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Examination of optimum shape of Savonius wind turbine with different number of blades using CFD technology

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Abstract. The research aimed at the development of a small wind turbine simulator which considers complex wind conditions in Japan. In this study, examination of optimum shape of Savonius wind turbine with different number of blades using computational fluid dynamics (CFD) technology. The 2 blades turbine generates a strong torque when the wind blows from a specific angle, and it is easy to start rotating. On the other hand, the 4 and 6 blades turbines can start rotating regardless of the angle of the wind.

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 "Savonius 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 Savonius 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 α" 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 are 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, Attack Angle is only limited between 0 and 179 degrees. When the number of blades is 3, 4, and 6, the Attack Angle is 120-degree cycle, 90-degree cycle, 60-degree cycle respectively. Thus, for the 3 blades, 4 blades, and 6 blades, the Attack Angle is only limited between 0 and 119 degrees, 0 and 89 degrees, 0 and 59 degrees.

Fig. 1. Savonius wind turbine.

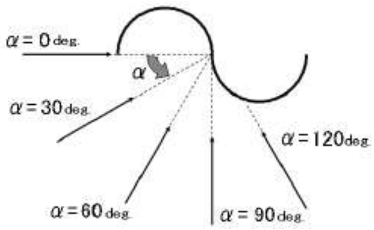


Fig. 2. Define of "Attack Angle".

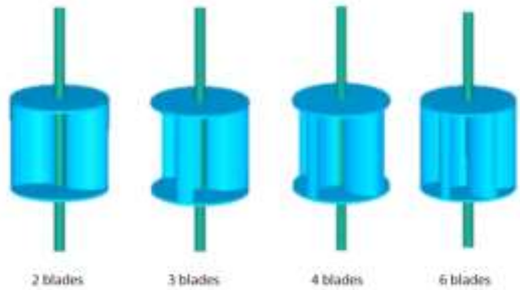


Fig. 3. The schematic image of the wind turbine structure.

3. Numerical Method

As shown in Fig. 4, the computational area is a cylindrical shape with the wind turbine enlarged to the outside, and a non-uniformly spaced grid 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 is 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)

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

As shown in Fig. 5(b), the rotational component of $\Delta \mathrm{T}$ 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).

$$\mathrm{Ct} = \frac{T}{qRA} \tag{2}$$

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, $A = RH$). Ct is called torque coefficient. It will be used in the next chapter to compare the characteristics of wind turbines.

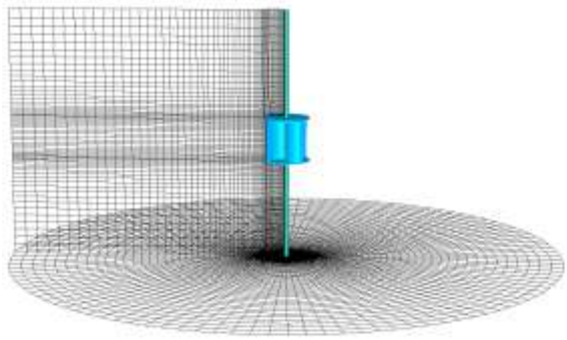
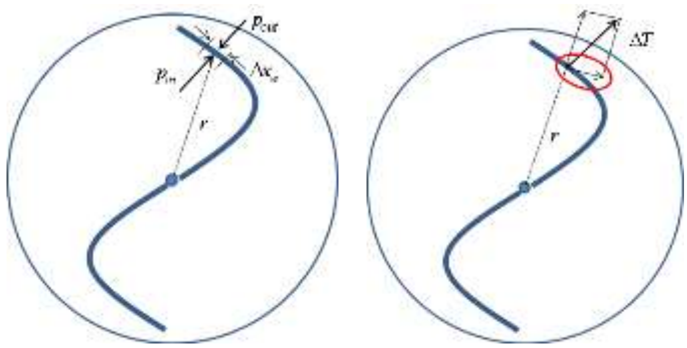


Fig. 4. Computational grid.



(a) Torque applied to the blade.

(b) Component of rotation direction of torque.

Fig. 5. Calculation of torque.

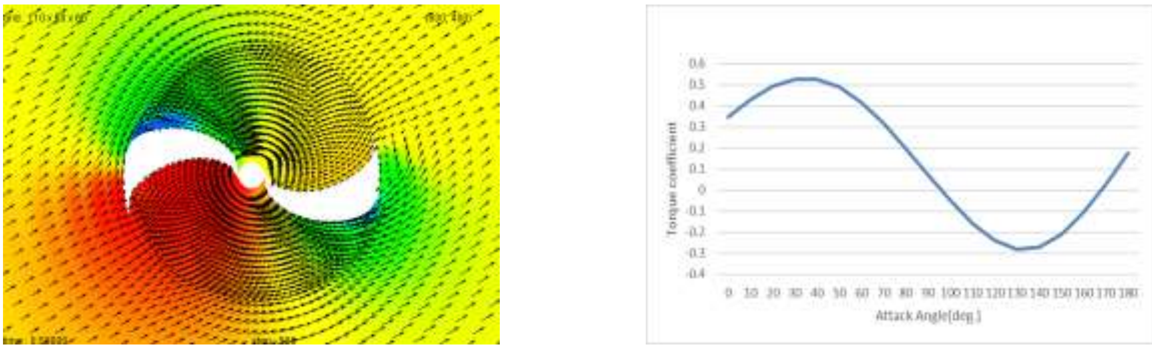
4. Results

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). 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 rotated. If the concave part of the wing is high pressure and the convex part is low pressure, the force to rotate the wind turbine is large which the wind turbine is easy to be rotated. If the convex of the blade is high pressure and the concave is low pressure, the force to rotate the wind turbine is small or negative which is hard to be rotated.

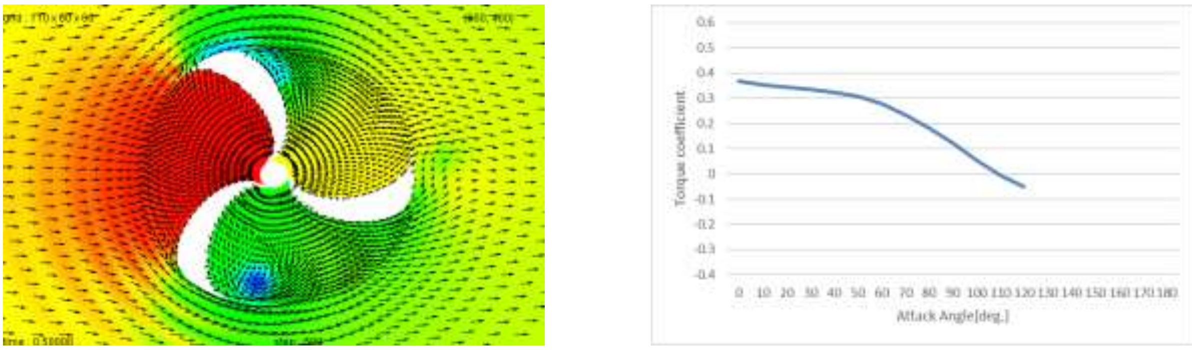
Fig. 6(b) shows the calculated torque coefficient of the 2 blades wind turbine in the different degrees between 0-180. The results indicate that the maximum value of the torque coefficient (starting force) corresponds the 30 degrees. That means that when the wind blows at 30 degrees, the wind turbine is easiest to be rotated. Fig. 6(a) is the flow field of the 2 blades wind turbine when the wind enters from 30 degrees. This result suggests that when the wind enters from 30 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 rotated under this degree. This tendency is qualitatively consistent with the experimental results [4]. Similarly, we get the most easily startup degrees (Attack Angle=0, 10, and 20) when the number of blades is 3, 4, and 6.

The startup characteristics of all wind turbines are compared in Fig. 10. The 2 blades turbine has the largest torque coefficient. However, when the Attack Angle is from 100 to 170 degrees, the torque coefficient is negative, that is, the wind turbine cannot be started to rotate. The 3 blades turbine has also negative torque coefficient. The torque coefficient is small for the 4 and 6 blades, however the there is no negative torque. In other words, the wind turbine can be started to rotate no matter which direction the wind blows from.



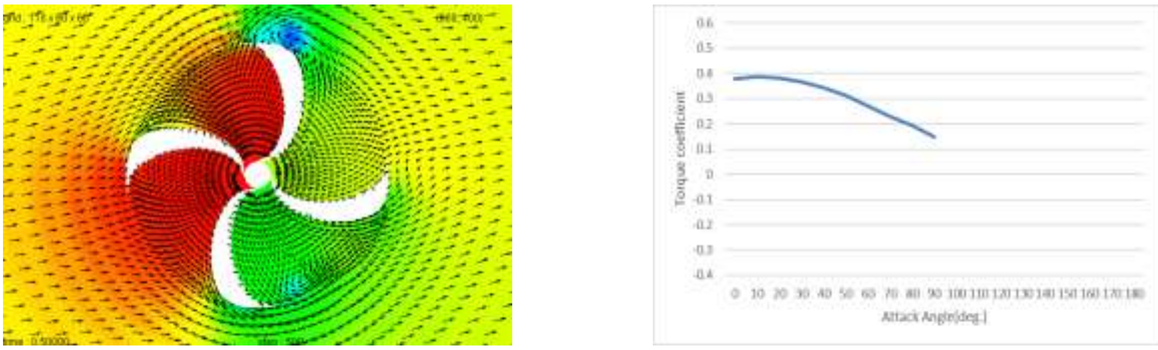
(a) Pressure field and velocity vectors. (b) The startup characteristics.

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



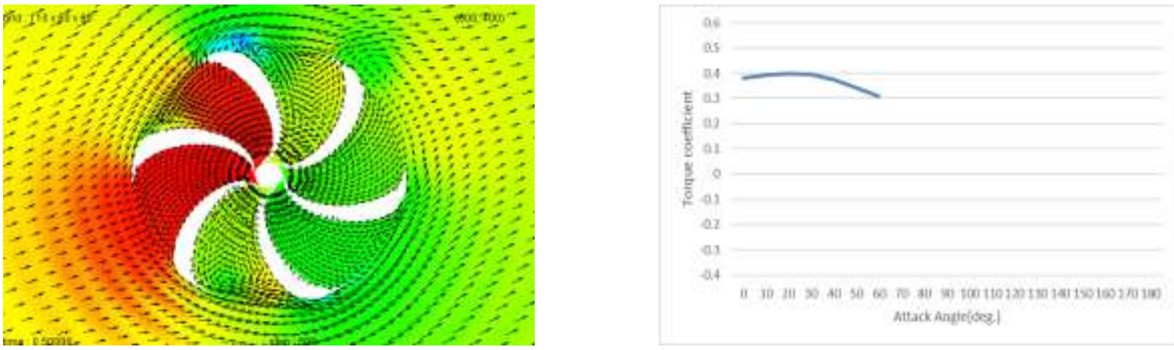
(a) Pressure field and velocity vectors. (b) The startup characteristics.

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



(a) Pressure field and velocity vectors. (b) The startup characteristics.

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



(a) Pressure field and velocity vectors. (b) The startup characteristics.

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

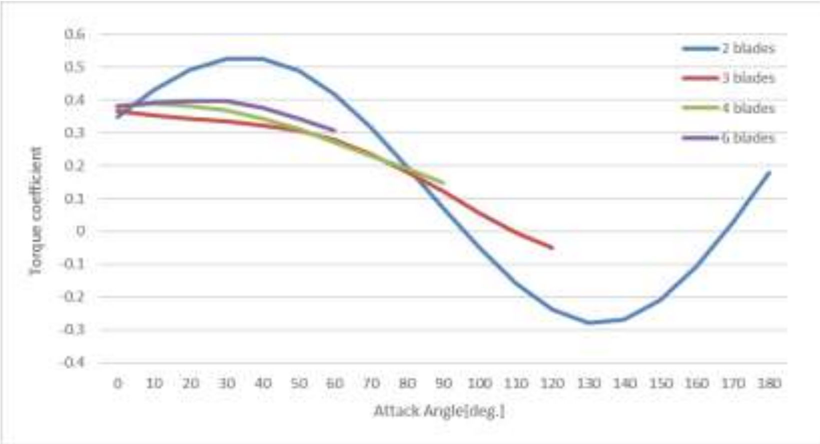


Fig. 10. The startup characteristics of the various wind turbines containing 2, 3, 4 and 6 blades.

5. Conclusion

We investigated the starting characteristics of Savonius wind turbines with different numbers of blades using CFD technology. Four Savonius 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.

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