Electrical Power and Energy Systems 105 (2019) 123–130

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

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

Influence of voltage polarity on the corona performance of ice-covered conductor

Qin Hu[a], Gaohui He[a,*], Lichun Shu[a], Xingliang Jiang[a], Hang Yang[a], Jinfeng Tan[b]

[a] State Key Laboratory of Power Transmission Equipment & System Security and New Technology, Chongqing University, Shazheng Street No. 174, Chongqing, China
[b] Chengdu Power Supply Company, State Grid Sichuan Electric Power Corporation, Chengdu, China

ABSTRACT

Corona performance of transmission lines in foul weather conditions, icing particularly, have attracted widely attentions. In this research, the influence of voltage polarity on corona performance of two icing categories, glaze and soft rime icing, is studied in corona cage via artificial icing method. The most important finding of this research is that a linear relationship is found between audible noise (AN) and the corona loss (CL) in dB above 1 W/m for the first time, the slopes of the line are voltage polarity-dependent. A 10.4 dBA and 13.7 dBA variation in the AN value for a 10 dB increase in the CL for negative and positive voltage respectively, with little influence icing categories. Moreover, the negative polarity conductors are attending to accumulate much more glaze ice than positive polarity conductors. Taylor cones and hemispheres are observed on the tip of glaze icicles when subjected to DC and AC electric field, respectively. For both icing categories, the CL of negative polarity conductors are bigger than that of positive polarity conductors, the contrary is the case of AN. When the voltage gradient is greater than 18.0 kV/cm, contrary to popular perception, the generated CL and AN of glaze ice-covered conductor are bigger than that of rain condition and fair weather, respectively.

1. Introduction

High voltage direct current (HVDC) systems have the advantages of no limit related to the amount of power or the transmission distance, and it is also much cost effective for a long distance power transmission compared to AC power transmission [1]. And as the demand for power increasing, constructions of large-scale extra-high voltage (EHV) and ultra-high voltage (UHV) DC transmission lines are ongoing. Till now, China have thirteen ± 800 kV UHV DC transmission lines in operating and a ± 1100 kV UHV DC transmission line is under construction. These EHV and UHV DC transmission lines, normally beyond 1500 km in length, are inevitably crossing cold regions or microclimate zones, where freezing rain or ice storm could happen frequently. Besides, the conductors height in EHV and UHV transmission lines could range from 47 m [1] to 210 m (at long-span transmission tower), where in-cloud icing could happen more frequently. Also, bundle conductors, widely used in EHV and UHV transmission lines, are attending to accumulate more ice compared to single conductors with same sectional area [2]. Severe power system icing could cause large-scale power outage, such as the 1998 blackout happened in Eastern Canada and U.S.A. [3] and the 2008 blackout happened in Southern China [4]. Mild power system icing could deteriorate the power system corona performance, including CL, radio interference (RI) and AN [5].

Compared to the investigations of conductor corona performance in foul weather conditions, such as rain [6–8], fog [9] and high altitude [10,11], the existing literatures of icing corona performance are insufficient. The CL of stranded conductor subjected to hoar frost is studied in [12]. Corona streamer propagation velocity on an ice surface are studied in [13], mainly considering the case of insulator icing flashover. The icing morphology [14], corona inception voltage [15] and CL [16] of glaze or rime ice-covered conductor are studied in corona cage. However, most of the reports on corona performance of icing conditions are about AC power system. Moreover, the AN of ice-covered conductor are missing. The available researches contain strong evidence that the conductor corona performance under icing condition is different from other foul weather conditions, the distorted conductor surface will cause severe corona effects.

This research aims to investigate the influence of voltage polarities on corona performance (including corona inception voltage, CL and AN) under glaze and soft rime icing conditions in a corona cage. And the correlation between CL and AN of ice-covered conductor is found for the first time. Moreover, comparisons of CL of icing condition with that in rain condition, and AN of icing condition with that in fair weather condition are also made.

2. Test facilities and procedures

The artificial icing and corona performance experiments in this research are all performed in a corona cage, locates in an artificial climate chamber. The cylindrical artificial climate chamber has a diameter of

* Corresponding author.
E-mail address: hegaohui@cqu.edu.cn (G. He).

https://doi.org/10.1016/j.ijepes.2018.08.010
Received 22 May 2018; Received in revised form 10 July 2018; Accepted 9 August 2018

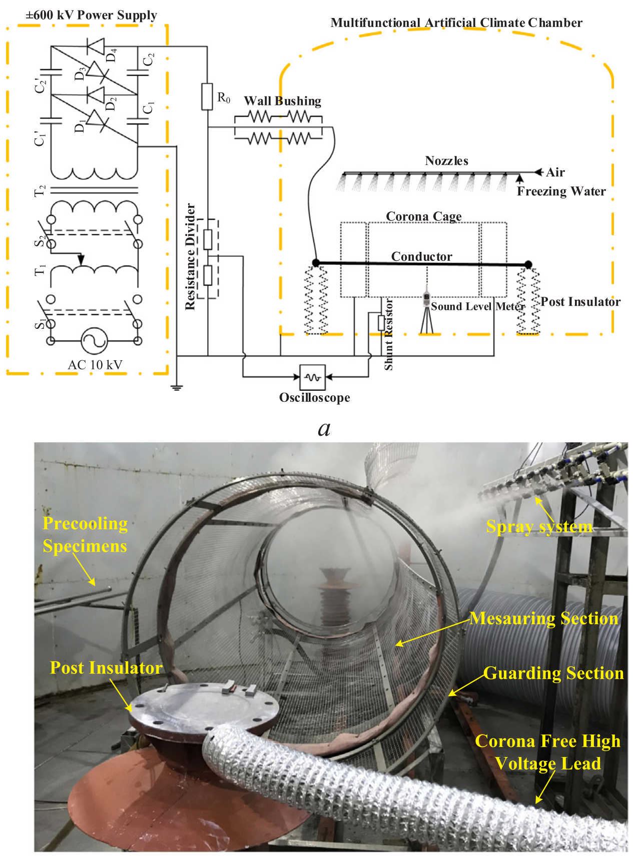

Fig. 1. Layout of the artificial icing experiments and corona performance experiments. (a) Diagram of artificial icing experiments and corona performance experiments, (b) photograph of corona cage, specimens and spray system during precooling process of artificial icing experiments.

7.8 m and a height of 11.6 m. Through proportion integration differentiation control system, the temperature of artificial climate chamber could be adjusted accurately from −45 ~ 40 °C. In the tests, the relative humidity of the artificial climate chamber is range from 81.6% to 89.4%. The different polarity voltages are supplied by a ± 600 kV power supply and measured by a high voltage resistance divider, their diagrams are shown in Fig. 1*a*.

2.1. Corona cage

The circular-section corona cage, as shown in Fig. 1*b*, has a diameter of 1.0 m and a length of 2.6 m, including a 2.0 m length measuring section and two 0.3 m length guarding sections. The two grounded guarding sections are insulated from the measuring section to eliminate the distortion effects. And the measuring section is grounded via a shunt resistor to measure the corona current. The cylindrical surface of the corona cage is made of metallic mesh, through which the water droplet could reach the conductor and the reflection of sound can be minimized.

2.2. Test specimen

Smooth conductor (aluminum tube) with a diameter of 37.6 mm and length of 3.5 m is used as specimen in this research. The diameter is analogous to the sub-conductor of bundles used in EHV and UHV DC transmission lines. And the coaxial arranged specimen is placed on two post insulators. To eliminate partial discharge beyond the measuring section, two metallic balls are installed at both ends of specimen, and power supply is applied to the specimen via a corona free high voltage lead, as shown in Fig. 1*b*.

The nominal conductor electric field intensity, defined as the voltage gradient of a smooth cylindrical conductor, is used in this research. Unless otherwise stated, the conductor electric field intensity in this research is the nominal conductor electric field intensity and is calculated according to (1) in a concentric configuration.

$$E = \frac{2U}{d_1 \ln(d_2/d_1)} \tag{1}$$

where, E is the nominal conductor electric field intensity, in kV/cm; U is the applied voltage, in kV; d_1 is the diameter of the conductor, in cm; d_2 is the diameter of corona cage, in cm.

2.3. Artificial icing experiment

The only variable is voltage polarity for same icing categories in the artificial icing experiment, and the main icing parameters are listed in Table 1. The artificial icing experiment includes four steps, preparation of purified freezing water, precooling, energized icing and ice harden process. Eleven air atomizing nozzles used in [16] are adopted in the spray system to produce fine and uniform distributed freezing water droplets around the conductor surface. The nozzles are mounted at 45 ± 5° to the horizontal. The input of the spray system including water and air, via adjusting the input air pressure the water droplet size could be adjusted for glaze icing and rime icing process. And the diagram and the picture of the spray system is showed in Fig. 1*a* and Fig. 1*b*, respectively.

Purified and deionized tape water is supplied to the industrial chiller to produce freezing water. The temperature and conductivity of the prepared freezing water are 5 °C and 24.5 ± 5 μS/cm, corrected to 20 °C as (2) [17]:

$$\sigma_{20} = \sigma_\theta (3.2\times10^{-8}\cdot\theta^4 - 1.\ 1\times 10^{-5}\cdot\theta^3 + 1.0\times 10^{-3}\cdot\theta^2 - 5.\ 2\times 10^{-2}\cdot\theta + 1.71) \tag{2}$$

where, θ is the freezing water temperature, in °C; σ_{20} is the conductivity corrected to the reference temperature of 20 °C, in S/m; σ_θ is the conductivity of the freezing water at temperature θ, in S/m.

Fig. 1*b* shows the picture of corona cage, specimens and spray system in the precooling process. The temperature of the artificial climate chamber is set to −5 ~ −8 °C and −11 ~ −14 °C for glaze icing and soft rime icing, separately. And the precooling process lasts for 30 min to achieve a thermal equilibrium between the specimen and ambient temperature. Note that the spray system is turned on to avoid freezing in the precooling process.

When the energized icing process start, the precooled specimen is placed at the axis of the corona cage. Then, 136.9 kV (E = 22.2 kV/cm) DC voltage of different polarities are applied to the specimen

Table 1
Icing parameters of artificial icing experiments.

	Negative glaze	Positive glaze	Negative soft rime	Positive soft rime
Icing voltage (kV)	−136.9	+136.9	−136.9	+136.9
Freezing water conductivity (μS/cm)	24.5 ± 5	24.5 ± 5	24.5 ± 5	24.5 ± 5
Ambient temperature (°C)	−5 ~ −8	−5 ~ −8	−11 ~ −14	−11 ~ −14
Medium diameter of water-droplet (μm)	59	59	38	38