Optimization design and simulation analysis of composite material anti-/deicing component for wind turbine blade

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Abstract. Wind turbine blades are prone to icing under extreme working conditions, which will reduce the efficiency of wind power generation and seriously affect the service life of wind power system. Therefore, the anti-icing problem of wind turbine blades has become one of the hot topics in wind power technology research. It is of great practical significance to develop anti-icing/deicing technology for wind turbine blades for the safe and effective operation of wind power. In this paper, the numerical simulation optimization design for composite material wind turbine blades anti-/deicing component was studied, and the orthogonal optimization method was employed to optimize the parameters of the wind turbine blade to prevent ice formation. The optimization group parameter group is obtained. Through the wind turbine blade temperature distribution simulation, the correctness of the optimization results of the composite material anti-/deicing component was analyzed. The purpose of this paper is to optimize the heat transfer of anti-/deicing component for composite material wind turbine blade, and lay a theoretical and technical foundation for effectively solving the problem of wind turbine blade icing, which proposing a new composite wind turbine blade anti-/deicing scheme.

1. Introduction
With the increasing environmental problems such as carbon dioxide emissions, acid rain and energy shortage, wind energy has been widely concerned and given priority to the development in the world as a clean and sustainable renewable energy [1-3]. Wind energy effectively avoids the environmental pollution problems caused by conventional energy. China has vast grassland and a long coastline. The reserves of wind energy resources are very rich. However, the abundant wind resources are mainly distributed in snowy areas in north of China, where the humidity is larger. The environment is extremely bad. When the wind turbine blade runs at low temperature below 0°C, especially encounters humid air, rain water, salt fog, and super cooled water droplets, the wind turbine blade suffers freezing phenomenon. The blades of the wind turbine will cause great harm after icing such as obstruction of rotation and imbalance of blades [4-6].

Wind turbine blades are prone to ice under extreme working conditions, which will reduce the efficiency of wind power generation and seriously affect the service life of wind power system. Because of the short development time of wind power generation in China, the research reports on anti-icing and de-icing of wind turbine blades are rare. As the most important part of the wind turbine, the operating efficiency of the blade directly determines the power generation capacity of the wind
energy. Therefore, the prevention and control of ice disaster of wind turbine is undoubtedly one of the key problems to be tackled in vigorously promoting wind power generation in China [7-10].

One of the technologies adopted by wind turbine blades is the use of an electro-thermal anti-/deicing protection system. The system is mainly used for anti-icing and de-icing under icing conditions [11-13]. The main method to prevent ice accumulation is to insert a number of electric heating wires into the composite anti-/deicing component and supply heating power. As shown in Figure 1, the anti-/deicing component is installed on the windward surface of wind turbine blade, and the composite material anti-/deicing component is installed at the leading edge position of the wind turbine blade. The anti-/deicing component for wind turbine blades consists of iron surface, insulated heat transfer layer, wire heating pad, adhesive layer and insulated heat insulation layer. The insulated heat transfer layer and insulated heat insulation layer are made of carbon fiber and glass fiber.

![Figure 1. Anti-/deicing component of wind turbine blade.](image)

### 2. Anti-/deicing component optimization design

The working conditions of wind turbine blades are very complicated in the high-cold and ice-prone zones, which there are many factors that influence the anti-icing and de-icing effects of wind turbine blades. These factors include blade height, ambient temperature, altitude pressure, cloud and fog parameters, etc. The decisive factors for the anti-icing and de-icing effects of wind turbine blades are far from enough to run. Under the working conditions, the heat transfer factors of the anti-/deicing components of wind turbine blades are complicated, and the factors restricting the anti-/deicing components in the process of anti-icing and de-icing are also very complicated, which makes it more difficult to optimize the design of the anti-/deicing components for wind turbine blades.

There are many methods of optimization analysis and calculation based on a large number of data in engineering. The optimal parameter method as described in Lu [14] plays an important role in statistical design. Some geotechnical researchers use reliability analysis method to evaluate the failure risk of engineering in the field of Engineering [15-17]. Horizontal factor acquisition method is usually used for topology optimization of various materials [18-21]. Some researchers focus on the PSB method and propose an improved PSB method for solving partially separable partial optimization problems [22-23]. In general, the practical engineering optimization design usually involves five or more parameters with major influence, and the orthogonal array optimization method is used to replace the actual experiment to optimize the experimental design [24-26]. Orthogonal analysis, as an optimization method widely used in engineering field, can effectively analyze the weight relationship of influencing factors. Thus in this paper, orthogonal analysis method is employed to optimize the main parameters of composite material wind turbine blade anti-/deicing component.

#### 2.1. Optimization parameters

By choosing and determining the most relevant variable parameters and optimization parameters, the optimization parameters are as follows: V denotes the air inflow velocity; T is the ambient temperature;
and \( \lambda \) indicates the thermal conductivity of the insulation heat transfer layer of the wind turbine blade; \( H \) represents the height of the wind turbine blade; \( U \) represents the supply voltage of the wind turbine blade anti-/deicing component; \( L \) represents the distance between the heating wires of the wind turbine blade anti-/deicing component.

2.2. Optimization design

Based on the above analysis, the orthogonal experiment is employed to determine the scheme of orthogonal experiment. At the same time, according to the multi-variable parameters of wind turbine blade anti-/deicing component, the factors and level of optimization variables are determined (see Table 1). The optimization process can be summarized as follows: the specific process is as follows:

Step 1: Establish orthogonal test table by orthogonal test. Step 2 is to determine optimization variables and optimization level according to multivariate parameter data structure. Step 3 is to design the orthogonal test table and confirm the test plan. Step 4 is to test the result by orthogonal algorithm and extract the test results. Step 5 is to carry out the optimization analysis and put forward the optimization test. Step 6: through the analysis of the optimization conditions of the project, comparing and analyzing the optimized test. Finally, get the optimization results of multivariable targets.

Thus, the orthogonal experimental table is designed to determine the test scheme, and the numerical simulation is carried out by using ANSYS software. According to the optimization analysis, the optimization test scheme is proposed and the final optimization results are obtained. According to the actual temperature distribution optimization problem, through the analysis of engineering optimization conditions, finally the results of multi-variable objective optimization are obtained.

| Parameters | \( V \) (m/s) | \( T \) (°C) | \( W \) (r/min) | \( \lambda \) (W/(m·K)) | \( H \) (m) | \( U \) (V) | \( L \) (mm) |
|------------|--------------|--------------|-----------------|-----------------|-----------------|-----------------|
| Test 1     | 4.5          | -8           | 25              | 15.2            | 70              | 200             | 15             |
| Test 2     | 4.5          | -10          | 40              | 18.6            | 80              | 300             | 20             |
| Test 3     | 4.5          | -20          | 50              | 23.5            | 90              | 500             | 30             |
| Test 4     | 6.0          | -8           | 25              | 18.6            | 80              | 500             | 30             |
| Test 5     | 6.0          | -10          | 40              | 23.5            | 90              | 200             | 15             |
| Test 6     | 6.0          | -20          | 50              | 15.2            | 70              | 300             | 20             |
| Test 7     | 12.9         | -8           | 40              | 15.2            | 90              | 300             | 30             |
| Test 8     | 12.9         | -10          | 50              | 18.6            | 70              | 500             | 15             |
| Test 9     | 12.9         | -20          | 25              | 23.5            | 80              | 200             | 20             |
| Test 10    | 4.5          | -8           | 50              | 23.5            | 80              | 300             | 15             |
| Test 11    | 4.5          | -10          | 25              | 15.2            | 90              | 500             | 20             |
| Test 12    | 4.5          | -20          | 40              | 18.6            | 70              | 200             | 30             |
| Test 13    | 6.0          | -8           | 40              | 23.5            | 70              | 500             | 20             |
| Test 14    | 6.0          | -10          | 50              | 15.2            | 80              | 200             | 30             |
| Test 15    | 6.0          | -20          | 25              | 18.6            | 90              | 300             | 15             |
| Test 16    | 12.9         | -8           | 50              | 18.6            | 90              | 200             | 20             |
| Test 17    | 12.9         | -10          | 25              | 23.5            | 70              | 300             | 30             |
| Test 18    | 12.9         | -20          | 40              | 15.2            | 80              | 500             | 15             |
3. Simulation analysis of anti-/deicing

As shown in Figure 2 below, the wind turbine blade anti-/deicing numerical simulation is produced by numerical simulation analysis of multi-field coupling. The purpose of this simulation is to analyze the results such as temperature field distribution in the leading edge and inner skin of the wind turbine blade anti-/deicing component. The section shape and chord span size of the blade anti-/deicing test piece is 1.83m. The section shape is adopted as NACA 0012, and the test numerical model is set 0 degree of attack. The simulation system is used to provide the maximum flow speed of 12.9 m/s. Therefore, the icing condition is set as described in the relevant literature.

In this paper, three-dimensional modelling software Pro/E is used to establish the anti-/deicing module external flow field geometric model, and the professional fluid meshing software ICEM is used to divide the external flow field grid. The meshes are structured and refined on the windward surface of anti-/deicing module to improve the accuracy of external flow field calculation.

The coupled system solves the convective heat transfer coefficient of the blade surface in the flow field by ANSYS Fluent software. Because the blades of wind turbine are affected by air flow during the rotating process, the temperature distribution of anti-/deicing components will be affected directly. Therefore, the distribution of convective heat transfer coefficient on the blade surface is solved by ANSYS Fluent software, and used as the thermal boundary condition to solve the internal heat transfer distribution in the anti-/deicing component.

4. Discussion and results

Based on the analysis of the above factors, a set of optimization parameters (Test 19) are obtained by minimizing the temperature difference on the iron surface of the wind turbine blade anti-/deicing component: V= 4.5 m/s, T= -10℃. At the same time, the optimum parameters of rotor anti-/deicing component structure are given as follows: W= 40 r/min, λ = 23.5 (W/(m K)), H= 70 m, U= 500V, L= 15 mm.

Figure 3 shows the temperature differences of the wind turbine blade anti-/deicing component surface. Through analysis and calculation, it is known that each group performs numerical simulation to solve the difference of temperature. By comparing the data, it can be seen that the surface temperature difference of the anti-/deicing component of the optimized wind turbine blade is the smallest, which shows that the optimization can play the role of homogenizing the surface temperature field.

The optimization of the surface temperature of the anti-/deicing component can improve the anti-icing uniformity of wind turbine blades, and improve the anti-icing performance and de-icing performance of the anti-/deicing component. Meanwhile, heat transfer homogenization can reduce the thermal stress concentration caused by uneven heat transfer, which reducing the thermal fatigue damage and improving the service life of wind turbine blades.

![Figure 2. Numerical simulation procedure.](image)
Considering the heat transfer of the inner skin of the wind turbine blade, the temperature inside the skin is measured in this optimization. When the wind turbine blade anti-/deicing component works, the heat transfer starts through the composite insulation layer to the inner skin. The heat accumulation of the skin will cause thermal fatigue and thermal damage of the inner structure of the blade skin. Therefore, in the heat transfer design of blade anti-/deicing component, the influence of the inner temperature of the inner skin is considered, and the influence of the heating process of anti-icing/deicing on the inner temperature of the skin is required to be minimal.

The temperature distributions inside the skin are shown in Figure 4. It is found that the minimum and maximum temperature ranges of the inner skins of the optimization group are very small. It is shown that the optimized wind turbine blade anti-/deicing component can reduce the fluctuation of the temperature inside the skins in the heating process of power supply and effectively avoid the influence of thermal fatigue on the blade skins.

**Figure 3.** Surface temperature differences of optimization tests.

**Figure 4.** Internal temperature distribution in the wind turbine blades.
At the same time, in the analysis of experimental data, the lowest temperature in the fifteenth group of data is found to be lower than others. Through the analysis of mathematical model, the lowest temperature value occurs in the position of poor grid quality in numerical simulation, which belongs to numerical simulation error.

5. Conclusions
In this present work, the anti-/deicing component of composite wind turbine blade is designed by combining orthogonal optimization method with numerical simulation technology. The temperature field distribution on the surface and inside the skin of composite material wind turbine blade anti-/deicing component can be solved by numerical simulation, which provides the basis for the heat transfer research of anti-/deicing component. The main conclusions of this paper are as follows.

Through orthogonal optimization analysis, the structural parameters of composite anti-/deicing component are as follows: \( V = 4.5 \, \text{m/s} \), \( T = -10 \, ^\circ\text{C} \). At the same time, the optimum parameters of rotor anti-/deicing component structure are given as follows: \( W = 40 \, \text{r/min} \), \( \lambda = 23.5 \, (\text{W} / (\text{m} \cdot \text{K})) \), \( H = 70 \, \text{m} \), \( U = 500 \, \text{V} \), \( L = 15 \, \text{mm} \).

The numerical simulation results are obtained by simulation method, and it can be found that the heat transfer homogenization of anti-/deicing component can reduce the thermal stress concentration caused by uneven heat transfer, which reducing the thermal fatigue damage and improving the service life of wind turbine blades.

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