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Attenuation and deformation characteristics of lightning impulse corona traveling along bundled transmission lines

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ABSTRACT

Comprehensive study of the impulse corona characteristics is helpful to understand the transient process and guarantee a suitable insulation design of power transmission systems. In this paper, first the attenuation and deformation characteristics of lightning overvoltage traveling along a 500 kV experimental transmission line are tested. Then the lightning impulse corona characteristics on different bundled conductors commonly used in the 110–1000 kV power transmission lines are experimentally investigated, the impulse corona *Q*–*V* data measured in the corona cage is transformed into those on the corresponding overhead lines. The influence of bundle geometry on corona is analyzed. Attenuation and deformation effects of lightning impulse corona along transmission lines are evaluated by comparing the simulation and test results. Simulation shows the amplitude and wave-front steepness attenuate remarkably, and the deformation of the voltage mainly happens when the impulse voltage exceeds the corona inception one.

1. Introduction

When lightning transient travels along an overhead line, the voltage waveform will be deformed and attenuated by several factors, including frequency dependent behavior of the conductor impedance, skin effect and the impulse corona discharge [1–3]. Among them, the corona decreases the conductor impedance and increases the coupling factors between lines as well. In order to precisely calculate the lightning overvoltage of power systems, the characteristics of the impulse coronas on different transmission bundled lines need to be tested and analyzed comprehensively [4,5].

Many researchers have studied the physics and discharge process of impulse corona [6–8]. In 1954, Wagner and Lloyd firstly carried out impulse corona experiments on an outdoor overhead line and measured the deformed voltage waveform [9]. Corona cage experiments were conducted by Maruvada in 1970s to analyze the lightning and switching impulse corona on 4 different kinds of bundled conductors [10]. During recent decades, several other experiments have been carried out to obtain the lightning impulse corona characteristics of conductors in the corona cage or conductors above the ground plane [11–14].

However, there is still a lack of experimental data covering the lightning impulse corona *Q*–*V* curves on bundled conductors presently used in power transmission of different voltage grades. In addition, how the geometry of different bundles influences the characteristics of the impulse corona also needs to be tested and analyzed comprehensively.

This paper provides the latest data and analysis from the continuous experimental research on impulse corona characteristics of different conductors commonly applied in 110–1000 kV power transmission systems, carried out in China UHV AC Test Base, Wuhan. Firstly the attenuation and deformation characteristics of the traveling lightning overvoltage are observed on a segment of 500 kV overhead transmission line, then the impulse corona *Q*–*V* curves measured in the corona cage are transformed into those on the corresponding overhead lines to build the impulse corona models for transmission conductors used in different voltage levels. The characteristics and influential factors of the lightning impulse corona are comprehensively investigated. Finally, the simulated deformation and attenuation effects of impulse corona along the transmission line are compared with the tested one, and the lightning transients on an actual UHV AC transmission line under impulse corona effect is studied. This paper is an extension of our conference paper [15], which has been completely revised.

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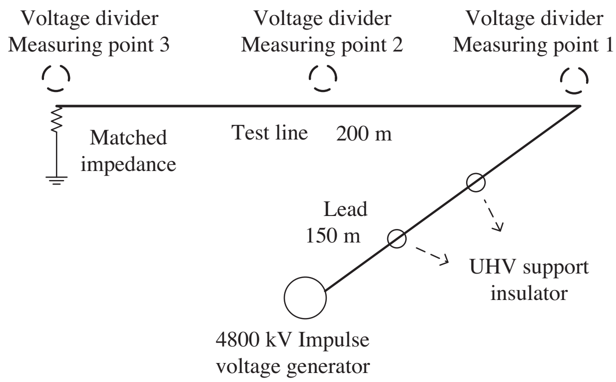

Fig. 1. Experiment setup of lightning impulse corona on the test line.

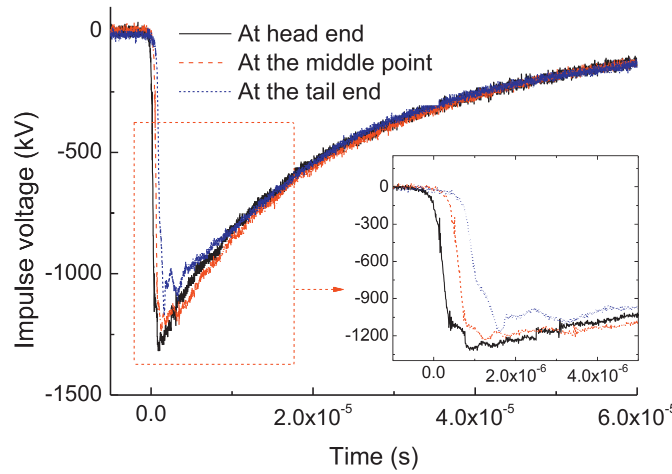

Fig. 3. Tested impulse voltage deformation along the HV line.

2. Lightning impulse corona experiment on the specimen transmission line

First, a 200 m testing section of 500 kV transmission line is set up to investigate the influence of lightning impulse corona on the wave deformation over actual high-voltage bundled transmission lines. In this experiment, lightning impulse voltages are applied by the generator at the head end of the line, and the noninductive matching resistor is connected between the line and the ground at the tail end. Impulse voltage dividers are installed to measure the traveling instantaneous voltages at different points along the line.

2.1. Equipment setup

The diagram and the photograph of the experiment setup are shown in Figs. 1 and 2(a) respectively. The experiment setup consists of a 4800 kV/720 kJ impulse generator as shown in Fig. 2(b), the test line, impulse voltage dividers, the lead wire and the matching resistor.

The length of the test line is 200 m, with bundled conductors of 4×LGJ630/45 s450, the same as applied on 500 kV AC power transmission in China. The heights of the hanging points on the towers of both sides are 21.6 m and 18.6 m, respectively.

The tail end of the test line is connected to the ground through the matching resistor, avoiding the influence of the reflection waves on the voltage measurement. The non-inductive resistor is applied to eliminate the voltage drop caused by the high-frequency components under lightning impulse, which consists of six 50 Ω non-inductive resistors in series, as shown in Fig. 2(c).

A 150 m HV lead wire is used to connect the generator and test line. To decrease the influence of corona around the lead on the measurement, a corrugated pipe is installed as the sheath outside the lead wire.

The impulse voltages along the test line are measured by the voltage dividers at three points: the head and tail end and the middle point, as shown in Fig. 2(d). The divider consists of 6 capacitors in series, with a ratio of 4747 and a measurement uncertainty of less than 2%. The transient parameters of the divider include the step response time $t_\alpha \leq 100$ ns, and the overcharge voltage coefficient $\beta \leq 20\%$. A four channels, 100 MHz, and 16 bit data acquisition system is used to record the signals.

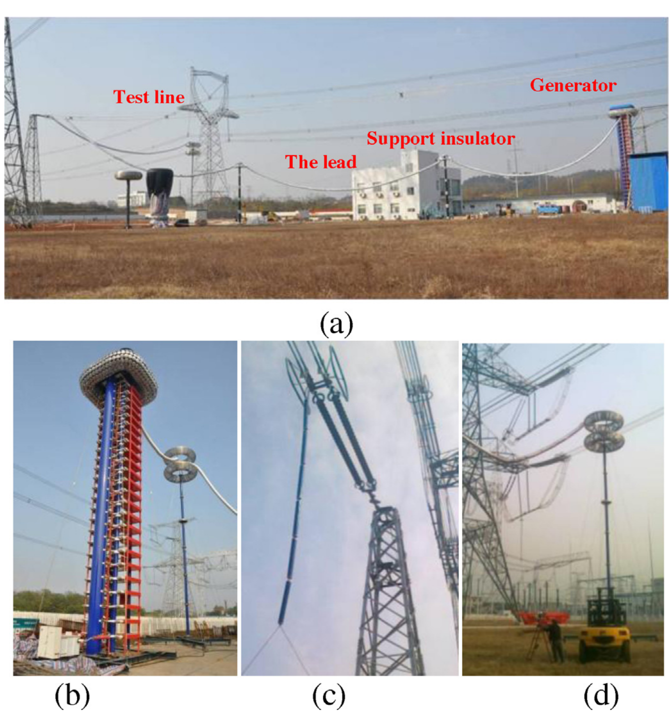

Fig. 2. Photographs of the experiment sets.

2.2. Impulse voltages along the test line

The magnitude of the applied impulse voltage in the experiment is approximately 50% higher than the corona inception voltage of the test line, which is 880 kV according to calculation. When a −1320 kV, 2.6/50 μs lightning impulse voltage is applied at the head of the test line, the instantaneous voltages on different measuring points along the line are shown in Fig. 3.

In this case, the crest of the voltage at the middle point is −1242 kV, 5.7% less than that at the head end. The voltage crest at the tail end is −1177 kV, 8.5% less than that at the head end. In addition, the rise time of the surge (the time it takes to rise from 0% to 100% of the maximum value) increases from 2.81 μs at the head end, to 2.90 μs at the middle point, and 3.02 μs at the tail end.

First, according to the experimental results, the attenuation and deformation of the lightning overvoltage by impulse corona could not be neglected, especially on high voltage bundled transmission lines. Furthermore, to separately evaluate the deforming influence of corona out of other influential factors such as the frequency dependent nature of conductors, simulation investigation based on corona model should be conducted.

Second, the characteristics of the impulse corona on transmission lines are correlated with several factors, such as the structure and height of the bundled conductors, the bundle spacing, the number and radius of the subconductors, spaces among the phases,