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Corona loss characteristics of bundle conductors in UHV AC transmission lines at 2200 m altitude

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ABSTRACT

Corona loss is the key parameter for evaluating operating economy of ultra-high voltage (UHV) and extra-high voltage (EHV) alternating current (AC) transmission lines and is one of important factors that need to be considered in line design and operation. At present, corona losses of 8 × LGJ-630 conductors, which are commonly used in ultra-high voltage alternating current (UHV AC) double-circuit transmission lines on the same tower, and 8 × LGJ-720, and 10 × LGJ-720 bundle conductors with a larger cross-section and more bundle number in high-altitude areas have not yet been studied. In the paper, the corona losses of the 8 × LGJ-630, 8 × LGJ-720, and 10 × LGJ-720 conductors were measured under conditions of dryness, artificial moderate rain, heavy rain and a wet conductor, based on the UHV corona cage built in Ping'an County, Xi'ning, China at an altitude of 2,200 m. By taking typical 1,000 kV UHV-AC double-circuit transmission lines on the same tower as an example, the electric field strengths on the surface of conductors in the corona cage and the actual lines were calculated. On this basis, the corona loss of the UHV-AC double-circuit transmission line in a high-altitude area was analyzed. The research results can provide data reference for constructing UHV transmission lines in high-altitude areas.

1. Introduction

Corona effects, such as corona loss, audible noise, and radio interference could be generated due to corona discharge from AC transmission lines, which influence line operation and the environment. The higher the voltage class, the more significant the corona effects, especially on an ultra-high voltage (UHV) grid. With the development of global energy interconnections, the strong smart grid, with the UHV power line as its backbone, is mainly used for transmitting clean energy, since the power production center is far away from the load center, UHV transmission lines will inevitably pass through high-altitude areas [1–3]. In high-altitude areas, with the decrease in atmospheric pressure, the corona onset gradient decreases [4,5], while ion mobility increases [6], which significantly increases corona loss [7].

At present, much research has been conducted on corona loss from AC conductors at different altitudes. In the 1960s and 1970s, based on a conductor test, the Bonneville Power Administration (BPA) of the USA proposed that only a few types of bundled conductor and meteorological factors were considered in recommended formula for predicting corona loss: however, with the constant development of conductor systems and measurement technology, the measured data of UHV and ultra-high voltage (UHV) lines demonstrate that the prediction formula shows a large error at low altitudes [8]. Elsewhere [9], the corona loss of two-bundle conductors was measured in an artificial climate laboratory at different altitudes in the 1980s. In other literature [10], corona loss from a single LGJ-185 conductor was measured by utilizing optical fibre technology. Then, Liu Yunpeng et al. in North China Electric Power University measured corona losses from conductors at different altitudes. Firstly, through the simulations in artificial climate laboratory in the range of 19 m to 4000 m, corona losses of 6 × LGJ-400/50 and 6 × LGJ-500/45 conductors were measured by using a movable corona cage, thus obtaining corona losses in dry

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conditions and at different rainfall intensities [11,12]. Based on corona loss characteristics of conductors under the windy and dusty weather conditions, the corona losses of 6 × LGJ-400/50 and 6 × LGJ-500/45 conductors were measured under different wind velocities, dust concentrations, and dust particle size distribution at three actual altitudes. They were the ultra-high voltage alternating current (UHV AC) test base in Wuhan (at an altitude of 19 m), Ping'an County, Xi'ning City, Qinghai Province (at an altitude of 2200 m) and Haiyan County, Haibei Prefecture (at an altitude of 3042 m) [13–15]: however, the data relating to corona loss from the 8 × LGJ-630/45 conductor commonly used in UHV AC double-circuit transmission on the same tower and the LGJ-720 conductor with a larger cross-section at high altitudes had not been measured.

The corona cage is an important method to research corona effects. In the study on AC corona loss, if the maximum electric field on the surface of the conductors in a corona cage is kept to be the same with that on a transmission line, the strength of the corona of the both are the same. As this equivalent condition can be set up very easily, additionally, the cage wall is much closer to conductors, as low test voltage is applied, high electric field strength around the conductors can be obtained, so the corona cage is widely used.

The corona onset characteristics are the main parameters considered in the design of the UHV AC power line, however, the corona loss characteristics are the main factors considered in the operation of the UHV AC power line. As a continuation research in Ref. [21], which focuses on determining the corona onset characteristics of UHV bundle conductors in high-altitude area. This study investigated corona loss characteristics from 8 × LGJ-630, 8 × LGJ-720, and 10 × LGJ-720 conductors under dry conditions, in moderate rain, heavy rain, and with a wet conductor by using the corona loss monitoring system for optical fibre transmission based on the UHV corona cage built in Ping'an County, Xi'ning City at an altitude of 2200 m. Through this research, the corona data of three bundle conductors at actual altitudes were firstly obtained. This provides reference for selecting UHV-AC transmission lines built in high-altitude areas.

2. Experimental arrangement

2.1. UHV corona cage

By using the UHV AC corona cage built in Ping'an County, Xi'ning City at an altitude of 2200 m (Fig. 1) [22], the corona experiments can be undertaken on bundle conductor commonly used in 1000 kV UHV AC power line. The corona cage with a square cross-section (8 m × 8 m) is composed of a 25 m long measuring section and two protective sections on each side of the measuring section, being 5 m long respectively, so the total length is 35 m. An artificial rain-test facility was installed on the top of the corona cage. The conductivity of rain ranges from dozens to hundreds uS/cm [22], however, the conductivity of rainwater has no influence on the corona characteristics [23], in this paper, the water of 300 uS/cm was used. By changing the amount of inflow water in its pipes, moderate and heavy rainfall were simulated. In this study, after conducting corona measurement testing under condition of heavy rain, water drops were hung on the surface of the conductors, thus measuring corona characteristics under the condition of having pre-wet conductors. In the experiment, the HOBO minitype weather stations (HOBO, USA) arranged around the corona cage were used to record rainfall rate.

By employing the integrated photoelectric corona loss measurement system, corona loss from bundled conductors was measured [16]. Optical pulse triggering guaranteed synchronous acquisition of data acquisition modules for optical communication at each distal end, overcoming time delay problems in the acquisition of corona current and voltage data.

2.2. Experimental method

For transmission lines, if the no-load current signals and phase voltage of lines were synchronously acquired at the entrance and the no-load current was capacitive, the corona loss P can be expressed as:

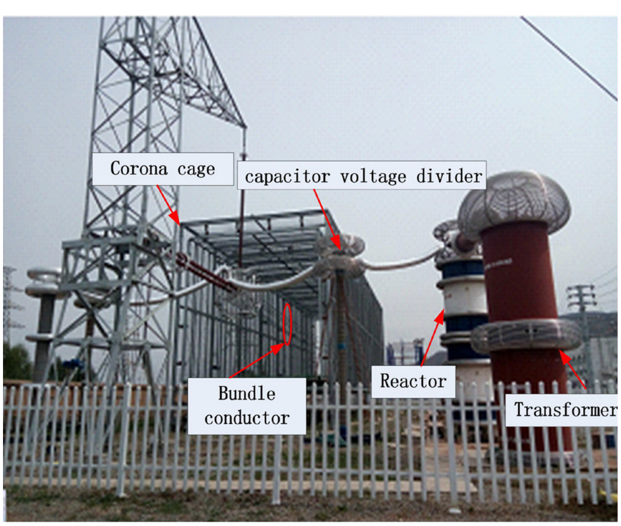
$$P = U I \cos \varphi \tag{1}$$

In the experiment, the TRF-800 capacitive voltage divider with a rated ratio of 3750:1 was used to measure voltage signal U. The current signal I was acquired through 0.5 Ω high-power and high-precision non-inductive resistor. Based on the above measurement system for corona loss, the voltage and current signals were acquired synchronously. By using the sine wave parameter method [17–19] to calculate the angle φ of the voltage.

3. Simulation of electric field strength upon the surface of conductors

The electric field strengths on the surfaces of conductors in the UHV corona cage, as shown in Ref. [21].

The layout of typical 1000 kV UHV-AC double-circuit transmission



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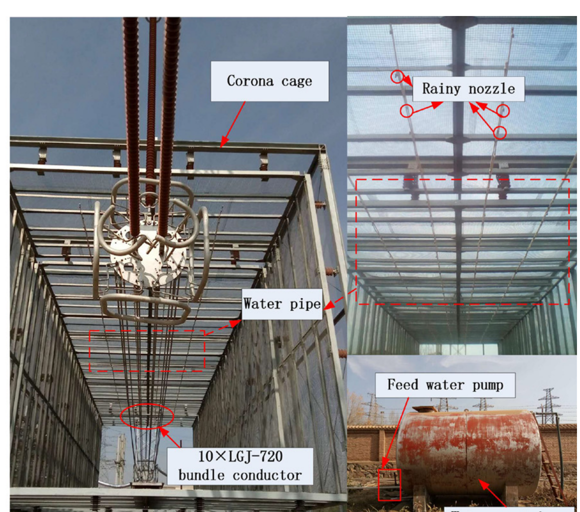

b

Fig. 1. General layout of experimental platform. (a) Corona cage; and (b) Artificial rainfall system.