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Comparison of methods for determining corona inception voltages of transmission line conductors

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A B S T R A C T

Corona inception voltages are important parameters for power transmission-line conductors. However, there is no specific criterion for the determination of the corona inception voltage on such conductors. A corona cage is an effective and economical means for testing transmission-line conductors as it allows the duplication of surface electric fields, and hence the corona phenomena, at lower conductor voltages. Measurements with an ultraviolet imager, a partial discharge detector, a current-measuring radio-frequency interference receiver, and a sound level meter were used to observe the transition region between no corona and strong corona and hence determine the corona inception voltages of two practical conductors, types LGJ500/35 and LGJ400/50. Good agreement was found between the four approaches. The corona inception voltage was also calculated from first principles after determining the electric field near the surface strands using a charge simulation method, and compared with the peak inception voltages found from the measurements. Comparison was also made with the values obtained be applying Peek's equation. In both the calculations, Peek's surface roughness factor '*m*' was applied with a value of 0.81 giving close agreement with the measurements.

1. Introduction

Corona discharge phenomena are quite common on both AC and DC transmission lines when the surface electric field is sufficiently high [1]. Corona results in audible noise (AN), radio frequency interference (RFI) and corona losses [2–4].

Much research has been done in recent years in this area [1,2,5–7]. Vinh statistically analyzed long-term audible noise and corona loss data under a variety of weather conditions [5,6] and Chartier investigated RFI and AN levels from particular conductors [7], but neither compared the inception voltages found from these different phenomena or the problem of defining the actual inception voltages under these conditions.

The corona inception voltage on cylinders was investigated by Peek who thereby developed his well-known empirical equation [8]. Successful attempts have been made to relate the corona inception voltage to the physical mechanisms of discharge with various electrodes and gases, for AC and DC and various environmental factors [9–14]. Yamazaki and Amoruso developed calculations of the effect of stranding on the corona inception voltage [15,16] but did not make measurements on actual conductors.

More recently UV corona imagers have been used to detect corona under outdoor daylight conditions [17,18].

In the present work a corona cage was used. This is a single-phase test facility in which conductors (single or bundled) are centered in a grounded cage. The close proximity of the grounded cage allows the surface electric field to be at the levels found on transmission lines in the field but at lower applied voltages. Corona cages have therefore been widely applied for predicting the corona characteristics of transmission lines [19–23].

Two new transmission-line conductors, of different construction, were used with a corona cage in the work described here. They were single conductors, not bundled, with a steel (7-strand) core surrounded by several layers of aluminum stranding. The behavior below, during and after the onset of corona was observed via four measurement systems: an ultraviolet (UV) imager, a partial discharge (PD) detector, a sound level meter and an RFI receiver (measuring the high-frequency component of the corona current).

A method to determine the mean inception voltage was devised and applied to the output of the above instruments. The outputs and these inception voltages were compared with each other and

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Fig. 1. General views of the corona cage used in the experiment.

the results of calculations using Peek's equation and a direct 'first-principles' approach.

2. Corona cage and conductors

2.1. Corona cage

The small corona cage designed at Tsinghua University and showed in Fig. 1 was used in this work. The dimensions of the inner cage are a square cross-section of 1.7 × 1.7 m and a length of 4 m, comprising a 3 m long central section for measurements and two 0.5 m-long guard sections to eliminate the end effects [24–27].

2.2. Experiment equipment

The two conductors employed in the present work were standard transmission-line conductors manufactured in China, having the codes LGJ500/35 and LGJ400/50. The former (hereinafter Conductor A) has 7 steel strands surrounded by 45 aluminum strands, the latter (hereinafter Conductor B) has 7 steel strands surrounded by 54 aluminum strands (see Table 1 and Fig. 2). The cross-sectional areas of the steel and aluminum are approximately 35 and 500 mm^2 respectively (Conductor A); and 50 and 400 mm^2 (Conductor B) – hence the 500/35 and 400/50 appellations.

UV, PD, current and audible noise (AN) levels were measured as indicated in Fig. 3. The HV AC source was set as 50 Hz. These experiments were carried out in Wuhan, Hubei Province, PRC, where the altitude is 23 m and the summer temperature was in the range 36–40 °C, with the relatively humidity in the range 47–59%.

3. The four instruments and related experimental results

3.1. Measurement of UV photon output

An Ofil Corporation 'Superb' ultraviolet imager was used to measure the photon production by electric discharges at irregularities on the conductor surface. Such UV imagers have been widely used for corona discharge detection in power systems and are discussed in greater detail in Ref. [28].

Table 1
Conductor parameters.

	A: LGJ500/35	B: LGJ400/50
Overall diameter (mm)	30.0	27.6
No. of steel/Al strands	7/45	7/54
Strand diameter (mm)	3.75	3.10
Steel cross-sectional area (mm^2)	34	52
Al cross-sectional area (mm^2)	498	400

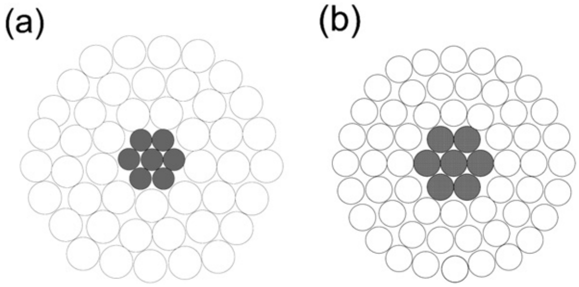

Fig. 2. Cross sections of (a) LGJ500/35 (Conductor A) and (b) LGJ400/50 (Conductor B).

The detector was placed in the same height as the conductor and with a sight-line normal to the conductor.

Fig. 4 shows three sets of measurements for Conductor A under virtually the same atmosphere conditions, and shows good repeatability. When the applied voltage was less than 100 kV, there was virtually no UV photon count so no corona discharge was occurring. As the voltage was increased, the corona discharge points grew in number and the photon detection began to increase gradually and then very rapidly above about 125 kV. Thus there are 4 regions: the no-corona region where the graph is flat and with zero gradient; the corona region where the graph has increasing gradient and strong positive curvature; the straight line region where the line has a high gradient and zero curvature; and finally there is often a small region where the gradient increases slightly (as in this case) or decreases slightly (as in some of the cases seen later). Using these definitions, the steep, zero-curvature third region could be determined and the best straight line through it found by regression analysis (least-squares method). This line was extended to intersect with the extended line through the first region data points. The voltage at this point was defined as the inception voltage and was found to be 123.4 kV. Using the results for Conductor B, which are plotted as in Fig. 5, the inception voltage was found to be 118.3 kV.

3.2. Measurement of partial discharge levels

Partial discharge detectors are not normally used to investigate the corona characteristics of power transmission lines because of

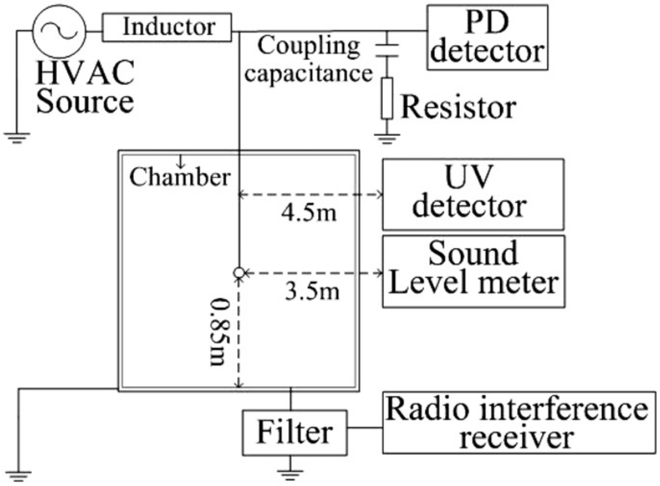

Fig. 3. Schematic diagram of the measurement system and corona cage.