Research on Wind Resistance and Monitoring Technology for Pole-line Structure in Transmission Lines

Hua Wang\textsuperscript{a}, Longlin Wang\textsuperscript{b}, Changxia Wu\textsuperscript{c}, Xi Peng\textsuperscript{d} and Litao Li\textsuperscript{e}

Guangxi Transportation Research & Consulting Co., LTD, Nanning 530007, China

\textsuperscript{a}wanghua15@mails.jlu.edu.cn, \textsuperscript{b}398908339@qq.com, \textsuperscript{c}283044416@qq.com, \textsuperscript{d}270158995@qq.com

Abstract. The research on wind resistance monitoring technology of typical cement pole-line structure in 10kv transmission line is carried out in view of the fact that the transmission lines in the coastal areas of South China are often threatened by typhoons. Firstly, a wind-resistant monitoring system for pole-line structures is established. Secondly, the method to determine the early warning value in the monitoring system is proposed and the whole finite element model of the pole-line is established. Then, the wind speed is transformed into wind load to determine the early warning value of wind speed according to the wind-pole fluid-solid coupling model. Finally, the correctness of the wind-resistant monitoring technology of the pole-line structure is verified by the results monitored by practical engineering. The research shows that the wind load on the surface of the conductor is non-uniform, which can be accurately calculated through the wind-pole fluid-solid coupling model; The structural response obtained by the whole finite element model of the pole-line structure can accurately reflect the actual stress state, which can be used to determine the early warning value of wind speed; The proposed wind-resistant monitoring system in transmission lines has been verified by practical projects and can be popularized.

1. Introduction

The wind resistance of the pole tower line in the transmission line is one of the key problems to be considered in the safety of the power network in the coastal provinces of China. The super typhoon in recent years has caused great damage to the power network [1-2]. For example, in 2014, the severe typhoon of "Rammasun" caused the 11859 cases of breakage or failure of transmission and distribution lines in the coastal area of Guangxi [3], which not only caused great economic loss, but also affected people's normal life. According to statistics that the most damaged in the typhoon is the cement pole under 10kV. Therefore, it is of great practical significance to carry out the research of the dynamic response and failure mechanism of pole-line structure under wind load, so as to form the wind resistance monitoring system suitable for this kind of structure, which is of great practical significance to ensure the stable operation of the power network [3].

Domestic and international researches show that the actual failure of the transmission line structure system under variable load (especially wind load) has obvious dynamic characteristics [4-5]. The dynamic adjustment coefficient is used to consider the wind load increase in the transmission line structure design in China, whose essence is still the pseudo-static analysis method. Because the wind
pressure is often a time variable and the wire and rod exist in the interaction, the vibration of the rod and line under the wind action has obvious coupling effect. The wind pressure is often a time variable and the wire and pole exist in the interaction, therefore, the vibration of the pole and line under the wind load has obvious coupling effect.

Therefore, it is necessary to establish a whole model of the rod line and at the same time, the wind speed is transformed into a time-varying wind load applied to the rod line structure in order to accurately obtain the response of the transmission rod at different wind speeds. The researchers have proposed the corresponding monitoring method for the displacement and movement of the tower, however, the interaction between the wire and the rod is not considered, and the wind load is also approximate simulation, which leads to the limited applicability of the method [6–8].

The wind-resistance monitoring technology of typical cement pole-line structures in 10kv transmission lines in south china coast is carried out in this paper. First, the wind-resistance monitoring system suitable for the pole-line structure is proposed. Second, the whole finite element model of the pole-line structure is established in order to determine the warning value in the monitoring system, and the wind speed and wind force relationship obtained based on the fine finite element analysis are applied to the model as time-varying loads to obtain the dynamic model of the pole-line structure under wind load, and then the wind speed warning value is determined. Finally, the wind-resistant monitoring system is established based on the actual engineering to verify the correctness of the proposed method.

2. Wind-resistance Monitoring System for Pole-line Structure in Transmission Lines

Wind speed, dynamic strain and pole-line mode are the most important monitoring parameters in wind resistance monitoring of pole-line structure, therefore, different sensors need to be installed in different positions of the pole. The wind speed and wind direction monitoring points are arranged at the same height as the wire, the pole-line mode monitoring points and the dynamic strain monitoring points are arranged at the top and the bottom of the pole respectively.

The types and quantities of sensors used for the various monitoring parameters are presented in Table 1.

| Monitoring parameter          | Configuration                          | Number   |
|------------------------------|----------------------------------------|----------|
| Speed and direction of wind  | Three-direction ultrasonic anemometer  | 1        |
| Bending moment at bottom of pole | Dynamic strain gauge                  | Not less than 4 |
| Vibration acceleration       | Magnetoelectric acceleration sensor    | 2        |

It becomes infeasible to use electricity as an instrument for power supply because the transmission poles are generally located in the field. Further, it is difficult to adopt the wired transmission mode for the reason that the monitoring point is often far away from the monitoring center. To overcome these difficulties, the power supply of the monitoring system is provided by a solar power supply system and a wireless network collector with a 4G transmission module, moreover, the data reception, storage, processing and presentation are all completed on the cloud platform processor. The pole-line wind resistance monitoring system is shown in Fig. 1.

An important function of the wind monitoring system is to be able to evaluate the security of the structure based on the real-time monitoring data, and early warning are issued in case of insecurity, therefore, it is crucial to set appropriate early warning values.
3. Determination of wind speed warning value

3.1. Determination of wind load

The wind speed is easy to obtain in the actual monitoring, however the force is needed in the dynamic analysis of the pole-line structure, therefore, it is necessary to transform the wind speed into the force (i.e. wind load) needed in the model.

The effect of wind on the wire is actually fluid-solid coupling. The fluid-solid coupling refined model of the wire and wind is established based on Ansys Workbench finite element analysis software in this paper, as shown in Fig. 2.

K-ε turbulence simulation is selected in the model, which assumes that the wire surface is smooth and non-filtration, the velocity and pressure of the wire and wind field on the coupling surface are equal and wind is considered as viscous incompressible fluid. The parameters of the model are as follows: a cuboid liquid model of 10m×10m×20m is established to simulate the wind; a cylinder of 0.024m diameter inside the model is used as a wire, using solid with a density of 2850kg/m³, and the wire surface boundary condition type is wall.

The four cases in wind speed of 5m/s, 10m/s, 20m/s, and 30m/s are discussed respectively, and the wind speed distribution cloud picture near the wire is shown in Fig. 3. As it can be seen, the wind speed is 13.64m/s at the upper and lower edge of the wire, 6.82m/s on the windward side of the wire, and the 3.41m/s at the position of the leeward side of the wire.

After obtaining the wind speed distribution, the traverse force under each wind speed can be obtained by indicating the integral for the whole wire by means of the relation of wind speed and wind pressure, afterwards, the average wind pressure can be obtained by dividing the force by the windward area of the wire, and the average wind pressure at different wind speeds is listed in Table 2.
Table 2. Average wind pressure applied on wire under different wind speed

| Number | Wind speed (m/s) | Average wind pressure (Pa) |
|--------|-----------------|---------------------------|
| 1      | 5               | 22.7                      |
| 2      | 10              | 80.8                      |
| 3      | 20              | 295.0                     |
| 4      | 30              | 634.6                     |

The relationship between the average wind pressure and the wind speed of the wire can be obtained through curve fitting analysis of the data in table, it has

\[ P = 1.1307V^{1.8589} \]  

where \( P \) is the average wind pressure of the conductor, whose unit is \( Pa \); \( V \) is the wind speed in units of \( m/s \).

The measured wind speed can be transformed into the average wind pressure of the wire through equation (1), and the force of the wire per extended meter can be obtained further, thus the transformation of the wind speed to the wind load is realized.

3.2. Dynamic analysis of pole-line structure under wind load

The 5 linear bar is the typical structure of the line in this paper. The height of the pole structure is 15m, and the span of line is 60m; the material of main pole is C30 concrete, the cross pole material is Q235 steel, and type LGJ-95/20 steel cored aluminium stranded wire is selected. The finite element model is established based on Ansys software, the main pole and cross pole are simulated by Beam189, and the conductor and ground wire are simulated by Link10. The model constraints are as follows: the bottom of the pole is a fixed constraint, the pole body and the cross pole share the node, node coupling is used for connection of conductor, ground wire and cross pole, the ground wire and the cross pole adopts to couple all translational degrees of freedom.

The finite element model of the 5 liner structure is shown in Fig. 4.

![Finite element model of cement pole-line structure](image)

The wind speed monitoring is carried out for the pole-line structure in the supporting project, and the wind speed data within 1 hour are taken, as shown in Fig. 5, the maximum wind speed is 9.3\( m/s \). The wind speed time period is transformed into the average wind pressure time period of the conductor by equation (1), and, the force is converted to the unit length of the conductor according to the diameter of the wire, as presented in Fig. 6.
The wind load is applied to the pole-line modal, and the dynamic response time-history such as acceleration, internal force, coupling force of the conductor and cement pole-line structure can be obtained by time history analysis using the direct product method.

The acceleration time-history at the top of the pole is shown in Fig. 7, the bending moment time-history at the bottom of the pole is exhibited in Fig. 8, and the maximum and minimum values of bending moment at bottom of pole and acceleration at top of pole are listed in Table 3.

Table 3. Dynamic results of cement pole

| Mechanical parameters                        | Maximal value | Minimum value |
|---------------------------------------------|---------------|---------------|
| Bending moment at bottom of pole (kN·m)    | 0.00          | -1.39         |
| Acceleration at top of pole (m/s²)          | 0.02          | -0.02         |

It can be seen from Figs. 7, 8 and Table 2 that the mechanical response of the pole-line structure under the action of wind load shows obvious dynamic time-history characteristics, but not static characteristics.

3.3. Determination of wind speed warning value

The most unfavorable position of the pole-line structure can be determined as the bottom section of the pole through the analysis of Section 3.2. Moreover, the ultimate bearing capacity of the bottom section of the pole can be easily calculated by using calculation method of flexural capacity of the section based on section parameters and reinforcement parameters of the bottom section of the pole.

The bending moment at the bottom of the pole is linearly related to the load applied to the pole body, therefore, the limited wind load under the flexural bearing capacity can be determined by the dynamic analysis model of the pole-line structure. The limited wind pressure derivation of model in this paper can be observer in Table 4.
### Table 4. Formatting sections, subsections and subsubsections

| State   | Bending moment at bottom of pole (kN·m) | Wind load (N·m) | Wind pressure (Pa) |
|---------|----------------------------------------|----------------|-------------------|
| Normal  | 1.39                                   | 1.21           | 71.39             |
| Limited | 8.06                                   | 7.04           | 413.98            |

It can be concluded from the Table 4 that the limited wind pressure that the pole-line structure system can withstand is 413.98 Pa. It can be obtained by equation (1) as follows

\[ V = \left( \frac{P}{1.1307} \right)^{0.538} \]  

(2)

Thus, the wind speed warning value of the pole-line monitoring system can be solved as 23.94 m/s.

The wind speed warning value determination procedure of the pole-line wind resistance monitoring system can be determined through the above analysis, as shown in Fig. 9.

![Fig. 9 The determination procedure of wind speed warning value in monitoring system for pole-line structure.](image)

4. Engineering validation

The proposed wind-resistance monitoring system of the pole-line structure is applied to the cement pod-line structure in a 10kv transmission line along the south china coast, the instrument layout is shown in Fig. 10. The correctness of the proposed method is verified by comparing the monitoring results with the results of the proposed dynamic analysis model.

![Fig. 10 Layout of monitoring instruments](image)
The measured acceleration time-history curve of a certain period of time is illustrated in Fig. 11. The 1st natural frequency of the structure is obtained by spectrum analysis, as shown in Fig. 12.

Furthermore, the wind speed monitoring results of this period are input into the dynamic analysis model to extract the acceleration signal at the top position of the pole shown in Fig. 6. The comparison of measured acceleration at top of pole and first-order frequency with those obtained by finite element analysis results are shown in Table 5.

Table 5. Comparison of measured acceleration and 1st frequency with those calculated by finite element analysis.

| Mechanical parameters                  | Finite element analysis | Measured  |
|----------------------------------------|-------------------------|-----------|
| Acceleration at top of pole (m/s²)     | 0.020                   | 0.0184    |
| 1st frequency (Hz)                     | 2.500                   | 2.812     |

It can be known from Table 4 that the maximum acceleration at the top of the pole is 0.020 m/s² by dynamic analysis, which is close to the measured maximum value of 0.0184 m/s², and the first-order natural frequency of the main pole is 2.5 Hz, which is also close to the measured value of 2.8 Hz. Therefore, it is shown that the pole-line dynamic analysis model established in this paper is correct.

The stress values at the bottom of pole in the dynamic analysis model are compared with the measured values, as shown in Fig. 13.

It can be seen from Fig. 13 that the measured stress results are very close to those of the dynamic analysis model, thus the correctness of the dynamic analysis model established in this paper is verified. It can also be shown that the finite element model of the pole-line can accurately reflect the actual stress state of the pole-line, and the wind speed warning value obtained by this method is reliable.

5. Conclusion
The research on wind resistance monitoring technique of the pole-line structure is carried out based on the typical cement pole-line structure in a 10 kv transmission line off the coast of South China. Firstly, the wind-resistance monitoring system of pole-line structure is established. Secondly, the method of...
determining the warning value in the monitoring system is put forward. Finally, the correctness of the method is verified by practical engineering. The following conclusions can be drawn:

1. The wind force on the surface of the conductor is non-uniform, and the wind speed can be converted into the wind load by the wind-wire fluid-solid coupling model.

2. The dynamic analysis model of the whole pole-line structure is established, and structural response by applying wind loads to the model can accurately reflect the actual stress state of the structure, which can be used to determine the warning value of wind speed.

3. The wind-resistance monitoring system of the transmission line has been verified which can be popularized.

Acknowledgments
This research is sponsored by Nanning Excellent Young Scientist Program (nos: RC20180108), Nanning Excellent Young Scientist Program and Guangxi Beibu Gulf Economic Zone Major Talent Program (RC20190206), Science & Technology Base & Talent Special Project of Guangxi Province (nos: AD19245152) and Guangxi Key Research and Development Project (nos: AB17292034). The corresponding author is Longlin Wang and anybody can consult him if one has any questions about this paper.

References
[1] Q.L. Pang, H.L. Gao, Q. Du, Y.B. Wu, K. Liu, Protection and control method for smart distribution grid, Power System Protection and Control. 38 (2010) 28-32+38.

[2] R.M. Huang, L.Q. An, R.L Zhang, C.L. Cheng, Y.F. Liang, Z.Q. Zhang, Windage characteristic analysis of transmission lines under typhoon-rain loads, Journal of Electric Power Science and Technology. 33 (2018) 89-95.

[3] Q. Xie, Y. Zhang, J. Li, Investigation on tower collapses of 500kV Renshang 5237 transmission line caused by downburst, Power Syst Technol. 30 (2006) 59-63+89.

[4] Q. Xie, J. Li, Current situation of natural disaster in electric power system and countermeasures, J Nat Disaster. 15 (2006) 126-131.

[5] H. Yan, Y.J. Liu, D.S. Zhao, Geometric Nonlinear Analysis of Transmission Tower with Continuous Legs, Adv Steel Struct. 1 (1996) 339-344.

[6] W.T. Huang, N.L. Tai, C.J. Fan, Study on icing monitoring system of different tower overhead transmission lines based on mechanics measurements, Power System Protection and Control. 40 (2012) 71-75+83.

[7] Y.X. Li, S.L. Zhao, A.M. Zhu, H.J. Xing, R. Shi, Study on Fatigue Property under Dynamic Load of Composite Cross-arm in 750 kV AC Transmission Line, Smart Power. 45 (2017) 46-49+68.

[8] M. Zhang, X.Y. Tang, L.X. Zhou, B. Wang, Power station 10 kV continuous tilt overhead line lightning protection reformation, Journal of electric power science and technology. 34 (2019) 169-174.