Research on Condition Assessment Method of Transmission Tower Under the Action of Strong Wind

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Abstract. Transmission towers are often subjected to the external damage of severe weather like strong wind and so on, which may cause the collapse due to the yield and fracture of the tower material. Aiming this issue, an assessment method was proposed in this paper to assess the operation condition of transmission towers under strong wind. With a reasonable assess index system established firstly, then the internal force of the tower material was solved and its stability was determined through the mechanical analysis of the transmission tower finite element model. Meanwhile, the condition risk level of the tower was finally determined by considering the difference among the influences of other factors like corrosion and loose of members, slope on the transmission tower through the analytic hierarchy process. The assessment method was applied to assess the wind-induced collapse of towers in 110kV BaoYi line in Wenchang City, Hainan Province, of which the result proves the method can assess the condition of transmission tower under strong wind and of guiding significance for improving the windproof capability of transmission towers.

1. Introduction

Recently, typhoon and other windstorm disaster weather frequently happened, which seriously affects the operation of transmission line located in coastal areas. According to incomplete statistics [1], more than 30 times failure of transmission line caused by typhoon happened in China's coastal areas since 2000, resulting in more than 100 collapses of tower and economic losses of nearly one billion RMB. Therefore, it is of great significance to improve the windproof capacity of transmission line by researching the condition assessment of transmission tower under strong wind, which can help master the safety level of towers and reinforce the windbreak weaknesses in the transmission line.

Banik [2] et al. consider the wind load factor, gust response factors and design wind speed three indicators, by drawing its wind resistance curve to assess the condition of the transmission tower under strong wind. The assessment items of the transmission tower in Guidelines for assessment of state of overhead transmission line[3] are comprehensively and finely divided, which is universal and adaptable. Guang-lin Yuan [4] et al. assessed the condition of transmission tower in mining subsidence area through the calculation of sink, tilt, curvature of single tower leg and comparison.
between the expected value and design allowable value of those three indexes. Additionally, Malhotra[5] et al. proposed a risk-based assessment method, by accumulating the different risk level caused by different wind speed which varies along the transmission line to conduct the risk assessment. Kai-quan Xia [6] et al. established a relatively complete assessment method for assessing condition of the transmission tower by using the analytic hierarchy process(AHP) to achieve the weight open calculation of assessment item and tower structure safety condition variable weight comprehensive calculation. Based on the fuzzy comprehensive assessment method, Hang Ji[7] proposed a quantitative assessment method combining the transmission line condition information with the fuzzy comprehensive assessment. Wei Duan[8] et al. proposed a method combining AHP and fuzzy comprehensive assessment to overcome the difficulty of quantifying the index in AHP and problem of neglecting the weight of the index in fuzzy comprehensive assessment.

The above researches are mostly from the perspective of line management and applied to the initial assessment of the transmission tower health condition, did not consider the effect of external load of strong wind and disaster weather on the operation condition of transmission line. Therefore, considering both factors mentioned above, the assessment items and index system including material, member, configuration and deformation of transmission tower were established with the safety of the transmission tower member under the strong wind assessed through the mechanical analysis. Meanwhile, the condition risk level of transmission tower was finally determined by considering the difference among the influences of other factors like corrosion and loose of members, slope on the transmission tower through AHP.

2. Establishment of assessment index system

The assessment index system includes three parts: assessment item, assessment standard and condition risk level of transmission tower:

2.1. Determination of assessment item

Select all the assessment items that affect the operation of the transmission tower under strong wind as shown in Figure 1, among them:

(1) Member: This item represents the stress of the transmission tower leg member, which is the most important factor that determines the safety of tower structure.

(2) Material: This item represents the shedding and corrosion situation of the galvanized layer of transmission tower members.

(3) Configuration: This item represents the loss of bolts and fittings at all connections on the transmission tower

(4) Deformation: This item represents the slope of transmission tower in vertical direction, a large slope of deformation will affect the foundation stability of the tower.

![Fig.1 Transmission tower condition assessment items](image)

2.2. Determination of assessment standard

The deterioration degree of the status of each assessment item can be converted to the parameters required for the assessment by using the assessment standard. The status is the general term of each technical indicator and operating condition of assessment items. For instance, the stress of the tower leg under the external strong wind is the status of the member item.
Table.1  Transmission tower condition assessment standard

| Assessment item | Status | Weight coefficient | Deterioration | Assessment standard | Basic deduction | Integrated deduction |
|-----------------|--------|---------------------|---------------|---------------------|----------------|----------------------|
| Material        | Corrosion degree | 1          | IV            | Most of the members are seriously rusty | 10             | 10                   |
|                 |        | II                   | III           | Large member of members are rusty | 8              | 8                    |
|                 |        |                      | II            | Small part of members are slightly rusty | 4              | 4                    |
| Member          | Stress of tower leg member | 4          | IV            | The stress is greater than the yield strength | 10             | 40                   |
|                 |        | III                  | III           | The stress is greater than the design strength but less than the yield strength | 8              | 32                   |
|                 |        |                      | II            | The stress is less than the design strength | 4              | 16                   |
| Configuration   | Loss and loose of members and bolts | 2          | IV            | More than 15% of the bolts are loose and a great loss in connection members | 10             | 20                   |
|                 |        | III                  | III           | 10%-15% of the bolts are loose and certain number of connections are lost | 8              | 16                   |
|                 |        |                      | II            | Less than 10% of the bolts are loose and a few loss in | 4              | 8                    |
| Deformation     | Slope of transmission tower | 1          | IV            | The ratio of top displacement to height is larger than 0.2 | 10             | 10                   |
|                 |        | III                  | III           | The ratio of top displacement to height is between 0.15 and 0.2 | 8              | 8                    |
|                 |        |                      | II            | The ratio of top displacement to height is between 0.1 and 0.15 | 4              | 4                    |

With reference to the provisions of the assessment standard in Guidelines for assessment of state of overhead transmission line[3], the status is divided into four grades with the coefficients are respectively 1, 2, 3, 4. Besides, select the standard for judging the deterioration degree of status and divide the deterioration into I, II, III, IV four levels according to the standard. Finally, the important parameter for the assessment of each item is calculated by multiplying the basic deduction points corresponding to the deterioration level by its weight coefficient. The status for each assessment item, standard for judging the deterioration degree and deduction points are listed in Table 1:

With reference to the accident level division of transmission tower in Regulations on Emergency Handling and Investigation of Electricity Safety Accidents [9], the transmission tower condition is divided into four risk levels according to the integrated deduction of each tower under the strong wind as shown in Table.2:

Table.2  Gradation of transmission tower condition under strong wind

| Integrated deduction | Condition level of transmission tower | Specific meaning of each condition level |
|----------------------|---------------------------------------|-----------------------------------------|
| >25                  | I                                     | Part of the status seriously exceed the standard value and the transmission line should immediately arrange for power outage |
|                      |                                       | Important status are close to or slightly above the standard value and the transmission line should be operated under monitor |
| 20-25                | II                                    | Part of the status are close to the standard value but the transmission line can continue |
| 15-20                | III                                   | All the status are within the warning value and the transmission line can be normally operated |
| <15                  | IV                                    | Part of the status are close to the standard value and the transmission line should immediately arrange for power outage |
|                      |                                       | Important status are close to or slightly above the standard value and the transmission line should be operated under monitor |
|                      |                                       | Part of the status are close to the standard value but the transmission line can continue |
|                      |                                       | All the status are within the warning value and the transmission line can be normally operated |
3. Establishment and solution of the assessment model

Based on AHP[10,11], with the difference of the influence of each item on the operation of transmission towers considered, the assessment model is established as shown in Figure 2. Meanwhile, combined with deterioration level of status in each assessment item, the model is solved as follows:

(1) Establish the judge matrix

\[ R = \begin{bmatrix}
1 & 1 & 1 & 1 \\
9 & 3 & 1 & 1 \\
9 & 1 & 7 & 9 \\
3 & 7 & 1 & 3 \\
1 & 7 & 1 & 3 \\
1 & 9 & 3 & 1 \\
\end{bmatrix} \]

By comparing the weight coefficient of four assessment item listed in Table.1, the relative importance of four items is judged and used to establish the judge matrix \( R \), size of which is 4×4, through the nine scale method.

(2) Solve the weight vector

The weight vector of the matrix \( R \) represents the weight coefficient of four items in the assessment model. By using the eigenvector method, the weight vector \( W \) is solved as \( W = (0.063, 0.7186, 0.1554, 0.063) \). Besides, the consistency of the solved vector should be checked according to the consistency formula of the judgment matrix as follows:

\[ CI = \frac{\lambda_{\text{max}} - n}{n - 1} \]

\[ CR = \frac{CI}{RI} \]

Where: \( n \) is the order of the matrix; \( \lambda_{\text{max}} \) is the maximum eigenvalue; \( RI \) is related to order \( n \); If \( CR \) is calculated less than 0.1, the consistency of the matrix is acceptable and can be used.

(3) Risk level of transmission tower under strong wind

According to formula (3), the integrated deduction of transmission tower can be calculated by multiplying the weight vector \( W \) by vector \( E \) consisting of the deduction of each assessment item. Then the risk level of transmission tower under strong wind can be judged with reference to the regulations listed in Table.2.

\[ R = WE^T = (0.063, 0.7186, 0.1554, 0.063) \]
4. Application of assessment methods

**Fig.3** Site picture of the wind-induced collapse of towers in Baoyi line II

On 15:00, July 18, 2014, typhoon Rammasun made a landfall in Wenchang City, Hainan Province, which caused numerous collapses of transmission towers. Figure 3 is the site picture of the wind-induced collapse of towers in Baoyi line II.

Taking the accident as the engineering background, the assessment method above is used to assess the collapsed tower. To ensure the accuracy of the assessment, combined with monitoring data of Rammasun at the location of Baoyi line II from 05:00 on July 18, 2014 to 03:00 on July 19, 2014, the wind speed and wind direction at Baoyi II line is drawn as Figure 4, in which the angle represents the angle between wind direction and east direction.

**Fig.4** Wind speed and direction diagram of Baoyi line II during typhoon Rammasun

Focusing on the predicated collapse time in Figure 4, which is inferred according to the relationship between the actual collapse direction and the typhoon wind direction, the collapse perhaps happened between 15:40 July 18th and 16:10 July 18th. During the predicated time, the angle between wind direction and transmission line is between 44° and 66° and the wind speed is 44.5m/s.

According to the analysis results above, the wind load on conductors, ground wires and tower body can be solved according to the corresponding formulas in Technical specification for tower structure design of overhead transmission line[12]. Then, apply the corresponding external wind load to the finite element model as shown in Figure 5 and solve the axial force of the tower leg member as listed in the following Table 3 and Table 4. Meanwhile, the axial stress of members on both windward side and leeward side are also calculated by using corresponding formulas in literature [12] with the material information listed in the following table. The stress are listed as follow: (The element on the windward side from bottom to top is 1、4、5、8、9、12)
windward $V_{10}$

Fig.5 Schematic diagram of applying load to the finite element model

Table.3 Stress of axial compressed members

| Element number | Axial tension force (kN) | Area (cm²) | Axial tension stress (MPa) |
|----------------|--------------------------|------------|---------------------------|
| 1, 4           | 223.63                   | 13.94      | 160.423                   |
| 5, 8           | 196.75                   | 13.94      | 141.141                   |
| 9, 12          | 184.72                   | 13.94      | 132.511                   |

Table.4 Stress of axial tension members

| Element number | Axial compression force (kN) | Area (cm²) | $\varphi$ | Axial compression stress (MPa) |
|----------------|-----------------------------|------------|-----------|--------------------------------|
| 2, 3           | 244.35                      | 13.94      | 0.399     | 439.32                         |
| 6, 7           | 214.18                      | 13.94      | 0.315     | 487.76                         |
| 10, 11         | 199.43                      | 13.94      | 0.315     | 454.17                         |

It can be seen from the results that the maximum axial compression stress of the tower leg members on the leeward side is 487.76 Mpa, which is beyond the yield strength of the material 345Mpa. Therefore, the deterioration level of the member item is IV and the deduction should be 40 according to the regulation in Table.1. Meanwhile, according the corrosion degree, loss and loose of members and bolts, slope of transmission tower obtained from the inspection records, the deterioration level of these three items are listed in Table.5:

Table.5 Deduction table of state quantities

| Assessment item | Weight coefficient of status | Deterioration | Deduction |
|-----------------|-----------------------------|---------------|-----------|
| Material        | 1                           | II            | 4         |
| Member          | 4                           | IV            | 40        |
| Configuration   | 2                           | III           | 16        |
| Deformation     | 1                           | III           | 8         |

It can be seen that $E=(4, 40, 16, 8)$ and the integrated deduction of transmission tower is calculated to be 31.986 by using formula (3). According to the regulation in Table.2, the transmission tower is in I level condition which means part of the status seriously exceed the standard value and serious accident is most likely happened. The assessment result is consistent with the actual collapse of the tower and the accuracy of the assessment method is verified.
5. Conclusion
In this paper, a method for assessing the condition risk level of transmission tower was established and applied to assess the wind-induced collapse of towers in 110kV BaoYi II line in Wenchang City, Hainan Province, of which the result proves the method can assess the condition of transmission tower under strong wind. The conclusions are drawn as follows:

1) The assessment index system is selected based on the consideration of all the factors that affect the operation condition of transmission towers, which reflects the theory of risk assessment.

2) The assessment model based on AHP fully considers the external load effect and the maintenance and operation factors of transmission towers under strong wind, which reflects the weight coefficient among different assessment items.

3) The assessment result of the wind-induced collapse in BaoYi II is consistent with the actual, which proves the method can accurately assess the condition of transmission tower under strong wind.

In general, the method can assess the condition level of transmission towers under strong wind and of guiding significance for improving the windproof capability of transmission towers.

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