ISSN: 2414-1895 DOI: 10.6919/ICJE.202006_6(6).0011

Research on Analysis Method of Wind Energy Resources of Wind Farm in Icing Region

Xiangdong Zhu[a], Huaikong Zhang, Dezheng Ning, Yonghui Lu, Siwei Wang, Jianbo Fu, Yuhua Wang, Shouyuan Fan, Yajun Zhang

China Energy Engineering Group Yunnan Electric Power Design Institute Co.,Ltd., Kunming 650051, China.

[a]M145340@foxmail.com

Abstract

The wind towers working in heavy icing areas often have different measurement deviations of the wind tower wind speed and wind direction channel for a long period of time due to the effects of freezing, which may cause serious tower collapse accidents, which will bring great development and subsequent development of wind farms. difficult. In this paper, through the comparative analysis method, it puts forward the principle of effective identification of wind tower freezing data, and on this basis, it systematically summarizes different processing strategies for freezing data, which provides a certain method for the analysis of wind measurement data in heavy icing areas Basis. In actual engineering projects, they should be applied according to the specific characteristics of different projects and according to local conditions and time.

Keywords

Icing data, Wind energy resource, Proactive coping strategies, Passive coping strategies.

1. Introduction

The problem of wind turbine blade freezing has become an important factor restricting the development and construction of wind power markets in icing areas. The measurement and evaluation of wind energy resources is an important technical prerequisite for the development and utilization of wind farms[1]. The accuracy of wind farm power generation assessment is the first key point is the accuracy of the wind speed calculation of the wind tower. Anemometer towers usually work in the wild and face harsh weather conditions such as high winds, heavy rain, radiation, low temperature, icing, and lightning strikes[2]. In the wind measuring process of the wind measuring tower, some sensor data are often missing or abnormal due to instrument damage, data transmission failure, icing and other reasons. The wind towers working in heavy ice areas often have different measurement deviations of the wind tower wind speed and wind direction channel for a long period of time due to the effects of freezing, which may cause serious tower collapse accidents, which will bring great development and subsequent development of wind farms.

2. Research methods of icing of wind farm

Icing models are mainly divided into two categories: empirical statistical models and physical models. The empirical statistical model is obtained based on historical data. The empirical statistical model can predict not only the frequency of icing, but also the growth rate and amount of icing[3,4,5]. In order to quantitatively estimate the amount of icing, the environmental parameters that the empirical model needs to consider are: ambient temperature, altitude, wind speed, wind direction, water droplet

ISSN: 2414-1895 DOI: 10.6919/ICJE.202006_6(6).0011

size distribution, structure shape and size. The disadvantages of the empirical model are: ① The accuracy of the empirical statistical model is lower than that of the physical model. ②A large amount of effective historical data is required[6,7]. As China's wind power industry has just emerged and there is a serious lack of historical data on the operation of wind turbines in icy environments, it is difficult to obtain empirical statistical models. Therefore, most of the current research work focuses on the physical model of icing and its numerical calculation. There are not many studies on fan blade icing models at home and abroad. Existing studies are based on the Makkonen icing model, and refer to the research results of wire and aircraft wing icing[8]. The research on wind turbine blade icing began in the 1980s, and mainly used two research methods: calculation and experiment. The ice wind tunnel icing test is the most direct and effective method for studying wind turbine blade icing. Due to the high technical level required to construct an ice wind tunnel, the most famous is the Green Ice Wind Tunnel from NASA in the United States. It is mainly used to carry out icing tests for aircraft, but a small amount of wind generator blade icing tests have also been conducted. Not many countries in the world have ice wind tunnels[9]. Experimental research is costly and is easily limited by experimental conditions. With the development of computing methods and computer hardware in recent years, numerical simulation methods have begun to be used more. In the early stage, the use of computer simulation technology to study the wind generator icing rules and characteristics, and later use of multi-functional climate chamber for verification, can greatly shorten the development cycle. Researchers in Europe and the United States have conducted some studies on the icing of the blades of horizontal axis wind turbines using the ice wind tunnel test[10]. The industry's research on icing mostly focuses on the wind turbine blade icing mechanism and wind turbine anti-icing technology, and there are relatively few resource evaluation studies on wind towers due to icing. One reason is that the wind tower market body The amount and investment account for a relatively small amount. Secondly, it is constrained by the short-term and rapid development model of the early stage of new energy development. The resource evaluation research of the wind tower caused by icing focuses on the identification of icing data and the processing of icing data.

3. Recognition method of icing data

3.1 Frost recognition and analysis of wind tower icing cycle

Low temperature and high humidity are the two necessary conditions for the icing scene, so the freezing phenomenon often occurs in areas with the above climatic characteristics.

The degree of ice damage to the wind tower is determined by two factors: ice thickness and duration. The heavier the ice cover, the longer the duration, and the greater the degree of damage. According to the life cycle theory, a life cycle of icing can be divided into the formation period, development period, maturity period and melting period. According to the icing mechanism, the two necessary conditions in the formation period are supercooling water and ice core. When the ambient air temperature is below 0 degrees (under standard conditions) and the humidity is high (90%), it is conducive to the formation of supercooled water, and then the supercooled water collides with the tower to form ice cores. During the formation period, the icing is not serious and the equipment is not destructive. The development period is the icing growth process, the temperature is further reduced, the supercooling water condenses on the surface of the ice, and the process of gradual growth and thickness increase is a stage of rapid growth. The maturity period is when the growth rate of icing slows down. During this period, the thickness of icing reaches its peak, which is also the period with the strongest destructive power. In severe moments, it can cause the collapse of the wind tower, mainly determined by the duration of low temperature and humidity. The thawing period is a process in which the growth of icing is suppressed and the thickness of icing gradually decreases, which may be caused by the rise of air temperature or the lack of sufficient supercooling water. The destructive ability is weakened, and the equipment is in a semi-working state.

The icing cycle in a winter can be continuous or discrete, which is mainly related to the environmental factors that affect icing. Generally, a complete day in a light ice area is a icing period, and the evening

ISSN: 2414-1895 DOI: 10.6919/ICJE.202006_6(6).0011

period is the formation period. The night is the development period, and the day is the thawing period; while the heavy ice area, due to the extreme cold in winter, may be an icing period throughout the winter.

In general, the impact of freezing on the wind tower and its observation sensors is divided into low to high according to the severity: instrument failure, freezing data and inverted tower.

The failure of the instrument mainly occurs during the formation, development and thawing periods of the icing period, and the instrument of a certain channel may not operate normally, resulting in invalid data. The freezing data occurs at the beginning of the maturity period and the thawing period and is defined as the abnormal operation of all wind speed channel equipment, and the collapse is an extreme event in the maturity period. Time, collapse accidents are very easy to occur, and the data collection of all channels after the occurrence is destroyed. See Figure 1for details.

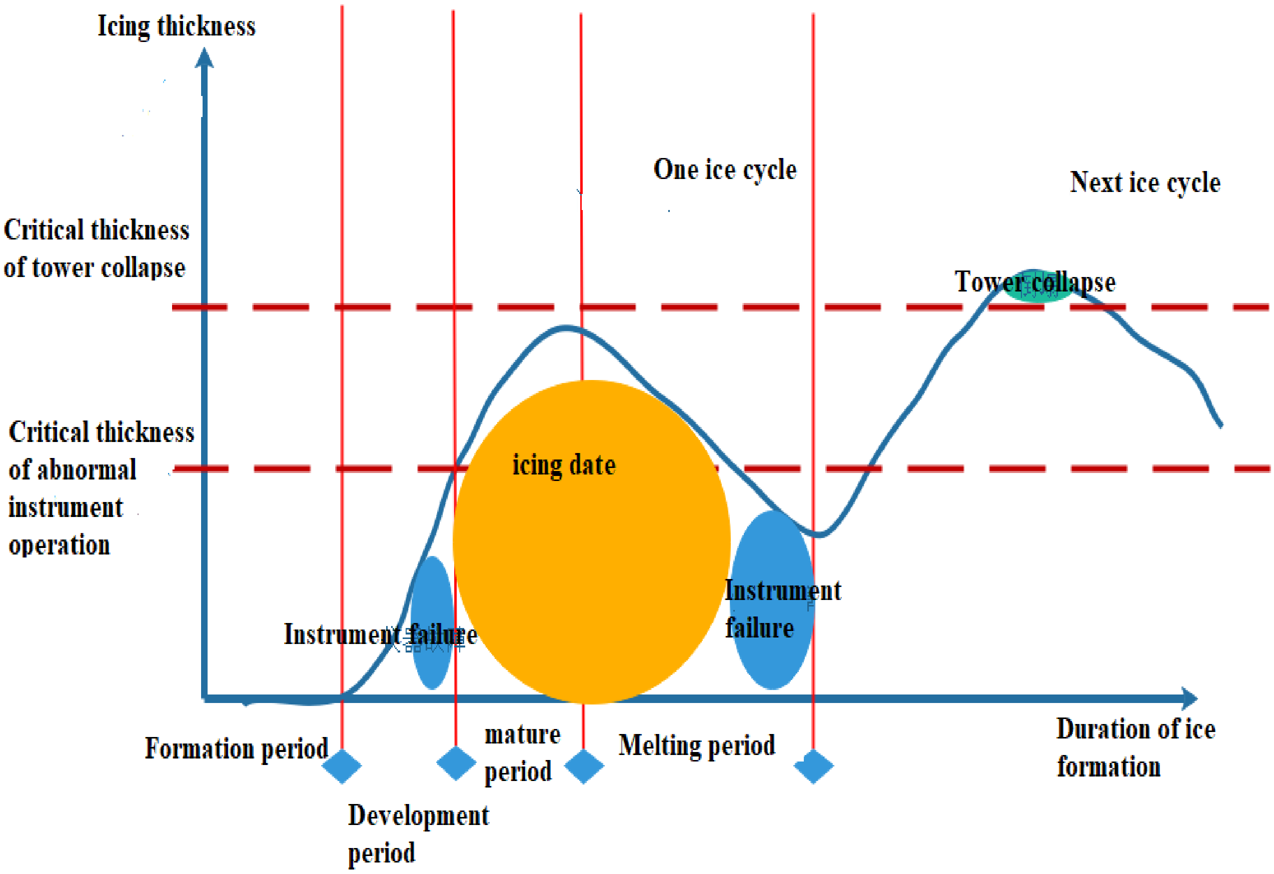

Figure1. The degree of influence of icing in different periods on the data quality of wind tower

3.2 Instrument failure caused by freezing

The short-term or even long-term failure of the wind tunnel instrument channel caused by freezing is relatively common, and its identification is also relatively routine. It is mainly divided into integrity inspection, rationality inspection (range inspection, trend inspection, relationship inspection) and correlation inspection. .

1) Integrity inspection

Integrity inspection includes quantity and chronological inspection, that is, the quantity of data should be equal to the quantity of data expected to be recorded, the chronological sequence of data should be consistent with the expected start and end times, and the middle should be continuous. Figure 2 is a schematic diagram of the analysis of a lack of time for an anemometer tower. In the winter, some data is missing due to freezing.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202006_6(6).0011

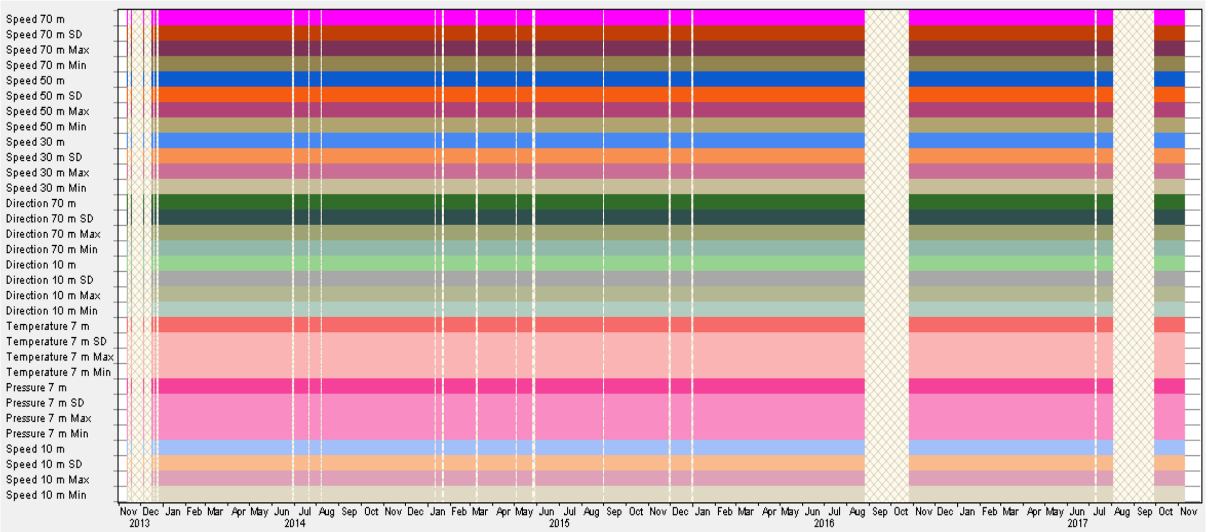

Figure 2. Schematic diagram of wind data integrity verification

2) Reasonability test

The rationality test is to test the wind measurement data of the wind measurement tower, determine whether the relevant parameters of each observation data exceed the effective range, and whether the change trend is reasonable, and compare the wind speed and wind direction data of different heights of the wind measurement tower at the same period Analysis, according to the effective value range, combined with the mutual reference verification of the data of the wind tower, analyze and judge the unreasonable wind data.

Correlation analysis is a statistical analysis method to study the correlation between two or more random variables of equal status. The data between different wind heights of the same wind tower often have a good correlation. Correlation testing is also a common method for identifying abnormal data. As shown in Figure 3, it is a typical correlation analysis result of instrument failure caused by freezing in Butuo County, Liangshan Prefecture, Sichuan Province.

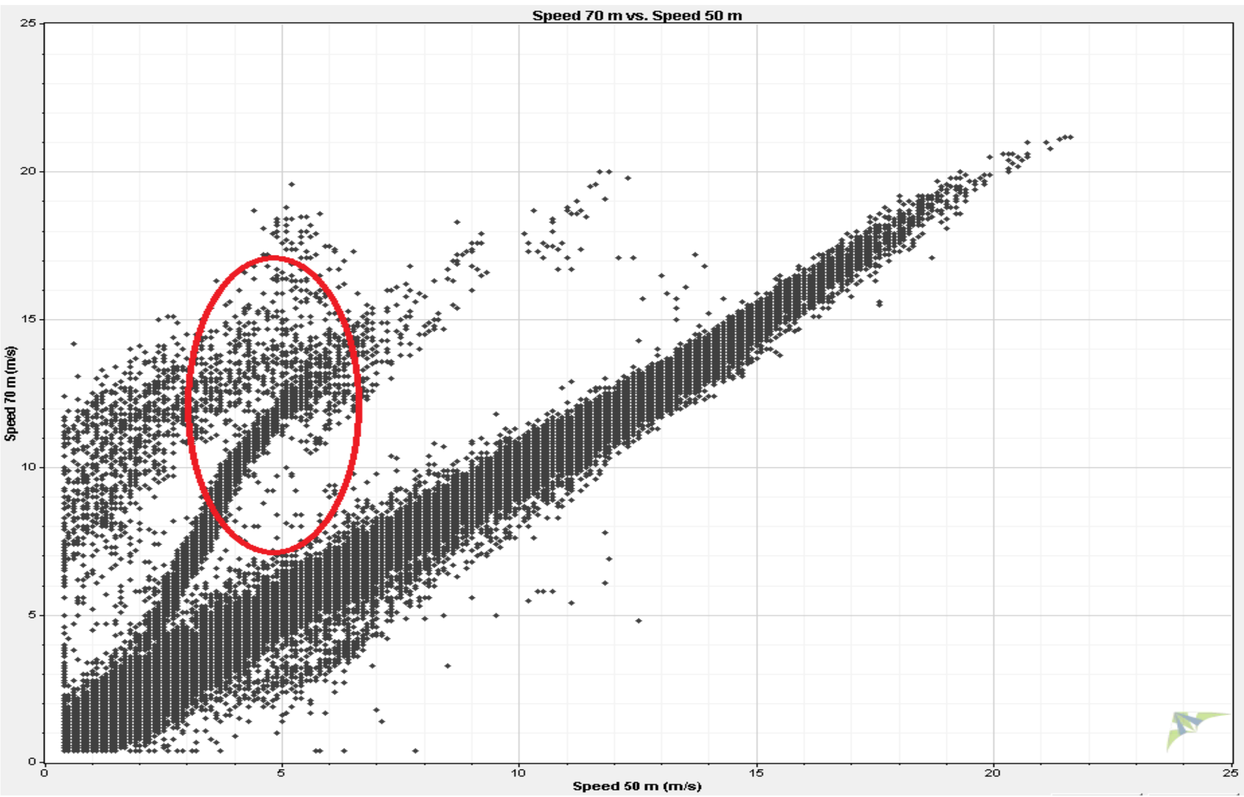

Figure 3. Schematic diagram of correlation analysis of wind data

ISSN: 2414-1895 DOI: 10.6919/ICJE.202006_6(6).0011

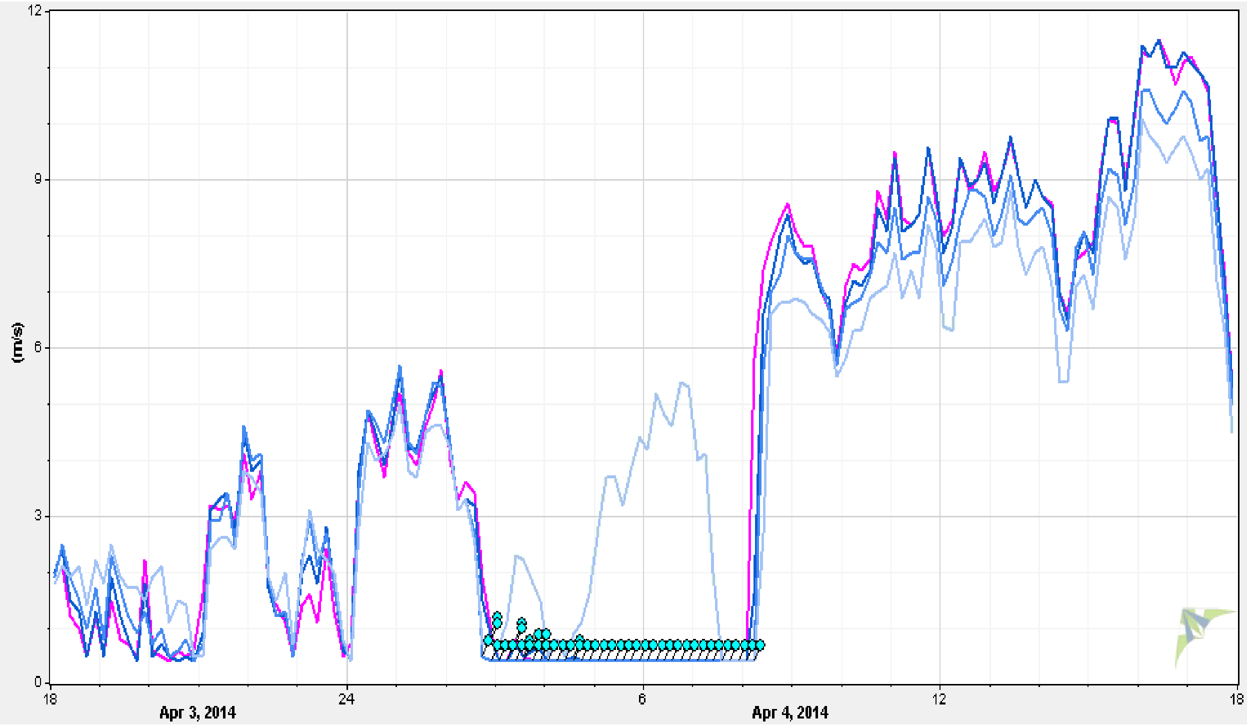

Figure 4. Obvious difference of wind speed data in different channels of wind tower

It can be seen from Figure 3and Figure 4:

(1) The freezing degree of the same wind measuring tower, the same freezing period, and different wind measuring channels show obvious differences. Often related to the wind speed at this time;

(2) The freezing characteristics of the same wind tower and different freezing periods also show obvious differences. Special attention should be paid when identifying abnormal data caused by freezing, and specific problems should be analyzed to prevent the same judgment standard from being used for all data .

4. Solutions for icing data

In the early stage of the development of wind farms, fully understand the objectivity and uncertainty of the existence of freezing, and adopt economic and reasonable response strategies are crucial to the investment decision, design and construction, operation and maintenance of wind farms. As shown in Figure 4-1, it is a coping strategy often used in actual work. An active response strategy, that is, to take active measures to respond before freezing occurs, is an ex ante intervention plan; while a passive response strategy is to take analysis and treatment plans after freezing occurs, which is a time response plan.

4.1 Proactive coping strategies

The active response strategy for freezing is divided into auxiliary observation, active lowering tower and installation of heating equipment.

1) Auxiliary observation

Auxiliary observation refers to the use of lidar or sodar to perform auxiliary wind measurement when freezing causes abnormal data of conventional wind towers, which provides more basic data for the development of wind farms. Active Tower

Actively lowering the tower, that is, before the arrival of winter each year (October to November), the high-rise tower is disassembled and reduced to 30 meters or 50 meters, and from March to April of the following year, the height of the tower is restored to normal Observe.

Figure 5. Schematic diagram of active descending tower construction

2) Heating equipment

By reducing the height of the tower, the risk of the wind measuring tower falling due to icing will be reduced, but the wind measuring equipment may still not work properly due to icing, so it is recommended to install a heatable anti-icing sensor during winter wind measurement. Including traditional mechanical and ultrasonic wind meters.

4.2 Passive coping strategies

The passive response strategy for icing data is divided into no processing, deletion and interpolation.

1）Do not process the icing data as "real" data. Since the wind measurement data during the freezing period is significantly lower than the true value, the wind energy resource analysis of the wind measurement tower is conservative. In addition, at present, most fan manufacturers have adopted three schemes for anti-icing coating, unit icing safety protection mode and blade heating de-icing system to deal with the icing of the fan, and try to avoid the shutdown of the fan due to icing and increase the power generation. This further led to the conservative and stable calculation of the power generation of the "no treatment" scheme.

2).Delete, that is, the icing data is regarded as "invalid" data, and delete the data under the premise that the effective data integrity rate of the wind measuring tower meets the requirements of the regulations. When the ratio of icing data is low (<5%), it is a simple and effective processing method.

3)Interpolation, that is, the icing data is regarded as "abnormal" data, and other data is used to interpolate it to obtain closer to the actual wind tower data. According to different sources of interpolation data, interpolation is divided into same-tower interpolation, different-tower interpolation, and interpolation based on mesoscale data.

Wind speed interpolation solves the unary linear regression equation of the form $y = ax + b$

In a wind farm area, there were two accidents of falling towers due to low-temperature rain and snow. There are different degrees of icing in each wind tower during the analysis year. Among them, the 30m wind speed channel with the highest complete data rate of the T3980 wind tower is 4.53%, and the T4013 wind tower 90m wind speed is 3.87%. The icing rate of the 90m wind speed channel of the T4014 wind tower is 4.43%. The icing period is relatively short and occurs from November to March each year, both of which are light wind months. At present, there are the following three processing strategies for the processing of icing data: 1) not processing, maintaining the objectivity and integrity of the original data; 2) deleting, that is, processing the data during the icing period when the data integrity rate is met Delete; 3) Interpolation, that is, the data in the icing period is regarded as invalid data, and other normal data or mesoscale data is used for interpolation. According to the actual situation of this project, the three treatment methods are now compared and analyzed. The results are shown in Table 1.

ISSN: 2414-1895 DOI: 10.6919/ICJE.202006_6(6).0011

Table 1. Monthly average wind speed statistics (m / s) of the three wind measuring towers with different icing methods at 90m height

（a-Not processed b-Delete c-Interpolated A-Average wind speed D-Wind speed E-difference）

Month	T3980					T4013					T4014				
	a	b		c		a	b		c		a	b		c	
	A	D	E	D	E	A	D	E	D	E	A	D	E	D	E
1	4.45	4.91	0.46	4.91	0.46	3.81	4.11	0.30	4.06	0.25	2.57	2.78	0.21	2.95	0.38
2	4.71	5.97	1.26	5.97	1.26	4.10	5.57	1.47	5.14	1.04	3.41	4.57	1.16	4.18	0.77
3	5.37	5.46	0.09	5.46	0.09	4.87	4.93	0.06	4.92	0.05	4.09	4.24	0.15	4.26	0.17
4	6.54	6.54	0.00	6.54	0.00	5.71	5.71	0.00	5.71	0.00	4.90	4.90	0.00	4.90	0.00
5	5.49	5.49	0.00	5.49	0.00	4.68	4.68	0.00	4.68	0.00	4.18	4.18	0.00	4.18	0.00
6	5.04	5.04	0.00	5.04	0.00	4.34	4.34	0.00	4.43	0.09	3.44	3.44	0.00	3.44	0.00
7	8.94	8.94	0.00	8.94	0.00	7.47	7.47	0.00	7.47	0.00	6.68	6.68	0.00	6.68	0.00
8	5.12	5.12	0.00	5.12	0.00	4.50	4.50	0.00	4.50	0.00	3.78	3.78	0.00	3.78	0.00
9	5.93	5.93	0.00	5.93	0.00	4.54	4.54	0.00	4.54	0.00	3.42	3.42	0.00	3.42	0.00
10	6.63	6.63	0.00	6.63	0.00	5.78	5.78	0.00	5.78	0.00	3.63	3.63	0.00	3.63	0.00
11	4.59	4.66	0.07	4.88	0.29	4.28	4.33	0.05	4.33	0.05	2.87	3.01	0.14	3.09	0.22
12	4.17	4.50	0.33	4.66	0.49	3.22	3.70	0.48	3.96	0.74	2.36	2.62	0.26	2.88	0.52
Annual	5.58	5.77	0.18	5.80	0.22	4.78	4.97	0.20	4.96	0.19	3.78	3.93	0.16	3.95	0.17

It can be seen from the above table that the annual average wind speed of each wind measuring tower varies with the strategy of icing data processing. The annual average wind speeds of the original data of the three wind towers T3980, T4013 and T4014 are 5.58m / s, 4.78m / s and 3.78m / s respectively, and the annual average wind speeds treated by the deletion method are 5.77m / s and 4.97m / s and 3.93m / s, the annual average wind speed treated by interpolation method is 5.80m / s, 4.96m / s and 3.95m / s respectively. In general, the processed data is larger than the unprocessed data. However, since the icing of the wind towers in this area occurs in the small wind month, the difference between the treatment and the non-treatment is not obvious.

Since none of the three wind measuring towers has carried out the measurement of meteorological parameters such as temperature, air pressure and humidity, there are certain difficulties in identifying and judging the ice formation and melting periods. In view of the fact that the current wind turbine anti-icing and de-icing technology is not yet mature, and there are few large-scale popularization use cases, it is recommended not to process the icing data and use the original data as input data for subsequent analysis, and the wind energy resource assessment will be conservative.

5. Conclusions and recommendations

The identification of invalid data caused by freezing is divided into three types: instrument failure, freezing data and inverted tower according to the degree of damage to equipment caused by freezing. Invalid data brought by the collapse of the tower can be identified by means of maintenance logs and site surveys, icing data can be identified by verifying the changes in each channel; and invalid data

ISSN: 2414-1895 DOI: 10.6919/ICJE.202006_6(6).0011

caused by instrument failures can pass the criteria of judgment, combined with range inspection and rationality Identify by inspection method. The active response strategy for freezing, that is, to take active measures to respond before freezing occurs, mainly including auxiliary observation, active lowering tower and heating equipment, etc. It is recommended that wind farm projects with severe icing and in the wind measurement stage adopt active Coping strategies to ensure the effectiveness of the collected data and facilitate accurate assessment of resources. The passive response strategy for freezing is to analyze and deal with the plan after freezing occurs, divided into non-processing, deletion and interpolation.

The quality of the data determines the accuracy of the resource assessment. The freezing phenomenon in the high and cold mountain areas often causes the effective data integrity rate of the project wind tower itself to be less than 80%. It is necessary to further study passive response strategies, such as external source data interpolation (close to the wind measurement) Tower, mesoscale data), the reliability of the results of the processing of invalid data caused by icing, and reducing the uncertainty of resource assessment. The response to freezing is a major problem facing the industry. In the wind energy resource assessment stage, the criteria for identifying icing data, the identification process, and the response strategy should be applied according to the specific characteristics of the actual engineering project, based on local conditions and time.

Acknowledgments

GSKJ2-X04-2019 Research on the key technology of wind farm design in heavy icing region.

References

[1] Lorenzo Battisti. Relevance of Icing for Wind Turbines[M]. Springer International Publishing, 2015.

[2] Davis, Neil N, Pinson, Pierre, Hahmann, Andrea N. Identifying and characterizing the impact of turbine icing on wind farm power generation[J]. Wind Energy, 19(8):1503-1518.

[3] Lorenzo Battisti. Relevance of Icing for Wind Turbines[M]. Springer International Publishing, 2015.

[4] Hu H. An Experimental Investigation on Surface Water Transport and Ice Accreting Process Pertinent to Wind Turbine Icing Phenomena[J]. 2015.

[5] guy fortin, Jean Perron. Wind Turbine Icing and De-Icing[J]. Aiaa Journal, 2009.

[6] Minghao Zhao, Dongxiang Jiang, Shaohua Li. Research on fault mechanism of icing of wind turbine blades[C]// World Non-grid-connected Wind Power & Energy Conference. IEEE, 2009.

[7] Y. Li, S. Wang, Y. Zheng. Design of wind tunnel experiment system for wind turbine icing by using natural low temperature[J]. Journal of Experiments in Fluid Mechanics, 2016.

[8] Nigel Swytink-Binnema, Charles Godreau, Cédric Arbez. Detecting instrumental icing using automated double anemometry[J]. Wind Energy, 2018, 22(2).

[9] Staffan Rydblom, Benny Thörnberg. Liquid Water Content and Droplet Sizing Shadowgraph Measuring System for Wind Turbine Icing Detection[J]. IEEE Sensors Journal, 16(8):2714-2725.

[10] Sharma D V W P K, India I. Design and Optimization of 150 m Higher Wind Monitoring Tower (Indian Condition) [J]. 2014, 3(2):85-89.