

CFD 技術を用いたブレード数の異なる S 字型風車の最適形状の検討

邢 浩* 桑名 杏奈 白雪妍
姚 丹 小林 春夫 (群馬大学)

Examination of optimum shape of S-shaped wind turbine with
different number of blades using CFD technology
Hao Xing*, Anna Kuwana, Xueyan Bai, Dan Yao, Haruo Kobayashi (Gunma University)

キーワード : S 字型風車, CFD, 最適化, 自己起動性
(S-shaped wind turbine, computational fluid dynamics, optimization, self-starting ability)

1. INTRODUCTION

There are wind turbines of various shapes, which use the wind energy for power generation. The vertical axis type is stable because it can put the heavy generator etc. at the bottom of the wind turbine, and it is considered to be suitable for installation in an unstable place like offshore. Vertical axis wind turbine (VAWT) as shown in Fig. 1 is called "S-shaped wind turbine" and has the following characteristics ⁽¹⁾: (a) simple construction with low cost; (b) wind acceptance from any direction for the operation; (c) low noise and angular velocity in operation; (d) reduced wear on moving parts; (e) various rotor configuration options; (f) high static and dynamic moment. In this study, the optimal shape of the S-shaped wind turbine with different numbers of blades was examined using the simulation technology for fluid phenomena.

2. DEFINITION OF THE SHAPE OF THE WIND TURBINE

Calculate the torque (static torque) generated when the wind blows around the fixed wind turbine blade to investigate the self-starting ability of the wind turbine. "Attack Angle" for the wind turbine is defined as shown in Fig. 2. The time average value of the torque generated during a certain time after a sufficient time has elapsed since the start of calculation is considered as the static torque. As shown in Fig. 3, calculate the static torque for a wind turbine with 2, 3, 4 and 6 blades to find out the

number of blades that can generate largest static torque. The weight of four types of wind turbines is same. That is, the thickness of the blades of a two-blade wind turbine is three times the thickness of the blades of a six-blade wind turbine. When the number of blades is 2, because the shape of the wind turbine is a 180-degree cycle. When the number of blades is 3, 4, and 6, the Attack Angle is 120-degree cycle, 90-degree cycle, 60-degree cycle respectively.

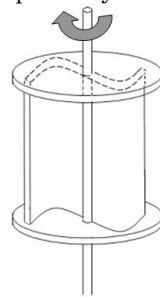


Fig. 1. S-shaped wind turbine.

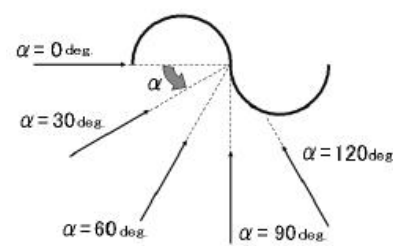


Fig. 2. Define of "Attack Angle".

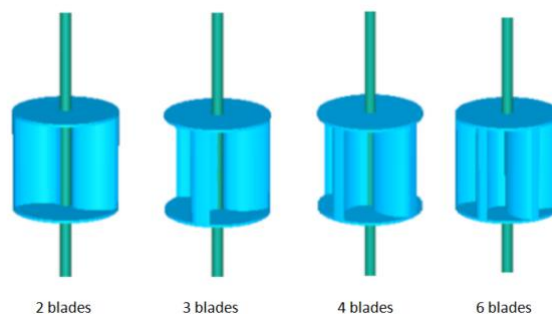


Fig. 3. S-shaped wind turbines with different number of blades.

3. NUMERICAL METHOD

As shown in Fig. 4, the computation area is a cylindrical shape with the wind turbine enlarged to the outside, and a non-uniformly spaced grids which became rougher as going away from the wind turbine is used. The number of grids was set to circumferential direction 110 × radial direction 60 × height direction 60.

Boundary conditions imposed a uniform flow at the far boundary, free flowing condition at the top and bottom of the calculation area. And no-slip condition is employed on the wind turbine blade.

The flow field around the wind turbine is governed by equation of continuity and incompressible Navier-Stokes equation. Reynolds number is set as 10^5 based on the radius of the rotor and the uniform flow. After converting fundamental equations to general coordinates, the calculation is performed by using the fractional step method⁽²⁾.

The time derivative is approximated by using the forward differences. Spatial derivative other than nonlinear term is approximated by using the central differences. When approximating a nonlinear term, using central differences when computing a flow with a large Reynolds number with a coarse grid becomes numerically unstable. However, even when the grid is not sufficiently fine, it is possible to calculate stably using the third-order upwind differences⁽³⁾. The upwind differences of the third order accuracy are an approximation expression using four points weighted upstream.

Torque generated by wind turbine is calculated according to the pressure difference between the front and the back of wind turbine blade in each micro area on the blade. By calculating the fluid by the method described above, the pressure at each grid point is obtained. The torque involved in the micro area of Fig. 5(a) can be calculated according to Eq. (1)

$$\Delta T = \Delta x_w (p_{in} - p_{out}) r \quad (1)$$

As shown in Fig. 5(b), the rotational component of ΔT is the torque associated with the micro-region. Similarly, calculations are performed for all areas on the blade, and integration of all the areas is considered as the total torque T . Furthermore, T is non-dimensionalized by the size of wind turbine according to Eq. (2).

$$C_t = \frac{T}{qRA} \quad (2)$$

where, q is dynamic pressure ($\rho/2$), ρ is air density, R is

radius of the turbine, A is the sweep area of the blade (assuming H is the rotor height, $A = RH$). C_t is called torque coefficient. It will be used in the next chapter to compare the characteristics of wind turbines.

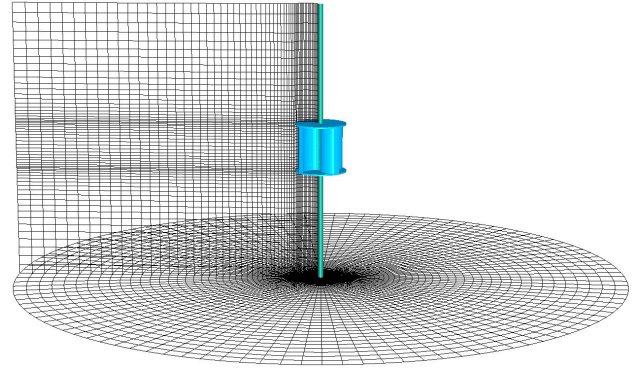
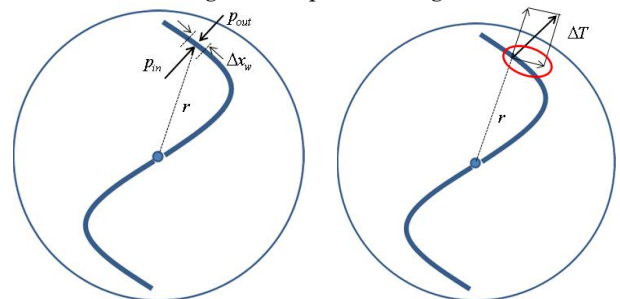


Fig. 4. Computational grid.



(a) Torque applied to the blade. (b) Component of rotation direction of torque

Fig. 5. Calculation of torque.

4. RESULTS

The graphs in Figs. 6,7,8 and 9 are some of the results of the startup characteristics of the wind turbine. The horizontal axis of graphs is the "Attack Angle" defined in Fig. 2, and the vertical axis is the torque coefficient (force to rotate the wind turbine) defined in Eq. (2). When the torque coefficient is biggest, the wind turbine is easiest to be driven. Otherwise, the smaller the torque coefficient, the more difficult it is to start.

Specifically, when the wind blows to the blade of the wind turbine, the pressure becomes larger where the side blown by the wind and the pressure becomes smaller at the other side of the blade, thus it can be driven. If the concave part of the wing is high pressure and the convex part is low pressure, the force to drive the wind turbine is large which the wind turbine is easy to be driven. If the convex of the wing is high pressure and the concave is

low pressure, the force to drive the wind turbine is small or negative which is hard to be driven.

Fig. 6(b) shows the different torque coefficient of the 2 blades wind turbine in the different degrees between 0-360. Since the shape of the wind turbine is 180 degrees periodic, the change in torque coefficient is also 180 degrees periodic. This result indicate that the maximum value of the torque coefficient (starting force) corresponds the 40 and 220 degrees. That means that when the wind blows at 40 and 220 degrees, the wind turbine is easiest to be driven. Fig. 6(a) is the simulation results of the 2 blades wind turbine when the wind enters at 40 degrees. This result suggests that when the wind enters at 40 degrees, the concave is the high-pressure field (red area), the convex is the low-pressure field (blue area), thus the wind turbine is easy to be driven under this degree. This tendency is qualitatively consistent with the experimental results (4).

On the other hand, Attack Angle is from 110 to 150 degrees, from 290 to 330 degrees, the convex of the blade is high pressure, the concave is low pressure, the force to turn the wind turbine is small or negative. This means the wind turbine can not to be start to rotate.

Figures 7-9(a) are the flow fields when the torque coefficient is maximized when there are 3, 4, and 6 blades, respectively. It is the Attack Angle at which the wind enters the concave of the blades. There is high pressure field between the blades.

Figures 7-9(b) show the fluctuations in the torque coefficient when there are 3, 4, and 6 blades, respectively. They show the startup characteristics. Due to the symmetry of the shape of the wind turbines, the cycle is 120 degrees when 3 blades wind turbine, 90 degrees when 4 blades wind turbine, and 60 degrees when 6 blades wind turbine.

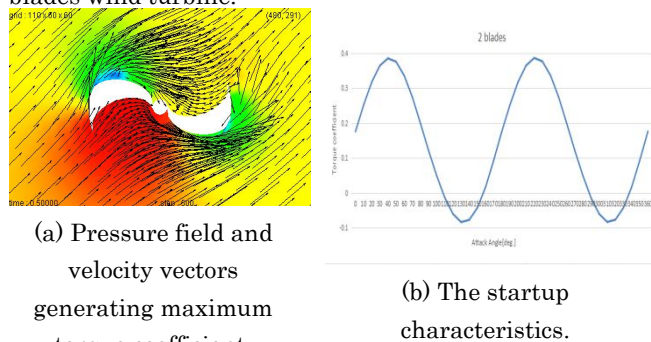


Fig. 6. The simulation results of 2 blades wind turbine.

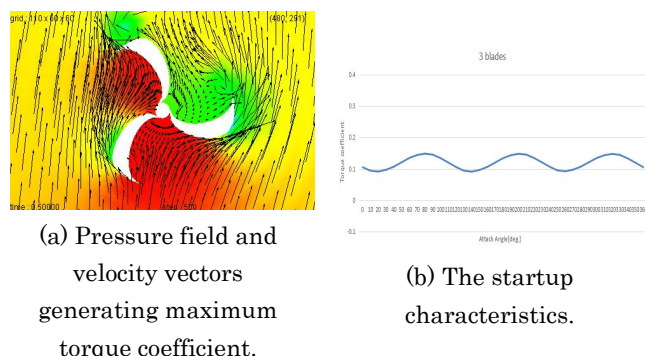


Fig. 7. The simulation results of 3 blades wind turbine.

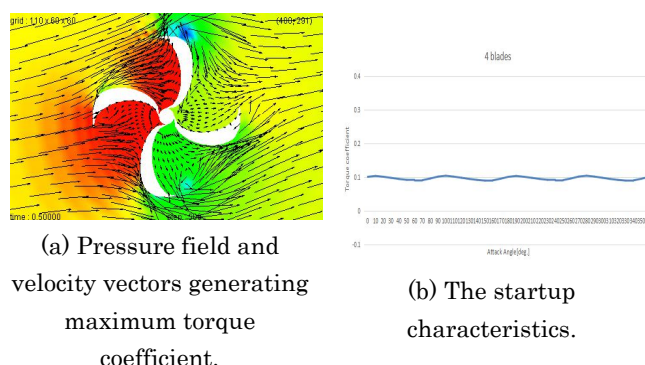


Fig. 8. The simulation results of 4 blades wind turbine.

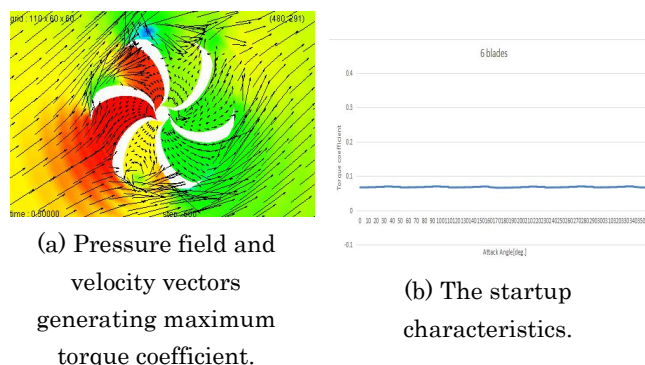


Fig. 9. The simulation results of 6 blades wind turbine.

The startup characteristics of all wind turbines are compared in Fig. 10. And Table 1 shows the average value of the torque coefficient for all Attack Angles. The 2 blades turbine has the largest torque coefficient. However, when the Attack Angle is from 110 to 150 degrees, the torque coefficient is negative, that is, the wind turbine cannot be started to rotate. The torque coefficient is small for the 3, 4 and 6 blades, however there is no negative torque. In other words, the wind turbine can be started to rotate no matter which direction the wind blows from.

It can be said that the 3 blades wind turbine is the

best shape in the sense that there is no negative torque and the average value of torque is the largest.

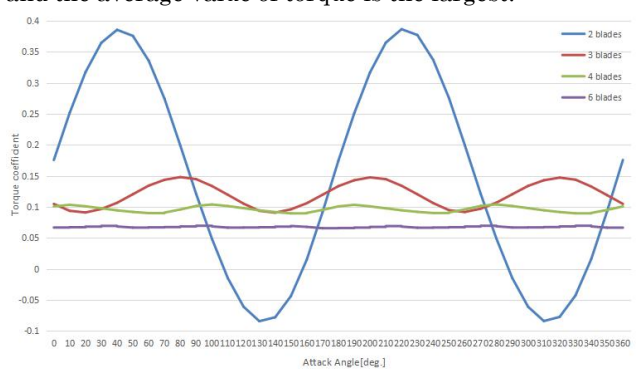


Fig. 10. The startup characteristics of the various wind turbines containing 2, 3, 4 and 6 blades.

Table1. Average of torque coefficients at all Attack Angles.

2blades	3blades	4blades	6blades
0.149565459	0.119328435	0.096412234	0.067758829

5. CONCLUSION

We investigated the starting characteristics of S-shaped wind turbines with different numbers of blades using CFD technology. Four S-shaped wind turbines with same weight of 2,3,4,6 blades were prepared. The 2 blades turbine generates a strong torque when the wind hits it from a specific angle, and it is easy to start rotating. On the other hand, the 4 and 6 blades turbines can generate positive torque and start rotating regardless of the angle of the wind. The 3 blades wind turbine with the largest average torque is the optimal shape.

文 献

- (1) J.V. Akwa, H.A. Vielmo and A. Prisco, "A review on the performance of S-shaped wind turbines", Renewable and Sustainable Energy Reviews, Vol. 16, No. 5, pp. 3054-3064, (2012).
- (2) N.N.Yanenko, "The method of fractional steps", Springer-Verlag, (1971).
- (3) T. Kawamura and K. Kuwahara, "Computation of high Reynolds number flow around a circular cylinder with surface roughness", AIAA Paper 84-0340, (1984).
- (4) I. Ushiyama and H. Nagai, "Optimum Design Configurations and Performance of S-shaped Rotors", Wind Eng., Vol. 12, No. 1, pp.59-75, (1988).