Study on the Performance of the Wind Turbine Airfoil with Icing

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Abstract. If the performance of the blade was properly assessed, which would help improve wind turbine performance, wind turbine blade aerodynamics at low temperatures could severely affect the output power of the wind turbine. The research on the performance of wind turbine blade with icing which had the three different shapes was carried out. The blades flow field and the lift coefficient were got from the free stream wind whose speed was 10m/s at different angles of attack, The Influences on the flow Field and aerodynamic performance were discussed, when the ice shape changed. The results show that:1) Model 1 has the best performance, with the maximum lift coefficient of 1.2853, its stall angle of 14 degrees, and the stalling phenomenon of icing blade is postponed;2) the difference in the icing shapes has less affected on the flow field distribution and the lift coefficient at the small angle of attack, and the distribution of flow field is more sensitive to the ice shape on the upper part of the leading edge at the large angle of attack.3) Ice the irregular icing shape can cause the oscillation phenomenon for the lift coefficient at the angle of attack from 0 to 20 degree.

1. Introduction
As a country of the wind power, wind turbines are used widely in CHINA, which is beneficial to energy supplements. Now, the supply of wind turbines power in northern occupies a large proportion in China's wind energy. But the wind turbines would freeze at low temperature, it is great disadvantage for its power output and safe operation [1-2]. So the aerodynamic problem should be paid more attention to in low temperature environment. Computational fluid dynamics (CFD) [3-5] method can deal with the complex flow problems of the wind turbine. With the rapid development of computer capabilities, CFD plays an increasingly important role on the aerodynamic performance analysis of wind turbines.

Foreign scholars first used numerical methods to make predictions on the formation of ice shapes [6-8]. Domestic scholars have begun to carry out corresponding research in recent years. Zhang Chiyu and others used the turbulence model with transition criterion to study the suction control for the upper surface and leading edge of the supercritical airfoil with icing. The results showed that laminar flow control could delay the transition of the clean airfoil surface, but it was not effective for icing airfoils [9].

Ren Pengfei and others studied the NRELS809 airfoil using business-oriented software called Fluent. The aerodynamic performance of the airfoil with icing in experiment was different from simulation with the software. Further, the aerodynamic performance of airfoil after icing was lower than that of airfoil without icing [10]. Wang Kun and others carried out the numerical simulation for hot air anti-icing system of aircraft and the prediction for the ice ridge. When the hot air anti-icing
system opened, the surface temperature could reach up to 308K, finally there were ice ridges on the upper and lower of the wing surface behind the heating area [11].

In this paper, the research on the performance of the three different shapes of wind turbine blade with icing was carried out by using computational fluid dynamics. The flow field and the lift coefficient of blades were got from the wind whose speed was 10m/s from 0 to 20 attack of angle. The Influences on the flow Field and aerodynamic performance were discussed, which could provide a reference for the correct assessment of wind turbine performance in low temperature environment. All calculations were done in ANSYS software, and the number of the total calculation examples was 33.

2. Model and Meshing

2.1 Model
The three different wind turbines models with icing were shown in Fig. 1. According to the different shapes of ice, they were respectively named "model_1", "model_2" and "model_3". The geometric data of these models were derived from the literature [12].

![Model Diagram](image)

Fig. 1 NACA0012 with icing

2.2 Meshing
Fig.2 showed the partition of the computational domain. The upper and lower boundary which belonged to the computational domain was 15 times that of the chord length. In order to ensure the orthogonal grids, the front of the computational domain used "C" structure, and the outlet boundary of the fluid was 30 times the length of the chord from the coordinate origin. The boundary condition consisted of the far field and the wall.

Fig. 3 showed the grid of the blade, including the global grid and the local grid for the leading and tail of the wind turbine blade. The first layer grid near the wall was about 1e-5m from the wall, and the total number of grid was about 80,000.
3. Calculation results
Figure 4 showed the pressure coefficient of the upper and lower surfaces of the blade after the convergence of the flow field calculation at 1.49° angle of attack. The "Exp" indicated the experimental value [13], and the "CFD" indicated the numerical calculation result.

It could be seen from Fig.5 that the trend of pressure coefficient calculated by the numerical calculation was not only consistent with the experimental, but also the accuracy of the calculated results agreed well with the experimental values.

Fig.4 the pressure coefficient comparison of the blade wall

Fig.5 showed the calculation results of the lift coefficient, which was about the three different shapes of wind turbine blade with icing from 0 to 20 degree angle of attack. It could be seen from the figure that the lift coefficient of the blade greatly fluctuated after icing. Model 1 had the highest aerodynamic performance, followed by model 3, and model 2 showed the obvious oscillation
characteristics, which is closely related to the shedding vortex of the leading edge. Under the small angle of attack (0~10 degree), by comparing with the lift curve of model 1 and model 2, it could be seen that the upper of the leading edge had a great influence on the aerodynamic performance of the blade. The aerodynamic performance of the blade was not sensitive to the icing at the lower of the leading edge.

Fig. 5 the lift coefficient of three different shapes

The maximum lift coefficient of model 1 was 1.2853 and the stall angle was 14 degree. The maximum lift coefficient of model 2 was 0.9498, which appeared at 18 degree, and it was 26.1% smaller than the maximum lift coefficient of model 1. The maximum lift coefficient of model 3 was 1.1166, which appeared at the 18 degree, and it was 13.13% smaller than the maximum lift coefficient of model 1. The static stall of model 2 was not obvious, and the stability of the lift became worse.

Fig.6 showed the flow field distribution of different blades with icing at 10° angle of attack. It could be seen from Fig. 6 a), b) and c) that there was no separation phenomenon between model 1 and model 3, but model 2 had a large eddy area above the suction surface behind the blade. By observing the state of the flow field, it also could be seen that the regular icing shape had little effect on the distribution of the flow field under the small attack angle. The distribution of the flow field between model 1 and model 3 was similar in general. There was only difference in the flow field at the tail edge.

Because of there was a certain angle between the ice shape and the incoming flow in model 2, the fluid passing through the ice shape would form a recirculation zone, and the vortex phenomenon would occur at the same time. As the flow went on, the vortex would further expand its influence area, and eventually lead to a larger recirculation zone in the flow field above suction surface of the blade. The aerodynamic performance of the blade decreased, and the lift coefficient reduced to 0.45, which was smaller than the lift coefficient of model 1 and model 3.
Fig. 6 shows the flow field distribution of different blades with icing at 10° angle of attack. Fig. 7 showed the flow field distribution of different blades with icing at 14° angle of attack. It also could be seen from Fig. 8 a)、b) and c) that the flow fields of the three models were separated under the larger attack angle. The flow field separation of model 1 was the weakest. Model 2 had a larger vortex area above the suction surface of the blade, with the shedding vortex phenomenon at the blade tail. Model 3 had two relatively weak vortices above the suction surface of the blade. At the large attack angle, both model 1 and model 3 showed a separation phenomenon. Compared to icing in the lower part of the leading edge, the icing in the upper part of the leading edge had a bigger influence on the change of flow field. The flow field disturbance caused by the ice in the leading edge was shown through the downstream flow field. The flow field was more sensitive to the ice shape in the upper part of the leading edge, which could also be seen by comparing the ice shape structure in Fig. 2.
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From the observation of the flow field, it could be seen that the existence of vortex region at the back of the blade would reduce the aerodynamic performance under the same angle of attack. The direct performance was the decrease of the lift coefficient. The size of the vortex region at the back of the blade determined the magnitude of the decrease of the lift coefficient.

4. Conclusion
In this paper, by using computational fluid dynamics, the research on the performance of the three different shapes of wind turbine blades with icing was carried out. The flow field and the lift coefficient of the blade were got from the free stream wind whose speed was 10m/s in different angles of attack. The Influences on the flow Field and aerodynamic performance were discussed. The conclusions were as follows.

1) The numerical simulation of NACA0012 airfoil is carried out by using computational fluid dynamics method. The distribution of pressure coefficient is in good agreement with the experimental...
results. The numerical results provide a reference for the aerodynamic performance evaluation of the wind blade.

2) At the attack of angle which was from 0 to 20 degree, the aerodynamic performance of model 1 is the highest, the performance of model 3 is the second, and the performance of model 2 is the worst, whose lift coefficient has an obvious oscillation characteristics. The maximum lift coefficient of model 1 is 1.2853, and the stall angle is 14 degree. The maximum lift coefficient of model 3 is 0.9498, appearing at 18 degree. The static stall of model 2 is not obvious.

3) The regular ice shape has little effect on the distribution of flow field at small angle of attack. The distribution of the flow field is more sensitive to the ice shape in the upper part of the leading edge under the larger angle of attack. At the same angle of attack, the existence of the vortex region at the suction surface of the blade reduces the aerodynamic performance, and the direct performance is the drop of the lift coefficient when the size of the vortex region at the suction surface determines the magnitude of the decrease of the lift coefficient.

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