Research on Transmission Line Icing Tower Broken Fault Probability Calculation Model

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Abstract. Icing in winter is an important disaster that affects the normal operation of transmission lines. Among them, icing is easy to lead to tower collapse and disconnection. Due to long recovery time, great economic loss and social impact, it poses an important threat to the stable operation and reliable power supply of power grid. At present, the research on ice covered tower breaking fault of transmission lines mainly focuses on the finite element simulation analysis and calculation or exponential function fitting calculation. Due to the complexity of the mechanism of transmission line icing tower breakage, the current physical mechanism research conclusion cannot explain the occurrence of icing tower breakage. The existing analysis methods cannot accurately describe the characteristics of transmission line icing tower broken fault probability. Therefore, this paper proposes a probability calculation model based on probability distribution statistics, which can quantitatively calculate the failure probability of transmission line icing tower breakage. It has important theoretical significance and practical application value to provide scientific basis for transmission line to deal with icing disaster in advance.

1. Introduction

Icing in winter is an important disaster affecting the normal operation of transmission lines. In 2008, southern China suffered the most serious ice disaster in history, among which Hunan power grid suffered the most severe loss. In the process of the ice disaster in Hunan power grid, the loss caused by the broken tower fault is the largest, 409 lines of 500kV transmission lines and 1077 lines of 220kV lines are iced and broken. The direct economic loss is more than 10 billion yuan. At the same time, in recent years, with the global extreme climate change, there are dozens of icing tower broken accidents in 220kV and above transmission lines. The recovery time is long, economic loss and social impact are great after the tower broken, which poses an important threat to the stable operation and reliable power supply of power grid.

At present, the research on ice covered tower breaking fault of transmission lines mainly focuses on the finite element simulation analysis and calculation or exponential function fitting calculation. Zhao et al. [2], Li et al. [3], Yao et al. [4], Du et al. [5], Jia et al. [6] used finite element analysis to analyze and calculate the stress conditions of tower and conductor under icing conditions. Zhu et al. [7], Xie et al. [8], Huang et al. [9] used exponential function to fit the failure probability of ice covered tower line break. It fails to reflect the probability distribution characteristics of transmission line icing tower
breakage. The existing methods are mainly used for anti-icing design of transmission lines and post analysis of ice covered tower breaking.
However, due to the complex mechanism of transmission line icing tower breakage, the current physical mechanism research conclusion still cannot explain the occurrence of icing tower broken. It is a probability event that the transmission line is iced and the tower is broken. The existing finite element analysis method or exponential function fitting method cannot accurately describe the characteristics of transmission line icing tower broken fault probability. Therefore, this paper proposes a probability calculation model based on probability distribution statistics, which can quantitatively calculate the failure probability of transmission line icing tower breakage. It has important theoretical significance and practical application value to provide scientific basis for transmission line to deal with icing disaster in advance.

2. Calculation Model of Transmission Line Icing Tower Broken Fault Probability

2.1. Analysis of Influencing Factors of Transmission Line Icing Tower Breaking
Under the condition of icing, when the icing reaches a certain degree and the external force such as wind force exceeds the design standard of transmission line, the tower collapse accident will occur. Therefore, the main factors affecting the transmission line icing tower breakage include: icing thickness, wind direction, transmission line anti icing strength and so on. This paper focuses on the modelling and analysis of these factors.

2.2. Calculation Model of Transmission Line Icing Tower Broken Fault Probability
Due to the random fluctuation of wind risk, ice accretion is accompanied by a series of changes such as melting, de-icing and sublimation. There is a probability change characteristic of transmission line icing tower breakage. The existing finite element analysis method or exponential function fitting method cannot accurately describe the characteristics of transmission line icing tower broken fault probability.
Therefore, this paper presents a calculation method for the probability of transmission line icing tower broken. The calculation flow is shown in Fig. 1, which is described as follows:

![Figure 1](image)

Figure 1. The flowchart for calculation of probability of transmission line icing tower broken.

(1) Establish the force calculation model of transmission line tower line
The finite element simulation model of tower line under icing condition is established. The stress distribution of tower line under different wind speed, angle between wind direction and conductor and
Icing thickness is calculated. It provides a basis for the calculation of the probability of line break of ice covered tower.

(2) Determination of ice resistance design strength of transmission line
According to the industry standard load code for overhead transmission lines (DL/T 5551-2018) [10], it is determined that: a) the design ice thickness in light ice area of transmission line is less than 10 mm, and the design wind speed is 10 m/s; b) the design ice thickness is 10-15 mm and the design wind speed is 10 m/s in moderate ice area; c) the design ice thickness is more than 20 mm and the design wind speed is 15 m/s in severe ice area. Therefore, the total design load of transmission line is determined. The design total load is used to characterize the design anti-icing wind load capacity of different types of transmission lines.

(3) Calculation of transmission line load rate under icing and wind
The ice thickness and wind speed of transmission lines in the past long series are counted, and the total load and load rate of different types of transmission lines under the conditions of icing, wind, and wind direction are calculated. The total load is divided by the total design load of transmission line to obtain the icing load rate of transmission line. The calculation formula [8] is as follows:

\[ R = \frac{f(T_{\text{ice}}, V_{\text{wind}}, \theta_{\text{wind}})}{S} \]  

where, \( R \) is the icing load rate of the transmission line, \( f(T_{\text{ice}}, V_{\text{wind}}, \theta_{\text{wind}}) \) is the total load of the transmission line calculated according to the model in step 1, \( T_{\text{ice}} \) is the given icing thickness, \( V_{\text{wind}} \) is the given wind force, \( \theta_{\text{wind}} \) is the angle between the given wind force and the transmission line, and \( S \) is the total design load of the transmission line calculated in step 2.

(4) Calculation of the probability distribution of ice covered tower breaking fault of transmission lines
Poisson distribution function is usually adopted to describe the distribution of transmission line fault probability in several former references [11, 12]. Therefore, the Poisson distribution function is used to fit and calculate the distribution of transmission line load strength and tower broken fault probability in our research. The Poisson distribution function is as follows:

\[ P(\text{ice fault}|R) = \frac{1}{1+e^{\beta R+\alpha}} \]  

where, \( R \) is the load rate of transmission line; \( \alpha \) and \( \beta \) are the two parameters of Poisson distribution function; \( P \) is the probability of line icing tower broken.

In order to calculate the parameters of Poisson distribution, the MCMC method [13-15] is employed to generate several samples of parameters, and then calculates the parameter distribution and probability distribution function.

(5) Calculation of failure probability of transmission line iced tower breaking
Given the icing thickness, wind speed and anti-icing strength, the ice wind load rate of transmission line under the condition is calculated, and then the fault probability of transmission line collapse tower and broken line can be obtained.

3. Case Study
Based on the data of icing tower breakage in a provincial power grid in recent ten years, the probability distribution of ice covered tower broken fault of transmission lines in the province is calculated, and the ice disaster process from January 24 to 29, 2018 is analyzed as an example. The details are as follows:

3.1. Establish the Force Simulation Model of Tower Line under Icing Condition
Based on COMSOL simulation platform, the finite element stress simulation model of tower line under icing condition is established, which can calculate the stress distribution of tower line under different wind speed, angle between wind direction and conductor, icing thickness, etc., which provides a simulation platform for calculating the fault probability of iced tower line breaking. The
following figure shows the force distribution results of tower line under the conditions of conductor icing of 10mm, wind force of 5m/s and angle between wind force and conductor of 90°. The figure 2 denotes that the maximum load strength is about $4.5 \times 10^9$ N/m².

![Force Distribution of Tower Line](image1)

**Figure 2.** Simulation results of tower line stress under icing condition.

3.2. **Determination of Ice Resistance Design Strength of Transmission Line**

According to the industry standard “load code for overhead transmission lines” (DL/T 5551-2018), combined with the calculation results of simulation calculation platform, the total design load of transmission line is determined.

3.3. **Calculation of Transmission Line Load Rate under Icing and Wind**

By Statistical analysis of transmission line icing thickness, wind speed and other observation data in the past 10 years, the transmission line load strength of each line is calculated. The line icing load rate is obtained by dividing the actual observed load by the total design load. The relationship between icing load rate and tower line breaking is shown as following figure 3. It can be noted that with the increase of load rate, the possibility of transmission line fault increases obviously.

![Rate-Icing Load vs Tower Breaking](image2)

**Figure 3.** Point map between icing load rate and tower line breaking.

3.4. **Calculation of the Probability Distribution of Ice Covered Tower Breaking Fault of Lines**

Poisson distribution is used to calculate the distribution of transmission line load strength and tower broken fault probability. Combined with MCMC method, the probability distribution of transmission line icing tower broken fault is calculated as shown in the figure 4. It can be seen from the figure that Poisson distribution function can well describe the characteristics of icing fault probability of transmission lines.
3.5. Calculation of Failure Probability of Transmission Line Iced Tower Breaking

According to the numerical prediction results of power grid micro topography icing, it was predicted in advance on January 22, 2018 that 500kV Line A and line B, 220kV line C, D, E, F and other lines from January 25 to 29 were seriously iced. The line parameters and icing growth are as Table 1 and figure 5.

Table 1. Icing growth forecast results of transmission lines.

| Icing line      | Predicted value of icing thickness / mm |
|-----------------|----------------------------------------|
|                 | 24h(January 25th) | 48h(January 26th) | 96h(January 27th) | 144h(January 28th) | 192h(January 29th) |
| 500kV line A    | 4.4                  | 8.8                | 12.7              | 16.1              | 22                 |
| 500kV line B    | 4.8                  | 9.6                | 13.9              | 17.7              | 20.8               |
| 220kV line C    | 5                    | 10                 | 14.5              | 18.5              | 21.5               |
| 220kV line D    | 4.6                  | 9.2                | 13.3              | 16.9              | 20                 |
| 220kV line E    | 5                    | 10                 | 14.5              | 18.5              | 21.5               |
| 220kV line F    | 3.6                  | 5.5                | 9                 | 11                | 17.8               |

According to the icing prediction data, the curve of transmission line failure probability with time in the future 192h is calculated as shown in the figure 5. The solid line in the figure represents the fault probability curve. The results in figure 5 show that the failure probability of transmission lines increases rapidly after 48 hours.

Figure 4. Probability distribution of transmission line icing tower broken fault.

Figure 5. Variation of icing fault probability of transmission line.
According to the prediction results, ice melting measures were taken in advance, which effectively avoided the accident of tower collapse and line break.

4. Conclusion
This paper analyzes the key influencing factors of transmission line icing tower breakage, and puts forward the calculation model of transmission line icing tower broken fault probability distribution, which can effectively describe the probability distribution characteristics of transmission line icing tower breakage, and quantitatively calculate the fault probability of transmission line icing tower broken line. The practical application shows that the calculation results are consistent with the actual situation. It provides scientific basis for transmission line to deal with icing disaster in advance.

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