Research on Wind Disaster Risk Assessment of Transmission and Distribution Lines

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Abstract. Based on the 10-year wind speed data, geographic data and grid data of Fujian Province, a wind disaster model of transmission and distribution lines including disaster-causing factor, disaster-embedded environment, disaster-bearing body and anti-disaster capability, is established. The geographical information system (GIS) technology is used to vectorize the wind disaster risk index of the transmission and distribution lines, and the distribution map of the wind disaster risk index based on the map of Fujian Province is obtained. The results show that the risk of wind disasters from coastal to inland is gradually decreasing. The risks from Fuzhou to Ningde and Xiamen to Quanzhou are the highest, and the maximum disaster index is 0.69 in Fuzhou.

Introduction

Global climate change has increased the intensity and frequency of typhoons. Economic losses caused by typhoons increase year by year in coastal areas, and the power grid in coastal areas also becomes vulnerable to disasters. For a long time, the typhoon has brought significant losses to the coastal power grid, accompanied by strong winds and rainstorms, as well as a series of disasters such as floods, landslides and debris flows, causing a large number of transmission and distribution line towers to be broken and tilted, leading to a large area of line failure[1,2,3,4,5]. Line trip data of various provinces and cities in coastal areas of China show that line failure caused by typhoon disaster has accounted for more than 20% of the total number of trip, which seriously affects the safe and stable operation of power grid[6]. In 2016, “Meranti” and “Megi” typhoon caused 11 trips of 500 kV lines, 51 trips of 220 kV lines, 109 trips of 110 kV lines, 4246 trips on 10 kV lines, and 5640 broken base in Fujian Power Grid. The "Meranti" typhoon caused historic damage to the 7-base 500 kV towers and the 15-base 220 kV towers.

At present, China's defense focus on meteorological disasters remains on the development of public early warning products, such as: near-surface wind field forecasting, construction of typhoon monitoring and forecasting system, development of typhoon disaster emergency system in heaven and earth, and analysis of impact factors of typhoon comprehensive disasters. There is still a lack of meteorological warning products for the power industry, and the power meteorological technology is still in the initial stage of development[6,7,8,9]. In the past ten years, the domestic scholars have carried out some research on typhoon warning methods for transmission and distribution lines[10]. Fujian Electric Power Company, East China Power Grid Corporation, Shandong Electric Power Company and other coastal network power companies have successively built grid typhoon disaster warning platforms[11,12,13]. The grid is usually connected to the typhoon forecast path and the wind circle range, and carried out safety warning for the line in the wind circle of the grid geographic information system. Some studies also considered the wind-resistant design parameters of the line tower.

However, the fault mechanism of transmission and distribution lines under typhoon is very complex, and the warning method must take into account the wind and rain spatial and temporal distribution, geographical environment characteristics, transmission and distribution line design and engineering practice. The current warning methods and models lack systematic description of typhoon disaster chain of transmission and distribution lines, which leads to the obvious lack of
pertinence and effectiveness of warning. Therefore, it is necessary to carry out research on typhoon and wind disaster technology for transmission and distribution lines.

**Data Description**

The basic data used in this paper include wind speed, topography, transmission and distribution line data of meteorological and power departments.

The meteorological data includes the maximum wind speed of Fujian provincial national meteorological station from 2006 to 2015, and the classification standard of maximum wind speed of the base center of the typhoon level of China meteorological administration. The wind speed that may affect the power grid are divided into four grades, and the frequency of each grade is calculated.

The topographic data includes the geographic coordinates, elevation and coastal distance of the location of the national meteorological station in Fujian Province. The geographic coordinates, elevation and coastal distance of each meteorological station are extracted by GIS, and then the topographical standard deviation of each site and the surrounding eight points is calculated. The degree of terrain fluctuation is represented by the standard deviation of the terrain.

The power grid data includes the 10kV public network lines in Fujian province and the repair and restoration time. From the more than 67,000 original fault data and GPMS grid database of Fujian Province in 2015, the 10kV public network line length, insulation rate, number of faults and repair time were extracted. The extracted grid data is mapped to each weather station for standardization processing.

**Wind Disaster Model of Transmission and Distribution Lines**

**Risk Assessment Method**

Wind disaster is a kind of natural disasters. The research on the risk of disasters depends on the natural attributes and needs to consider the disaster-causing factor and disaster-embedded environment. When a disaster occurs, the resilience depends on the rescue capability and risk prevention of the disaster site. Therefore, from the social level, it is necessary to consider the disaster-bearing body and anti-disaster capability.

The disaster-causing factor can be considered as the damage intensity and frequency caused by strong wind to lines, towers and stations. The sensitivity of disaster-embedded environment to the outside world mainly refers to the stimulation and inhibition of strong winds by different elevations, slopes and water system coverage. Vulnerability refers to the damage degree of lines and towers in the affected areas. Anti-disaster capability mainly refers to the capability of disaster prevention and recovery after disaster.

Based on the above theories, the wind disaster function of transmission and distribution lines can be expressed as:

\[
    \text{Hazard} = f(\text{Disaster-causing factor}, \text{Disaster-embedded environment}, \text{Disaster-bearing body}, \text{Anti-disaster ability})
\]

In the expression, the risk, sensitivity and vulnerability are directly proportional to the size of the risk, while the anti-disaster ability is inversely proportional to the size of the risk. In addition, due to the different effect intensity of each evaluation factor on the formation of disaster risk, different weights should be assigned to each factor. Therefore, the disaster risk index evaluation model can be expressed as:

\[
    T = (W_H \cdot V_H)(W_E \cdot V_E)(W_S \cdot V_S)(W_R \cdot (1 - V_R))
\]

Where, \( T \) represents the hazard index, \( V_H \) represents the risk index of the disaster-causing factor, \( V_E \) represents the sensitivity index of the disaster-embedded environment, \( V_S \) represents the vulnerability index of the disaster-bearing body, and \( V_R \) represents the index of anti-disaster ability.
Due to the differences in the units of the actual values of the evaluation indexes, in order to eliminate the differences in the order of magnitude and dimension of each index, the normalization processing should be carried out before calculation.

$W_H$, $W_E$, $W_S$, $W_R$ represent the weight of each evaluation factor respectively, and the value of which is from 0 to 1 and $|W_H| + |W_E| + |W_S| + |W_R| = 1$. Factor weights were obtained by the analytic hierarchy process, and expert opinions could be referred to appropriately. The greater the weight, the greater the impact of the index on the wind disaster. Figure 1 is a schematic diagram of the hazard formation principle of wind disaster that the formation of wind disaster mainly consists of four parts, including the hazard factor, the disaster-embedded environment, the disaster-bearing body and the anti-disaster ability.

![Figure 1. Principle of hazard formation.](image)

**Risk Assessment Model**

According to the theory of disaster formation and risk, the formation of wind disasters on transmission and distribution lines involves disaster-causing factor, disaster-embedded environment, disaster-bearing body and anti-disaster ability. The above factors are modeled respectively, where:

**Assessment model of disaster-causing factor:**

$V_H = W_{H1} \cdot V_{H1}$, where $V_{H1}$ is the normalized value of the maximum wind speed index and $W_{H1}$ is the weight of the maximum wind speed.

**Assessment model of disaster-embedded environment:**

$V_E = W_{E1} \cdot V_{E1} + W_{E2} \cdot V_{E2}$, where $V_{E1}$, $V_{E2}$ is expressed as the index normalization value of the topographic index and the coastal distance index respectively, $W_{E1}$, $W_{E2}$ is the corresponding weight.

**Assessment model of disaster-bearing body:**

$V_S = W_{S1} \cdot V_{S1}$, where $V_{S1}$ is the normalized value expressed as the overhead line, including the line length, the overhead insulation rate, and the number of annual failures, $W_{S1}$ is the corresponding weight.

**Assessment model of anti-disaster ability:**

$V_R = W_{R1} \cdot V_{R1}$, where $V_{R1}$ is the normalized value of the average repair and restoration time, $W_{R1}$ is the corresponding weight.
Calculation of Risk Index

**Identification of the Weight.** The weight of the four factors in the wind disasters risk of transmission and distribution lines is judged by the experts in advance to judge the relative importance of each index, and the average of the scores of the experts is taken. Then the judgment matrix is constructed, and the weight of the judgment matrix is calculated by the norm column average method. And the consistency test is carried out to check whether the judgment matrix has the consistency of satisfaction. If the consistency of the judgment matrix is not accepted, the matrix needs to be re-adjusted or constructed until the result is satisfactory. The weights are determined by the analytic hierarchy process, and the weight of the four factors are shown in Table 1.

<table>
<thead>
<tr>
<th>Disaster-causing factor($W_{d1}$)</th>
<th>Disaster-embedded environment($W_{e1}$)</th>
<th>Disaster-bearing body($W_{s1}$)</th>
<th>Anti-disaster ability($W_{r1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.34</td>
<td>0.27</td>
<td>0.29</td>
<td>0.10</td>
</tr>
</tbody>
</table>

**The factor Index.** The maximum wind speed grade that may affect the power grid is set to four, as shown in Table 2. The weight corresponding to each grade shall be the frequency of power grid failure corresponding to the disaster-causing factor in the case of this grade, and the classical weight grade coefficient in the disaster risk assessment is adopted. The frequency of each station in the corresponding grade is calculated and standardized. The risk index of disaster-causing factor is obtained according to the weight of the corresponding grade.

<table>
<thead>
<tr>
<th>Disaster-causing factor</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
<th>Level 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum wind speed (m/s)</td>
<td>17-25</td>
<td>25-32</td>
<td>32-41</td>
<td>&gt;41</td>
</tr>
<tr>
<td>Weight coefficient</td>
<td>1/10</td>
<td>2/10</td>
<td>3/10</td>
<td>4/10</td>
</tr>
</tbody>
</table>

The topographic index and the coastal distance index of the corresponding stations can be found by referring to table 3 and table 4. And the risk index of the disaster-embedded environment can be calculated by weighted synthesis.

<table>
<thead>
<tr>
<th>Elevation(m)</th>
<th>Topographic standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Level 1(≤1)</td>
</tr>
<tr>
<td>Level 1 (≤100)</td>
<td>0.9</td>
</tr>
<tr>
<td>Level 2 (100-300)</td>
<td>0.8</td>
</tr>
<tr>
<td>Level 3 (300-700)</td>
<td>0.7</td>
</tr>
<tr>
<td>Level 4 (≥700)</td>
<td>0.6</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>The Coastal distance (km)</th>
<th>Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10</td>
<td>1</td>
</tr>
<tr>
<td>10-50</td>
<td>0.75</td>
</tr>
<tr>
<td>50-100</td>
<td>0.5</td>
</tr>
<tr>
<td>100-150</td>
<td>0.35</td>
</tr>
<tr>
<td>150-200</td>
<td>0.2</td>
</tr>
<tr>
<td>200-300</td>
<td>0.1</td>
</tr>
</tbody>
</table>

The line index and secondary weight coefficient of the disaster-bearing body are shown in Table 4. According to the data processing, the length of the 10kV public network line, the insulation rate and the number of faults are standardized to obtain the risk index of transmission and distribution lines, and then the risk index of the disaster bearing body is calculated by weighted synthesis.
Table 5. The weight of disaster-bearing body.

<table>
<thead>
<tr>
<th>Disaster-bearing body factor</th>
<th>Line length(km)</th>
<th>Insulation rate(%)</th>
<th>Years of failures(Number)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight coefficient</td>
<td>1/3</td>
<td>1/3</td>
<td>1/3</td>
</tr>
</tbody>
</table>

The risk index of anti-disaster is obtained by standardizing the time of emergency repair and restoration, and the anti-disaster ability index is calculated by weighted comprehensive calculation.

In order to eliminate the influence of different orders of magnitude, all the data are processed by maximum standardization. \( P' = \frac{P - P_{\text{min}}}{P_{\text{max}} - P_{\text{min}}} \), Where, \( P' \) is the normalized value, \( P \) is the original value, \( P_{\text{max}} \) is the maximum value and \( P_{\text{min}} \) is the minimum value.

According to the above hazard model, weight distribution and risk index of each factor, the power grid risk index is calculated by weighted synthesis.

**Results of Wind Disaster Risk Assessment**

Based on GIS technology, the index of disaster-causing, disaster-embedded environment, disaster-bearing body and anti-disaster capability are converted into geographical data for annotation and displayed on the map. The wind disaster risk index of transmission and distribution lines is vectorized by GIS and transformed into spatial information data based on the map of Fujian province. The distribution of wind disaster risk index is shown in figure 2.

It can be seen from the figure that the overall wind disasters risk from coastal to inland is gradually decreasing. The risk from Fuzhou to Ningde and Xiamen to Quanzhou is the highest. The maximum disaster index is 0.69 in Fuzhou and the minimum disaster index is 0.22 in Sanming.

In combination with the four aspects of the impact of the wind disaster, the causes of the serious wind disasters in coastal areas are analyzed.

Firstly, coastal areas are often suffer from typhoon attacks positive influence is bigger. Then, the central part of Fujian are Mountains of Daiyun and Jiufeng, due to the coastal areas are mainly concentrated on the windward slope of the mountain range, it is easy to cause heavy precipitation under the effect of terrain uplift, and the greater the slope, the stronger the wind speed. The coastal area is close to the sea, the low terrain leads to high sensitivity to the environment of the disaster and the coastal area is relatively developed economy, the number of transmission and distribution lines is large, so the failure rate is relatively high, especially in Fuzhou. The failure rate in coastal developed areas is relatively high, resulting in relatively long repair time, and weakening the ability of anti- disaster.
Summary

(1) Based on the disaster chain of transmission and distribution lines, the wind disaster model of transmission and distribution lines was constructed based on the four aspects of disaster-causing factor, disaster-embedded environment, disaster-bearing body and anti-disaster capability.

(2) Based on GIS, the wind disaster risk distribution map of transmission and distribution lines is drawn. The results show that the coastal areas in the eastern of Fujian are very likely to cause strong winds, resulting in high risk of wind and disasters on transmission and distribution lines.

Acknowledgement

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References


