Research on probability estimation of critical threshold kernel density of icing tension for transmission lines with different tower types

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Abstract. Tension sensor plays an important role in anti-icing work of transmission line, but in the process of back calculating ice thickness, it needs to accurately calculate important parameters such as vertical span, horizontal stress and vertical load, which leads to cumbersome work procedures. Therefore, in this paper, the wavelet decomposition algorithm is used to correct the tension value during non-icing period. The results show that the modified tension value can effectively improve the accuracy of icing thickness calculation by 28.88%; secondly, the pulling force values under the conditions of icing ratio of 0.3 and 0.5 are calculated. Finally, the kernel density function is used to give the thresholds of issuing ice melting warning and starting ice melting pulling force for the straight-line tower and tension tower lines. The conclusion of this paper is simple and accurate.

1. Introduction
Due to the unique micro terrain conditions in Southwest China, many local microclimate regions are formed, and the probability of extreme low temperature and freezing rain events in these microclimate regions in winter is much higher than that in other regions[1-2]. At the same time, due to the influence of "quasi static front", Southwest China will suffer serious transmission line icing events every winter, which poses a serious threat to the stable supply of power energy.

In order to deal with ice covered events of transmission lines, in recent years, the power department has installed online monitoring equipment, and its components include: tension measurement sensor, micro meteorological sensor, video, etc[3-4]. Through real-time measurement of transmission line icing tension value and real-time observation of on-site icing situation by video technology, the real situation of line icing can be grasped from a macro perspective. Although the advanced technology and equipment are well used in the anti-icing work of transmission lines, there are still some shortcomings. For example, the inversion calculation of the line icing thickness by the measured tensile force requires accurate calculation of the line vertical span under different icing thickness conditions; secondly, it is necessary to calculate the vertical load and horizontal stress according to the change characteristics of vertical span based on the state equation; finally, the equivalent icing thickness of the line is calculated[5]. It can be seen that the accurate calculation of line icing thickness by tension value needs to ensure the accurate calculation of important variables such as vertical span, vertical load and horizontal stress.

Therefore, based on the measured value of direct transmission line tension, this paper calculates the critical threshold of tension when the line releases ice melting warning and starts ice melting. Through
multi sample data and combining with kernel density function, the distribution law of critical threshold of tension of transmission lines with different tower types and different voltage levels is studied. It can effectively overcome the shortage of reverse calculation of icing thickness by using pull value to issue line icing warning. The conclusion of this paper can effectively improve the accuracy of ice melting early warning.

2. Materials and Methods

Fig.1 shows the overall technical route of this study. The tension values of each on-line monitoring terminal without icing are collected, and the horizontal specific load and vertical load of the tangent tower and tension tower are calculated respectively. These two parameters are taken as the reference values for solving the equation of state of the two tower types. Therefore, according to the known reference values, the equation of state can be used, the parameters of horizontal specific load and vertical load under any icing condition are solved.

In order to study the critical threshold of pulling force when releasing line ice melting warning and starting ice melting through pulling force value, according to the advance specification of electric power department, the conditions of releasing line ice melting warning and starting ice melting icing ratio during icing period are 0.3 and 0.5 respectively, where the icing ratio is the ratio of equivalent icing thickness (density is 0.9g / cm$^3$) to design ice thickness.

In this paper, the horizontal specific load and vertical load of the line under the conditions of icing ratio of 0.3 and 0.5 are calculated respectively, and the corresponding tension value of the straight tower and tension tower under the conditions of meeting the two icing ratios is obtained. For the straight tower, because the insulator is set perpendicular to the ground, only the calculated vertical load is the tension value; for the tension tower insulator string is not perpendicular to the ground, so it is necessary to calculate the horizontal specific load and vertical load resultant force, which is the tension value of the tension tower. Finally, the kernel density function is used to analyse a large number of sample data to find the distribution law of critical early warning value of tension for different tower types.
In the research work of this paper, firstly, wavelet decomposition algorithm is used to modify the tension monitoring value of icing monitoring terminal\(^6\):

\[
\psi_{a,b}(t) = \frac{1}{\sqrt{a}} \psi \left( \frac{t-b}{a} \right) \quad a, b \in \mathbb{R}, a > 0
\]

In formula (1), \(a\) is the scaling factor, \(b\) is the translation factor. In this paper, wavelet decomposition is used to correct the tension value, as shown in Fig.2:

Fig.1. General research technical routes.

Fig.2. Technical process of tension correction based on wavelet decomposition algorithm.
the calculation formula for the condition of releasing the early warning of ice melting and starting
the ratio of ice melting to icing is as follows:

\[ \beta = \frac{f}{s} \] (2)

In formula (2), \( f \) is the actual equivalent icing thickness of the line, \( s \) is the design ice thickness for lines.

The solution expression of line state equation is [7]:

\[ g\beta^3 + \left( -F_y + \frac{f^2 g^2 E}{24 F_y} \cos^2 \beta \right) + \]

\[ aE(t - t) \cos \beta g\beta^2 - \frac{f^2 g^2 E}{24} \cos^2 \beta = 0 \] (3)

In formula (3), \( gi \) is the horizontal stress to be calculated under the condition of different icing ratio, \( F_y \), \( fb \) are the horizontal stress and vertical load calculated under the condition of no icing.

In this paper, the kernel density function is used to analyze a large number of sample data to find the distribution law of critical early warning value of tension for different tower types. The theoretical calculation model is [8]:

\[ p = \frac{1}{n \Delta l} \sum_{i=1}^{n} k \left( \frac{x - x_i}{\Delta l} \right) \] (4)

In formula (4), \( n \) is the number of research samples, in this paper, the value is 410, \( \Delta l \) is a window function, \( x_i \) is the corresponding pull value of each sample terminal under the condition of different icing ratio.

3. Results & Discussion

In the research of this paper, the accuracy of the final conclusion depends on the accuracy of the tensile measurement value to a large extent. According to the actual situation, because the tension sensor is installed on the conductor, it is affected by extreme environment such as low temperature and high temperature for a long time, which leads to a definite error in the real-time tensile value. Therefore, before the research and analysis, the tension value needs to be corrected, in this paper, wavelet transform is used to denoise the tensile value and eliminate the abnormal value[8], so as to ensure the accuracy of the basic calculation data.

Fig.3 shows the change trend of tension value during the period of no icing at a certain terminal. It can be seen that the fluctuation range of tension value is large. According to the actual situation, during the period of no icing, the transmission line is mainly affected by the wind force, and the tension value should fluctuate in a small area. As shown in the figure, the difference between the maximum and minimum tension values in the sampling period is 72kg, if the data of abnormal pull value is not preprocessed, there will be a large error in the calculated pull threshold of icing warning.

![Fig.3. Variation trend of tensile force during non-icing period.](image-url)
Therefore, this paper uses wavelet transform algorithm to decompose the tension value data with multi-layer wavelet basis function, and determines the wavelet basis function to be selected according to the signal-to-noise ratio calculated by different wavelet basis functions, so as to effectively realize the correction of tension value. Through calculation, when db6 wavelet basis function is used, the maximum signal-to-noise ratio is 16.12dB, which shows that the pull value denoising effect is the best. Therefore, this paper uses the basis function to preprocess the tension value data.

Fig.4 shows the comparison results between the tension value before and after correction and the real value. It can be seen that the icing thickness calculated by the tension value after wavelet decomposition is close to the real situation. The relative errors between the icing thickness calculated by the tension value before and after correction and the real value are 13.58% and 42.46% respectively. It can be seen that the corrected tension value can effectively improve the accuracy of icing thickness calculation by 28.88%.

For the straight tower, this paper gives the ice melting warning and starting ice melting pull value according to the different design ice thickness. Fig.5 shows the ratio of the pull value corresponding to the ice free pull value under the condition of 0.3 icing ratio of 700 sets of icing monitoring terminal lines when the design ice thickness is 20 mm. It can be seen that the distribution of pull ratio is relatively concentrated, ranging from 1 to 3, and 92% of the pull ratio is between 1 and 1.5, which indicates that for the line with a design ice thickness of 20 mm, when the pull value is 1-1.5 times greater than the ice free pull value during icing, it is necessary to issue ice melting warning.
Based on the above calculation results, this paper uses the same method to calculate the ratio of tension value to non-ice tension value under the condition of icing ratio 0.5, and then uses the kernel density function to calculate the probability distribution of tension ratio. Fig.6 shows the probability distribution of tension ratio under different icing ratios. It can be seen that when the tension value is 1.56-1.8 times of non-ice tension value, it is necessary to start ice melting, It is effective for 93.36% samples.

Fig. 6. Probability distribution of pull ratio under different icing ratios.

Similarly, for the 10 mm design ice thick line, when the pull value is 1.1-1.3 times of the non-ice pull value, it is necessary to issue the line ice melting warning; When the pull value is 1.265-1.495 times of the non-ice pull value, it is necessary to start ice melting. For 15mm design ice thick lines, when the pull value is 1.2-1.35 times and 1.44-1.62 times of the non-ice pull value respectively, it is necessary to issue ice melting warning and start ice melting. For 30mm ice thick lines, when the pull value is 1.3-1.6 times and 1.76-2.16 times of the non-ice pull value respectively, it is necessary to issue ice melting warning and start ice melting. For 40mm ice thick line, when the pull value is 1.5-2.5 times and 2.18-3.63 times of the non-ice pull value, it is necessary to issue ice melting warning and start ice melting.

For the tension tower, according to the range of different design ice thickness and maximum equivalent length, the values of ice melting warning and starting ice melting pulling force are given, as shown in Table 1. It can be seen from tab.1 that when the design ice thickness of the line is 20 mm, the equivalent length is greater than 500 m, and the calculated pull value is 3 times of that without icing, the ice melting warning needs to be issued; when the calculated pull value is 3.6 times of that without icing, the ice melting needs to be started.

Table 1. Early warning of ice melting on tension tower line and threshold of starting ice melting pulling force.

| Design ice thickness (mm) | Equivalent length (m) | Ice melting warning | Start ice melting |
|--------------------------|-----------------------|--------------------|-------------------|
| 10, 15                   | >2000                 | 2                  | 2.3               |
|                          | 1000-2000             | 3                  | 3.45              |
|                          | <1000                 | 4.5                | 5.2               |
| 20                       | >500                  | 3                  | 3.6               |
|                          | <500                  | 4.5                | 5.4               |
| 30, 40                   | >1000                 | 3.5                | 4.6               |
|                          | <1000                 | 5.5                | 7.2               |

4. Conclusions
In view of the shortcomings of the current research on anti icing of transmission lines, this paper uses the tension monitoring value to calculate the icing thickness of transmission lines. Firstly, the wavelet decomposition algorithm is used to correct the tension sampling value. Secondly, the corresponding tension values under the conditions of line icing ratio of 0.3 and 0.5 are calculated according to the line
state equation, finally 410 sample data are taken as an example to study the distribution of critical tension threshold of transmission lines with different tower types and voltage levels by using kernel density function. The main results are as follows: when DB6 wavelet basis function is used, the effect of tension value denoising is the best; the relative errors between the calculated ice thickness and the real value before and after the tension value correction are 13.58% and 42.46%, respectively. The corrected tension value can effectively improve the accuracy of ice thickness calculation by 28.88%; the pull ratio of different tower type lines when issuing ice melting warning and starting ice melting is given.

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