WIND TUNNEL TESTS AND NUMERICAL SIMULATIONS ON THE PERFORMANCE EFFECTS OF ICING ON WIND TURBINE BLADE

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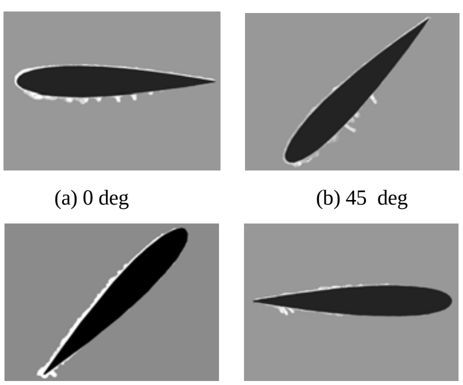
***Abstract**:* The icing effects on a wind turbine blade with NACA0015 airfoil were researched by wind tunnel test and numerical simulation. Under different wind speeds and flow fluxes of water spray with wind, the ice accretions on blade surface at some typical attack angles were measured. The numerical computations were carried out on the iced airfoils obtained by the tests. The lift and drag coefficients of the blade before and after ice accretion were simulated and the lift-drag ratio were calculated. The icing affects blade aerodynamics performance greatly and ice accretions are quite different at different attack angles.

1. INTRODUCTION

Wind tunnel test and numerical simulation were carried out for the icing effects on a wind turbine blade with NACA0015 airfoil used for SB-VAWT. By changing wind speed, water flow flux in wind and attack angle, the icing accretions were researched in a small scale wind tunnel. Further, numerical computations were carried out on the iced airfoils obtained by the tests. The icing effects on the aerodynamic performance of blade airfoil were discussed.

2. RESULTS AND DISCUSSION



(a) 0 deg (b) 45 deg

(c) 135 deg (d) 180 deg

Figure 1: Icing on blade surface at different attack angles

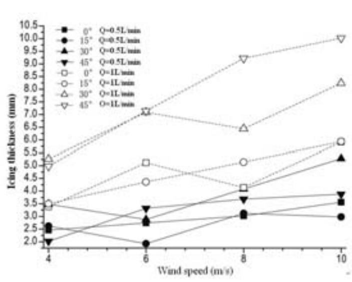


Figure 2: Maximum icing thickness at the leading edge

Figure 1 shows the icing accretions on blade surface at 4 kinds of attack angle under the conditions of wind speed of U=10m/s and water flow flux of Q=1L/min. The icing occurs on blade surface for all cases. It shows that the icing characteristics depend on the attack angle of blade.

Figure 2 shows the measured maximum thickness of icing at the leading edge. At the attack angel with larger projection area of blade, the icing thickness is large. With the increasing of wind speed and water flow flux, the icing thickness increases, and the increasing gradient under large flux is larger than that of small flux.

Based on the numerical simulation, the drag coefficient and lift coefficient of blade airfoil without and with icing obtained by tests were calculated. The lift-drag ratio was also calculated. The aerodynamics of blade airfoil changes greatly with the existence of icing. The maximum decreasing of lift-drag ratio reaches about 70%. The reason can be explained that the icing changes the flow fields and pressure distributions on blade surface which produce much drag force and affect the lift greatly.

3. CONCLUSION

The water flow flux and wind speed are the two main factors which greatly affects the ice accretion on blade surface. The ice area increases with the increasing of wind speed generally. The icing amount becomes more at the attack angel which the blade has large projected area. The icing on blade surface affects the aerodynamic performance of blade largely. Under certain condition in this study, the maximum decreasing of lift-drag ratio reaches about 70%.

4. REFERENCES

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Wind tunnel tests and numerical simulations on the performance effects of icing on wind turbine blade

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Abstract—**The icing effects on a wind turbine blade with NACA0015 airfoil were researched by wind tunnel test and numerical simulation. The tests were carried out by using a small scale wind tunnel. Under different wind speeds and flow fluxes of water spray with wind, the ice accretions on blade surface at some typical attack angles were measured. Furthermore, the numerical computations were carried out on the iced airfoils obtained by the tests. The lift and drag coefficients of the blade before and after ice accretion were simulated and the lift-drag ratio were calculated and analyzed. According to the results, the icing affects blade aerodynamic performance greatly and ice accretions are quite different at different attack angles.**

Keywords-wind turbine; icing; aerodynamic performance; wind tunnel test; numerical simulation

I. Introduction

For the wind turbines established in cold area, blade icing is a big problem which causes large effects on wind turbine performance. Therefore, researchers have done lots of works on the studies of icing problem mainly focused on the Horizontal Axis Wind Turbine in the past [1, 2]. However, the Vertical Axis Wind Turbine (VAWT), especially the Straight-bladed VAWT (SB-VAWT) becomes more and more popular in the field of small scale wind energy utilization in recent years [3, 4]. The main advantages of SB-VAWT are simple design, low cost and good efficiency, etc. However, it is also affected by icing problem in cold regions [5]. In this study, the icing effects on a wind turbine blade with NACA0015 airfoil which is often used for SB-VAWT were researched by wind tunnel test and numerical simulation. By changing wind speed, water flow flux in wind and attack angle of blade, the icing accretions were researched. Furthermore, the numerical computations were carried out on the iced airfoils obtained by wind tunnel tests. The icing effects on the aerodynamic performance of blade airfoil were discussed.

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II. Methods Followed

A. Wind Tunnel Test

NACA0015 airfoil was selected for the airfoil of blade designed and made for wind tunnel test. Both the blade span size and chord size were 0.3 m. The wind tunnel is a small scale one with outlet size is 0.4×0.4 m^2. Fig. 1 shows the schematic diagram of the test system. Wind tunnel drew the cold air from out with the temperature between -10℃ to -4℃. The wind speed (U) used is 4, 6, 8 and 10m/s. To supply icing environment, a water spray nozzle was set in outlet. The flow flux of water (Q) in air was 0.5 and 1L/min. 0 °, 15°, 30°, 45°, 135°, 150°, 165° and 180° were used as the attack angle of blade (α).

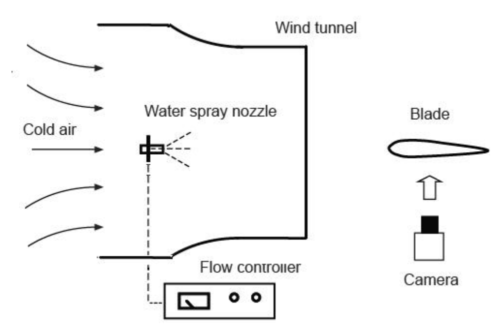


Figure 1. Schematic diagram of experimental system

B. Numerical Computational Method

The numerical simulations were carried out by using the 2 dimensions incompressible Navier-Stokes equation. The computations were based on the finite volume method with unstructured grid method. The κ–ε turbulence model was used. The blade was set in a 1.5 m×1.5 m area shown in Fig.2.

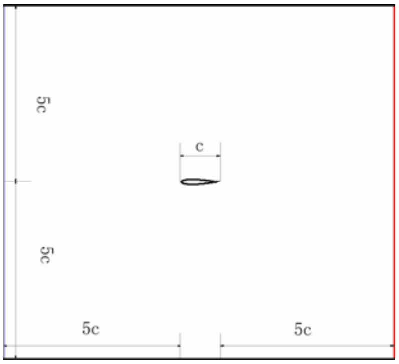


Figure 2. Flow field area for computation

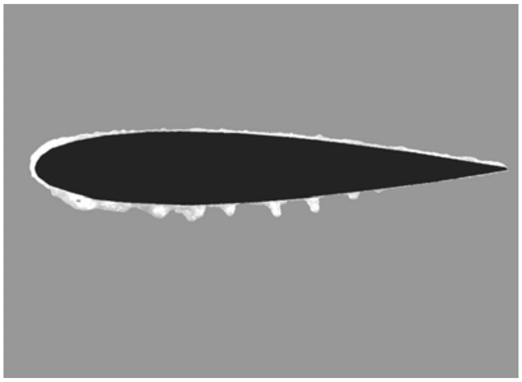
III. RESAULTS AND DISCUSSIONS

A. Wind Tunnel Test Results

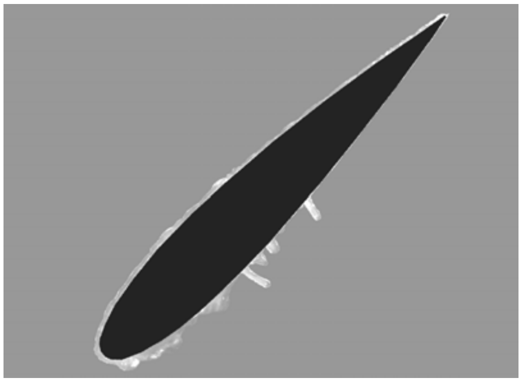
Figure 3 shows the photos of icing situations on blade surface at 4 attack angles under the conditions of U=10m/s and Q=1L/min. It can be seen obviously that icing occurs on blade surface for all cases. However the ice accretions are quite different. For the condition of α =0 deg and 45 deg, icing at the leading edge is rather thick. A thin layer of icing can be found on the upper side of blade surface. On the contrary, for the icing on down side, the icing area reduces with the increasing of attack angle. At α =135 deg and 180 deg, the icing near trailing edge and on upper side is more than other part of blade surface, especially there is no icing near the leading edge at α =180 deg.

Figure 4 shows the photos of icing situations on the test blade surface under different wind speeds at the same attack angle and flow flux. It can be easily found that large wind speed will increase the amount of icing on blade surface. The icing on upper side becomes more with the increasing of wind and the icing on down side increases also. Figure 5 shows the effects of water flow flux in wind at the same attack angle and wind speed. Like the condition of wind speed, with the increasing of flow flux of water, the icing amount increases. Therefore, it can say that the wind speed and water flow flux in wind are the two key factors affecting icing on blade surface.

Figure 6 shows the measured maximum thickness of icing at the leading edge and at the trailing edge of all test cases. It shows that icing characteristics depend on the attack angle. At the attack angel with larger projection area of blade, the icing thickness is large. With the increasing of wind speed and water flow flux, the icing thickness increases, and the increasing gradient under large flux is larger than that of small flux.



(a) 0 deg



(b) 45 deg

(c) 135 deg

(d) 180 deg

Figure 3. Icing on blade surface at different attack angles

(a) U=6m/s

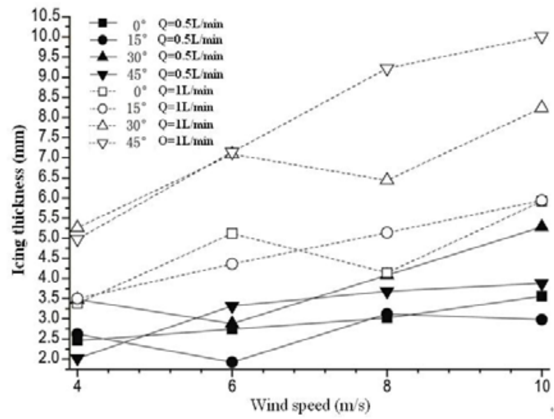
(b) U=10m/s

Figure 4. Icing on blade surface at different wind speeds

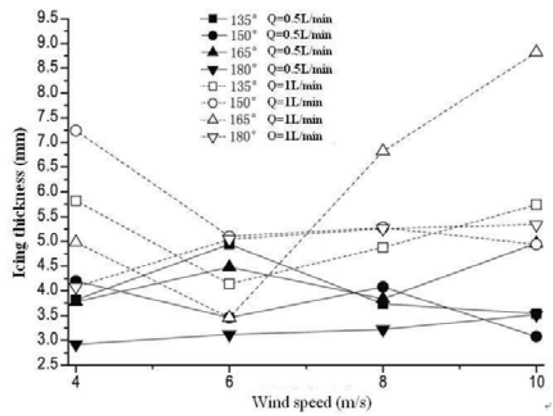
(a) Q=0.5L/min

(b) Q=1L/min

Figure 5. Icing on blade surface at different water flow fluxes



(a) at leading edge



(b) at trailing edge

Figure 6. Icing thickness at the leading and trailing edge

B. Numerical Computaion Results

By numerical simulation, the drag coefficient (C_D) and lift coefficient (C_L) of blade airfoil without and with icing obtained by tests were calculated. The lift-drag ratio (C_{LD}) was also calculated for it is an important factor evaluating blade aerodynamic performance. These were defined and expressed as follows:

$$C_D = \frac{D}{\frac{1}{2}\rho c U^2} \quad . \tag{1}$$

$$C_L = \frac{L}{\frac{1}{2}\rho c U^2} \quad . \tag{2}$$

$$C_{LD} = \frac{C_L}{C_D} \tag{3}$$

Where D is the drag (N), L is the lift (N), ρ is the density of the air (kg/m^2), c is the chord (m), u is the wind speed (m/s).

TABLE Ⅰ LIFT-DRAG RATIO

Attack angel (deg)	Flow flux (L/min)	Wind speed(m/s)			
		4	6	8	10
0	Without	0	0	0	0
	Small	0.02	0.64	0.47	-1.65
	Large	-0.06	0.68	0.93	-2.21
30	Without	-1.5	-1.5	-1.5	-1.5
	Small	-0.65	-0.84	-0.77	-0.73
	Large	-0.76	-0.79	-0.79	-0.74
150	Without	-1.01	-1.01	-1.01	-1.01
	Small	-0.28	-0.24	-0.42	-0.40
	Large	-0.29	-0.40	-0.38	-0.32
180	Without	0	0	0	0
	Small	0.62	1.89	1.28	1.59
	Large	1.42	0.57	0.46	0.38

Table Ⅰ shows the calculated results of lift-drag ratio. It can be obviously found that the aerodynamics of blade airfoil changes greatly with the existence of icing. For α=0 deg and 180 deg, the C_{LD} is not zero because the icing makes the airfoil turn into asymmetrical structure and produce lift. However, for the other two attack angels of α=30 deg and 135 deg, the C_{LD} decreases greatly. The maximum decreasing of C_{LD} reaches about 70% (α=150 deg, U=4m/s, Q=0.5L/min). The reason can be explained that the ice accretion makes the blade airfoil irregular and more anomalous and rough. It leads to change the flow fields and pressure distributions on blade surface which produce much drag force and affect the lift greatly.

IV. CONCLUSIONS

By using the wind tunnel experiments and numerical computational methods, the ice accretions on the blade airfoil of NACA0015 used for the SB-VAWT and the icing affects on the aerodynamic characteristics of blade were studied. The conclusion can be summarized as follows:

The water flow flux in wind and wind speed are the two main factors that greatly affect the ice accretion on blade surface. The ice area increases with the increasing of wind speed generally. The icing amount becomes more at the attack angel which the blade has large projected area.

According to the numerical computation results, icing on blade surface affects the aerodynamic characteristics of blade airfoil largely. Under certain condition in this study, the maximum decreasing of lift-drag ratio reaches about 70%.

ACKNOWLEDGMENT

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