Flow Field Analysis of Wind Power Generation System

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Abstract. The purpose is to solve the problem of wind power curtailment in the wind power generation system. A new type of wind power generation system made of flexible blades is proposed. Combined with the experimental method and numerical simulation method, the impeller blades are analyzed by flow field. The values of the lift coefficient of the leaves under different working conditions were obtained and analyzed. The optimum curvature and the range of the best angle of attack are determined. The influence of the parameters such as the curvature of the blade and the angle of attack on the hydrodynamic performance of the blade and impeller in the power generation system is obtained. The results showed that the best curvature K was 0.019 and the best angle of attack was 20°. Therefore, it can be concluded that it reveals the influence of blade curvature and angle of attack on the lift coefficient.

1. Introduction

As the world's energy consumption increases, carbon dioxide emissions are also increasing. It causes global warming. The resource depletion and environmental degradation have brought severe challenges to countries all over the world [3]. Since the 10th Five-Year Plan, China's total energy consumption has grown too fast. The pollutant emissions ranked the forefront of the world [7]. The greenhouse gas emissions account for 25% of the world's total. China's economy has reached a critical stage of "transition and development" [5]. Since the implementation of China's sustainable development strategy, its main line can be expressed as "science, green, low carbon." Energy conservation, efficiency improvement and reasonable control of energy demand are important tasks of energy strategy [2].

With the continuous increase of energy consumption, the wind power industry has developed rapidly. Wind energy resources are abundant and widely distributed in china. It is mainly distributed in the northern and southeastern coastal areas. According to the evaluation of Chinese Academy of meteorological sciences, China's wind energy reserves is about 253GW [1]. Offshore wind energy is far more abundant than land-based wind energy, which is about three times more than it. Therefore, as a clean and renewable energy, wind energy has important value in the sustainable development.

2. State of the art

Since 2006, the installed capacity of wind power generation around the world has shown an upward trend [4]. From 2007 to 2009, the growth rate of new installed capacity of the whole world is larger, and the maximum can reach 45%. The maximum installed capacity can reach 32%. Since 2010, due to the impact of the global economy, the growth of new installed capacity has slowed down. The growth rate of the total installed capacity has dropped to 20%. By the end of 2011, the global cumulative installed capacity of wind power generation reached 237669MW. China's new installed capacity growth has gradually slowed down. The number of new installed capacity is 17630.9MW. The
cumulative installed capacity of China is 62364.3MW. It indicates that China's wind power industry from the rapid development stage to the adjustment period in 2011 [6].

During the working of electric system, the hydropower station generating unit is in the functions of peak load regulation of power grid and emergency standby. Hydro turbine generating unit has two kinds of braking methods: electric braking and mechanical braking. In general, the mechanical braking method creates the braking effect through the fraction drag generated by the touching of brake valve and brake ring, whereas the electric braking works through consuming the main power in a form of electricity and generating reverse electromagnetic force in the motor. The wind power generation system has a wide range of applications. In the 80s of the last century, a great deal of research was done abroad. However, the early development of wind power generation system has a high risk, which led to private companies do not want to take risks alone. Therefore, the research funding of MEMS gyroscope mostly comes from the government abroad. The United States relies mainly on universities [5]. The main MEM research university is Stanford University, Georgia Institute of Technology, University of California, Los Angeles, and Dreiberi Laboratory (CSDL). Europe has a national research in France LETI (Information and Electronic Technology Laboratory). Germany has a non-profit Fraunhofer Institute and the German Institute for wind power generation system. In addition, there are some universities and research institutes in Switzerland. In 2002, ADI published a gyro system program. The gyro adopts the capacitive micromechanical gyroscope of the body processing method. The micro machined structure and the readout circuit are integrated on the same substrate.

The generating unit employs traditional braking method: mechanical braking method, which is reliable, convenient and widely applicable, with low energy consumption. Its braking effect will not be influenced by faults like power interruption or short-circuit of line owing to its high reliability and safety. However, this mechanical braking method also has some shortcomings, for example, the powder generated during the braking process may enter the ventilation ducts, and powder accumulation during long periods of time will downsize the cross-section area of ventilation ducts and result in loss in cooling effect. During the process of braking, the surface temperature of the braking ring will increase rapidly, leading to thermal distortion and even crack. The airlock sometimes cannot fall itself, so our personnel will inspect the wind tunnel at every stop of it, which also lowers its level of automation.

The increase of installed capacity of wind power will inevitably lead to the increase of power generation in wind power generation system. However, due to the seasonal and environmental factors, wind power has its own volatility and randomness, which has a certain impact on grid connection. At the same time, the wind resources are unevenly distributed, and the large wind field is far away from the load center. Due to the limitation of peaking capacity, the wind power consumptive capacity is weakened. The phenomenon of wind power rationing has become a prominent problem. In order to solve this problem, in the "12th Five-Year" period, the government put forward the requirements of wind power consumption. The relevant policies have been introduced to support decentralized development of wind power generation. The development of small-scale distributed wind power generation is actively promoted. Therefore, a new type of wind turbine generator has been developed, whose blade is made of flexible material [10]. When the force is different, the curvature of the blade will change in different degrees, and the lift effect of the fluid can be taken into full use to extract the wind energy. At the same time, a wind collecting hood with wind collecting effect is arranged outside the impeller of the wind power generation system to increase the wind speed at the entrance of the fan. It provides more power for the wind turbine to do its work. The wind turbine has the advantages of simple structure, low starting wind speed, and strong mobility and flexibility. The utility model is suitable for providing power generating power for residents in the covered blind area of China's power grid, and establishing a separate power supply system, which solves the regional non-electric problems caused by the remote area and the difficult construction of the power grid [9]. At the same time, it can also take full advantage of the local wind resources, to avoid the wind power curtailment condition and other problems.
3. Methodology
In all wind power system equipment, the most important component is the impeller part. The impeller is the most important part that affects the efficiency of wind turbine. The shape of the blade on the impeller directly affects the aerodynamic performance of the blade. As the core part of the wind turbine, the pneumatic performance of the blade directly dominates the conversion efficiency of the wind turbine.

3.1. Experimental study method
The experimental object consists of two cascades. Each leaflet contains 3 identical blades. Taking the middle of the leaves as a test blade, the test blade is made of rigid material. The span length is 200mm, the section arc length is 60mm, the thickness is 3mm, and the curvature of each group is different. At the face of the blade pressure and suction, the ten holes are drilled evenly and inserted into the piezometric tube and numbered [8].

The ambient temperature is 25 °C, the atmospheric pressure is 88.92kpa, the air density is 1.04Kg / m³, and the wind speed v of the closed experimental section is set to 5m / s. There were 5 kinds of leaves, and each group of leaves were tested under 6 angles of attack. The experimental conditions are shown in Table 1.

| \( K \) | \( \alpha/\degree \) | \( V / \text{m/s} \) | \( d/\text{mm} \) | \( h/\text{mm} \) | Total number of test groups |
|---|---|---|---|---|---|
| 0 | 5 | | | | |
| 0.009 | 10 | | | | |
| 0.013 | 15 | | | | |
| 0.017 | 20 | 5 | 200 | 70 | 30 |
| 0.026 | 25 | | | | |
| 0.030 | 30 | | | | |

3.2. Numerical simulation method
CFD is an abbreviation for Computational Fluid Dynamics. Through the numerical calculation of the computer, the numerical simulation method is used to replace the fluid experiment, and the fluid flow state and the heat conduction are solved and analyzed.

The cascade geometry is established, and the cascade structure is the same as that of the cascade in the test experiment. They are composed of two cascades. Each leaflet contains 3 identical blades. The blade length is 200mm, the section arc length is 60mm, and the thickness is 3mm. The size of the calculated domain is the same as that of the experimental wind tunnel. The distance between the inlet end and the outlet end is 3000mm. Width and height are 900mm.

The geometric model is meshed. The unstructured grid is more practical for boundary complex problems. Therefore, the tetrahedral unstructured mesh is used as the basic element, and the mesh of the mesh surface is refined. The total number of total domains is 3.1 million. The quality of the grid is checked, and the distortion of Skewness is 0.25. The maximum value is 0.42. Therefore, the quality of the grid is considered to meet the calculation requirements. The fluid is set to air and the reference back pressure is set to 88.92 kPa. The inlet boundary is set to the velocity inlet boundary and the inlet speed is 5 m / s. The exit boundary is set to free outflow. The other surfaces of the blade and the computational domain are non-slip wall boundary conditions, and they are adiabatic. For turbulence computation, the RNG model is adopted, and the second-order upwind scheme is chosen in the difference scheme to ensure a high computational accuracy.

The straight blade and the blade with 0.017 curvature are chosen as the object to carry out numerical simulation, so as to obtain the pressure difference on the blade. Then, it is substituted into the lift coefficient calculation formula to solve the lift coefficient value. The lift coefficient is compared with the experimental results. The comparison results show that the simulation results are basically consistent with the experimental results, and the relative average error is about 5%. Thus, it
is considered that the numerical simulation method is correct. Through the experimental study of the lift characteristics, the range of the optimum curvature and the optimum angle of attack are found. In order to accurately determine the optimum working conditions of blade, 14 kinds of blades with curvature between 0.013 and 0.026 are chosen as the object of study, and three kinds of angle of attack are chosen at 15°, 20° and 25° respectively. The specific calculation conditions are shown in Table 2, and the number of calculation groups is 42. By numerical simulation, the optimum blade shape and optimum angle of attack are obtained by comparing the magnitude of each lift system.

| $K$   | $\alpha/^{\circ}$ | $V$/m/s | d/mm | h/mm | Total number of test groups |
|-------|--------------------|---------|------|------|-----------------------------|
| 0.013–0.026 | 15/20/25     | 5       | 200  | 70   | 42                          |

4. Result analysis and discussion

4.1. Experimental results

Through the blade surface pressure test, the pressure difference $F$ in the normal direction of the blade surface was obtained. From the previous analysis, the blade $F$ deformed by the force $F$ can be decomposed into the horizontal direction of the component and vertical force. Assuming that each test point on the blade is a micro-area, the component $F_{Li}$ of the pressure difference $F_i$ in each vertical area is obtained experimentally. The $F_{Li}$ is brought into the lift coefficient calculation formula (1), and the lift coefficient on the region is approximated. Finally, the average value $C_{L_i}$ of the lift coefficient of the 10 regions is obtained, and the advantages and disadvantages of the lift characteristics are represented.

$$C_{L_i} = \frac{F_{Li}}{\frac{1}{2} \rho \nu^2 \cdot c} \tag{1}$$

Leaf lifting coefficient $C_L$ is influenced by curvature $K$ and angle of attack $\alpha$. The law of the lift coefficient with the angle of attack is shown in Figure 1 and Figure 2.

Fig.1 The relationship between lift coefficient and attack angle on layer blade

![Fig.1 The relationship between lift coefficient and attack angle on layer blade](image-url)
As can be seen from Figure 1, the lift coefficient of all leaf types increases first and then decreases with the increase of the angle of attack $\alpha$. The angle of attack of the maximum blade and the maximum lift coefficient of curvature of 0.009 is less than 15°. The other three kinds of leaf lift coefficient corresponding to the maximum angle of attack are greater than 20°. The lift coefficient is much larger than the first two leaves. The leaf with a curvature of 0.017 has the largest lift coefficient at an angle of attack of 20°.

![Fig.2 The relationship between lift coefficient and attack angle on back blade](image)

As can be seen from Figure 2, the value of the lift coefficient of the back leaves is similar to that of the front layer, and they all increase first and then decrease. When the angle of attack is the same, the lift coefficient of the later blade is larger than the lift coefficient of the front blade. Combined with the above two figures, the best angle of attack is between 15° and 25°.

Figure 3 and Figure 4 is the lift coefficient with the curvature of the law. When the angle of attack is fixed, with the increase of the curvature of the blade, the lift coefficient increases first and then decreases. From the figure, the curvature of the blade is 0.017, and the lift coefficient is the largest, so the best curvature appears between 0.013 and 0.026.
Through the above analysis, the lift coefficient of the back layer leaves is larger than the lift coefficient of the front layer leaves under the corresponding working conditions. This indicates that the lift characteristics of the late leaves are better than those of the front leaves. When the curvature of 0.017 leaves at an angle of attack of 20°, the lift coefficient of the front and back leaves is the largest in all working conditions. Thus, the curvature of 0.017 and the angle of attack of 20° were studied.

4.2. Numerical simulation results
The numerical values of the lift coefficient of each group were calculated by numerical simulation. Figure 5 and Figure 6 show the influence of the curvature and the angle of attack on the lift coefficient.
0.014 0.016 0.018 0.020 0.022 0.024 0.026
0.85
0.90
0.95
1.00
1.05
1.10
1.15
1.20
1.25
1.30
1.35
1.40
1.45

Curvature K

0.014 0.016 0.018 0.020 0.022 0.024 0.026

Fig.5 Relationship among lift coefficient, curvature and attack angle on layer blade

Fig.6 Relationship among lift coefficient, curvature and attack angle on back blade

From the figure, when the angle of attack is 15°, the best curvature is 0.018. When the angle of attack is 20°, the best curvature is 0.019. When the angle of attack is 25°, the best curvature is 0.020. Thus, with the angle of attack increased from 15° to 25°, the best curvature from 0.018 to 0.020 gradually transition. In all the calculated cases, when the curvature of 0.019 leaves is at an angle of attack of 20°, the lift coefficient reaches the maximum. As can be seen from Figure 5, when the angle of attack is 15°, the lift characteristics of the front blade are the worst. When the angle of attack is 20°, the lift characteristics are in the best condition. When the angle of attack is 25°, the lift characteristic is at the normal level. As can be seen from Figure 6, when the angle of attack is 25°, the lift characteristics of the back leaves are the worst. When the angle of attack is 20°, the lift characteristics
are in the best condition. When the angle of attack is 15°, the lift characteristic is between 20° and 25°. In summary, the best curvature of the blade is 0.019, and the best angle of attack is 20°.

5. Conclusion

Through the combination of experiment and numerical simulation, the flow field analysis of flexible blade wind turbine impeller in new wind power generation system is carried out. The lift coefficients obtained by experimental tests. The lift coefficients of the blades under different working conditions are obtained and compared, and the optimum curvature and the optimum angle of attack are determined. The results show that the optimum curvature appears between 0.013 and 0.026, and the optimum angle of attack is between 15° and 25°. In the experimental conditions, when the curvature of 0.017 leaves at an angle of attack is 20 °, the lift coefficient reaches its maximum. In order to determine the optimum working conditions of the blade more accurately, 14 kinds of blades are selected in the optimum range of curvature, and three angles of attack are set at 15°, 20° and 25°. A numerical simulation model was established. The numerical simulation is carried out and the correctness of the model is verified. By analyzing the results, the best curvature K of the leaves is 0.019, and the best angle of attack is 20°. It reveals the influence of blade curvature and angle of attack on the lift coefficient.

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