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The Characteristic analysis on Galloping of Conductor under extreme cold condition in Arctic

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Abstract. This paper describes meteorological condition under extreme cold condition in Arctic. Because icing is an important condition for galloping of the conductor, icing condition of the conductor under extreme cold condition in Arctic is analyzed, influence of temperature about icing of the conductor is obtained. Elasticity modulus of the conductor under low temperature condition is derived by the formula, the calculation model of galloping value of the conductor is established, and carry out simulate calculation and analysis about galloping amplitude and dynamic tension of the conductor, and galloping characteristic of the conductor under extreme cold condition in Arctic is obtained. The calculation results in this paper will provide some reference for design of the conductor under extreme cold condition.

1. Introduction

The global energy internet takes the ultra-high voltage and intelligent grid as the main carrier, it is one of the important direction of State Grid to realize interconnection in the continent, intercontinental networking and global inter-connection, connect "one Arctic and one Equator"(Arctic, Equator) large energy base, and build up the global energy internet in future. However, environment condition in Arctic area is greatly different to that in other area of the world, for example temperature in polar extreme cold area is low to -40°C—-60°C, it is almost below 8°C in summer, historical lowest temperature observed in Siberia is minus 70 degree. Historical lowest temperature observed at Arctic point is minus 59 degree. Winter season in Arctic starts from November until next April, it is long about 6 months. The lowest temperature of -70°Chas been recorded in Verkhoyansk of Siberia.In winter, average wind speed in Arctic area is about 10m/s. Above extreme environment in Arctic area is issue which must be considered during construction of the global energy internet, solution of conductor galloping etc issue under extreme cold condition in Arctic area is one of the key loop to realize the global energy networking.

Galloping of the conductor in the power transmission line is self-excitation vibration with large amplitude at low frequency. Analysis calculation of galloping load characteristic of the conductor under influence of strong non-linear characteristic is very complicate. At present, some research are carried out about general icing wind condition in foreign country and China. No effective research achievement is available for galloping dynamic characteristic of the conductor under extreme meteorological condition, especially under multiple factor coupling condition. At present, research achievement about galloping characteristic of the conductor under extreme cold condition in Arctic is very few, this paper mainly carries out analysis about meteorological condition when galloping occurs under cold condition, which selects three typical temperature for calculation of galloping amplitude and tension. The calculation result can provide certain reference for anti-galloping design in extreme cold area in Arctic.

2. Icing condition analysis of conductor under extreme cold condition

Because influence of temperature about icing is great and icing is the important condition for galloping, now influence of temperature about icing is analyzed. Temperature which icing is mostly liable to occur is -6℃—0℃. According to statistical record in Power industry standard of the People's Republic of China （DL/T 5158-2012）《Technical code for power meteorological survey》, lowest icing temperature is -9℃, shown as above table 4-3. According to record of 《Anti-icing working booklet for overhead power transmission line of State Grid》, shape of rime mainly consists of two type: one is over cold fog is quickly frozen as small particle ice block when it contacts cold object on the ground, it is called as particle rime, its structure is very compact. Another type is crystalline rime which is formed by condensation of water and steam during evaporation of fog, structure is loose, it will fall under slight vibration. Therefore density of rime is small, weight is light, destruction about the wire and the tree are less than that of glaze. When rime on the wire is serious, the wire will be broken, which will cause power off. Under general conditions, meteorological condition that rime causes icing on the line mainly consists of: relative humidity of air is above 85%, wind speed is greater than 1m/s, air temperature and surface temperature of the conductor range from -13℃ to -8℃.

In case air temperature is too low, over cold water droplet becomes snow, which doesn't form icing on the power transmission line. Icing accidence in cold north area is light than Yunnan, Guizhou, Hunan and Hubei etc in south area. Therefore the conductor isn't easy to be iced at extreme low temperature in extreme cold area in Arctic, and galloping of the conductor is difficult to form.

For galloping value calculation under low temperature conditions, it only calculates condition with temperature of 0℃ and -12℃, icing on the line. When temperature suddenly drops down to -20℃, temperature is lower and there is no icing, galloping condition of the line will not be considered.

3. Model of Galloping

Basic dynamics movement equation on galloping as follow.

$$M\ddot{u} + C\dot{u} + Ku = F \qquad\qquad （1）$$

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_z includes resistant force F_D, lift force F_L and torque F_M

$$\begin{cases} F_D = \rho U_z^2 L D C_D / 2 \\ F_L = \rho U_z^2 L D C_L / 2 \\ F_M = \rho U_z^2 L D^2 C_M / 2 \end{cases} \qquad\qquad （2）$$

In which, ρ is density of airflow; D is windward size of the conductor; 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, data of the wind tunnel test and fit curve data figure are given in figure 2. For D type icing, basic parameters of the conductor obtained according to demand are shown as table 2. Data of wind tunnel test and fit curve are shown as figure 2. For non-linear movement equation of galloping, time-integral method is applied to solve value.
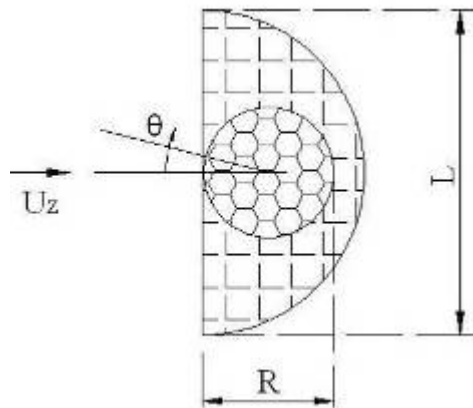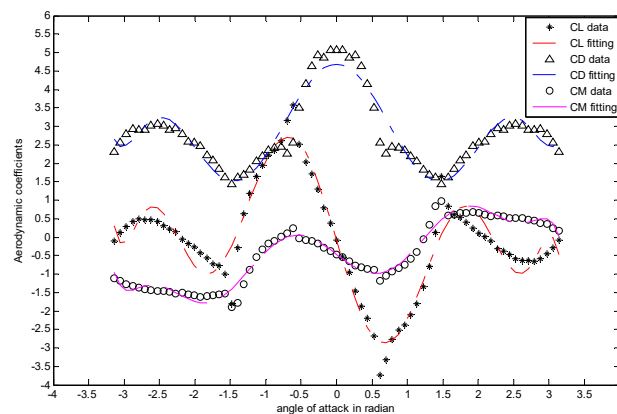
Figure.1 Section of D type icing

Figure.2 Lift. drag and moment coefficients of the D-shaped conductor
Where CD—drag; CL—lift; CM—moment.

4. Galloping calculation parameters

Table. 1 Physical parameters employed to simulate galloping

Parameters	Notation	Units	data
Axial rigidity	**AE**	**10^6N**	**26.8**
Torsional rigidity	**GJ**	**Mmrad-1**	**101**
Horizontal component of tension	**H**	**10^3N**	**20.73**
Diameter of bare cable	**d**	**10^{-3}m**	**26.8**
Horizontal distance between adjacent towers	**Lx**	**m**	**146.78**
Damping ratio in the y direction	**ξy**	**10^{-2}**	**2.0**
Damping ratio in the θ direction	**ξθ**	**10^{-2}**	**3.79**
Mass per unit length	**μ**	**kgm^{-1}**	**1.347**
wind speed	**U**	**m/s**	**5**
static attack	**α**	**degree**	**-15**
Elastic modulus	**E**	**（N/mm^2）**	**65000**

Table 1 are parameters of the conductor for galloping calculation. Because low temperature will affect calculation parameters of the conductor, testing of elasticity modulus of the conductor isn't available because of limitation of test condition. Elasticity modulus of the steel core aluminium twisted wire 400/35 is derived within scope of -250℃—250℃.

$$E = \frac{Pl_0}{A\Delta l}$$

（3）

In which, P is imposed tension; l_0 is original length of conductor; A is crossing section area; Δl is elongation quantity.

Linear expansion coefficient of aluminium is λ_{AL}=23×10-6/°C; linear expansion coefficient of steel is λ_{ST}=11.5×10-6/°C.

When temperature drops down, Δt is reduced temperature, it is positive if it rises up, and it is negative if it drops down, E' is comprehensive elasticity modulus of the conductor at low temperature. Assuming initial length is constant, influence of elasticity modulus of the material is derived according to linear expansion coefficient.

$$E' = \frac{Pl_0}{A\Delta l'} = \frac{Pl_0}{A\Delta l(1+\lambda\Delta t)} = \frac{E}{(1+\lambda\Delta t)}$$

（4）

Elasticity modulus of aluminium at low temperature

$$E'_{AL} = \frac{E_{AL}}{(1+\lambda_{AL}\Delta t)}$$

（5）

Elasticity modulus of steel at low temperature

$$E'_{ST} = \frac{E_{ST}}{(1+\lambda_{ST}\Delta t)}$$

（6）

Comprehensive elasticity modulus at low temperature

$$E' = \frac{E'_{ST}A_{ST}+E'_{AL}A_{AL}}{(A_{ST}+A_{AL})}$$

（7）

According to formula (5), refer to following figure for calculation result of elasticity modulus of the conductor within scope between -250°C and 250°C.
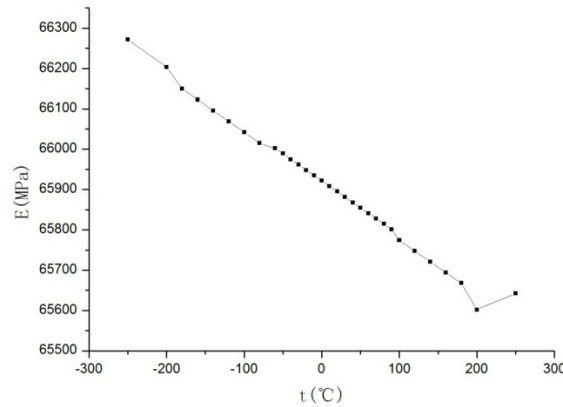

Figure.3 Elasticity modulus change curve of conductor LGJ-400/35 under different temperature

Seen from figure 3, elasticity modulus of the conductor drops down following temperature rise. When temperature is -60°C, elasticity modulus rises up about 0.1624% compared to that at constant temperature of 20°C. Even absolute value is very small, but magnitude order of the elasticity modulus is very great, and increase is great, influence about vibration characteristic of the conductor will be analyzed later.

5. Galloping calculation

Galloping calculation is based on finite element model and calculation parameters, and time integral algorithm simulate method has been selected, and calculation results with 0℃, -12℃ and -20℃ three typical temperature are shown as from **Figure.4** to **Figure.6.**
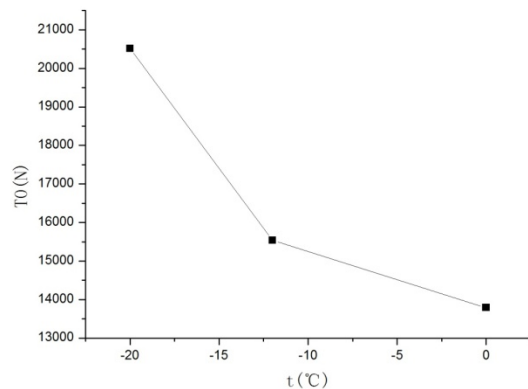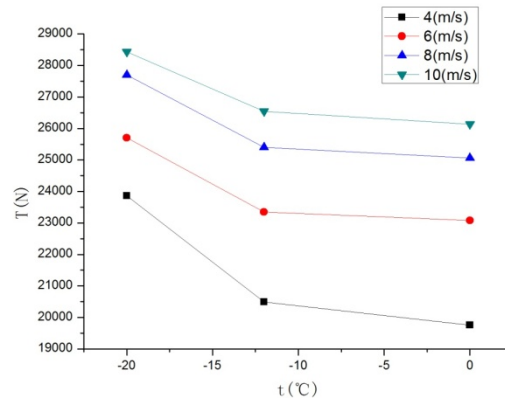
Figure.4 Initial tension under different temperature   Figure.5 Galloping tension under different temperature
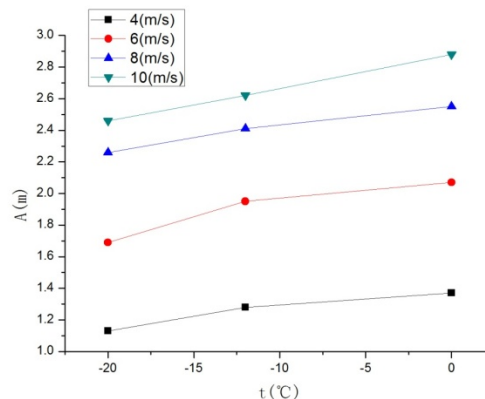
Figure.6 Galloping amplitude under different temperature and wind speed

Following temperature drop, the sag of the conductor is reduced, when temperature of the conductor is reduced to -12℃ and -20℃ from 0℃, initial tension increases, it is increased to 24.1% and then 31.8% from 21.3% calculation breakage force. According to calculation results in figure.4-9— figure.4-10, galloping amplitude of the conductor is reduced at same wind speed. When temperature is reduced to -12℃, galloping amplitude is reduced compared to that at 0℃, the dynamic tension force is reduced, ratio to initial tension force is reduced; temperature continues drop down, because there is no icing, the line is difficult to generate galloping.

6. Conclusion

This paper mainly analysis and simulate the galloping amplitude and tension on galloping of conductor   under extreme cold condition, which selects three typical temperature for calculation. It can be seen from calculation result, which can't form icing on the conductor at extreme low temperature in cold area in Arctic, and it isn't easy to form galloping on the line. Following temperature drop, galloping amplitude of the conductor is reduced at same wind speed, and dynamic tension is reduced; If temperature continues drop down, the line isn't liable to generate galloping. Therefore in Arctic area, when average temperature in winter reaches -20—-40℃, icing galloping possibility of the transmission line is very small. Average air temperature in Summer is about -8℃, galloping possibility of the power transmission line in summer is very great in Arctic area.The calculation result can provide certain reference for anti-galloping design in extreme cold area in Arctic.

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