Research on Multi-Factor Ice Disaster Risk Evaluation Model for Transmission Line

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Abstract. With the development of the transmission line scale and the improvement of the voltage level, the height and span of the tower are increasing, and the ice disaster occurs frequently in some areas, which has become an important factor affecting the security and stability of the power grid. Based on the analysis of the ice and ice flashover mechanism, this paper firstly discusses ice disaster influencing factors from three main angles, such as the potential fault of transmission line, operation and maintenance characteristics and meteorological conditions, and then uses multi factor classification method to build the ice disaster risk evaluation model for transmission line. Further, taking the 220kV and above transmission lines in a certain area of South China as a research object, this paper evaluates all the lines and towers ice disaster risk, obtains the lines or towers with high risk level using the model, and the evaluation results have been verified on site. Finally, combined with the rating of risk evaluation factors, this paper formulates a special anti-icing measure to ensure the safe and stable operation of transmission lines.

1. Introduction

In recent years, with the development of the transmission line scale and the improvement of the voltage level, the height and span of the tower are increasing. Under extreme weather conditions, the ice load on transmission towers and power lines is increasing. The ice on transmission line will lead to the mechanical and electrical performance of the channel decline sharply, which will further cause the occurrence of ice disasters, such as conductor galloping, insulator flashover, tower collapse and others[1].

Compared with other natural disasters, the loss of power grid caused by ice disaster is very serious. Transmission line icing is a complex process affected by micro topography, micro meteorology and climate factors. Furthermore, ice disaster often occurs under the bad weather conditions. And it leads to the transmission line maintenance becomes more and more difficult, causes long-term shutdown of power system, and even causes devastating damage to local power grid, which will affect people’s production and life[2].

In order to improve the ability of the power grid to resist the ice disaster, this paper analyses the mechanism of the ice disaster in-depth. Firstly, the paper discusses ice disaster influencing factors from three main angles, such as the potential fault of transmission line, operation and maintenance characteristics and meteorological conditions, and builds an ice disaster evaluation model using the multi factor classification method for transmission lines; then, taking all 220kV and above lines in a
province as an example, using the evaluation model to obtain the lines and towers with high ice risk level. Finally, combining with the scores of various factors, this paper formulates a special anti-icing measure to ensure the safe and stable operation of transmission lines[3].

2. Analysis of icing mechanism
For transmission lines, when the ice thickness and weight reach a certain degree, it will form a huge load pressure on tower, conductor, ground wire, insulator and other key lines. With the unbalanced tension caused by conductor galloping and ice covering falling off, the transmission line is easy to cause pole fall, tower fall, wire break and other ice disasters. The mechanism of transmission line icing includes three different aspects:

2.1. The thermodynamic equilibrium mechanism of transmission line icing
The icing process is a physical process in which the liquid supercooled water drops impinge on the conductor surface to release latent heat and solidify, which is closely related to heat exchange and transfer. The quality, thickness and density of the ice depend on the heat balance of its surface.

2.2. Hydrodynamics mechanism of transmission line icing
The icing process is a friction and collision process between the supercooled water droplets in the air and the conductor surface, which is related to the ambient temperature, the content of liquid water in the air, the diameter of supercooled water, the wind speed and direction, the freezing coefficient, the water droplet capture coefficient, the ice thickness and the ice weight[4].

2.3. The coupling mechanism of current and electric field with environmental factors of transmission line icing.
For the high-voltage transmission line, not only the thermal effect of the current on the conductor thermal balance, but also the different electric field intensity has a complex influence on the movement track of the polar supercooled water drop near the conductor, which further has an effect on the structure and shape of the transmission line icing.

Transmission line icing is determined by meteorological conditions, which is a comprehensive physical phenomenon determined by temperature, humidity, convection of warm and cold air, circulation, wind and other factors. In China, transmission line icing mainly occurs in southwest, northwest and central China. In southwest China, especially in Guizhou province, the average temperature is almost all higher than 0℃, but influenced by Siberian cold current and Pacific warm current, rime appears every winter. The average number of rime days is 3-15 days. The short-term rime icing has a huge impact on the power system[5].

The research shows that the necessary conditions of transmission line icing include three points:
- Freezing temperature below 0 ℃.
- The relative humidity of air is above 85%.
- The wind speed is greater than 1 m/s.

In addition to meteorological factors, topography and geography also affect the formation of transmission line icing. In winter, the transmission line icing of windward slope is more serious than leeward slope. Besides, the transmission line icing in the watershed or tuyere is more serious than other terrain. Because of sufficient water vapor, the impact of river water on transmission line icing is also obvious. At the same time, the status of transmission lines also has an impact on ice disaster, for example, the aging defects of devices often become the outbreak point of ice disaster.

3. Building the evaluation model of ice disaster risk
This paper makes an in-depth analysis on the ice disaster factors for transmission line from three main angles: the potential fault of transmission line, operation and maintenance characteristics and meteorological conditions. And then grasps the internal relationship between the disaster occurrence probability and the disaster causing factors. Based on this, finally, builds the evaluation model of
transmission line ice disaster by adopting multi-factor classification scoring method, as shown in the
figure below[6-7]. The evaluation model of transmission line icing disaster is shown in Figure 1.

![Evaluation model of transmission line icing disaster](image)

Figure 1. Evaluation model of transmission line icing disaster

The evaluation model is divided into three layers, from the bottom layer to the top layer is data
resources layer, evaluation model layer, alarm and countermeasure layer. The data resources layer
provides basic data support for the evaluation model layer. The evaluation mode layer classifies and
scores the disaster causing factors to get the evaluation results of ice disaster. The alarm and
countermeasure layer gives the risk level alarm and prevention measures according to the single and
comprehensive points deduction, provide auxiliary decision-making suggestions for the manager.

### 3.1. Evaluation factors of ice disaster

According to the analysis of transmission line ice disaster mechanism in chapter 2, the disaster
evaluation factors are divided into three categories: potential fault, operation and maintenance
characteristics and meteorological conditions[8].

**Potential fault**: If there are historical fault cases of transmission lines, the possibility of secondary
fault will be increased. The fault types closely related to icing fault include: ice flash trip fault,
broken or broken string fault, tower deformation fault, tower tilt fault.

**Operation and maintenance characteristics**: In areas with similar meteorological conditions, the
probability of ice disaster is related to the operation characteristic. The operation characteristic of the
line in the icing disaster factors include: anti-icing line, weak anti-icing section, state evaluation
conclusion, line reinforcement, ice area, icing data, icing warning device.

**Meteorological conditions**: In the evaluation of transmission line icing disaster, we mainly analyse
five factors from meteorological server: forecast of freezing disaster, temperature, humidity, rainfall,
wind speed.

### 3.2. Ice disaster evaluation method

The evaluation model of transmission line ice disaster risk is based on the risk evaluation results of
single tower. The ice disaster risk evaluation result of icing disaster comes from the multi factor
comprehensive score evaluation. The weight factor is introduced into the evaluation algorithm, which makes the model more adaptive[9]. The evaluation is calculated as follows:

\[ S = A_1 + A_2 + A_3 \]

(1)

\( S \) - total score deduction of target tower.
\( A_1 \) - Cumulative points deducted for the category of hidden trouble of the target tower.
\( A_2 \) - Cumulative points deducted for the category of operation characteristic of the target tower.
\( A_3 \) - Cumulative points deducted for the category of climate and environment of the target tower.

\[ A_i = \sum_{j=1}^{n} \omega_j \times B_j, i = 1,2,3 \]

(2)

\( \omega_j \) - Using the improved entropy weight analytic hierarchy process to determine the weight of disaster evaluation factor \( A \).
\( B_j \) - The deduction points of disaster evaluation factor \( B_j \). The statistics of points deduction rules is shown in Figure 2.
\( n \) - number of bottom layer disaster factors \( j \) under disaster factor \( i \).

Figure 2. Hierarchy diagram of evaluation factors of transmission line icing disaster

In this paper, the improved entropy weight analytic hierarchy process is used to analyse the disaster factors, hidden trouble, operation characteristic, climate and environment fault hidden dangers, operation and maintenance characteristics and climate change weight factors, as shown in the following table:

In this paper, the improved entropy weight analytic hierarchy process is used to analyse disaster factors. The weight factors of hidden trouble, operation characteristic, climate and environment are shown in Table 1:
Table 1. Weight table of disaster factors A

| Factor weight | Category of hidden trouble | Category of operation characteristic | Category of climate and environment |
|---------------|-----------------------------|-------------------------------------|-------------------------------------|
| \( \omega_l \) | 0.3                         | 0.3                                 | 0.4                                 |

Through the analysis of the evaluation model of ice disaster, the weight of each bottom disaster factor \( B_j \) is assigned, as shown in Table 2, and the comprehensive evaluation value can be calculated by the accumulation method.

Table 2. Deduction rules of ice disaster factors \( B_j \)

| Evaluation factors of icing \( B_j \) | Scoring basis | Deduct points |
|---------------------------------------|---------------|---------------|
| Ice flash trip fault \( B_1 \)       | Ice flash trip Fault history | 1             |
| Broken or broken string fault \( B_2 \) | Broken or broken string Fault history | 3             |
| Tower deformation fault \( B_3 \)    | Tower deformation Fault history | 3             |
| Tower tilt fault \( B_4 \)           | Tower tilt fault history | 3             |
| Anti-icing line \( B_5 \)            | Whether it is an important anti-icing line | 2             |
| Weak anti-icing section \( B_6 \)    | Historical ice cover ratio over 1.0 | 2             |
| State evaluation conclusion \( B_7 \) | Whether the state evaluation conclusion is abnormal | 3             |
| Line reinforcement \( B_8 \)         | Whether the line is reinforced | -3            |
| Ice area \( B_9 \)                   | Ice area with ice thickness is between 10-20 mm | 2             |
|                                    | Ice area with ice thickness is greater than 20 mm | 3             |
| Icing data \( B_{10} \)              | The maximum icing ratio is 0.3-0.4 (including 0.4) | 3             |
|                                    | The maximum icing ratio is 0.4-0.5 (including 0.5) | 4             |
|                                    | The maximum icing ratio is greater than 0.5 | 5             |
| Icing warning device \( B_{11} \)    | Tension change value is within 500 | 1             |
|                                    | Tensile force change value is beyond 500 | 3             |
| Forecast of freezing disaster \( B_{12} \) | Meteorological freezing level is 1 | 1             |
|                                    | Meteorological freezing level is 2 | 3             |
|                                    | Meteorological freezing level is 3 | 3             |
|                                    | Meteorological freezing level is 4 | 5             |
|                                    | Meteorological freezing level is 5 | 5             |
| Temperature \( B_{13} \)             | -3-0 degrees | 1             |
|                                    | -5—3 degrees | 2             |
|                                    | Less than - 8 degrees | 3             |
| Humidity \( B_{14} \)                | 40%-60%      | 1             |
|                                    | 60%-80%      | 2             |
|                                    | More than 80% | 3             |
| Rainfall \( B_{15} \)                | Less than 38.3mm | 3             |
|                                    | More than 38.3mm | 2             |
| Wind speed \( B_{16} \)              | Less than 3m/s | 1             |

According to the above evaluation calculation formula 1 and 2, the evaluation value of the target tower is obtained. The evaluation result is divided into four grades (normal state, attention state, abnormal state and serious state). The reference values of each grade are divided as shown in Table 3.

Table 3. Evaluation state table

| Number | Assessment result  | Score range |
|--------|--------------------|-------------|
| 1      | Normal state       | 0~5         |
| 2      | Attention state    | 6~11        |
3 Abnormal state 12–15
4 Serious state More than 16

4. Case analysis and results
In this paper, the evaluation model is used to evaluate the 220kV and above voltage level transmission lines in 2019. It is found that the freezing index of the location of a line #015 tower is level 3, with 3 points deducted; the temperature of the tower is -1.4 ℃, with 2 points deducted; the humidity is 98.0%, with more than 80% warning line, with 3 points deducted; the line is not reinforced, with 3 points deducted. In the comprehensive evaluation, 12 points will be deducted in total and 3 points will be deducted in maximum, and the disaster evaluation grade is abnormal. The project team inquired the ice covering trip fault record. At 11:02 on February 19, 2019, due to the line ice melting, the sag decreased, and the trip was caused by the insufficient distance between phase A and phase B, which was consistent with the evaluation results.

According to the countermeasure rules, it is found that the lowest temperature of the tower in the next three days is -1.4 ℃, -1.4 ℃ and -1.4 ℃, respectively, and the freezing prediction level is maintained at Level 3. Therefore, the short-term decision-making suggestions are put forward: strengthen patrol inspection, conduct line ice melting if necessary[10], and arrange personnel to stay and monitor if the phenomenon of ice coating increases. Long term decision-making suggestions: introduce ice melting device and improve emergency management mechanism.

5. Conclusions
This paper makes an in-depth analysis on the mechanism of ice disaster, designs a multi-factor ice disaster evaluation model, completes the case analysis with good effect and high accuracy, and develops short-term and long-term special anti-ice measures to ensure the safe and stable operation of transmission lines.

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