Optimization Design on Anti-galloping Device of Long-span Section over Yellow River in 500kV Yangdong Transmission Lines II & III

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Abstract. To enhance the anti-galloping capability of the Long-span Section over Yellow River in 500kV Yangdong Transmission Lines II & III, this text will research the anti-galloping optimization design scheme of the double-swing anti-galloping device, which is widely used in the ultra-high voltage line at present. According to the existing anti-galloping standards and Technical Conditions, this Report will conduct optimization design targeting pendulum bob mass distribution and theoretical pendulum length of double-swing anti-galloping device, so as to provide reasonable and effective design scheme for the Long-span Section over Yellow River in Yangdong Transmission Lines II & III, and to provide reference for proposal and formulation of anti-galloping design scheme of other lines, thus providing scientific basis and effective guarantee to enhance anti-galloping and galloping suppression capabilities of smart grid.

1. Introduction

The ice-coating galloping of power transmission line is a kind of wind-induced vibration disaster of low frequency (0.1-5Hz) and large amplitude (about 20-300 times as large as conductor diameter), which mainly occurs in winter and spring[1-3]. Our country is vast in territory, including all kinds of topographies and landforms all over the world; in addition, the climate in recent years has abnormal change, the power grid technology is constantly developing, and its scale is expanding continuously, the meteorological conditions and geographical conditions where the power transmission line is located are more complicated, so the work of dealing with conductor ice-coating galloping disaster of ultra-high and extra-high voltage lines which are responsible for cross-region power transmission refers to profound complexity and severe terrain. For the conductor ice-coating galloping is featured by large amplitude value and long duration, it may cause severe damage to the power grid system easily, thus causing severe accidents breaking and falling of power transmission line, pole and tower collapse, device and its part damage, discharging tripping, etc.

Spacer damper with rotational clamps and double-swing are both anti-galloping devices which have been widely used. The Anti-galloping Design Standard for Overhead Transmission Line (Q/GDW 1829-2012)[4] and Technical Conditions for Double-swing Anti-galloping Device (Q/GDW 717-2012)[5] gives suggested values of main structural parameters of double-swing anti-galloping device. However, for the values in the Table only refer to a certain scope, their exact calculation methods and value taking modes are not defined, and special structure types of some lines are not considered (such as large-span line structure involved in this thesis), so there are still some problems during actual engineering application, such as artificial value taking difference affected by subjective experience factor, and product difference due to different manufacturer’s raw materials, processing technologies and production modes, which
cause different effects during the actual engineering line application. With regard to most of lines, their anti-galloping and galloping suppression capabilities are enhanced obviously, but the effect is not very obvious for a few lines. In essence, this is because that the understanding of pendulum bob mass and theoretical pendulum length of double-swing anti-galloping device mentioned above is not profound, the value taking is conducted only referring to above listed situations and based on engineering experience, and the requirement of avoiding motivation of galloping which is specified in the “stability mechanism” may not be met. Therefore, this thesis will attempt to analyze and define value taking methods of pendulum bob mass and theoretical length specified in this mechanism from multiple points of view, and propose reasonable and effective anti-galloping scheme for the Long-span Section over Yellow River in Yangdong Transmission Lines II & III.

![Figure 1. Accident Caused by Galloping](image)

(a) Tower Collapse  (b) Flashover

2. Design Situation of Long-span Section over Yellow River in Yangdong Transmission Lines II & III

The Long-span Section over Yellow River in 500kV Yangdong Transmission Lines II & III is located within the territory of Dongming County of Shandong Province. From the perspective of geographical location, this line section is located at the boundary between Henan Province and Shandong Province, and the terrain refers to open plain belt, and the line tendency refers to southeast - northwest. According to the diagram of galloping region distribution of Shandong Power Grid of State Grid (Version 2016), it can be known that this section is located in the level 2 galloping area.

The detailed design parameters of the conductor are as shown in the Table below.

| Design Parameter | Valuing |
|------------------|---------|
| Span             | 1,133m  |
| Conductor        | 4×AACSR-320 |
| Tension          | 450mm   |
| Maximum Design Wind Speed | 89520N |
| Maximum Design Ice Thickness | 33m/s |

3. Modelling Considering Ice-coating Conductor Galloping with Anti-galloping Device

The modelling based on curved beam theory can fully embody the bending resistance, torsion resistance and 3D stress coupling characteristics of the large cross section conductor\[^6\,^7\]. The dynamics equation set describing j-step modality of each freedom degree is shown as below.

\[
M_j \begin{bmatrix} x'_j \\ y'_j \\ z'_j \end{bmatrix} + K_j \begin{bmatrix} x'_j \\ y'_j \\ z'_j \end{bmatrix} + C_j \begin{bmatrix} x'_j \\ y'_j \\ z'_j \end{bmatrix} = f_{st,j} \begin{bmatrix} x_j \\ y_j \\ \theta_j \end{bmatrix}
\]

(1)

In the formula, this thesis will analyze the 3rd-5th step of modalities which are frequently seen in the long-span conductor galloping, so the modality marks are \(j=3\), 4 and 5; and \(M, K\) and \(C\) are respectively
system mass, rigidity and damping matrix; \( f_{nl}, f(x, y) \) respectively refers to non-linear item of each freedom degree.

\[
M_j = \begin{bmatrix}
m_{j,11} & m_{j,22} & m_{j,33} \\
m_{j,22} & m_{j,22} & m_{j,23} \\
m_{j,31} & m_{j,32} & m_{j,33}
\end{bmatrix};
K_j = \begin{bmatrix}
k_{j,11} & k_{j,22} & k_{j,33} \\
k_{j,22} & k_{j,22} & k_{j,23} \\
k_{j,31} & k_{j,32} & k_{j,33}
\end{bmatrix};
C_j = \begin{bmatrix}
c_{j,11} & c_{j,22} & c_{j,33} \\
c_{j,22} & c_{j,22} & c_{j,23} \\
c_{j,31} & c_{j,32} & c_{j,33}
\end{bmatrix}.
\tag{2}
\]

In the formula, \( m, k \) and \( c \) respectively refer to mass, rigidity and damping coefficient of different freedom degrees under various step modalities.

According to the “galloping stability mechanism”, the core judgment conditions lies in the Routh-Hurwitz stability criterion, and the characteristic polynomial of the formula (1) can be written as below.

\[
f_j(\lambda) = |M_1 \lambda^2 + C_1 \lambda + K_1|
\tag{3}
\]

The expansion equation is:

\[
f_j(\lambda) = \lambda^6 + \lambda^5 \alpha_1 + \lambda^4 \alpha_2 + \lambda^3 \alpha_3 + \lambda^2 \alpha_4 + \lambda \alpha_5 + \alpha_6
\tag{4}
\]

From the Routh-Hurwitz stability criterion, we can know that the condition of system stability is:

\[
\Delta_1 = \alpha_1 > 0; \Delta_2 = \begin{vmatrix}
\alpha_1 & 0 & 0 \\
a_2 & \alpha_3 & \alpha_2 \\
a_3 & a_4 & a_3
\end{vmatrix} > 0; \Delta_3 = \begin{vmatrix}
a_1 & 0 & 0 & 0 \\
a_2 & \alpha_3 & \alpha_2 & 1 \\
a_3 & a_4 & a_3 & a_2 \\
a_4 & a_5 & a_4 & a_3 \\
a_5 & \alpha_6 & a_5 & a_4 \\
a_6 & a_6 & a_5 & a_4
\end{vmatrix} > 0; \Delta_4 = \alpha_1 \alpha_2 > 0.
\tag{5}
\]

Conversely, if some item among \( \Delta_1, \Delta_2, \ldots, \Delta_6 \) is not positive, it means that the system is of linear instability.

4. Conductor-Analysis on Anti-galloping System Stability and Anti-galloping Scheme

4.1. Analysis on Vibration Prevention of Pneumatic Parameters

Select the crescent ice-coating which is frequently seen in the ice-coating galloping of long-span conductor.

![Figure 2. Curve of Pneumatic Resistance Coefficients of Different Ice-coating Thicknesses along with Change of Angle of Attack](image1)

![Figure 3. Curve of Pneumatic Lift Force Coefficients of Different Ice-coating Thicknesses along with Change of Angle of Attack](image2)

Affected by such eccentric ice-coating, after the conductor suffers from wind function, there will be a certain pneumatic lift force, resistance and torque. After utilizing mature flow field numerical
simulation software, the change of pneumatic coefficient formed on the 4×ACSR-320 conductor with crescent eccentric ice-coating under different ice-coating thicknesses along with the angle of attack is as shown in the following group of Figures.

![Figure 4. Curve of Pneumatic Torque Coefficients of Different Ice-coating Thicknesses along with Change of Angle of Attack](image)

4.2. Analysis on Examples and Optimization Design Scheme

According to Anti-galloping Design Standard, the overall mass of double-swing anti-galloping device in single span is not more than 7%, and the weight of single bob is 9kg. Distribution schemes and theoretical pendulum lengths which different spans and total mass ratios of double-swing anti-galloping device correspond to. Different schemes are numbered here to facilitate the statement of the subsequent calculation analysis.

| Total Mass Ratio | Quantity of Double-swing Anti-galloping Devices | Distribution Scheme | Theoretical Pendulum Length/mm | Scheme No. |
|------------------|-----------------------------------------------|---------------------|-------------------------------|-----------|
| 4.5%             | 32                                            | 8-8-8-8             | 450                           | 1.1       |
|                  |                                               |                     | 550                           | 1.2       |
|                  |                                               |                     | 650                           | 1.3       |
|                  |                                               |                     | 450                           | 2.1       |
| 5.5%             | 40                                            | 10-10-10-10         | 550                           | 2.2       |
|                  |                                               |                     | 650                           | 2.3       |

Utilizing the stability theory criterion, substitute parameters which represent above mentioned schemes, value taking situations of structural parameters of lines mentioned in Table, thus obtaining the stability change situations of lines at different ice-coating situations and wind speeds in different installation schemes of various double-swing anti-galloping devices.

![Figure 5. Galloping characteristics of lines without any anti-galloping device](image)
From the below Figures, it can be known that in different design and installation schemes, the double-swing galloping device will generate obvious influence on instable galloping characteristics of various spans of conductors, and the detailed conclusions are shown as below:

1. After the three gears of conductors are added with double-swing anti-galloping devices, the galloping wind speeds are all increased slightly, and the instability intervals under various ice-coating thicknesses are changed, and most of them show the tendency of shrinkage;

2. The total mass and quantity of double-swing ant-galloping device has relatively obvious influence on galloping characteristics of each gear of conductor; the greater the double-swing total mass is, the more the quantity will be, the higher the galloping wind speed will be, the smaller the instability intervals under various ice-coating thicknesses will be, and the better the overall anti-galloping capability shown by the line will be;

3. Compared with total mass, quantity and other relevant factors, the theoretical pendulum length has relatively weak influence on galloping characteristics of each gear of conductor; however, increasing the pendulum length will also obviously improve the anti-galloping capability of three gears of conductors.

In a word, based on the combination of quantification and qualitification, this time, the recommended schemes for the anti-galloping design of Long-span Section over Yellow River in 500kV Yangdong Transmission Lines II & III are above mentioned 1.3, and 2.3, i.e. the total mass of double-swing anti-galloping devices added into three gears account for 5.5% of the total mass of conductor, while the theoretical pendulum length refers to the upper limit 650mm ruled in the standard.

![Figure 6. Galloping Characteristics of Lines with different anti-galloping devices](image)

### 5. Summary
Based on sufficient investigation of design parameters of the Long-span Section in Yangdong Transmission Lines II & II, this thesis has studied existing anti-galloping standards and design conditions of newly built lines, and after combining the typical galloping instability mechanism, the instability wind speed intervals of various gears of lines under different eccentric ice-coating thicknesses are worked out, so as to provide recommendation scheme on anti-galloping design for the Long-span...
Section over Yellow River in 500kV Yangdong Transmission Lines II & III. After contrastive analysis, the following conclusions are concluded:

1. Installing the double-swing anti-galloping device can effectively improve the anti-galloping capability of line; the larger the total mass of double-swing anti-galloping device is, the longer the pendulum length will be, and the smaller the galloping instability interval of line section will be;

2. The anti-galloping scheme of the Long-span Section over Yellow River in Yangdong Transmission Lines II & III recommended by this thesis refers to the scheme of “cable cleat rotary spacer + double-swing anti-galloping device”; in which, see relevant standards for installation and layout modes; the percentage of the total mass of double-swing anti-galloping device shall reach 6.5%, and the theoretical pendulum length is selected as 650; then the theoretical anti-galloping capability shown by the conductor – anti-galloping device system is the best.

Acknowledgments
Related research against this article was supported by CEPRI Self-raised project, “Research on Mechanical Model of Transmission Line Conductor Zero-frequency Damping Device Based on Nonlinear Energy Sink Technology”.

References
[1] Doocy E. S., Hard A. R., Rawlins C. B..(2009)Transmission line reference book: wind-induced conductor motion.
[2] Guo Y. l., Li G. X., You C. Y.. (2003)Transmission line galloping. China Electric Power Press, Beijing.
[3] Li X. M., Zhu K. J., Li J. H.. (2011)Research progress of transmission line galloping analysis and prevention methods. High Voltage Technology, (02): 484-490.
[4] State Grid Beijing Institute of Economics and Technology, China Academy of Electric Power Sciences, State Grid Corporation of the People's Republic of China, et al. (2013)Anti-dancing Design Specification for Overhead Transmission Lines. State Grid Corporation, Beijing.
[5] China Academy of Electric Power Sciences. (2012)Technical Conditions for Double Pendulum Anti-Dance Devices. Beijing: State Grid Corporation, Beijing.
[6] Zhao B., Cheng Y. F., Wang J. C., et al. (2016)Effects of damping spacer and double pendulum anti-dancer on galloping characteristics of ice-covered UHV conductors. High Voltage Technology, 42 (12): 3837-3843.
[7] Zhao B., Cheng Y. F., Wang J. C., et al. (2017)Theoretical analysis and Countermeasures of ice-covered dancing disaster on overhead lines in Hubei Province in early 2015. Vibration and shock, 36 (10): 93-97.