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Numerical Simulation Research on Flow Field Characteristics of Umbrella Wind Turbine

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Abstract

Taking the 5 kW umbrella wind turbine as the research object, the finite element simulation software ANSYS was used to carry out numerical simulation research on the flow field characteristics of the wind turbine under different shrinkage angle conditions, and the following conclusions were drawn. As the shrinkage angle increased, the pressure difference between the front and rear surfaces of the blade decreased gradually . The wake velocity deficit decreased with the increase of the constriction angle . As the shrinkage angle increased, the flow separation position of the blade moved to the leading edge, the flow separation area increased, and the flow separation phenomenon was serious. Through the above research, the variation trend of the flow field characteristics of the umbrella wind turbine with the shrinkage angle could be obtained, which laied a research foundation for the optimization of the umbrella wind turbine structure.

Keywords

Wind Energy; Wind Turbine; Shrinkage Angle; Power Control.

1. Introduction

The world's energy situation is developing towards a clean and low-carbon direction, and the development of new energy has received more and more attention, and wind power plays an important role in the development of new energy. Large-scale grid-connected wind power can solve the problem of power shortage to a certain extent, but for some remote islands, pastoral areas, forest areas, farms, fishing boats and other areas that are difficult to cover by power grids, small and medium-sized wind turbines can be distributed. effective approach to the problem. Due to the special application environment of distributed wind turbines, it is often accompanied by sudden changes in gusts and a large range of wind speed fluctuations, and the climate is relatively harsh, which has stricter requirements on the stability of the output performance of small and medium-sized distributed wind turbines. Therefore, this study proposed an umbrella-shaped wind turbine that controls its output power by controlling the retraction angle of the wind rotor by a servo motor to fold the wind rotor and change the sweep area of the wind rotor. The umbrella fan model can fully expand the blades to maintain the maximum output state when the wind speed is lower than the rated wind speed. When the incoming wind speed is higher than the rated wind speed, the output power of the umbrella wind turbine can be kept stable near the rated value by adjusting the retraction angle of the wind rotor. When the cut-out wind speed is exceeded or extreme weather such as typhoon is encountered, the retraction angle of the wind rotor can be adjusted to the maximum state to ensure that the generator and blades of the umbrella wind turbine are not damaged by strong winds and extreme weather. Because the flow field characteristics of wind turbines affect the performance of wind turbines such

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as structural dynamic characteristics, blade load distribution and noise, it is of great significance to further optimize the performance of umbrella wind turbines by studying the flow field characteristics of umbrella wind turbines under different constriction angle conditions.

Due to the limitations of the complexity and economy of experimental research, many researchers currently use the CFD numerical simulation method to study the flow field characteristics of wind turbines. D.B. Stoyanov et al.[1] proposed the method of tip speed ratio correction to improve the wind turbine output power decline in the case of ice accumulation. A 5MW NREL wind turbine was numerically simulated under 12 different freezing conditions (including different temperature, wind speed, droplet diameter and liquid water content). The results show that the proposed method can effectively reduce the power loss caused by ice accumulation in cold climate. B. Dose[3] et al. used two different tower concepts to study downwind wind turbine output performance. The obtained numerical results show that the truss tower causes more severe tower shadowing than the tubular tower, and the recovery of the wake wind speed behind the rotor is also slower. YAN[4]et al. conducted a numerical study on the aerodynamic performance of a Darrieus vertical axis wind turbine with Gurney flaps, and studied the flow around a single airfoil and the wind turbine by using the Navier–Stokes equations with different Reynolds numbers. field changes. Xiao Z[5] studied the aerodynamic performance of a vertical axis wind turbine through CFD software, and found that when the number of blades is constant, the wind energy utilization efficiency of the wind turbine first increases and then decreases with the increase of blade width. Li Deyin[6]conducted a numerical simulation of the flow field of a 300 W horizontal axis wind turbine with S-shaped blades. It was concluded that as the yaw angle increases, the output power of the wind turbine decreases; with the increase of the yaw angle, the degree of the wind turbine's wake drift increases, and the speed deficit decreases. Zhang Xuyao[7]set up different wind shear index conditions for a 33 kW horizontal axis wind turbine, and studied the influence of wind shear strength on the flow field change and aerodynamic load distribution of the horizontal axis wind turbine.

In this paper, the numerical simulation method was used to study the flow field characteristics of the 5kW umbrella wind turbine under different retraction angles, and obtained the variation characteristics of the surface pressure and wake velocity of the wind rotor. The results of the analysis will provided data reference for future umbrella wind turbine design and related work.

2. Umbrella Wind Turbine

The umbrella-shaped wind turbine design concept is shown in Figure 1. The wind turbine is configured in the downwind direction, and the output power is adjusted by folding the blades at the hub. When the incoming wind speed V1 is lower than the rated wind speed, the wind wheel does not undergo any shrinkage; When the incoming wind speed V2 exceeds the rated wind speed, the umbrella-shaped wind turbine reduces the power output by increasing the folding angle of the blades, and controls its output power to stabilize near the rated value. When the incoming wind speed exceeds the cut-out wind speed or encounters extreme weather, the umbrella-shaped wind turbine can adjust the shrinkage angle to the maximum state and fully retract the blades, thereby avoiding the wind turbine from being damaged by high winds. The angle between the blades and the plane of rotation perpendicular to the generator shaft is the shrinkage angle, which is represented by γ.

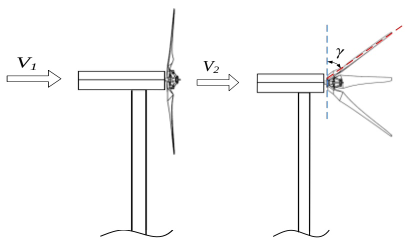

Figure 1. Conceptual schematic diagram of umbrella-shaped wind turbine

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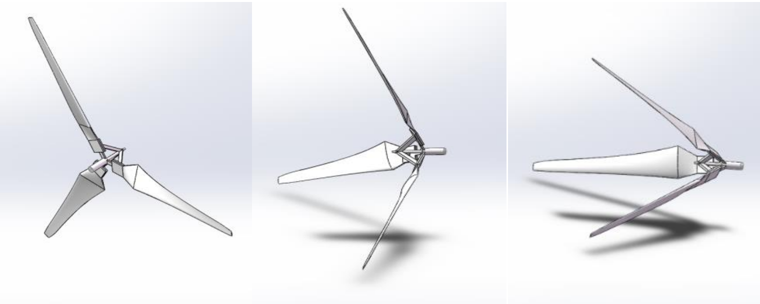
3. Numerical Simulation Model Establishment

3.1 3D Model

Umbrella wind turbine blades used NACA63415 airfoil. On the premise of not affecting the accuracy of the numerical simulation results, the structure of the umbrella-shaped wind turbine was simplified, and the wind wheel model of the 5kW umbrella-shaped wind turbine under different contracting angle conditions was obtained, as shown in Figure 2.



(a) 0° (b) 35° (c)60°

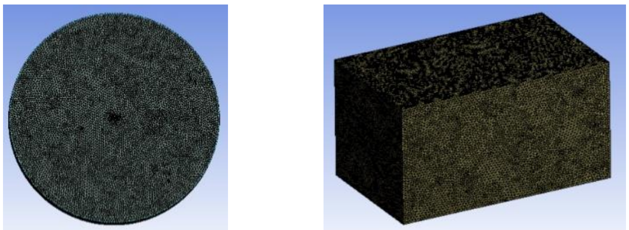
Figure 2. Simplified model of wind rotor under different shrinkage angles

3.2 Construction of Computational Domain

The calculation area included two parts: the rotating inner domain and the stationary outer domain. The rotation inner domain was used to simulate the rotation of the wind turbine rotor, and it was represented by a cylinder larger than the diameter of the rotor [8]. The static outer domain was used to simulate the air flow field where the wind turbine was located, which was represented by a cuboid. The diameter of the wind rotor when the umbrella wind turbine is not retracted is 5m. Set the length of the static outer domain to 6D (D is the diameter of the wind wheel), and the width and height to 4D.

3.3 Meshing

Due to the complex geometry of the umbrella wind turbine, tetrahedral unstructured meshes were used for analysis. The grid size of the rotating inner domain was set to 40mm, and the minimum size was 5mm. The mesh size of the computational outer domain was set to 220mm, and the minimum size was limited to 20mm. Figure 3 shows the meshing diagram of the inner domain of rotation and the outer domain of calculation after the deflection of the wind rotor of the umbrella wind turbine.



(a) Rotation domain grid (b) Computational domain grid

Figure 3. Example of meshing

3.4 Turbulence Model and Boundary Conditions

In this paper, the SIMPLE iterative algorithm was used to solve the problem, and the SST K-ω turbulence model was used for numerical calculation. The SST k-ω turbulence model is a good combination of the k-ε turbulence model and the k-ω turbulence model by using a mixed function. It has the characteristics of the k-ε turbulence model to deal with free flow and the characteristics of the k-ω turbulence model to deal with the wall-constrained flow [9].

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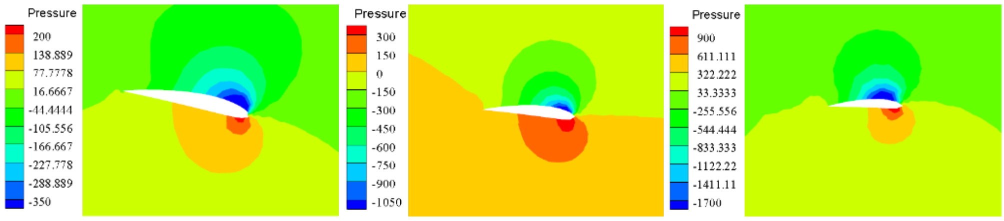
The interface of the calculation domain at the wind direction of the wind turbine was selected as the inlet, and the boundary condition of the inlet was defined as Velocity inlet, and the turbulence intensity was set as 5%. Outflow was used as outflow boundary condition, and relative pressure was set as 0 Pa. The computing domain interface at downwind of wind turbine was selected as outflow boundary condition. The four surfaces of the computational domain, the upper, lower, left, and right surfaces, as well as the rotor composed of blades and hubs, were set as no-slip wall boundary conditions. The interface between the rotation domain and the rest domain of the calculation area was defined as interface. The maximum number of iteration steps was set as 1000, and the convergence residual was set as 10-4. After the setting was completed, it was entered into CFX-Solver for calculation.

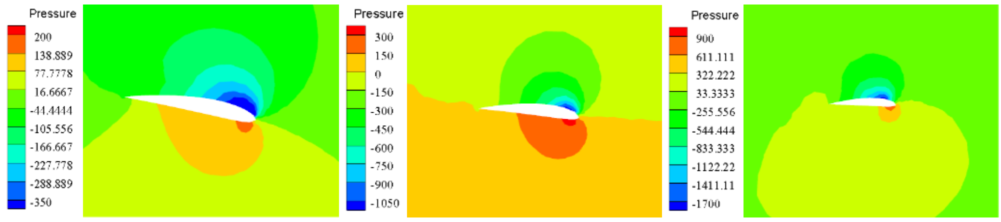
4. Analysis of Numerical Simulation Results

Due to the shrinkage Angle condition, the aerodynamic force distribution of the umbrella wind turbine will be changed, which will affect its flow field. This study, the pressure, velocity and flow separation are studied respectively, and the influence of the shrinkage angle on the flow field characteristics of the umbrella wind turbine is analyzed.

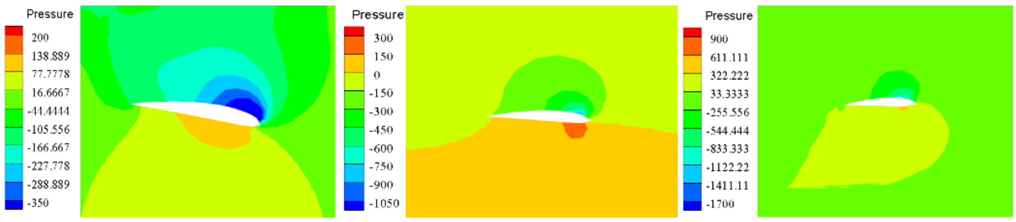
4.1 Pressure Variation Characteristic



a) 0º, 0.25R section b) 0º, 0.55R section c) 0º, 0.95R section



d) 35º, 0.25R section e) 35º, 0.55R section f) 35º, 0.95R section



g) 35º, 0.25R section h) 35º, 0.55R section i) 35º, 0.95R section

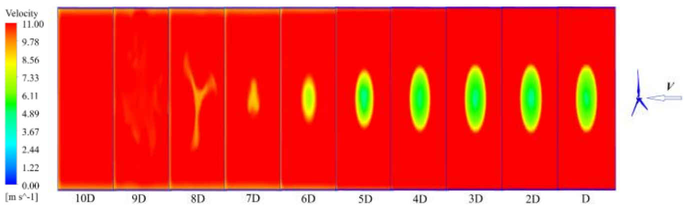
Figure 4. Pressure variation at different sections of blade

The blades vertically upward without wind turbine shrinkage were selected, and the sections with relative radii of 0.25 R, 0.55 R, and 0.95 R were selected with the hub as the center of the circle to explore the pressure difference changes at each section of the umbel wind turbine under different shrinkage angles. The results are shown in Figure 4. At different shrinkage angles, the maximum pressure difference at different sections of the blade occurred at the leading edge. At the blade root (0.25 R section), as the shrinkage angle increases, the negative pressure area on the suction side does not change significantly, the positive pressure area on the pressure side decreases at a 60º shrinkage angle, and the pressure difference at the blade root decreases slightly trend. In the middle (0.55R section) and tip (0.95R section) of the blade, with the increase of the shrinkage Angle, the range of the high pressure area on the pressure surface and the low pressure area on the suction surface decreases significantly, and the pressure difference between the pressure surface and the suction surface also gradually decreased.

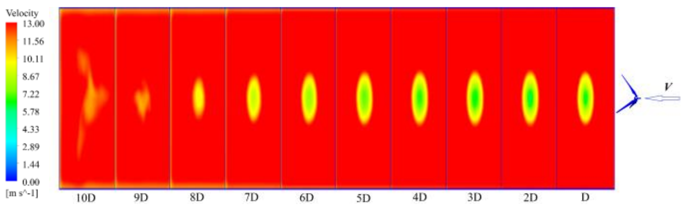
4.2 Wake Variation Characteristics

The wake will be generated when the inlet wind flows through the wind turbine, which is essentially caused by the speed loss caused by the conversion of wind energy into mechanical energy through the rotation of the wind turbine. In the power regulation process of the umbrella wind turbine, the shrinkage Angle of the wind turbine will be changed due to its special power regulation mode, which will affect the wake to a certain extent.

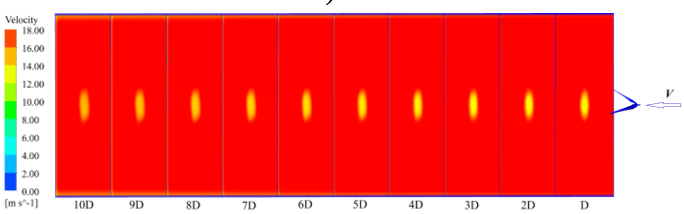
In order to explore the distribution of wake diameter and wake size at different sections behind the wind wheel, sections at 1-10D distance behind the wind wheel of an umbrella wind turbine under different shrinkage angles were selected for study. The wake cloud diagram is shown in Figure 5. When the incoming air flows through the umbrella wind turbine under different working conditions, the velocity deficit of different layers is generated, but the velocity deficit is also different because of the different shrinkage Angle. The wake distribution of the umbrella wind turbine is symmetric under different shrinkage angles, and the wake diameter decreases with the increase of shrinkage Angle, which is caused by the decrease of the diameter of the wind wheel due to the increase of shrinkage Angle. Umbrella in different working condition of shrinkage Angle different cross-section wake after rotor speed wind turbines with the spatial distribution of consistent, lowest speed wind turbines in the center, outward along the rotor diameter, velocity increased, eventually is consistent with the wind to flow, this is due to the center of the vortex, produced by the rotation of wind turbines attached vortex and tip vortex caused different influence.



a) 0º



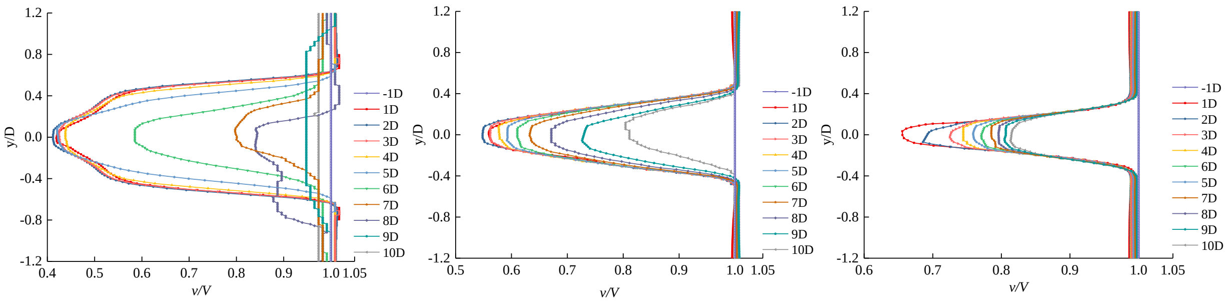
b)35º



c)60º

Figure 5. wake cloud at different sections behind the wind turbine

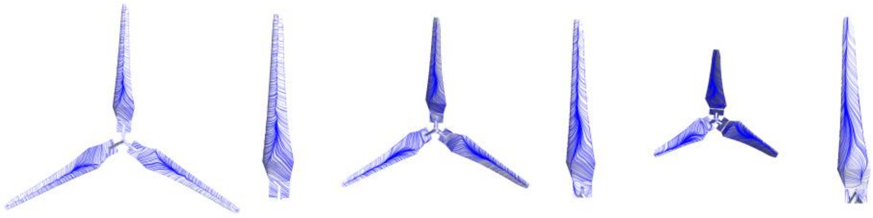
In order to have a more intuitive understanding of the spatial distribution of the wake velocity at different sections behind the wheel of the umbrella wind turbine under different working conditions, the wake velocity at different sections behind the wheel was extracted along the Y-axis direction with the origin of coordinates as the center (the value was positive along the Y-axis direction, and the value was negative along the Y-axis direction). The wake velocity v and the distance Y along the Y-axis were used to make the flow wind speed V and the wind turbine rotation diameter D dimensionless. The changes of wake velocity in spatial distribution are shown in Figure 6. Based on the analysis of Figure 6, it can be seen that after the inlet air flows through the plane of the wind turbine, the speed decreases significantly due to the work done on the wind turbine. However, the position of the minimum wind speed on the 10 interfaces of the wind turbine under different shrinkage Angle conditions is also different. When the shrinkage Angle is 0º, the maximum velocity deficit occurs at the position 2 days after the wind turbine plane. When the shrinkage Angle is 36º and 60º, the maximum velocity deficit occurs 1 D behind the plane of the wind turbine. When the shrinkage Angle is 0º, the velocity deficit degree is strong, and the lowest wind speed behind the wind wheel is about 45% of the incoming wind speed. When the shrinkage Angle increased to 35º, the speed deficit degree of the umbrella wind turbine also weakened, and the lowest wind speed behind the wind wheel is about 55% of the incoming wind speed. When the shrinkage Angle increases to 60º, the speed deficit of the umbrella wind turbine is further weakened, and the minimum wind speed behind the wind wheel can reach more than 65% of the incoming wind speed in the 60º shrinkage Angle condition.



a) 0º b)35º c)60º

Figure 6. Dimensionless velocity variation of wake at different cross sections

4.3 Flow Separation Characteristic



a) 0º b)35º c)60º

Figure 7. limit streamline diagram of umbrella wind turbine blades

Flow separation is a common phenomenon in fluid mechanics, which is often accompanied by the flow around the wind turbine blade, and has a great impact on the aerodynamic performance of the wind turbine. Therefore, it is very necessary to study the flow separation of the wind turbine blade. In order to vividly show the flow separation phenomenon on the blade surface, the streamline when the distance between the fluid and the object surface was infinitely close, that is, the limit streamline, was used to describe it. Figure 7shows the limit flow diagram of suction surface flow separation of umbrella wind turbine under different shrinkage angles. The flow separation of different layers occurs in the umbrella-shaped wind turbine operating at different shrinkage angles. When the shrinkage Angle is 0º, the blade flow separation line is located at half the distance from the blade leading edge, and the flow separation area is small at this time. With the increase of umbrella shrinkage Angle, the position of blade flow separation line gradually moved forward, and the flow separation area gradually increased. When the shrinkage Angle increases to 60º, the flow separation position occurs at a quarter of the distance from the blade leading edge. At this time, the flow separation area is the largest, and the increase of the flow separation area may lead to the stall characteristics of the wind turbine.

5. Conclusion

Under different shrinkage angles, the maximum pressure difference at different sections of the blade occurs at the leading edge. With the increase of the shrinkage Angle, the range of the high pressure area on the pressure surface and the low pressure area on the suction surface decreased significantly, and the pressure difference between the pressure surface and the suction surface also gradually decreased.

Under different shrinkage angles, the velocity deficit degree and velocity recovery of the wake flow of the umbrella wind turbine are different. When the shrinkage Angle is 0º, the velocity deficit degree of the umbrella wind turbine is strong, and the velocity deficit degree decreases gradually with the increase of the shrinkage Angle.

Under different shrinkage angles, the flow separation position of the umbrella wind turbine changes. When the shrinkage Angle is 0º, the flow separation occurs at the position half away from the blade leading edge, and the flow separation area is small. As the shrinkage Angle increases, the flow separation area increases. When the shrinkage Angle is 60º, the flow separation occurs at a quarter of the blade from the leading edge, and the flow separation area is the largest.

Acknowledgments

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