Numerical simulation of flow field in umbrella wind turbine

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Abstract. Umbrella wind turbine can control the swept area by adjusting the shrinking angle of the rotor so as to ensure that output power is near the rated value. This is very helpful for the utilization of wind energy in sandstorms and typhoon-prone areas of our country. In this paper, Fluent software is used to simulate the velocity field and pressure field of 5kW Umbrella Wind Turbine at 0°, 45° and 60° angle of contraction. The results provide a theoretical basis for further improving the power adjustment mechanism of Umbrella Wind Turbines. At the same time, it also provide a reference for our country to perfect the wind energy utilization system about the typhoon environment in the coastal areas.

1. Introduction
Wind energy is highly concerned because of its advantages such as wide resources and no pollution. First of all, China is rich in wind energy resources. According to the relevant data, the total reserves of wind energy resources at the altitude of 10m above the ground in China are about 4.35 billion kW, ranking the first in the world[1]. Secondly, wind energy doesn’t produce harmful substances that polluted environment during energy conversion[2]. Therefore, many countries have promulgated a series of policies to encourage the utilization of wind energy. It is estimated that the electricity provided by renewable resources will account for 30% ~ 40%, of which wind power occupies the vast majority[3]. However, the wind resources are unstable, fluctuate greatly due to the influence of geographical environment and time. For example, sandstorm often occur in northern China and multiple typhoons in coastal areas, so the utilization rate of wind energy can’t be optimistic. In response, this project research and develop an umbrella wind turbine. When the wind speed is lower than the rated wind speed, the maximum power tracking can make the wind turbine maintain the maximum power output[4]. When the wind speed is higher than the rated wind speed, by adjusting the rotor angle of contraction to guarantee that the output power in the vicinity of the rated value[5]. To ensure that the umbrella wind turbine from gale and extreme weather damage, this article simulate the Umbrella wind turbine rotor model using Fluent software, study the flow field distribution of velocity and pressure under different angles of contraction, and to provide a theoretical basis for better control of the power output of the umbrella wind turbine.

2. Establish a mathematical model

2.1. Wind wheel 3D model
In this paper, a three-dimensional Umbrella wind wheel with a power of 5kW, a diameter of 4.8m and a number of blades of 3 was modeled. Using profilii software to export airfoil two-dimensional discrete point coordinates; through Excel software into three-dimensional space coordinates, and save as TXT
file; importing 10 cross-section of the leaf element data in SolidWorks, build the rotor model by stretching, stakeout, array and other commands.

![Airfoil curve](image1.png) ![Blade three-dimensional model](image2.png) ![Wheel three-dimensional model](image3.png)

(a) Airfoil curve (b) Blade three-dimensional model (c) Wheel three-dimensional model

Fig. 1 Wind wheel modeling process

2.2 Mesh

Before meshing, it is necessary to construct a rotating domain and a static domain model in the Geometry module in ANSYS. The rotating field is used to simulate the rotation of the umbrella rotor, with a circle larger than the diameter of the rotor to show. The static domain is used to simulate the air flow field where the wind wheel is located, with a 35m×10m×10m rectangle said. Through the use of Boolean operation, provide the basis for the subsequent numerical simulation.

Due to the irregular surface of the blade, the unstructured grid is used to mesh the inner flow field, and the mesh near the blade is properly encrypted. External flow field geometry relative rules, the use of structured mesh. The generated mesh is shown in Figure 2.

![Static field meshing](image4.png) ![Rotating field meshing](image5.png)

(a) Static field meshing (b) Rotating field meshing

Fig. 2 The Grid partition graph

2.3 Set the boundary conditions

- Set the inlet boundary: define the inlet of the flow field as inlet, and select the velocity inlet as the inlet boundary condition. The incoming velocity is uniform and irrespective of wind shear, the direction of wind speed is perpendicular to the inlet of the flow field.
- Set the exit boundary: define the exit of the flow field as outlet, and select the outflow as the exit boundary condition. The reason is that the air flow through the wind turbine caused energy loss, the size of pressure and velocity at the exit of the flow field are unknown.
- Set the boundary of the wall: Define the wall in the calculation domain as the solid wall, then define the rotor as the wall, and the other parameters are software defaults.

3. Analysis of flow field characteristics of umbrella wind wheel

3.1 Pressure field analysis

Umbrella wind turbine in operation, the blade windward and leeward pressure distribution varies greatly. Therefore, in order to ensure stable and reliable operation of the wind turbine. It is necessary to simulate the pressure field when the rotor angle is 0°, 45° and 60°.
3.1.1 Shrink angle 0°, wind speed 11m / s, speed 220rpm. When the shrinking angle is 0°, the umbrella wind turbine is not retracted at the rated wind speed of 11m / s, which is equivalent to the horizontal axis wind turbine. The pressure distribution on the blade surface will affect the output power of the wind turbine, as shown in Figure 3 nephogram.

![Figure 3](image_url)

(a) Windward side  
(b) Leeward side

Figure 3 pressure nephogram of the blade at shrinkage angle 0°

As shown in the figure: When the shrinkage angle is 0°, the pressure distribution on the windward side and the leeward side of the blade is gradually reduced from the tip part to the root part, and the leeward surface changes more obviously. From the windward surface to the leeward side, the reduced extent of pressure distribution is increased, and a low pressure area is formed at the part of the windward side near the root of the blade. Because of the pressure difference between the windward side and the leeward side of the blade, lift is generated on the blade. And the greater the pressure changes, the greater the corresponding lift in the blade, the greater output power.

3.1.2 Shrink angle 45°, wind speed 15m / s, speed 240rpm. When the incoming wind speed exceeds the rated wind speed, umbrella wind turbine began to do the retractable movement. The shrinkage angle of the wind turbine changes from 0° to 45°. As the swept area decreases, ultimately control the power output and reduce damage to the blades. The following picture shows the simulated nephogram.

![Figure 4](image_url)

Fig. 4 Pressure nephogram of blade at angle 45°

![Figure 5](image_url)

Fig. 5 Airfoil surface pressure nephogram at shrinkage shrinkage angle 45°

When the shrinking angle is 45°, the maximum pressure point is generated near the windward side of the blade. The reason for this phenomenon is that during the rotation of the umbrella wind turbine, the windward side of the blade is firstly subjected to air resistance. Therefore, the air flow velocity in the system also decreases rapidly. Through the analysis of Bernoulli equation, a large pressure will be generated on the blade, resulting in a flow separation on the leeward side of the blade. This area not only formed a swirl zone, and the pressure was reduced faster. Analysis the Figure 5 shows that the cross-section pressure coefficient at the pressure surface presents the trend of decreasing firstly then increasing, and the cross-section pressure coefficient value of the suction surface also gradually increases.

Overall, when the wind speed increases to 15m / s, and the windward surface pressure of the blade in the angle of 45° is significantly lower than that of 0°, it indicates that the contraction action of umbrella wind turbine can reduce the damage to the blades caused by the large wind speed, play a role in protecting the blades.
3.1.3 Shrink angle 60°, wind speed 20 m/s, speed 194 rpm

Fig. 6 Airfoil surface pressure nephogram at shrinkage angle 60°

The results show that when the wind speed continues to increase to 20 m/s, the Umbrella wind wheel shrinks from 45° to 60°, and the swept area continues to decrease. As a result, the pressure on the pressure surface of the umbrella wind turbine blade instantly increases, the pressure difference between the windward surface and the leeward surface increased significantly. Compared with 0°, 45° further shelter, reduce damage to the blade.

3.2. Velocity field analysis

The flowing wind through the rotating umbrella wind wheel, the speed will have a relative degree of loss. A clearer description of the velocity field distribution of umbrella wind turbine under different wind speed and contraction angles, it is necessary to simulate and analyze the velocity field under different working conditions.

3.2.1 Shrink angle 0°, wind speed 11 m/s, speed 220 rpm

As can be seen from the figure, during the rotation of the wind wheel, when the flowing wind passes through the area under the downwind direction, some of the wind energy can be directly absorbed by the blade, resulting in a loss phenomenon of the flowing wind speed, causing the wind speed flowing over the windward direction of the blade to decline, resulting in a sharp reduction in output. If the wind turbine is spinning, its maximum speed is essentially at the tip of the blade. As a result of the centrifugal force, the wake region is flowing along the radial direction and at the same time the imbalance of the pressure gradient causes a loss of axial velocity.

3.2.2 Shrink angle 45°, wind speed 15 m/s, speed 240 rpm
The results show that when the wind speed is higher than the rated wind speed, the umbrella wind turbine starts to shrink, and the blade changes from the fully expanded state into an umbrella shape, the windward side speed gradient decreased significantly, the velocity at the blade root reaches the minimum, and the flow separation area gradually decreases, from it can be seen that the low speed zone of the umbrella wind turbine is mainly concentrated in the rotation zone and the wake area of the wind turbine. In the leeward side of the blade, the local high-speed phenomenon appears at the rotation center, along the blade exhibition direction, the velocity showed a decreasing trend. The main reason is that tip vortices and tail vortices are produced in two parts of blade tip and blade tail. At the same time in the horizontal direction, the leeward low velocity region has obvious enlarging tendency, the nearby flow field has an obvious gain effect and the flow velocity of the surrounding flow field is aggravated. In the vertical direction, From the root to the tip gradually extend out of the low-speed area, Concentrated on both sides of the tip.

3.2.3 Shrink angle 60°, wind speed 20m/s, speed 194rpm

When the shrinkage angle of the umbrella wind turbine reaches the limit position, three groups of uniform closed loops are formed on the windward side of the blades in the lower wind direction, and the velocity distribution gradually decreases from the outside to the inside; the wake phenomenon is significantly enhanced in the upwind area, Wake area continues to increase, wakes along the horizontal direction of continuous growth. The asymmetrical velocity distribution area appears on the leeward side of the blade, and the closer to the root of the blade, the velocity distribution is the more uneven. The main reason is the constant change of velocity, which makes the vorticity distribution on both sides of the wind turbine relatively uneven. Moreover, the greater velocity reduction extent in the wake area, the larger the low speed area, the stronger the ability of the wind wheel to work.

4. Conclusion

In this paper, the 5kW umbrella wind turbine is taken as the research object, through three-dimensional modeling, meshing, boundary condition setting, etc. Finally, the velocity field and pressure field of the wind wheel are simulated at different shrinkage angles, different wind speeds and different speeds, the conclusions are as follows:
• By simulating the pressure field of the wind turbine under three different conditions, the results show that with the shrinkage angles increase, the pressure of the windward and leeward surfaces of the blade gradually decreases, it indicates that the contraction action of umbrella wind turbine can reduce the damage to the blades caused by the large wind speed, play a role in protecting the blades.

• By simulating the velocity field of the wind turbine in three different conditions, the results show that with the wind turbine Shrinkage angle increases, the velocity of flowing wind through the blades is decreases, which extent gradually increase, Therefore, the power output of the umbrella shaped wind turbine is controlled, and effective avoidance is realized.

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