantity and length of icicle air gaps and the conductivity of the water film on the ice surface, and then affect the flashover arc path and icing flashover voltage. The icing flashover voltages of energized ice-covered insulators are higher than that under non-energized condition and their difference becomes larger with the increase of icing degree while the effect of shed configuration on the icing flashover performance gradually becomes less apparent when the icing becomes heavier.

1. Introduction

In recent 20 years, composite insulators have been widely applied to the high voltage (HV) transmission systems due to their advantages of light weight, high mechanical strength, excellent resistance to pollution flashover and less maintenance (Liang et al., 1999). However, under icing condition, the smaller gap distance between sheds is easier to be bridged by icicles, which leads to the significant decrease of the electrical performance and even the flashover incidents (Li et al., 2007; Jiang et al., 2011). Due to the complex landform and physiognomy characteristics in China, numerous transmission lines are inevitably subjected to atmospheric icing with different degrees. The resulting flashover accidents on ice-covered insulators have been reported in recent years. In particular, the great uncommon icing disaster that occurred in January and February, 2008, brought serious damage to many power networks in South China and resulted in a lot of tower collapsing, line breaking and flashover accidents on ice-covered insulator strings. These disasters, which lead to great loss of national economy and serious disturbance of daily life, have taken a lot of attention around the world.

The electrical performance of insulators under icing conditions is one important basis for the external insulation selection and design of transmission lines in icing regions. At present, the flashover performance and discharge mechanism of ice-covered insulators have been deeply investigated by many researchers. It has been found that the flashover voltages of insulators under icing conditions were about 40% of these under snow-covered conditions (Fujimura et al., 1979). Among different ice types, the flashover voltages of glaze ice-covered insulators were lowest (Phan and Matsuo, 1983). In order to characterize the degree of glaze ice on insulators, the average thickness of the ice on a rotating cylinder under the same experimental condition was widely adopted (Farzaneh and Kiernicki, 1995, 1997; Hu et al., 2007; Jiang et al., 2013a, 2013b, 2013c). Then the relationships between the icing flashover voltage and ice thickness were obtained. Moreover, the weight of the ice on the insulator (Jiang et al., 2002, 2007, 2013a, 2013b, 2013c), the thickness of the ice on the shed surface (Farzaneh and Chisholm, 2009a, b) and the average length of icicle at the edge of sheds (Yu et al., 2012; Liu et al., 2013; Li et al., 2011) were also employed by different investigators to indicate the icing degree, and the relations between these characteristic parameters and flashover voltages were discussed. Based on these studies, the equivalence relations among these parameters characterized the icing degree were deduced (Zhang et al., 2009; Jiang et al., 2013a, 2013b, 2013c).

* Corresponding author.
E-mail address: huqin@cqu.edu.cn (Q. Hu).

http://dx.doi.org/10.1016/j.coldregions.2016.04.010

Although different characteristic parameters have been adopted to characterize the degree of the ice covering on insulators and a lot of tests about their icing insulation performance have been carried out by a lot of investigators around the world (Farzaneh and Kiernicki, 1997; Hu et al., 2007; Jiang et al., 2013a, 2013b, 2013c; Farzaneh and Chisholm, 2009a, b; Li et al., 2011), these studies mainly aim at porcelain or glass insulator strings only under non-energized icing condition (Hu et al., 2007; Jiang et al., 2013a, 2013b, 2013c), or only under energized icing condition (Farzaneh and Kiernicki, 1997; Liu et al., 2013; Farzaneh and Chisholm, 2009a, b). Concerning composite insulators, the comparison of the influences of icing degree on their icing characteristics and flashover performances under non-energized and energized ice accretion conditions has not been reported at present. For these purposes, the non-energized and energized glaze ice accumulation tests are conducted on 2 types of typical 220 kV composite insulators under different icing degrees in this paper. Combining with the simulating calculations of electric field distribution, the monitoring of leakage current and the recording of flashover arc paths, the influences of icing degree on ice growth characteristics and flashover performance of composite insulators under non-energized and energized icing conditions are comprehensively compared and analyzed. The results can provide valuable reference to the establishment of relevant insulator icing test procedures and the engineering application of composite insulators in icing regions.

2. Test facilities, specimens and procedures

2.1. Test facilities

The experimental investigations are carried out in the artificial climate chamber which has a diameter of 7.8 m and a height of 11.6 m. The minimum temperature in the climate chamber can be adjusted to −45 ± 1 °C, which can meet the requirements of artificial wet-grown ice accretion (Institute of Electrical and Electronics Engineers (IEEE), 2009). Two rows of fog nozzles customized according to IEC standard are installed in the chamber so as to produce a spray with median volume diameter between 80 μm and 120 μm and form environment conditions of wet-grown ice deposit (Hu et al., 2007). The wind velocity in the chamber can be adjusted to 0–12 m/s so that the temperature and the fog particles in the chamber can be distributed uniformly. The power is supplied by a 500 kV/2000 kVA testing transformer with a maximum short circuit current of 75 A, which meets demands of energized icing and flashover tests of composite insulators. The power supply is introduced through a tailor-made 330 kV class wall bushing. The applied voltage is measured by a 500 kV capacitive voltage divider and oscilloscope. The schematic circuit of tests is shown in Fig. 1.

2.2. Test specimens

Test specimens consist of 2 types of typical FXBW-220/160 composite insulators. Type A is a conventional composite insulator, while type B is an improved one which is obtained by uniformly replacing four large sheds on type A insulator with other four extra large sheds with a diameter of 300 mm. Their profiles are presented in Fig. 2 and some technical parameters are given in Table 1, where D_0 is the rod diameter, $d_1/d_2/d_3/d_4$ are shed spacings, $D_1/D_2/D_3/D_4$ are shed diameters, $N_1/N_2/N_3/N_4$ are shed numbers, H is the dry arcing distance and L is the leakage distance.

2.3. Test procedures

2.3.1. Ice accumulation procedure

Before the ice accumulation, the specimens are carefully cleaned to ensure removing of all traces of dirt and grease and then dried naturally. Operational experience has indicated that insulators in service might be contaminated before and during the ice accretion, the solid-layer method and icing-water conductivity method are widely used to simulate these two pollution process in icing tests, respectively (Farzaneh and Chisholm, 2009a, b). Previous research has revealed that there was an equivalent relationship between these two methods on the flashover performance of ice-covered insulator strings (Jiang et al., 2010). Since the use of the icing-water conductivity method can easily control the uniformity of the contaminants and reduce the dispersion of test results, this method is adopted to simulate contaminations on insulator surface in tests. The conductivity of the freezing water (corrected to the values at 20 °C) is 370 μS/cm.

Both the field tests and the laboratory investigations have shown that the glaze with icicles among all types of the ice is the most likely to cause the flashover of transmission line insulators (Farzaneh and Kiernicki, 1995, 1997; Hu et al., 2007; Farzaneh and Chisholm, 2009a, b). Therefore, this paper mainly focuses on the wet-grown glaze ice deposit. The experimental parameters of ice accumulation are summarized in Table 2. In order to make the freezing water in the climate chamber as similar as the super-cooling water in natural conditions, the freezing water is pre-cooled to a temperature ranging from 3 to 4 °C before spraying (Institute of Electrical and Electronics Engineers (IEEE), 2009).

Two identical insulator specimens, one is energized and the other is not, are suspended vertically and simultaneously tested in the chamber. During ice accretion process, the leakage current flowing through the ice surface is recorded by a shunt of 50 Ω (shown in Fig. 1). The data are continuously recorded through a data-acquisition (DAQ) system composed of a personal computer, a NI USB-6215 data-acquisition card and Labview Software. Leakage current is sampled at a rate of 5000 samples/s. The ice weight is recorded by a weight sensor with

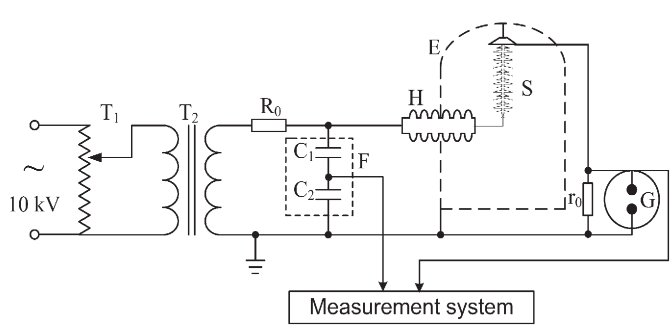

Fig. 1. Schematic circuit of tests. (T_1 is the voltage regulator, T_2 is the testing transformer, R_0 is the protective resistor ($R_0 = 5000\ \Omega$), F is the voltage divider ($C_1 = 1000$ pF, $C_2 = 1053$ nF), H is the wall bushing, E is the climate chamber and S is the specimen, r_0 is shunt resistor ($r_0 = 50\ \Omega$), G is the TVS protecting tube).

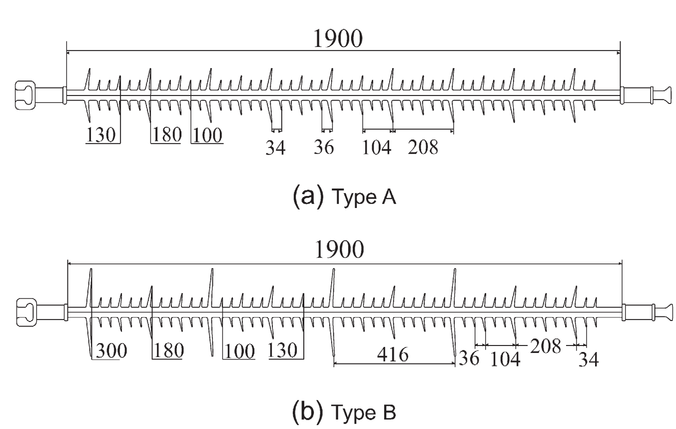

Fig. 2. Profiles of the tested 220 kV composite Insulators.