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The Aerodynamic Analysis for Iced Four Bundled Transmission Lines with Typical Crescent

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Abstract: Despite the fact that the wind tunnel tests have been carried out on iced transmission lines subjected to wind load, it is not practical to do wind tunnel tests due to its high cost. This paper describes a detailed numerical simulation method that can be used to instead of wind tunnel tests. Based on the galloping mechanism of iced transmission lines, the aerodynamic test was simulated with the typical crescent super-large thickness iced four bundled conductors. One of the results highlighted in this study is that the wind angle of attack had significant influence on the aerodynamics of iced conductors. The Den-Hartog and O.Nigol coefficient were calculated to determine galloping of iced transmission lines, comparing with the reference of wind tunnel test in the Zhejiang university, the range of the wind angle of attack to the bundled conductor which can lead to gallop is larger than single wire, but the absolute value of amplitude is less than the single conductor, split conductor is more likely to gallop than single conductor.

Keywords: Aerodynamic force, Den-Hartog mechanism, Galloping, iced four bundled conductor, O. Nigol mechanism.

1. INTRODUCTION

The countries like America, Canada, the Netherlands, Japan, and Russia have carried out considerable research on the galloping in wind tunnel. Alonso *et al.* [1, 2] have studied the aerodynamic coefficient of non-circular cross-section and researched the galloping of a simple two-dimensional structure. Liliend [3, 4] did the wind tunnel test with single iced conductors, the ice was simulated by silicone.

In China, Li Wanping *et al.* [5] did the wind tunnel test for the typical crescent super-large thickness iced three bundled conductors, the static and the dynamic aerodynamic characteristics were obtained. It is therefore required to consider the difference between static test results and negative damping of dynamic aerodynamic force.

The drag, lift and moment coefficient of iced transmission lines are the basis of galloping mechanism analysis. In terms of domestic wind tunnel test, only a small amount of dynamic and static aerodynamic characteristics test [6, 7], it is the lack of effective technologies and data to prevent the galloping. Due to the variety of ice shape, we need to spend a great amount of money to research the aerodynamic force of the iced transmission lines, because it is unrealistic to get the aerodynamic data only through the wind tunnel test. Therefore, the numerical simulation can be chosen for studying the aerodynamic characteristics of iced transmission lines instead of wind tunnel test [8-10].

With the development of electric power facilities, the capacity of power systems have also increased greatly as lager scale conductors and insulators have been used in most of the transmission lines. A lot of transmission lines have been put to use bundled conductors. According to the available data, the split conductors are easier to gallop than single wires under the same geographical and climate conditions [11]. A series of experimental data in Germany demonstrated that split conductors were more likely to gallop than single conductors. For example, a 275 kv transmission line with bundled conductors in Japan observed galloping many times in a year, however, when these bundled conductors were replaced by single wires, the accident of galloping disappeared. In France, a 225 kv transmission line with single conductor had no galloping accident for 15 years, but with the same conditions and same wires in the form of bundled conductors, the galloping accidents happened frequently [12-17].

The sub-conductors are fixed by spacers in every sub-span, it is difficult to reverse when ice makes the conductor eccentric, the torsional stiffness are much larger than the same cross section of single conductor, the configuration of single conductor is not the same as bundled conductor, so the ice shape is different from each other, which results to the sensitivity of galloping differently [18]. Single conductors are likely to gallop when the wind speed is from 8 to 15 m/s, but to the bundled ones, the wind speed range is 4 to 23 m/s [19]. It can be seen that bundled conductors can gallop at lower wind speed than single wires, and the range of wind speed is larger than single conductor.

2. THE GALLOPING MECHANISM OF ICED TRANSMISSION LINES

Den. Hartog [20, 21] considered when the ice covered the conductors, the iced conductor with crescent section produces eccentric load, the wind force acts on the conductors is

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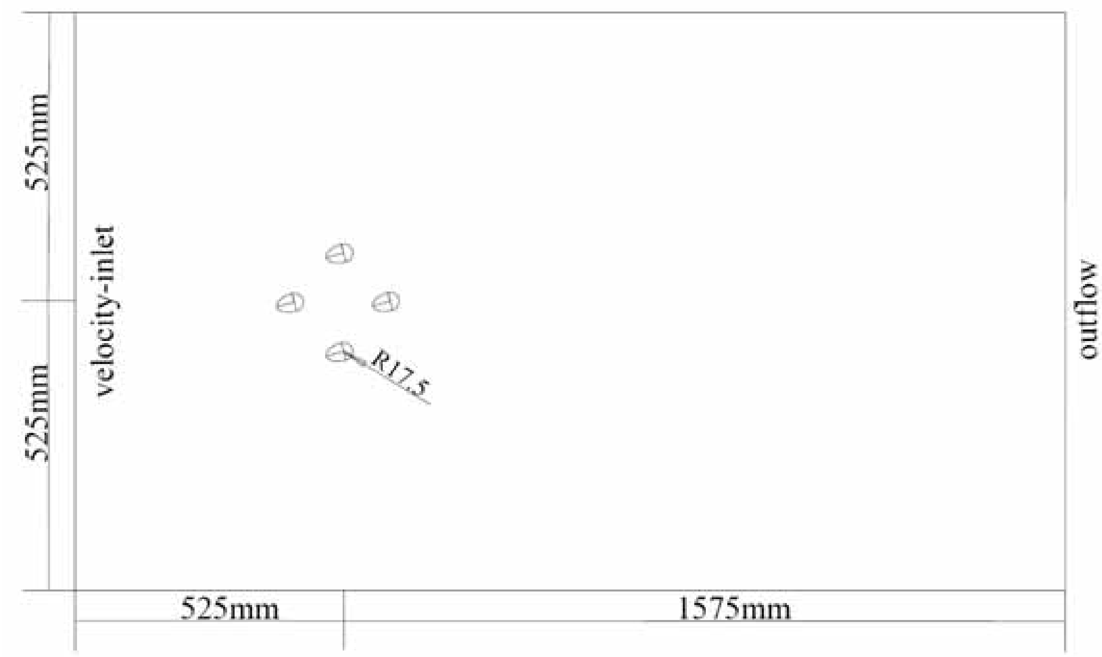

Fig. (1). Schematic diagram of rectangular area.

decomposed into horizontal force and vertical component. The galloping occured when the vertical aerodynamic force is greater than that of the conductor itself. O.Nigol [22, 23] considered overhead transmission lines which moved up and down, and also had a twist. The galloping happened when frequency of the transverse vertical vibration is equal to the torsional frequency of transmission line.

2.1. Vertical Galloping Mechanism

Galloping mechanism of crosswind direction (Den. Hartog mechanism) [20, 21] is the most representative galloping excitation mechanism. Aerodynamic damping less than zero is the necessary condition of instability to gallop.

$$\delta_D = C_D + \frac{\partial C_L}{\partial \alpha} < 0 \tag{1}$$

Where, δ_D is the coefficient of Den-Hartog; C_L is the lift coefficient; C_D is the drag coefficient;

α is the angle of attack in degrees;

2.2. Torsional Galloping Mechanism

O.Nigol [22, 23] has observed that overhead transmission lines also had a twist. Torsional galloping mechanism (Nigol mechanism) is similar to the Den. Hartog mechanism, where the necessary condition of instability to the galloping is expressed as follows:

$$\delta_N = \frac{\partial C_M}{\partial \alpha} < 0 \tag{2}$$

Where: δ_N is the coefficient of Nigol; C_M is the Moment coefficient; α is the angle of attack in degrees.

3. NUMERICAL SIMULATION ON AERODYNAMIC CHARACTERISTICS OF ICED FOUR BUNDLED CONDUCTORS

The steel-cored aluminum strand LGJ-600/45 was chosen, the diameter of the conductor was 35 mm, the ice thickness was 21 mm. Truncated conductor models with crescent section were combined by a half circle and semi-elliptical, the minor axis of the elliptical was equal to the radius of the conductor, the major axis was 38.5 mm. Because the ice caused the center of gravity shift, the model of iced conductor was established with 15 degree angle. The rectangle area was chosen which was $30D \times 60D$, the center of conductor placed at the original point, the distance from inlet boundary was $15D$, from outlet boundary was $45D$, from the left and right boundary is $15D$. As shown in Fig. (**1**).

The wind speed in the test was 10m/s, the influence of turbulent flow should be considered, so the turbulence intensity was 6%, the Reynolds's number can be calculated as follow:

$$\mathrm{Re} = Ud / v \approx (2.4 \sim 3.6) \times 10^4 \tag{3}$$

Where, d is the diameter of wire, v is the kinematic viscosity of air.

The study of iced four bundled conductors was similare to the single wires, four sub-conductors were studied respectively, the four sub-conductors of A, B, C, D were in the square array, the spacing between each sub-conductors was 400 mm. The iced conductor with crescent section was symmetrical, therefore, it was only needed to monitor the aerodynamic coefficient for the wind angle of attack in the range of $0° \sim 180°$, the angle of attack increased by $10°$, the wind angle of attack was defined as shown in Fig. (**2**).

Figs. (**3-5**) show lift, drag and moment coefficient of iced four bundled conductors with crescent section at angle of

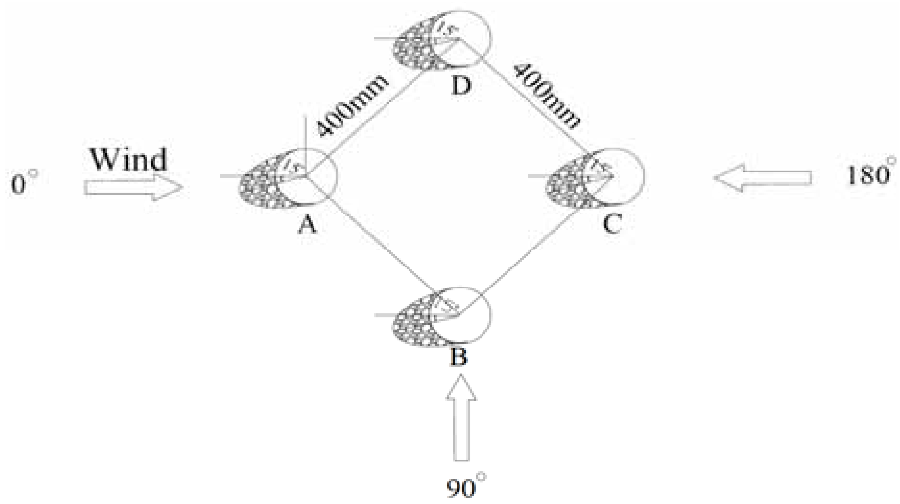

Fig. (2). The modal of four bundled conductors with crescent section.

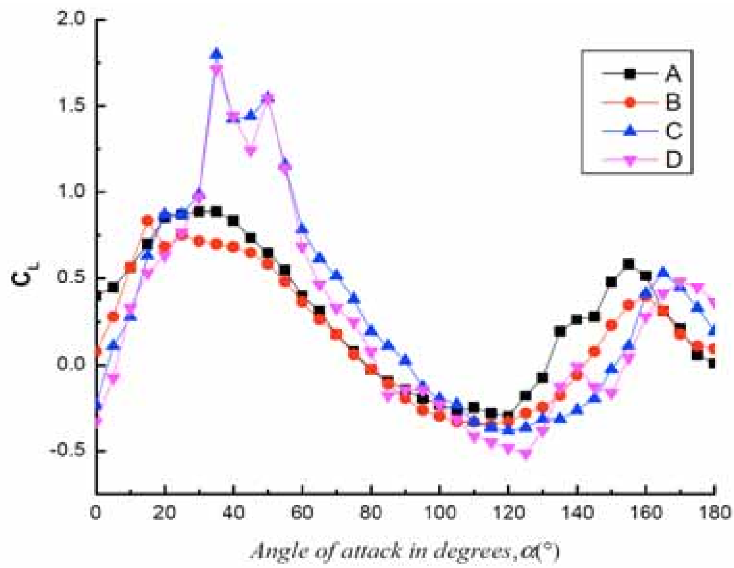

Fig. (3). Lift coefficient of iced four bundled conductors.

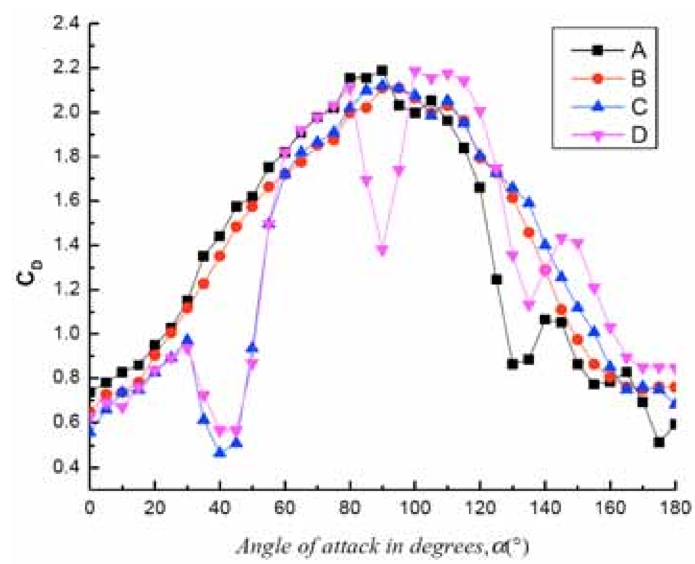

Fig. (4). Drag coefficient of iced four bundled conductors.

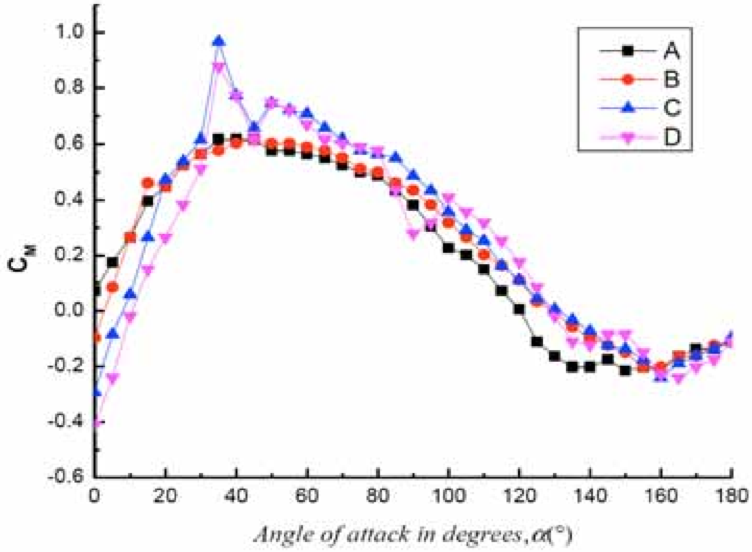

Fig. (5). Moment coefficient of iced four bundled conductors.

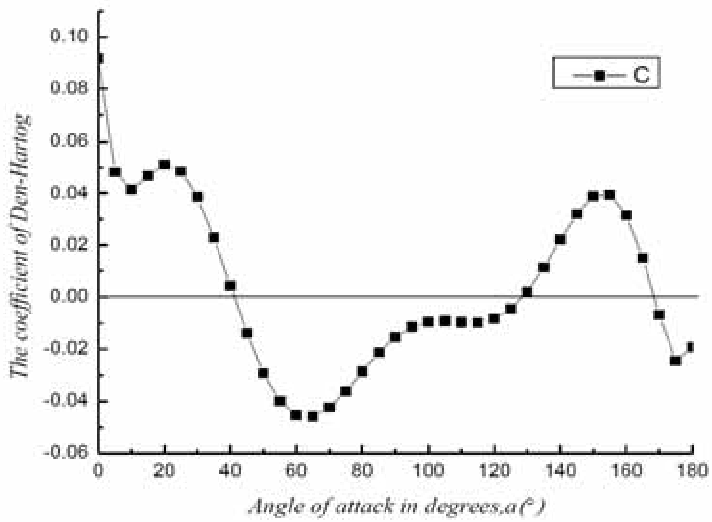

Fig. (6). The Den-Hartog coefficient of C.

attack from 0° to 180°. The Den-Hartog and Nigol coefficient of C are shown in Figs. (**6**, **7**). It can be seen that sub-conductors at downstream were seriously affected by the ones at upstream, showing that aerodynamic coefficients of each sub-conductor were not consistent. When angle of attack was from 0° to 90°, aerodynamic coefficients of A was the same as B at upstream because there was no wake influence, at 40° wind angle of attack, aerodynamic coefficients of the sub-conductor C and D in wake spreading centers were affected seriously by wake stream, where the drag coefficient dropped apparently, but the lift coefficient and moment coefficient was found significantly increased. This showed that it is necessary to consider the aerodynamic coefficients of each sub-conductor respectively.

Figs. (**6**, **7**) show Den-Hartog and Nigol coefficient curve of sub-conductor C. It can be seen from Fig. (**6**) that, when the wind Angle of attack in the range of 40° - 130° and 170° - 180°, Den-Hartog coefficient is less than zero, the system would be instable, at the same time, Nigol coefficient is less than zero in the range of 40° - 160°, torsional galloping is prone to happen in these regions.

Figs. (**8** and **9**) show Den-Hartog and Nigol coefficient curve of single conductor with the same type from wind tunnel test at Zhejiang University [24], as can be seen from the figure, compared with the single conductor. The range of the wind angle of attack to the bundled conductor is bigger than that of single conductor, but the absolute value is less than the single conductor, so split conductor is more likely to gallop than single conductor, the amplitude of galloping will be less than single conductor.

CONCLUSION

Numerical experiments studying the aerodynamic characteristics of iced four bundled conductors with typical ice-coating sections, truncated conductor models with crescent

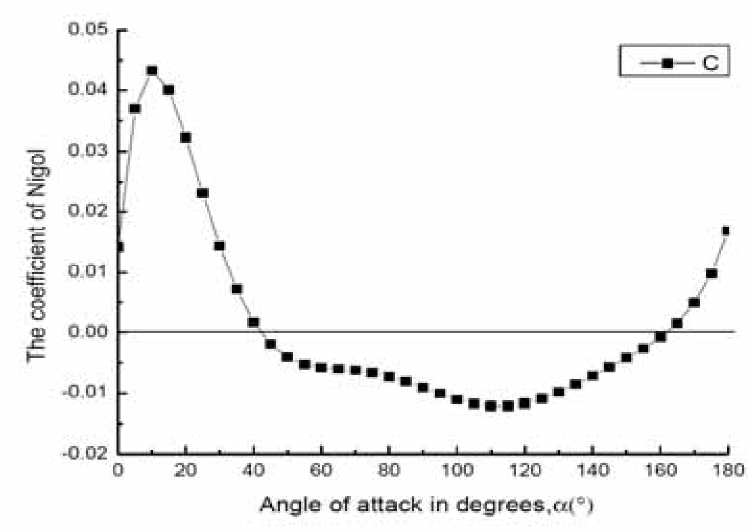

Fig. (7). The Nigol coefficient of C.

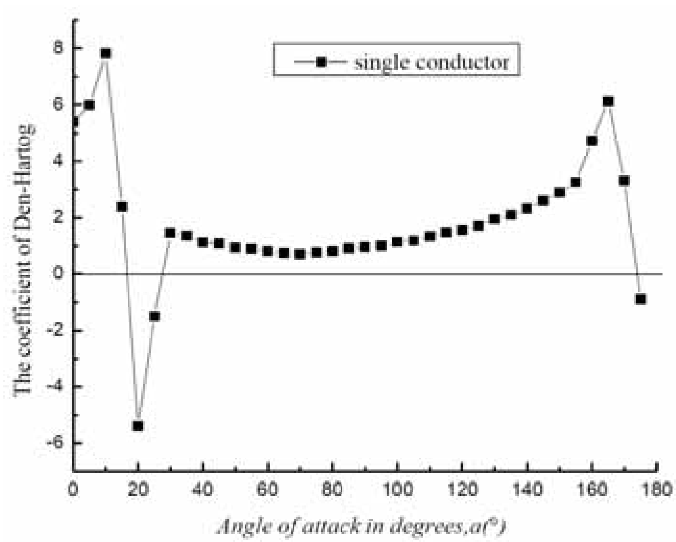

Fig. (8). The coefficient of Den-Hartog of iced single conductor.

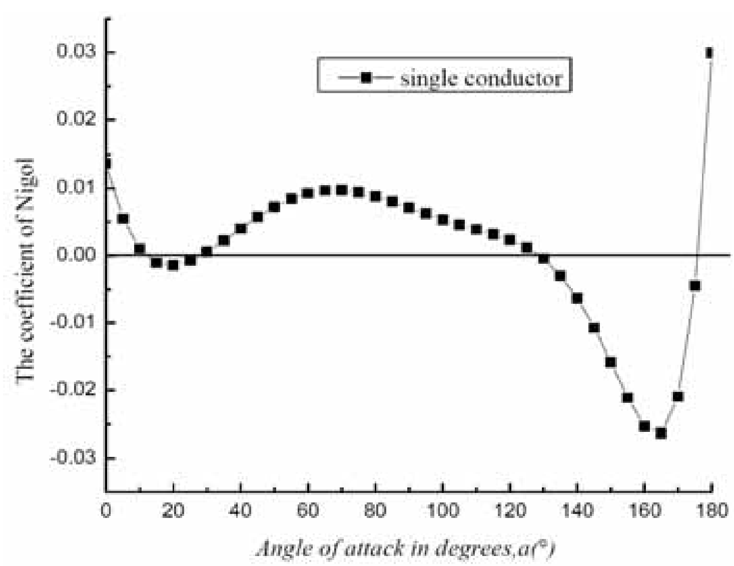

Fig. (9). The coefficient of Nigol of iced single conductor.

section were made, three component force coefficients of iced four bundled conductor with crescent section were calculated for different wind angle of attack, the influence of each sub-conductor was considered. It can be seen that sub-conductors at downstream were seriously affected by the ones at upstream, aerodynamic coefficients of each sub-conductor are not consistent. Compared to the iced single conductor, the aerodynamic parameter changed due to the influence from waking of sub-conductors. The ice changed the cross section shape of conductor, and the center of gravity to the iced conductor shifted, the initial wind attack angle was changed which made the influence of sub-conductors more complicated. The range of the wind angle of attack to the bundled conductor which can lead galloping is bigger than single conductor, but the absolute value of amplitude is less than the single conductor, therefore split conductor is more likely to gallop than single conductor.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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