Study on Galloping Characteristics of Large-section Carbon Fiber Composite Core Conductor

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Abstract. This paper establishes the finite element galloping model of large-section carbon fiber composite core conductor, and selects three kinds of large-section conductors to analysis on galloping characteristics, i.e. carbon fiber composite core large-section conductor JLZ2X1/F2A-1660/95-492, 1,250mm² large-section aluminum conductor steel reinforced JL1/G2A-1250/100-84/19 and 1,520mm² aluminum conductor aluminum-alloy reinforced JL1X/LHA1-1040/550-487, thus obtaining galloping amplitudes and galloping tension values of three kinds of conductors. In addition, this paper compares the galloping characteristics of such three conductors, thus obtaining galloping characteristics of large-section carbon fiber composite core conductor. The research achievement provides technical support for anti-galloping design of carbon fiber conductor on the power transmission line.

1. Introduction

The structure of carbon fiber composite core conductor is similar to that of the traditional aluminum conductor steel reinforced, and the main difference is that the former one replaces the traditional steel core with single piece of high-strength thermally resistant carbon fiber composite core, and to obtain relatively high current carrying capacity, the soft aluminum strand or thermally resistant aluminum alloy is adopted to replace original common conductive aluminum strand generally. The carbon fiber conductor has an extensive application prospect in the UHV power transmission line, and it is significant to implement relevant studies on carbon fiber conductor in UHV power transmission line deeply.

From 2008 to 2010, the power scientific research, design and construction company such as China Electric Power Research Institute had successfully solved a series of key technologies in conductor, matched fittings, construction process and technology through efforts, and had completed the research, manufacturing and engineering application & research of large-section conductors i.e. 900mm² and 1,000mm² successively, and has applied them into the Ningdong - Shandong ±660kV DC power transmission demonstration project, Jinping - Sunan ±800kV UHV DC power transmission project, Xiluodu - Zhejiang Jinhua ±800kV UHV DC power transmission project, Hami South - Zhengzhou ±800kV UHV DC power transmission project. In 2014, it completed the research & manufacturing and engineering application & research of 1,520mm² large-section conductor, and this conductor has been successfully applied into the Lingzhou - Shaoxing ±800kV UHV DC power transmission project.

In a word, the carbon fiber conductor has above technical advantages, while our country has accumulated a certain experience in the research & development and application of large-section conductor, possessing conditions of further researching and developing large-section carbon fiber composite core conductor, while at present, the research fields of large-section carbon fiber composite
core conductor and its relevant technologies are still empty at home and abroad. It is necessary to further research the anti-galloping of large-section carbon fiber composite core conductor, thus providing technical support for the design and running of power transmission line.

The conductor galloping is self-excited vibration of low frequency and large vibration amplitude after eccentric icing of the conductor, and it belongs to the coupling vibration of fluid and solid (structure). Through data investigation, it is known that the researches on exiting power transmission line galloping and control technology are mainly target existing aluminum conductor steel reinforced, aluminum alloy conductor steel reinforced and corresponding ground wire, while the researches on galloping of large-section carbon fiber composite core conductor, and control methods are to be further conducted based on existing research achievements and according to characteristics of large-section carbon fiber composite core conductor, thus providing technical support for anti-vibration and anti-galloping design of large-section carbon fiber composite core conductor.

2. Galloping Finite Element Model
Basic dynamics movement equation on galloping as follow

\[ M \ddot{u} + C \dot{u} + Ku = F \]

In which, \( M, K, C \) are structure quality matrix, rigidity matrix and damping matrix respectively; \( u \) is displacement vector; \( F \) is load vector. According to the theory that fluid induces vibration, air dynamic load of the icing conductor with length of \( L \) under horizontal wind load at speed of \( U \) includes resistant force \( F_D \), lift force \( F_L \) and torque \( F_M \):

\[
\begin{align*}
F_D &= \rho U^2 L D C_D / 2 \\
F_L &= \rho U^2 L D C_L / 2 \\
F_M &= \rho U^2 L D^2 C_M / 2
\end{align*}
\]

In which, \( \rho \) is density of airflow; \( D \) is conductor diameter, and \( L \) is the shape and length of ice coating \( C_D, C_L, C_M \) are resistant force, lift force and torsion coefficient respectively, they are related with section area of the conductor, icing shape and thickness of the conductor, movement status and the corresponding attack angle etc factors, they are generally obtained from the wind tunnel test.

Common icing status of the conductor is shown as figure 1, in which \( \theta \) is the ice coating angle, and \( U \) refers to wind speed.

The finite element model of large-section carbon fiber composite core conductor is shown as Figure 2. Three kinds of large-section conductors are selected, which including carbon fiber composite core large-section conductor JLZ2X1/F2A-1660/95-492, 1,250mm² large-section aluminum conductor steel reinforced JL1/G2A-1250/100-84/19 and 1,520mm² aluminum conductor aluminum-alloy reinforced JL1X/LHA1-1040/550-487; The parameters can be shown in Table 1.
Figure 1 D-type Ice Coating Section

Figure 2 Finite Element Model of Conductor

Table 1 Calculation Parameters

| Conductor Model          | JLZ2X1/F2A-1660/95-489 | JL1/G2A-1250/100-84/19 | JL1X/LHA1-1040/550-487 |
|--------------------------|-------------------------|------------------------|-------------------------|
| Calculated Section Area  | 1660.76                 | 1250                   | 1592                    |
| of Aluminum (mm$^2$)     |                         |                        |                         |
| Conductor Diameter (mm)  | 49.2±0.5                | 47.9                   | 48.69±0.5               |
| Unit Length Mass of      | 4.81378±0.0963          | 4.2539                 | 4.389±0.088             |
| Conductor (kg/m)         |                         |                        |                         |
| Rated Tensile Force of   | ≥401.63                 | 330.25                 | 326.22                  |
| Conductor (kN)           |                         |                        |                         |
| Elastic Modulus of       | 76.5                    | 65.1                   | 55±3                    |
| Conductor(GPa)           |                         |                        |                         |
| Span (m)                 |                          | 300, 500               |                         |
| Wind Speed (m/s)         |                          | 8, 10, 12, 15 and 18   |                         |
| Initial Wind Attack Angle | -15                     |                         |                         |
| Ice Type/Ice Thickness   |                          | D /10                  |                         |
| (°)                      |                         |                        |                         |

3. Analysis on Galloping Characteristics Result
The solution of equations of galloping can be acquired by using the time integral method. The galloping amplitude value of conductor directly influences phase spacing of conductor, the larger the galloping amplitude value is, the smaller the phase spacing will be, and the easier the discharging tripping among phases will be. The detailed analysis on calculation results of galloping is shown as below.

3.1 Analysis on Galloping Amplitude
Middle spans of 300m and 500m respectively are selected as calculating spans of power transmission line, and the galloping response is acquired. The D-type ice coating is selected, with ice thickness of
10mm. The 20% of calculated breaking force of respective conductor is taken as initial tension of conductor, and calculation Parameters are shown in Table 1.

The three kinds of conductors i.e. carbon fiber composite core large-section conductor JLZ2X1/F2A-1660/95-492, 1,250mm² large-section aluminum conductor steel reinforced JL1/G2A-1250/100-84/19 and 1,520mm² aluminum conductor aluminum-alloy reinforced JL1X/LHA1-1040/550-487 are selected to calculate amplitude value on galloping respectively, and the obtained results of galloping amplitude are shown in Figure 3 – Figure 4.

Conductors with span of 300m and 500m generate order-2 galloping and order-3 galloping respectively, and five wind speeds within the scope of 8-18m/s are selected, i.e. 8m/s, 10m/s, 12m/s, 15m/s and 18m/s. The results in Figure 5 and Figure 6 show that galloping amplitude value of using the carbon fiber composite core large-section conductor JLZ2X1/F2A-1660/95-492 will be reduced by about 3-5% than that of the 1,250mm² large-section aluminum conductor steel reinforced LJ1/G2A-1250/100, and will be reduced by about 7% than the 1,520mm² aluminum conductor aluminum-alloy reinforced JL1X/LHA1-1040/550-487 with similar section. It can be seen that due to characteristics such as light weight and high tension, the galloping amplitude value of carbon fiber conductor is smaller than that of aluminum conductor steel reinforced and that of aluminum conductor aluminum-alloy reinforced with similar section.
3.2 Galloping Tension

The calculated parameters of galloping tension are the same as calculation conditions of galloping amplitude value. Similarly, the three kinds of conductors i.e. carbon fiber composite core large-section conductor JLZ2X1/F2A-1660/95-492, 1,250mm$^2$ large-section aluminum conductor steel reinforced JL1/G2A-1250/100-84/19 and 1,520mm$^2$ aluminum conductor aluminum-alloy reinforced JL1X/LHA1-1040/550-487 are selected to analyse and calculate galloping tension respectively, and the calculated results of galloping tension can be obtained from Figure 5 and Figure 6.

**Figure 5 Galloping Tension (300m, Order-2 Galloping)**
![Figure 5](image)

**Figure 6 Galloping Tension (500m, Order-3 Galloping)**
![Figure 6](image)

The initial value of galloping tension of the carbon fiber composite core large-section conductor JLZ2X1/F2A-1660/95-492 is 20% of the calculated breaking force (401.63KN), i.e. 80.326KN, much greater than the initial tension (66.05KN) of the aluminum conductor steel reinforced JL1/G2A-1250/100-84/19, and then the initial tension (65.244KN) of the 1,520mm$^2$ aluminum conductor aluminum-alloy reinforced JL1X/LHA1-1040/550-487. From Figure 5 - Figure 6, it can be known that along with the increasing of wind speed, the galloping tension values of three kinds of conductors are all increased. The galloping tension of carbon fiber composite core large-section conductor JLZ2X1/F2A-1660/95-492 is increased by about 11-15% in case of comparing with that of the aluminum conductor steel reinforced JL1/G2A-1250/100-84/19. The galloping tension of the carbon fiber composite core large-section conductor JLZ2X1/F2A-1660/95-492 is increased by 7-13% in case
of comparing with that of the 1,520mm² aluminum conductor aluminum-alloy reinforced JL1X/LHA1-1040/550-487.

4. Conclusions
This paper establishes the finite element galloping model of large-section carbon fiber composite core conductor. Through comparing and analysing on the three kinds of large-section conductors, the galloping characteristics of carbon fiber composite core large-section conductor are obtained.

After using carbon fiber composite core conductor, and under the same ice coating conditions, for the single weight of carbon fiber conductor is relatively small while the tension is relatively large, the galloping amplitude value of the carbon fiber composite core large-section conductor can be reduced by about 3%-5% than that of the 1,250mm² aluminum conductor steel reinforced, and can be reduced by about 7% than that of 1,520mm² aluminum conductor aluminum-alloy JL1X/LHA1-1040/550-487 reinforced with similar section. Along with the increasing of wind speed, the galloping tensions of three kinds of conductors are all increased; and the galloping tension of the carbon fiber composite core large-section conductor JLZ2X1/F2A-1660/95-492 is increased the most. The calculation result of this paper provides technical basis for the anti-galloping design of carbon fiber conductor.

Acknowledgements
Project Supported by Science and Technology Project of State Grid Corporation of China- (5202011600TX).

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