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Research on Wind Turbine Selection Based on Different Heavy Icing Data Processing Strategies

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ABSTRACT. *The selection of wind turbine icing processing technology is related to the safe and stable operation of wind farms during icing. Based on the processing strategy of wind data, this paper studies the impact of different processing strategies on the calculation of wind turbine power generation, and gives different measurements. The calculation method of power generation amount under wind data condition puts forward that the selection of units in the ice-covered area can adopt the method of power cost comparison, and use the differential internal rate of return to determine whether the wind turbine active ice-coating technology is adopted.*

KEYWORDS: *wind turbine icing, data processing strategy, icing processing, unit selection*

1. Introduction

In recent years, China's wind power industry has developed rapidly, and its installed capacity has ranked first in the world. The follow-up wind power industry development will be further increased. In 2019, China National Wind Power added 25.74 million kilowatts of grid-connected installed capacity, and the cumulative grid-connected installed capacity reached 210 million kilowatts, accounting for 10.4% of the total installed power generation capacity.

China's wind energy resources are mainly concentrated in the cold three North (Northeast, Northwest, North China) areas and the southeast coastal areas with high humidity. Among them, Yungui, Liangguang, Lianghu, Jiangsu and Zhejiang are the

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regions with rapid development of wind power in China. In low temperature and humid environments, the wind turbine blades in these areas have serious icing problems. The icing problems of the wind turbine blades will affect the aerodynamic profile of the blades, causing additional loads and additional vibrations of the wind turbine, reducing the blade and the unit The service life leads to the failure of the unit and affects the power generation capacity of the wind farm. Wind turbine blades running on ice will reduce the power generation of the wind turbine by 10% to 20%, causing overload operation of the wind farm, and even causing local damage or overall collapse of the wind turbine. It can be seen that the problem of wind turbine blade icing has become an important factor restricting the development and construction of the wind power market in ice-covered areas.

Winter is also a good time for wind resources to be abundant. These areas with relatively severe ice cover have a very dramatic loss of electricity due to ice cover. Therefore, anti-icing technology has become one of the key technologies to ensure the safe and high-quality operation of wind power. First, it is an important measure to improve the quality and efficiency of the wind power industry. Therefore, it is necessary to study the influence of icing on power generation in the calculation of power generation of wind farms in ice-covered areas, and to propose a guide method for wind turbine selection in ice-covered areas.

2. Wind turbine icing model and processing technology

Icing is formed by supercooled water droplets hitting an object with a temperature below freezing[1]. Icing is a term used for post and telecommunications and power systems, that is, icing in meteorology. Line operators call it frost, ice, ice, etc. The former Soviet Union called it mist deposit or ice accretion [2], which is commonly used in the world. At present, there is not enough research on icing systems in the field of wind power, and most of them focus on the research of icing of wind turbine blades, and the current status of icing research (icing type, physical parameters, mechanism, formation conditions) mainly refers to transmission lines and aircraft. Wing covered ice research results.

2.1 Wind turbine blade icing model and numerical calculation

1) Icing model

Icing models are mainly divided into two categories: empirical statistical models and physical models. At present, there are not many studies on wind turbine 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. In 2000, Makkonen proposed an ice model of rime, rain, and wet snow on the surface of an object. The model [3] is:

$$\frac{\mathrm{d}M}{\mathrm{d}t} = \alpha_1 \alpha_2 \alpha_3 wvA \tag{1}$$

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In the formula, α1: collision rate; α2: capture rate; α3: freezing coefficient; w: mass concentration; v: particle velocity; A: cross-sectional area of the surface of the object.

Compared with wire glazing, the icing process of aircraft is more similar to that of wind turbine blades. More research has been carried out on aircraft icing models and numerical calculations at home and abroad [4]. Aircraft airfoil and wind turbine blade airfoil Similarly [5], many wind turbine blade airfoil designs refer to the wing type, and even use the wing airfoil data directly.

2) Progress in numerical calculation

The research on wind turbine blade icing began in the 1980s [6], 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. In 2010, Muhammad S. Virk of Narvik University in Norway and others studied the relationship between the angle of attack and icing of large wind turbine blades. In 2012, Fernando Villalpando and Marcelo Reggio of the University of Quebec in Canada The aerodynamic performance of the airfoil after icing was studied [7]. In 2012, Muhammad S. Virk performed icing calculations on NREL 5 MW large-scale horizontal-axis wind turbines based on the Makkonen model. In 2014, Etemaddar used LEWICE software to study the effect of eight parameter changes on the icing morphology and considered rough degree [8]. In 2017, Yi Xian and others from the State Key Laboratory of Aerodynamics established a three-dimensional numerical method and calculation program suitable for the calculation of the water droplet collection rate of large wind turbines during the freezing process of supercooled water droplets hitting the wind turbine surface.

2.2 Calculation of wind turbine icing power loss

In 2009, the Elforsk report on the power loss of wind farms in northern Sweden used the power data corresponding to the wind speed of 10 min to draw the summer power curve. Based on this, the ratio of actual and ideal power generation in a certain period was calculated. After sensitivity analysis, it is believed that the power ratio is lower than 85% due to blade icing. The loss in winter with temperatures below 2 ° C is much more severe than in summer. From October 2005 to March 2009, 6.6% was lost in summer and 27% in winter. Malmsten of Gotland University in Sweden conducted case studies on 10 wind farms in Sweden, using MEKKA (Modern Era Retrospective-analysis for Research and Applications) Reanalyze the data to establish the nonlinear relationship between the daily wind speed and daily power generation in the summer period, and deduce this functional relationship to the winter daily wind speed and daily power generation as the expected power generation, and compare it with the actual power generation for quantitative analysis Loss of electricity generated by winter ice-covered climate. This method can capture the overall icing trend, that is, the northern part of Sweden is covered more frequently than the southern part, and the power generation loss is more serious. ErikM uses statistical and physical methods to establish ice accumulation models

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and compares them with actual data provided by IceMonitors, an ice load measuring instrument in the same period, and HoloOplics, a detector used to determine the type of ice accumulation. Using ERA4mei_im meteorological data to simulate ice load, to analyze the correlation with long-term meteorological data, establish a functional relationship between power loss and ice load. The results show that although the physical model does not take into account the density correction of the blade surface ice shedding and ice accumulation during ice melting, the overall results are good.

In recent years, auxiliary tools such as de-icing, de-icing, and anti-icing have been developed rapidly. Therefore, it is also necessary to verify the impact of the use of commercial de-icing and anti-icing systems on wind power output during blade icing.

2.3 Icing technology of wind turbine

The technical difficulties of wind turbine icing are mainly blades, and others can be easily achieved by technical means. Blade icing is divided into passive (coating, blade rapid pitch vibration), active (hot air heating, electric heating, ultrasonic deicing)) Two large types. The passive type can increase power generation by about 0.2%, and the active method can greatly increase power generation. Icing technology has been developed for 60 years and has been a worldwide problem. It has only been used in batches in recent years.

In icy climates, it is very difficult to realize the anti-icing capability of wind-powered blades, which are large-scale, high-speed objects. As early as the 1960s, European wind turbines and blade manufacturers joint research institutions began to develop blade anti-icing technology. At present, there are a few foreign wind turbine manufacturers that can provide wind turbines with blade anti-icing capabilities. The research in China started late, and related technologies are being developed and tested.

The anti-icing technology of wind power blades can be generally divided into two categories: blade anti-icing technology and blade de-icing technology. The so-called blade anti-icing is to prevent the surface of the blade from being covered with ice to ensure that the blade can continue to operate in a frozen climate. The so-called blade de-icing, that is, after the blade surface is covered with ice, the ice layer on the blade is removed to make the blade have the conditions for operation.

3. Analysis of the impact of data processing strategies on power generation calculation

3.1 Passive data processing strategy

The passive response strategy for iced data is divided into non-processing, deletion and interpolation. Combined with the recognition of icing data, the passive processing method of abnormal data caused by icing:

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1) No processing, that is, the icing data will be regarded as "real" data, because the wind measurement data during the icing period is significantly lower than the true value, resulting in a conservative analysis of wind energy resources of the wind measurement tower. In addition, at present, most wind turbine 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 wind turbine, and try to avoid the shutdown of the wind turbine 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 to say, the icing data is regarded as "invalid" data, and delete the data under the premise that the effective data integrity rate of the wind tower meets the requirements of the regulations. When the proportion 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.

3.2 Comparative study of different data processing strategies

A comparative study is made on the results of wind power data processing strategy calculation.

Taking the southwest X wind farm as an example, the ice cover time accounts for 4.64% of the whole year. It can be seen from the table that the wind speed increases by 4.7% and the power generation increases by 7.9%, that is, the sensitivity coefficient of wind speed and power generation is 1.68.

If the method of deleting icing data is used in the calculation, the wind speed frequency distribution becomes the wind speed distribution in the icing time period is the same as other time periods, 4308 × (100% -4.64%) = 4108, compared with 3992, it is still overestimated by 2.9% If the sensitivity coefficient is used, that is, 4308 × (100% -4.64% × 1.68) = 3972h, which is basically consistent with 3992h which does not process the original icing data.

The interpolated icing data is closely related to the correlation coefficient of the interpolated reference data. Generally speaking, the correlation coefficient should not be lower than 0.7.

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Table 1 Comparison table of power generation calculation results of different icing treatment schemes

Scheme	Data Processing Strategy for Icing	Wind Speed (m/s)	Wind Speed Comparison (Based on Option 1)	Calculate hours	Comparison of hours (Based on Option 1)
1	Raw icing data is not processed	7.41	1.000	3992	1.000
2	Delete icing data	7.76	1.047	4308	1.079
3.1	Interpolated icing data 0.7	7.70	1.039	4290	1.075
3.2	Interpolated icing data 0.6	7.704	1.040	4300	1.077
3.3	Interpolated icing data 0.5	7.715	1.041	4311	1.080
3.4	Interpolated icing data 0.4	7.729	1.043	4323	1.083

Note: 0.7, 0.6, 0.5, 0.4 in the interpolation data indicates that the correlation coefficient.

If active icing processing technologies such as electric heating, hot air, etc. are used, the method of deleting data and interpolating icing data is closer to the actual power generation. If passive processing of icing is used, such as blade coating, the original coating is not processed Ice data is closer to power generation.

3.3 The impact of proactive coping strategies on power generation

The active response strategy is to actively respond to wind measurement during icing, and is divided into auxiliary observation, active lowering tower and installation of heating equipment. The purpose is to ensure effective wind measurement during icing.

After adopting the proactive response strategy, if the wind measurement data still has anomalies, the data processing strategy in section 3.2 is adopted.

After adopting the proactive response strategy, if the data is normal, then the unit ice treatment technology should be considered. If the unit does not use icing technology, it needs to be reduced accordingly. If the unit uses icing technology, it is necessary to reduce the thunderstorm and self-consumption power brought by the icing technology. Thunderstorms, ice-covered heating equipment failures have caused a drop in wind turbine availability, generally around 1%, and self-consumption power is generally 30 to 60 kW. Icing calculation and unit selection。

4. Case analysis of icing area selection

In addition to the considerations for conventional unit selection, suitable wind treatment technologies need to be studied for wind farms in icing areas. Converted to economy, that is, the relationship between increased power generation revenue and initial investment, maintenance, and consumption of icing technology. Assuming that the reduction factor is 0.75 without considering icing. Calculate the differential internal rate of return of the project's increased investment, and calculate the required additional hours at a base rate of 8%:

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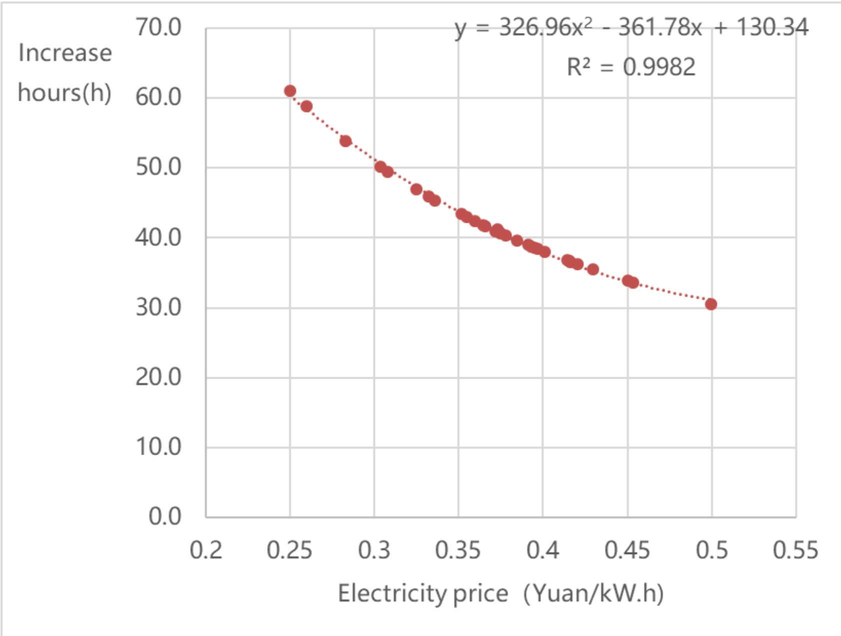

Figure. 1 Increase the relationship between hours and electricity costs

It can be seen that when the power consumption is greater than 1.75%, the active de-icing method can be adopted, that is, to meet the economic requirements.

Combining the relationship between the time ratio and power consumption, the general time ratio and wind speed sensitivity coefficient are 1, and the wind speed and power sensitivity coefficients are between 1.5 ~ 2, that is, the time and power sensitivity coefficients are 1.16%. Considering that the active deicing method will bring about a 1% reduction in availability (such as thunderstorms, equipment failures, etc.), it can be accumulated 2.5% during calculation, that is, when the cumulative time of icing is 219h, 7d You can use the active deicing method when it is less than this time. It is recommended to use the passive deicing method. In the actual project, you can first understand the icing situation in the construction area. If the icing is heavy, the active response strategy can be used to accurately calculate the power loss, which is used for the selection of the unit icing treatment technology.

For areas suitable for active deicing technology, if the number of thunderstorm days is more than 40d, it is recommended to use hot air heating technology; others are suitable for electric heating technology, and the lightning protection design of wind turbines should be strengthened.

In the specific project, taking Wuke Wind Farm as an example, it can be calculated that the de-icing method is not used, the annual power generation hours

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are 3150h, and the equivalent hour after the de-icing method is 3336h, an increase of 186h.

Judging from the calculation results, the unit using the active icing treatment plan is significantly more economical than the conventional unit, so the active deicing plan is recommended. If the calculation economy does not meet the requirements, passive deicing is used.

Table 2 Comparison of icing technology

Scheme	No icing technology	Active icing technology
Model	3.0-147	3.0-147
Total capacity(MW)	50	50
Annual on-grid electricity of wind farm(万 kW • h)	15750	16680
Estimated static investment (ten thousand ¥)	40000	40595
Unit kilowatt static investment (yuan / kW)	8000	8119
Unit power investment (yuan / kW · h)	2.54	2.43
Economic comparison ranking	2	1
Difference Internal Rate of Return Benchmark	Benchmark	243%

5. Conclusions and recommendations

5.1 Summary

In the selection of the unit, the data processing strategy should be combined with the icing method. When the unit does not use active icing technology, it is recommended that when the icing data is not processed, the power generation is relatively close to the actual situation. When the wind measurement adopts an active response strategy, it can accurately calculate the power generation loss due to icing. When the unit adopts the active icing technology: the method of icing interpolation is used. The key lies in the correlation coefficient. When the correlation coefficient is greater than 0.8, the calculation result is basically appropriate relative to the actual value. When the wind measurement adopts an active response strategy, the calculation result can be considered close to the true level. According to the calculation results of icing, the method of comparing the cost of electricity can be used, and the difference internal rate of return can be used to determine whether to adopt the active icing technology of wind turbines.

In the actual project, you can first understand the icing situation in the construction area. If the icing is heavy, the active response strategy can be used to accurately calculate the power loss, which is used for the selection of the unit icing treatment technology.

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5.2 Recommendation

The response of wind turbine icing is a major problem facing the industry. In the wind energy resource assessment phase, the icing data discrimination criteria, identification process and response strategy should be applied according to the specific characteristics of the actual engineering project, according to local conditions and time.

The quality of the data determines the accuracy of the resource assessment. The icing phenomenon in the high and cold mountain areas often causes the effective data integrity rate of the project wind measuring tower itself to be even lower than 80%. Therefore, when setting up the wind measuring tower, the impact of icing should be considered first, and the active Coping strategies, accurate assessment of wind energy resources and power generation calculations, provide data support for the selection of icing treatment technology for the unit.

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