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Algorithm Research on Icing Load Detecting for the Overhead Transmission Line

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Abstract. In this paper, the icing mechanism and force of overhead transmission lines were studied. The inclined parabolic equation of overhead transmission lines was derived and on this basis, calculation methods of sag, long lines and stress had been discussed. The paper got the inclined parabolic form of the equation of state based on the relationship between the different states of overhead lines and overhead transmission line icing load detection algorithm which combined with measured climate parameters, coordinate data and wire parameters. This paper made simulation experiment according to overhead transmission line icing load algorithm proposed verifying the correctness of the ice load detection algorithm.

Introduction Icing Mechanism

In recent years all over the country ice and snow disasters constantly, especially in the south of the freezing rain weather to local power supply system bring serious damage. The problem of Overhead Transmission Line Icing always was concerned by power enterprises. In many areas icing causes the load of transmission lines increased. So this will result in the break down lever (tower), flashover accident, causing huge economic losses to society [1-3]. For example, in 1954, 14 transmission lines in the power system in Hunan severely destroyed for Icing. In 1984 Guizhou provincial power grids has a massive ice storm and in net up to 27.37% of the transmission lines of 131 trips, resulting in paralysis of the power system. In 1987, Icing load weather has appeared in Henan region. In Nanyang transmission tower poles ice coating thickness is reached the 150-200mm, greatly exceeds the design standards, leading to the tower broken interrupt transmission [4-5]. In Shangqiu, the 75% -80% of transmission lines does not work properly due to the glaze. In 1993, 500kV high voltage transmission lines of Jingmen in Hubei Province, there were a serious the iced accident, leaving a total of seven towers collapsed, causing economic losses of more than 10 million [6-7]. In 2005, for a long time, a wide range of frozen rain and snow come to Chongqing, Hubei and Hunan, resulting in at least 17 transmission lines paralysis, affect the time amounted to more than a month. In 2008, of about 1.28 million square kilometers in southern China in 19 provinces of Jiangxi, Hunan, Guizhou, Hubei, Anhui and other homeland suffered more than 50 years of rare freezing rains and snow. Meantime, the 5709 power transmission line has faults and outages for iced, the number of 2418 lines was damaged. China Southern Power Grid Company lost in the accident: more than 120,000 seats of transmission line towers damaged; over 7000 lines damage [8-10].

In order to ensure the normal operation of the power grid, we need to real-time monitor the ice cover on the overhead lines. So we can do more in-depth studies on line icing, and take timely measures to prevent the further development of the overlying ice causing line failure.

Ice Mechanism and Calculation of Overhead Line

The Linear Mechanism of Ices

From the perspective of meteorology, atmospheric can be divided into three levels from top to bottom: ice layer, heating layer and air-conditioning layer. Through a warm layer of snow fell from the ice layer melted into water droplets, water droplets into the layer of cold air near the ground, rapid cooling, the cooled water droplets when exposed to the ground below 0 ^oC objects (such as wires, Tower), frozen form iced. Therefore, ice is a comprehensive physical phenomenon affected by ambient temperature, air humidity, cold and warm air convection and circulation, as well as wind speed and direction and other factors. Usually the weather conditions of transmission lines producing Icing are that temperature and equipment surface temperature reaches <0 ^oC, air relative humidity > 80% and the wind speed >1 m / s.

The Thickness of the Lines in the Ice Conversion

Icing on overhead lines is generally divided into two categories: glaze and rime .Rime according to its texture can be divided into soft rime, hard rime (also known as mixed with glaze). The glaze is a smooth and transparent crystal; its density can be as high as 0.9 g/cm^3. The ice thickness is an important parameter of the output circuit Icing Monitoring System. Different types of ice will cover transmission lines under different weather conditions. In order to facilitate the calculation, this algorithm unified to glaze physical parameters.

The length of the transmission line assuming has been beat iced is x, the diameter of the transmission line is D, the quality of the ice beat is m_x.So

$$m_x = \frac{0.9\pi x}{4}\left[(D+2b)^2 - D^2\right]\times 10^{-3} = 0.9\pi x b(b+D)\times 10^{-3} \tag{1}$$

We can get standard ice thickness

$$b = \frac{1}{2}\left(\sqrt{D^2 + \frac{4m_x \times 10^{-3}}{0.9\pi x}} - D\right) \tag{2}$$

The Than-Load Calculation

The γ_1 is self-gravity unit load on the cross-sectional area of the wire unit, assuming the total sectional area of wire is A (mm^2), load wire self-gravity units is P_1 (N/m), The quality of the wires per unit length is q (kg/m),So

$$\gamma_1 = \frac{P_1}{A} = \frac{9.80665q}{A} \tag{3}$$

Assuming the diameter of the transmission line is D (mm), so:

$$P_2 = \frac{0.9\pi g}{4}\left[(D+2b)^2 - D^2\right]\times 10^{-3} = 0.9\pi g b(b+D)\times 10^{-3} \tag{4}$$

Formula (3) and (4) associated can be drawn γ_2, so

$$\gamma_2 = 0.027728\left[\frac{b(b+D)}{A}\right] \text{(N/m.mm2)} \tag{5}$$

When transmission lines is iced, vertical total units load is P_3 load is so we can get P_3 and γ_3 by P_1, P_2, and γ_1, γ_2,

$$P_3 = P_1 + P_2 \quad \text{(N/m)}$$

$$\gamma_3 = \gamma_1 + \gamma_2 \quad \text{(N/m.mm}^2\text{)} \tag{6}$$

Algorithm Research on Overhead Transmission Lines Ice Load

Oblique Parabolic Equations and the Relevant Formula

For simplification, assuming the load distribution is hoisted along two connections between the points, rather than along the transmission line. As shown in Figure.1, γ distribution in straight lines $\overline{AB}$, Coordinate plane is established within the plane of the transmission line. Its original tap is at the point of A which are on the left hanging. We selected as the Y-axis direction in the direction of loads. The direction of the X axis is perpendicular to the load direction. Two suspension points in the coordinate system of the difference in height are h (m). The distance in horizontal direction is l (m), the angle between the straight line $\overline{AB}$ and the X axis is called β . Bear the load of overhead transmission lines per unit length per unit cross section called γ . N/mm^2.m or MPa/m.

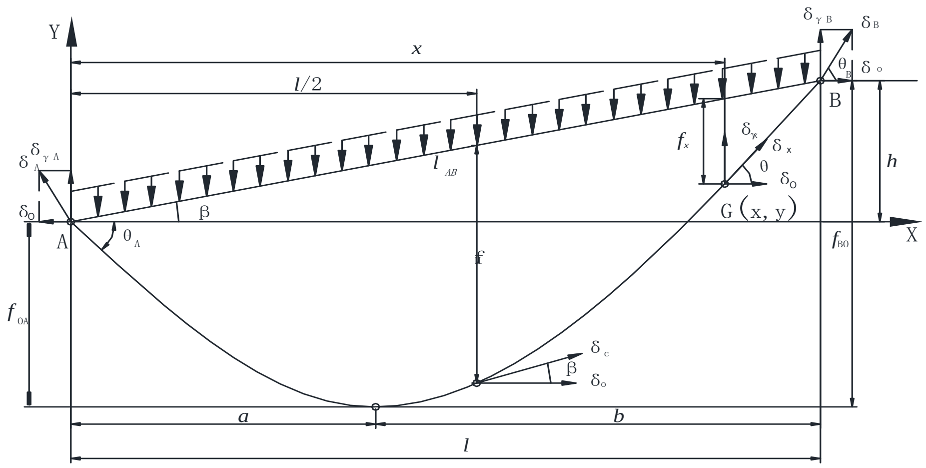

Figure.1 Force diagrams of parabola approximation for the transmission line

We can get any point on the wire $G(x, y)$ whose torque balance equation

$$\begin{cases} \delta_o y + \delta_{\gamma x} x - (\dfrac{x}{\cos\beta}\gamma)\dfrac{x}{2} = 0 \\ \delta_o h + \delta_{\gamma A} l - (\dfrac{l}{\cos\beta}\gamma)\dfrac{l}{2} = 0 \end{cases} \tag{7}$$

Where δ_o is wire at the lowest point of the horizontal stress,(N/mm^2); $\delta_{\gamma A}$ is the hanging point A wire axial stress δ_A of Vertical component (N/mm^2);l is span,(m);h is suspension point height difference,(m).

Possible solutions to the above equation wires were hanging curve equation

$$y = \frac{\gamma x^2}{2\delta_o \cos\beta} + (\frac{h}{l} - \frac{\gamma l}{2\delta_o \cos\beta})x \tag{8}$$

The formula (8) called Transmission Lines "inclined parabolic equation.By this equation, we can get overhead transmission lines on the road at any point in the stress formula:

$$\delta_x = \frac{\delta_o}{\cos\beta} + \gamma(y - y_{l/2}) \quad \text{(N/mm}^2\text{)} \tag{9}$$

Line length between the two suspension points formula is

$$L = \frac{l}{\cos\beta} + \frac{\gamma^2 l^3 \cos\beta}{24\delta_o^{\,2}} = \frac{l}{\cos\beta} + \frac{\gamma^2 l^3}{24\delta_c^{\,2}\cos\beta} \tag{10}$$

The Equation of States of Overhead Transmission Lines

Assuming the transmission lines without tension length of ΔL_0 meters, manufactured when the temperature is t_0, the elastic modulus is E, The temperature coefficient of expansion is α , When the temperature was raised to t Power lines under axial tensile stress δ .The length of the transmission line ΔL_0 becomes ΔL .Force and temperature as n segments progressively loaded applied to the transmission line by elastic deformation of the Hu-Ke law and linear temperature elongation can write formula after loaded transmission line wire length.

$$\Delta L = \Delta L_0 \left(1 + \frac{\delta}{En}\right)^n \left[1 + \frac{\alpha(t - t_0)}{n}\right]^n \tag{11}$$

So show (11) into a series and find the approximate value

$$\Delta L \approx \Delta L_0 \left(1 - \frac{\delta}{E}\right)[1 - \alpha(t - t_0)]$$

$$\approx \Delta L_0 - \frac{\delta}{E}\Delta L_0 - \alpha(t - t_0)\Delta L_0 \tag{12}$$

Integrating (12) along the entire file

$$L_0 = \int_0^L \Delta L_0 = L\left[1 - \frac{\frac{1}{L}\int_0^L \delta_x dL}{E} - \alpha(t - t_0)\right] = L\left[1 - \frac{\delta_{av}}{E} - \alpha(t - t_0)\right] \tag{13}$$

When the geometric length has been a state where two different meteorological fixed in the power transmission lines within the same file, then the two different states were transformed to the same initial state obtained when the two transformed the line length should be equal. We therefore established according to the basic principles of the basic equation of state of the transmission line conductors.

Suppose L_0 is the original line length of the transmission lines in the stall, the manufacturing temperature t_0 and there is no force. L_1 is the length of the state I (The parameters of the transmission line where the plane is l_1, h_1, t_1, γ_1, δ_1, δ_{av1}); L_2 is the length of the state Ⅱ (The parameters of the transmission line where the plane is l_2, h_2, t_2, γ_2, δ_2, δ_{av2}). Relationship of the A and B using the above formula can be listed

$$L_1\left[1 - \frac{\delta_{av1}}{E} - \alpha(t_1 - t_0)\right] = L_2\left[1 - \frac{\delta_{av2}}{E} - \alpha(t_2 - t_0)\right] \tag{14}$$

Above is the original line length setting basic equation of state generally, we can get the suspension point contour oblique parabolic equation of state

$$\left(\frac{l_1}{\cos\beta_1} + \frac{\gamma_1^2 l_1^3 \cos\beta_1}{24\delta_1^2}\right)\left[1 - \frac{1}{E}\left(\frac{\delta_1}{\cos\beta_1} + \frac{\gamma_1^2 l_1^2}{24\delta_1 \cos\beta_1}\right) - \alpha(t_1 - t_0)\right]$$

$$= \left(\frac{l_2}{\cos\beta_2} + \frac{\gamma_2^2 l_2^3 \cos\beta_2}{24\delta_2^2}\right)\left[1 - \frac{1}{E}\left(\frac{\delta_2}{\cos\beta_2} + \frac{\gamma_2^2 l_2^2}{24\delta_2 \cos\beta_2}\right) - \alpha(t_2 - t_0)\right] \tag{15}$$

Where δ_1, δ_2 is the stress of two states in the lowest point in the transmission line plane, N/mm2; l_1, l_2 is span within the plane of the two states under the power lines, m; L_{01}, L_{02} is the length of the two states, m; β_1, β_2 is height difference between the transmission line plane suspension points in the two states, t_1, t_2 is the temperature of the transmission line two states.

Inclined parabolic equation of state can eventually be simplified finishing in no wind conditions

$$\delta_{02} - \frac{E\gamma_2^2 l^3 \cos^3\beta}{24\delta_{02}^{\ 2}} = \delta_{01} - \frac{E\gamma_1^2 l^3 \cos^3\beta}{24\delta_{01}^{\ 2}} - \alpha E\cos\beta(t_2 - t_1) \tag{16}$$

In formula δ_{01}, δ_{02} respectively for the two states under the lowest point of the horizontal stress of the Transmission Line.

Example of Ice Load Algorithm

Above introduced overhead transmission lines inclined parabolic equation and the formula of long lines, stress and so on. On this basis, we will be examples to illustrate the overhead transmission lines overlying ice load algorithms.

Example: the span of transmission lines is l=200 m, Suspension height difference of points h=0 m, Transmission line materials is ACSR, Comprehensive cross-sectional area A=425.24 mm^2, The outside diameter of the wire D=26.82 mm, Transmission line horizontal stress in the standard state δ_0=53.955 N/mm^2, The transmission lines elasticity coefficient E=65000 N/mm^2, Transmission wire manufacturing temperature t_1=40 ^{o}C, Integrated temperature linear expansion coefficient a=0.0000205 (1/^{o}C), γ_o =0.0311 N/m.mm^2 , Transmission lines to ensure calculated breaking force T_b =98700 (N), Ambient temperature t_2 =-50 ^{o}C, Carrier type coefficient C=1, (Assumed than upload, height difference, span in the same plane). To establish coordinate system in accordance with the above requirements, in this coordinate system to measure the coordinates of the point on the transmission line.We can obtain the following set of data on the Table 1.

Table 1 .Coordinate data

X(m)	0	20	40	60	80	100	120	140	160	180	200
Y(mm)	0	0.9	1.6	2.1	2.4	2.5	2.4	2.1	1.6	0.9	0

According to the above parameters and data in the Table 1 to calculate the ice thickness of transmission wires, power lines, and the total load of ice.

Solution of the Relevant Data before Freezing

By a section on the inclined parabolic equation for the transmission line is:

$$y = \frac{\gamma x^2}{2\delta_o\cos\beta} + (\frac{h}{l} - \frac{\gamma l}{2\delta_o\cos\beta})x$$

All parameters will now into can calculate parabolic equation:

$$y = 0.000288205x^2 - 0.057641x$$

Transmission wire before the ice load is set to G_o, According to the definition:

$$G_o = L_o\gamma_o A$$

Where L_o line length without ice, by a section on the line length formula is:

$$L_o = \frac{l}{\cos\beta} + \frac{\gamma_o^{\ 2} l^3\cos\beta}{24\delta_o^{\ 2}}$$

Lead to the related parameters of transmission line before freeze and line length can be calculated out:

$$L_o = 200.1107 \text{ mm}$$

Then lead L_o, γ_o, A in to the load calculation formula can get out transmission lines before freeze.

$$G_o = 2646.46\text{N}$$

The Data Related to Solve When Frozen Transmission Lines

Now the hypothesis of transmission line after the ice is that elongation of the frozen transmission conductor can be neglected comparing with its linear elastic.So, we will regard the frozen power lines comparing with the original wire just as that load ratio change and other parameters constant. Now the original wire load ratio is called γ_0. Transmission line load ratio after freezing is called γ.The curve fitting of transmission line state is shown in Figure.2.

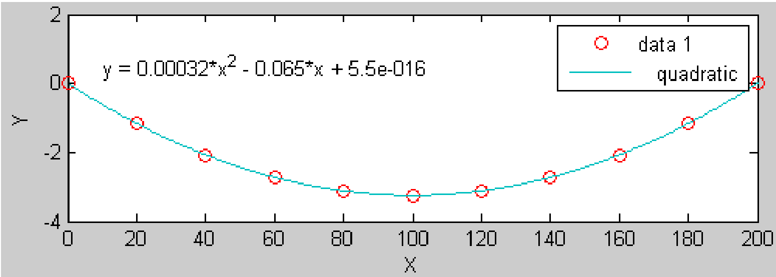

Figure.2 The curve fitting of transmission line states

Get the equation

$$\text{y} = 0.00026x^2 - 0.052x$$

Make the comparison with inclined parabola equation of transmission line, we can get

$$\frac{\gamma}{\delta} = 0.00052$$

To calculate the thickness will need state change equation of inclined parabola form:

$$\delta_{02} - \frac{E\gamma_2^2 l^3 \cos^3\beta}{24\delta_{02}{}^2} = \delta_{01} - \frac{E\gamma_1^2 l^3 \cos^3\beta}{24\delta_{01}{}^2} - \alpha E\cos\beta(t_2 - t_1)$$

To transpose deformation can be obtained:

$$\delta = \delta_0 - \frac{E\gamma_0^2 l^3 \cos^3\beta}{24\delta_0{}^2} - \alpha E\cos\beta(t_2 - t_1) + \frac{E\gamma^2 l^3 \cos^3\beta}{24\delta^2}$$

Known parameters of wire into type can get:

$$\delta = 106.78 \text{ N/mm}$$

$$\gamma = 0.0551 \text{ N/m.mm}^2$$

You can calculate the ice thickness:

$$b = \frac{\sqrt{\frac{A(\gamma - \gamma_o)}{0.006932} + D^2} - D}{2}$$

Take the above data to get the ice thickness: b=9.92mm
The total load of transmission lines and ice is:

$$G = L(\gamma_o A + 0.9 \times \pi \times g \times b \times (b + D) \times 10^{-3})$$
$$= 4668.02N$$

Conclusion

In this paper, the curve equation, state equation and related formula were got through analyzing the stress of the overhead wires. Combination of the line ice mechanism and climate environment parameters, the relation of the line of ice load with the state of the transmission line is obtained .It proposed providing a theoretical basis for detection algorithm on transmission lines ice load.In the end, the process of ice load calculation is given by an example in detail and verifies the correctness of the algorithm.

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