ISSN 2616-5880 Vol. 4, Issue 1: 19-24, DOI: 10.25236/AJMC.2023.040104

Inflection point temperature characteristics of carbon fiber composite core conductors

Lv Zhonghua[1], Li Dongxue[1], Zhang Ji[1], Yang Feng[2], Wang Yao[2], Lv Ming[1]

[1]State Grid Liaoning Electric Power CO, LTD., Power Electric Research Institute, Shenyang, 110015, China
[2]School of Energy and Mechanical Engineering, Shanghai University of Electric Power, Shanghai, 201306, China

Abstract: *Carbon fiber composite core conductor is a new construction, which is new overhead transmission times the capacity of the conductor. Transmission line times the capacity of the transformation project has great potential for exploration, but due to the short time put into actual operation, the research is relatively weak, and cannot accurately assess its characteristics, therefor resulting in the further promotion of carbon fiber conductor application is limited. In this paper, based on the geographical characteristics of carbon fiber conductors in actual operation, a set of" inflection point temperature" model for carbon fiber conductors is built, measuring the stall distance L, height difference angle β and initial temperature t0 of carbon fiber composite core conductor. So based on the stall distance L, height difference angle β and initial temperature t0 to calculate the carbon fiber composite core conductors, the theoretical basis at the inflection point temperature, which is for the further study of the arc sag characteristics of the multi-capacity conductor can be made.*

Keywords: *carbon fiber composite core conductor; doubled capacity conductor; inflection point temperature; arc sag*

1. Introduction

In recent years, with the rapid development of China's economy, the demand for electricity is growing, the transmission capacity of existing lines is difficult to meet the needs of the growing load, overload problems may lead to power outages and power outages, so there is an urgent need to increase the capacity of existing lines to alleviate the contradiction between power supply and demand. The use of carbon fiber composite core conductor (ACCC, Figure 1) to replace the traditional steel-core aluminum stranded wire (ACSR) is one of the measures to increase the capacity of China's transmission lines, carbon fiber composite core conductor has a series of performance advantages such as light weight, high strength, high load capacity, high temperature resistance, low arc droop [1-2]. However, as the carbon fiber composite core has relatively poor torsion, bending and radial pressure resistance properties, the requirements for construction are relatively high, which requires more precise calculations before construction [3]. Traditional steel-core aluminum stranded wire normal working temperature of only 70 ℃ ~ 80 ℃ and the coefficient of thermal expansion of the steel core and aluminum alloy wire difference is small, so in the steel core aluminum stranded wire work when the steel core and aluminum alloy wire at the same time under stress, but the carbon fiber composite core wire normal working temperature can reach 200 ℃,when the working temperature rises, and because of the carbon fiber core and aluminum alloy wire thermal expansion coefficient difference is large, so in the carbon fiber composite core wire working temperature rises, there will be a safety hazard, the field is in urgent need of non-contact measurement of the inflection point temperature [4].

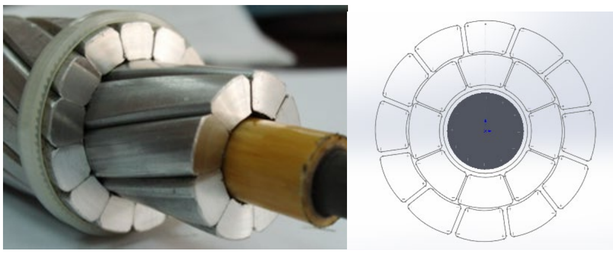

Figure 1: Physical drawing and cross-section of carbon fiber composite core conductor

ISSN 2616-5880 Vol. 4, Issue 1: 19-24, DOI: 10.25236/AJMC.2023.040104

2. Calculation model for carbon fiber composite core conductors

Because of the wire rigidity relative to the geometry of the suspension has very little effect, the wire can be assumed to be a flexible suspension line, according to the suspension line equation can be more accurate to get the wire arc droop, but the suspension line equation involves hyperbolic function, the calculation of complex is not easy to apply, engineering usually use parabolic to simplify the calculation [5-8]. In this paper, in the case of considering the horizontal file distance [9], adding the influence of the height difference between the two towers, such as Figure 2, that is, in the oblique file distance, the wire will be approximated as an oblique parabola, at the midpoint of C is the maximum arc at the point C is subject to tension for T_0, according to the maximum arc and line length calculation formula within the oblique file distance as follows:

$$f_{\mathrm{m}} = \frac{ql^2}{8T\cos\beta} \tag{1}$$

$$L = \frac{l}{\cos\beta} + \frac{q^2 l^3 \cos\beta}{24TA} \tag{2}$$

where:

f_{m}—is the wire radius, m;

L—is the length of the composite core wire ,m;

l—for the file distance ,m;

q—is the wire load，N/m;

T—is the horizontal tension at the lowest point of the wire, N;

β—is the height difference angle;

A—is the wire cross-section,mm^2。

It is known from existing experience that the wire is subjected to different loads under different meteorological conditions, coupled with changes in operating temperature, both of which can cause the wire length to change, thus causing a change in tension and arc sag. By (2) formula calculated from the known file within the carbon fiber composite core wire length L, minus the elastic elongation of the wire and the temperature elongation of the wire can be obtained file within the carbon fiber composite core wire initial length L_0, such as formula(3):

$$L_0 = L - \frac{T}{EA} - \alpha\left(t - t_0\right) \tag{3}$$

Assuming that the wire tension T_1 is known under certain operating conditions, and since the initial wire length of the wire is constant, equation (4) can be obtained.

$$L_1 - \frac{T_1}{EA} - \alpha\left(t_1 - t_0\right) = L_2 - \frac{T_2}{EA} - \alpha\left(t_2 - t_0\right) = L_0 \tag{4}$$

The previous equation is then brought into equation (4) separately to simplify to obtain the following equation.:

$$T_2 = T_1 - \frac{EAp_1^2 l^2 \cos^3\theta}{24T_1^2} + \alpha Et_1 A\cos\theta + \frac{EAp_2^2 l^2 \cos^3\theta}{24T_2^2} - \alpha Et_2 A\cos\theta \tag{5}$$

The equation (5) is generally referred to as the equation of state of the wire, that is the use of Newton's iterative method or discriminant method in the case of known tension T_1, to obtain the tension to be sought T_2, and thus to obtain the maximum arc of the wire f_{m}. It can be seen from the analysis that the correct calculation of the arc of the carbon fiber wire is not simply the calculation of the size of the tension, the key is to calculate the temperature of its inflection point and its corresponding tension size.

ISSN 2616-5880 Vol. 4, Issue 1: 19-24, DOI: 10.25236/AJMC.2023.040104

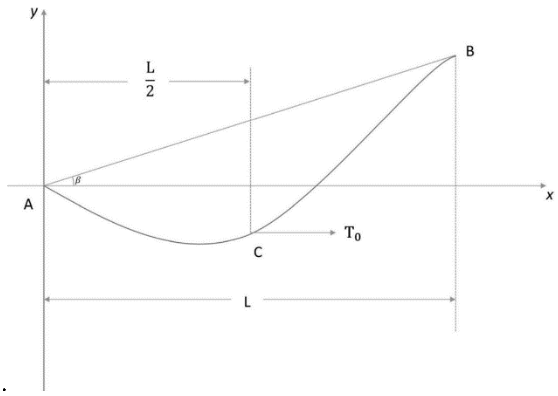

Figure 2: Schematic diagram of the erection status of carbon fiber composite core wire

3. Conductor inflection point temperature calculation

3.1 Analysis of inflection point temperature

The overhead transmission conductor is generally composed of two parts, the internal load-bearing core and the external conductive strand. Therefore, for any kind of overhead transmission wire, due to the different properties of the material, the linear expansion coefficient of the material has a certain difference. When the conductor works, the ampacity increases, resulting in the temperature of the wire, which will aggravate the increase in the length difference between the inner core wire and the outer strand, resulting in the gradual reduction of the force of the outer conductive strand, when the wire heats up to a certain temperature, the force of the external strand is basically zero, at this time the overall load of the wire is borne by the internal core, and the wire temperature at this moment is the "inflection point temperature". Compared with the traditional steel core aluminum stranded wire, the force is always borne by the steel core and the aluminum stranded wire, so there is no need to consider the influence of the inflection point temperature on the operating state. However, for carbon fiber composite core wire, its long-term allowable operating temperature is above 150 °C, according to existing experience, all tension of carbon fiber composite core wire during operation is borne by the composite core, that is, the operating temperature of the wire is above the inflection point temperature. Because the calculation of wire tension and arc sag of carbon fiber composite core above the inflection point temperature is quite different from the calculation of traditional wire, the key to correctly calculating the arc sag value of carbon fiber composite core wire is to calculate the corresponding tension after finding its inflection point temperature.

The inflection point temperature measured by the actual test of the arc sag characteristics will have a greater impact on the inflection point temperature due to the change of gear spacing, which will cause a large error, and it is very difficult and complex to obtain the inflection point temperature of the wire by experimental measurement at any gear spacing, in order to simplify the difficulty of line construction and subsequent scientific research, this paper does not consider the plastic creep deformation of the wire and the influence of core wire twisting on stress, and keep the elastic modulus of the wire unchanged[10]。 Then the elongation of the composite core wire is equal to the elongation of the carbon fiber core and the elongation of the aluminum alloy wire to obtain the following equation:

$$\Delta L = \Delta L_a = \Delta L_i \tag{6}$$

Under the premise of not considering the weather, the temperature rise of the lead leads to fullness and the wires are restrained by tension ΔL ΔL_a ΔL_i:

$$\Delta L = \frac{\sigma}{E} + \alpha\left(t - t_0\right) \tag{7}$$

$$\Delta L_a = \frac{\sigma_a}{E_a} + \alpha_a\left(t - t_0\right) \tag{8}$$

$$\Delta L_i = \frac{\sigma_i}{E_i} + \alpha_i\left(t - t_0\right) \tag{9}$$

ISSN 2616-5880 Vol. 4, Issue 1: 19-24, DOI: 10.25236/AJMC.2023.040104

where:

ΔL 、 ΔL_a 、 ΔL_i —Elongation for composite core wires, aluminum alloy wires and carbon fiber cores respectively，m；

σ 、 σ_a 、 σ_i —Stress for conductors, aluminum alloy wires and carbon fiber composite cores, respectively

E 、 E_a 、 E_i —Modulus of elasticity of the wire, aluminum alloy wire and carbon fiber composite cores, respectively.

α 、 α_a 、 α_i —Coefficients of thermal expansion for conductors, aluminum alloy wires and carbon fiber composite cores, respectively.

t 、 t_0 —Represents the current temperature and the initial temperature;

From the above simultaneous equation, take (7) and (8) and simplify:

$$\sigma_{\mathrm{a}} = \left[+ \left(\alpha - \alpha_a \right) \left(\mathrm{t} - \mathrm{t}_0 \right) \right] \cdot \mathrm{E}_a \tag{10}$$

From the above simultaneous equation, (7) and (9) are reduced to:

$$\sigma_i = \left[+ \left(\alpha - \alpha_i \right) \left(t - t_0 \right) \right] \cdot E_i \tag{11}$$

The above (10) and (11) formulae indicate the magnitude of the stress on the aluminum alloy wire and the carbon fiber composite core respectively, when the temperature reaches the inflection point temperature, as the aluminum alloy wire is no longer under stress, it can be obtained, simplified to obtain (12) for the relationship between the inflection point temperature and the inflection point temperature is the tension at the maximum point of the arc pendant.

$$t_c = \frac{T_C}{EA\left(\alpha_a - \alpha \right)} + t_0 \tag{12}$$

where:

T_C —is the tension of the wire at the maximum point of the arc sag at the inflection point temperature;

A— is the cross-sectional area.

The initial wire length and the change in elongation of the wire in any state are added together to equal the wire length at this time, and then the wire length L_m at the maximum tension of the wire is the sum of the initial length of the wire and the total elongation of the elastic and thermal expansion ΔL_m, and the wire length L_c at the inflection point temperature is the sum of the initial length of the wire and the total elongation of the elastic and thermal expansion ΔL_c, based on the above relationship you can invert the initial wire length, you can get the following equation.

$$\mathrm{L_m} - \mathrm{L_c} = \Delta \mathrm{L_m} - \Delta \mathrm{L_c} \tag{13}$$

Expanding the above equation (13) according to the calculation method of line length and elongation yields the following equation:

$$\left(\frac{L}{\cos\beta_m} - \frac{L}{\cos\beta_c} \right) + \left(\frac{q_{\mathrm{m}}^2 L^3 \cos\beta_m}{24{T_m}^2} - \frac{q_{\mathrm{c}}^2 L^3 \cos\beta_c}{24T_{\mathrm{c}}^2} \right) = \left[\frac{T_m - T_C}{EA} + \alpha\left(t_m - t_c \right) \right] \cdot L \tag{14}$$

And because the transmission line in the actual engineering use of the arc sag is small, arc sag and the ratio of file distance is generally only within a few percent, file transmission line length is only about a few thousandths of a percent growth than the distance between the suspension point, so the maximum tension in the wire and the temperature α of the inflection point to do the same, so the simplification (9) has.

ISSN 2616-5880 Vol. 4, Issue 1: 19-24, DOI: 10.25236/AJMC.2023.040104

$$\frac{T_C^3}{EA}+\left[\frac{L^2 q_m \cos\beta}{24{T_m}^2}-\frac{T_m}{EA}+\alpha\left(t_c-t_m\right)\right]{T_C}^2-\frac{L^2\cos\beta}{24}{q_c}^2=0 \tag{15}$$

Eq. (15) also expresses the relationship between T_c and t_c, bringing Equation (12) into it:

$$\frac{\alpha_a}{\alpha_a-\alpha}{T_c}^3+\left[\frac{L^2 q_m EA\cos\beta}{24{T_m}^2}-T_m+\alpha EA\left(t_0-t_m\right)\right]{T_C}^2=\frac{L^2\cos\beta}{24}{q_c}^2 EA \tag{16}$$

Eq. (16) is a one-dimensional cubic equation with respect to T_c Further simplification of (16) gives:

$$T_C^3+\left[\frac{L^2 q_m EA\cos\beta}{24{T_m}^2}-T_m+\alpha EA\left(t_0-t_m\right)\right]\left(\frac{\alpha_a-\alpha}{\alpha_a}\right)T_C^2=\frac{L^2\cos\beta}{24}{q_c}^2 EA\left(\frac{\alpha_a-\alpha}{\alpha_a}\right) \tag{17}$$

Namely:

$$\mathrm{T_C^3}+\mathrm{K}\mathrm{T_C^2}+\mathrm{N}=0 \tag{18}$$

Of which:

$$\begin{cases}\mathrm{K}=\left[\dfrac{L^2 q_m EA\cos\beta}{24T_m^2}-T_m+\alpha EA\left(t_0-t_m\right)\right]\left(\dfrac{\alpha_a-\alpha}{\alpha_a}\right)\\ N=-\dfrac{L^2\cos\beta}{24}q_c^2 EA\left(\dfrac{\alpha_a-\alpha}{\alpha_a}\right)\end{cases}$$

In this case, if it is at a flat gear pitch, the angle β is taken to be 0 degrees. The unknown in the equation, T_c, can be found by programming the Newtonian approximation iteratively, and then the temperature t_c and tension T_c at the point of inflection can be obtained. This method removes the restriction on finding the inflection point temperature to the position of the pitch and can be used to calculate the inflection point temperature for both diagonal and flat pitches.

3.2 Analysis of example parameters

For equation (18) as described previously in an example, the conversion relationship between tensio n Tc and inflection point temperature is as follows.

$$\begin{cases}\mathrm{T}_{c1}=\sqrt[3]{-\dfrac{K}{2}+\sqrt{\left(\dfrac{K}{2}\right)^2+\left(\dfrac{N}{3}\right)^3}}+\sqrt[3]{-\dfrac{K}{2}-\sqrt{\left(\dfrac{K}{2}\right)^2+\left(\dfrac{N}{3}\right)^3}}\\ \mathrm{T}_{c2}=\omega\sqrt[3]{-\dfrac{K}{2}+\sqrt{\left(\dfrac{K}{2}\right)^2+\left(\dfrac{N}{3}\right)^3}}+\omega^2\sqrt[3]{-\dfrac{K}{2}-\sqrt{\left(\dfrac{K}{2}\right)^2+\left(\dfrac{N}{3}\right)^3}}\\ \mathrm{T}_{c3}=\omega^2\sqrt[3]{-\dfrac{K}{2}+\sqrt{\left(\dfrac{K}{2}\right)^2+\left(\dfrac{N}{3}\right)^3}}+\omega^3\sqrt[3]{-\dfrac{K}{2}-\sqrt{\left(\dfrac{K}{2}\right)^2+\left(\dfrac{N}{3}\right)^3}}\end{cases}$$

Of which: $\omega=\dfrac{-1+\sqrt{3}i}{2}$

The conversion relationship between tension and inflection point temperature is obtained in practice by solving a cubic equation for Tc, as all other values are known constants, and after obtaining Tc the final inflection point temperature t0 is obtained.

ISSN 2616-5880 Vol. 4, Issue 1: 19-24, DOI: 10.25236/AJMC.2023.040104

4. Conclusion

In this paper, after combining the characteristics of carbon fiber composite core conductors, the height difference between two suspension points at the same pitch is considered on the basis of the horizontal pitch, which in terms of the height difference angle β. parabolic formula is used to introduce the calculation method of "inflection point temperature", and calculation model is built for carbon fiber composite core conductors. In practical engineering or experimental use, the calculation no longer limited to the flat or sloping pitch, but only requires the measurement of the actual height difference angle at the site, which can then be brought into the formula to obtain the inflection point temperature according to the actual situation. By optimizing the calculation of the inflection point temperature, the calculation of the arc pitch of the conductor can be made more accurate and provide a reference method for subsequent researchers.

References

[1] Alawar A ,Bosze E J ,Nutt S R . A composite core conductor for low sag at high temperatures[J]. IEEE Transactions on Power Delivery, 2005, 20(3):2193-2199.

[2] Y.Z. Ju, Q.C. Li, Y.N. Meng. A comparative study of carbon fiber composite core conductors and conventional conductors[J]. East China Electric Power 2011, 39(7):4.

[3] C.Y. Shen, F.H. Yin, X. Yan, et al. Research on the arc sag characteristics of stranded carbon fiber composite core conductors[J]. Power Grid Technology,2021(012):045.

[4] H.X. Wei. Preparation and characterization of carbon fiber composite wire cores[D]. Shandong University, 2010.

[5] C.G. Yao, L. Zhang, C. X. Li, et al. A method for measuring ice thickness of conductors based on mechanical analysis and arc sag measurement[J]. High Voltage Technology,2013, 39(5):6.

[6] L.M. Wang, B.Q. Sun, R. Hou et al. Fault calculation analysis and improvement measures for 500kV compact lines in North China[J]. High Voltage Technology, 2009(9):6.

[7] H. Cai. Design and application of heat resistant aluminum alloy conductors with aluminum clad steel cores[J]. Non-ferrous metallurgy design and research,2021, 42(5):5.

[8] H. Cai, B.Y. Zhu, X.X. Lu. Study on the performance and application of two types of capacitance-enhancing conductors[J]. Jiangxi Electric Power, 2021, 45(8):5.

[9] Y.L. Zhang. Analysis and calculation of tension arc sag characteristics of multiplied capacity conductors[J]. Power Construction, 2006, 27(9):3.

[10] G.Z. Wang, H.S. Huang. Calculation of stress and arc sag in energy-saving expanded conductors[J]. Wire and Cable,2009(5):4.