

Numerical simulation on a straight-bladed vertical axis wind turbine with auxiliary blade

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Abstract. To improve the starting performance of the straight-bladed vertical axis wind turbine (SB-VAWT) at low wind speed, and the output characteristics at high wind speed, a flexible, scalable auxiliary vane mechanism was designed and installed into the rotor of SB-VAWT in this study. This new vertical axis wind turbine is a kind of lift-to-drag combination wind turbine. The flexible blade expanded, and the driving force of the wind turbines comes mainly from drag at low rotational speed. On the other hand, the flexible blade is retracted at higher speed, and the driving force is primarily from a lift. To research the effects of the flexible, scalable auxiliary module on the performance of SB-VAWT and to find its best parameters, the computational fluid dynamics (CFD) numerical calculation was carried out. The calculation result shows that the flexible, scalable blades can automatic expand and retract with the rotational speed. The moment coefficient at low tip speed ratio increased substantially. Meanwhile, the moment coefficient has also been improved at high tip speed ratios in certain ranges.

1. Introduction

According to the relative position of the axis and the direction of the wind, wind turbines can be divided into horizontal axis wind turbine (HAWT) [1] and vertical axis wind turbines (VAWT). With the many attributes the straight-bladed vertical axis with the advancement of low vibration, low noise, high safety, and the simple structure [2-3] has become very popular. Meanwhile, the vertical axis wind turbines have an increasing share in the small and middle wind turbine market year by year, and it also gets more attention of experts and scholars [4-7].

Based on the working principle of the VAWT, it can be divided into the lift type and drag type. With them, the Darrieus wind turbine and the Savonius rotor were the typical representative of the VAWT by lift and drag type. Under low wind speeds, the performance does not start off well. However the blade does have high tip speed ratio, with high rotor power efficiency characterizes lift-type. Compared to a lift type wind turbine, drag type can start by itself quickly, but rotor power efficiency is low at high tip speed ratio. To solve the contradiction between the starting performance and high rotor power efficiency of the VAWT, a large number of researchers are studying it. For the Darrieus wind turbine, the installation of guide plates around the wind turbine to improve the rotor power efficiency and the starting performance was widely adopted by some scholars. For the condition

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of the VAWT with guide plate, CFD numerical calculation was carried on by Wang Xin [8-10], the result shows that guide plate can effectively improve the turbine inflow wind speed. Then the rotor power efficiency can be enhanced. B.D.A Itan [11] placed the curtain in front of the Savonius wind rotor, and W.T.C Hong [12] has designed a novel omni-direction-guide-vane (ODGV) around a vertical axis wind turbine, both the aims were to improve the inflow wind speed around the wind turbine. About the Savonius wind machine, the optimal design was taken with structure parameters by some scholars, including blade aspect ratio, blade overlap ratio, the number of stages, geometry of the blade, number of blades [13-15]. Also to improve the rotor power efficiency, front guide plate was proposed by Golechato, which could reduce the blade return resistance [16]. Mohamed [17] through numerical simulations discussed the impaction on performance from different guide plates.

To improve the condition of a drag-type wind turbine in high speed with low rotor power efficiency and lift-type wind turbine starting by itself, an innovative vertical axis wind turbine with a flexible, scalable auxiliary blade was put forward. As the low-speed wind turbine works, the flexible blade is open, creating a triangle edge, increasing the drag force. As the speed increases, due to the effect of centrifugal force, the flexible blade can be curled into by-blade; then the by-blade returns to the dynamic characteristics, becomes a kind lift blade completely: at this moment, the lift is the mainly driving force. By testing the torque output characteristics under different wind and rotating speeds, the two-dimensional wind turbines carried computational fluid dynamics (CFD), resulting in the effectiveness of the new type of wind turbine. In this study, the influence on the performance of this new wind turbine was discussed as a function of different tip speed ratios, which could provide the theoretical basis and guidance for practical applications.

2. Basic Theory

Figure 1 shows the three-dimensional structure of the new wind turbine. To express the work theory clearly, the figure of three-dimensional (Figure 1) and two-dimensional (Figure 2) depict two blades, while the model was with four blades in the calculation, thus consistent with the actual situation.

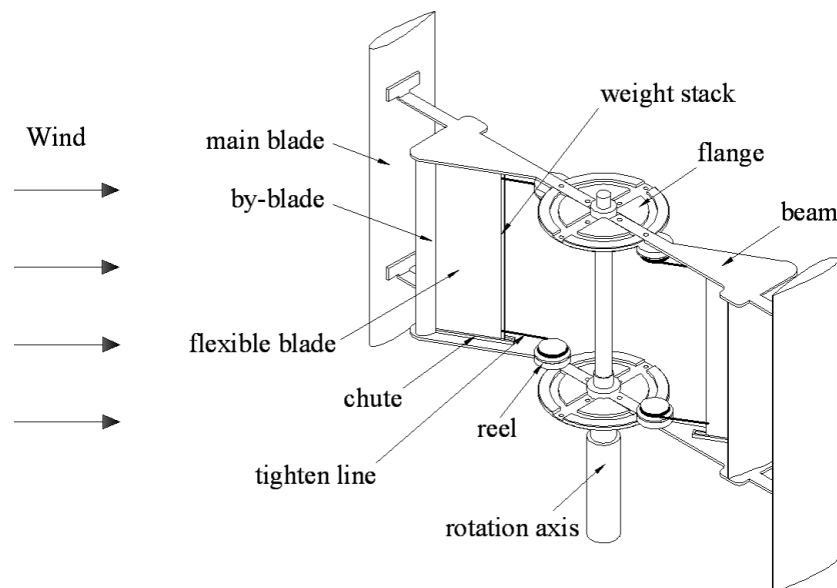


Figure 1. 3D view of the new type SB-VAWT

Main blades installed on the rotation axis by beams and flange; by-blades installed between the upper and lower beams which rotate around the rotation axis together with main blades. At the most thickness of by-blade, there is a round hole. The rotating drum was instrumented in round hole of the by-blade. One end of flexible blade connected to the drum through the bar hole on the by-blade, and

the other end fixed weight stack. By attaching the lower and upper-end instrument to the chute, the weight stack could then be connected to the reel of the tightening line. The drum and the end of reels respectively, were equipped with torsion spring and spiral spring. In the initial state of wind turbines, the flexible blade was in a state of tension under the role of spring force (Figure 2).

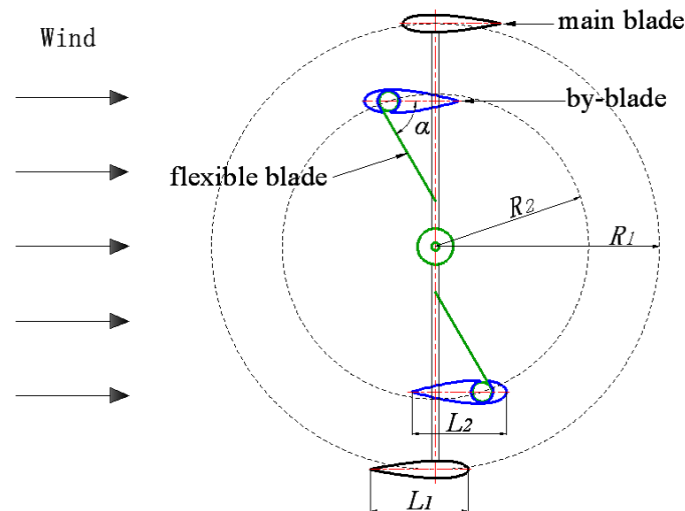


Figure2. 2D schematic of the new type SB-VAWT

At low speed of wind turbine, the strength of torsion spring and centrifugal force were smaller than the strength of spiral spring, so the flexible blade was open. Triangle drag blade could produce larger driving moment so that the new wind turbine can start by itself at low wind speed. With the rotational speed increase, the centrifugal force (provided by weight stack) increases gradually, at the same time, the flexible blade shrinks slowly under the action of centrifugal force. When the speed reached a certain value, the flexible blade curled into the by-blade completely. The by-blade recovered its original edge profile. At this state, the lift characteristics of the main blade and by-blade play gradually, rotating moment of wind turbine mainly produced by the main blade, and the by-blade also provided a certain amount of driving moment. At this time, the rotor power efficiency had been improved under the high rotational speed.

From the initial condition, obtaining the high rotor power coefficient and optimal aerodynamic performance of the blade, we needed to apply different pre-tightening forces on the torsion and spiral springs, choose different weight stacks, change the rate range from the beginning of the telescope; and control the curled by blade from the rotational speed within the weight stack.

3. Numerical simulations

To explore the working mechanism of the flexible blade deeply, and to research the characteristics of the rotor moment at different tip speed ratio, unsteady CFD calculation about this new wind turbine was carried out. Because the straight-bladed vertical axis wind turbine has the same cross section shape in the height direction, the influence of the length direction can be ignored, and the results of the two dimensional model can also have a high reliability according to the previous research results [18]. The unit length (1m) was selected for two-dimensional numerical simulation calculation. In the process of calculation, to reduce the amount of calculation, we removed the unnecessary structure characteristics like the beam, which does not much affect the calculation accuracy of numerical calculation; hence, we just retain the blade.

For comparing with the wind tunnel experimental results conveniently, blade number is 4, NACA0018 airfoil blade was selected by main blade, NACA0025 airfoil blade (drum are necessary added at the maximum thickness of the by-blade) was selected by by-blade. The main structural

parameters of this numerical calculation were shown in Table 1. Compare the change of moment coefficient with the added auxiliary scalable blades, the operating conditions of the main blade, including the main blade and the auxiliary blade, and all the blades, calculated, and the moment coefficient curve of different combinations of blade obtained. Also, the wind speed in this calculation was 6 ms^{-1} and 10 ms^{-1} .

Table 1. Main structural parameters of the wind turbine

Parameter	Value
Main blade radius, R_1	0.4m
By-blade radius, R_2	0.25m
Main blade chord, L_1	125mm
By-blade chord, L_2	120mm
Angles between by-blade and soft blade, α	60 degree

3.1 Computational Region and Mesh Division

To make the flow fully development, we avoided the calculation of the areas too narrow or too small, which may have an adverse impact on results, the calculation area was set to $10D \times 4D$ rectangular area. The calculation model put in the length direction of the symmetry axis and 3D distance to the inlet in calculation area, such as shown in Figure 3.

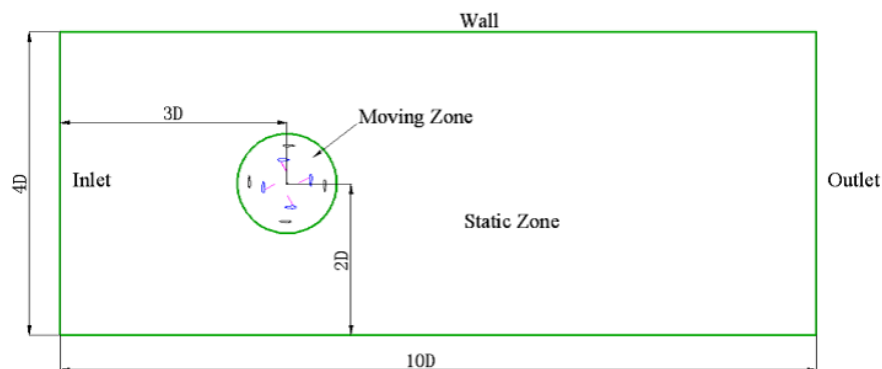


Figure 3. Calculation region and boundary conditions

Using sliding mesh technique, the computational area was divided into a static and a rotating areas, and the wind turbine was wrapped in the rotating area. The setting of the boundary in the computational area included: the boundary between static and rotational area set as slip boundary, outlet boundary set as pressure export, upper and lower boundary set as slip surface, blade surface set as no slip wall, inlet boundary and set as constant speed entrance.

The Gambit software generates the computation grid. The whole calculation area meshes. Around the blade, the grid is encrypted. The grid node density utilized in the rotor domain is higher than in the other domains. The growth rate of layer is 1.05, the maximum cell squish is 1.97407×10^{-1} (0 is the best quality, 1 is the worst quality), so the calculation of boundary layer is very good. The number of elements is about two hundred to three hundred thousand cells, such as shown in Figure 4.

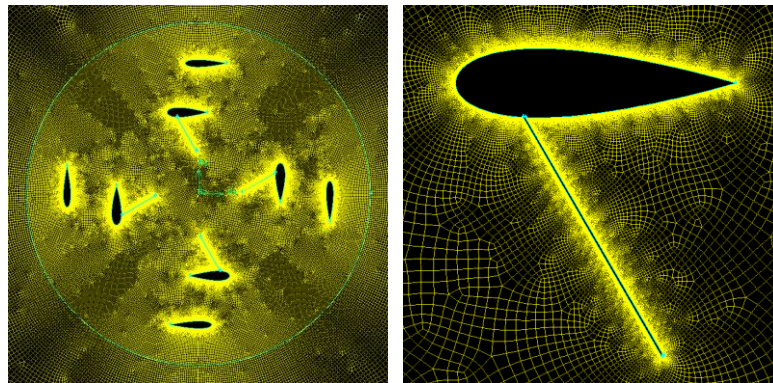


Figure 4. Moving zone mesh and local mesh

3.2 Calculation setting

The calculation based on the model of RNG k- ϵ used the standard wall function method to solve the problem of low Reynolds number. On the control equation of the discrete format, pressure interpolation adopted Standard method, pressure and velocity coupling used SIMPLE algorithm. To ensure the calculation precision, the momentum equations, turbulence kinetic energy k equation and dissipation rate ϵ equation all adopted the second order upwind format.

In the conventional VAWT CFD calculation, the state of blade was constant, but in this paper, the position of flexible blade was changing at different rotational speed, the model need to grid by time. For the purpose of simplified calculation and finding out the optimal tip speed ratio flexible blade completely into by-blade, fixed the position of the flexible blade, just calculate the moment coefficient at different tip speed ratio.

4. Results and discussion

The moment coefficient (C_m) and tip speed ratio (λ) defined as Equation (1) and (2). The two parameters are important parameters for measuring the performance of the wind turbine.

$$C_m = \frac{M}{\frac{1}{2}\rho A U^2 R} \quad (1)$$

$$\lambda = \frac{\omega \cdot R}{U} = \frac{\pi n R}{30 U} \quad (2)$$

Where n is the rotor speed rpm; R is the rotor radius, m; U is the flow speed, ms^{-1} ; M is the wind turbine moment, N/m ; ρ is the air density; A is the swept area of wind turbine, m^2 .

Figure 5 shows the wind turbine moment curve between the moment coefficient and the tip speed ratio. Figure 5 (a) is for $U = 6 \text{ ms}^{-1}$ and Figure 5 (b) is for $U = 10 \text{ ms}^{-1}$. “All blade” includes flexible blade, by-blade and main blade in the figure.

By comparing the traditional SB-VAWT and adding the flexible blade, the low tip speed improved. However, the coefficient decreased. This result is in agreement with the Savonius rotor on the moment coefficient change trend. After completely curled into by-blade, the moment coefficient of the wind turbine which has double blades compared with the original almost has the same change trend, the biggest moment coefficient is almost the same, but the overall move towards low tip speed ratio. This provides favorable conditions for using the wind power at lower tip speed ratio.

Comparing the change of the moment coefficient curve under $U = 6 \text{ ms}^{-1}$ and $U = 10 \text{ ms}^{-1}$, it can be seen that the change trend of the moment coefficient at different wind speeds is consistent, but with the increase of wind speed, the moment coefficient increases at the same tip speed ratio. The figures show that with the increase of wind speed, also wind energy efficiency undergoes a certain degree of increase.

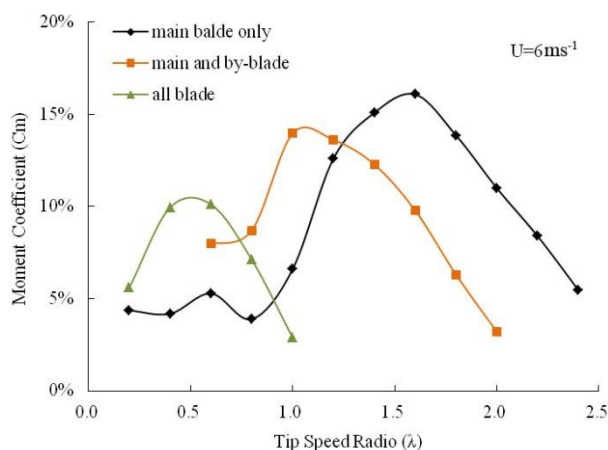


Figure 5. (a)

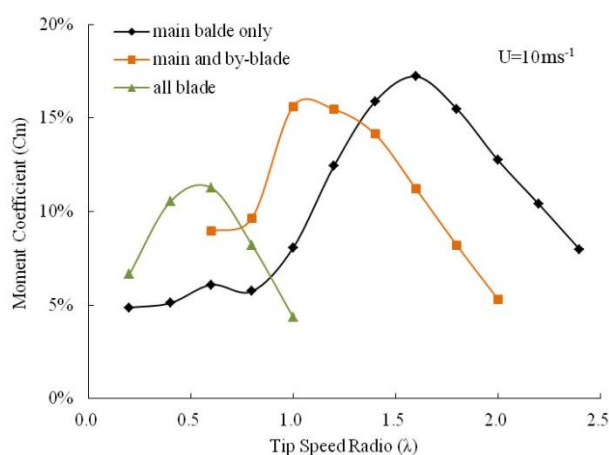


Figure 5. (b)

Figure 5. Moment coefficients of the rotor (a) $U = 6 \text{ ms}^{-1}$; (b) $U=10\text{ms}^{-1}$

5. Conclusions

This paper puts forward a new type of straight-bladed vertical axis wind turbine with flexible, scalable blades in the rotor, and its aerodynamic characteristics were studied by means of numerical simulation. From the above results, we can conclude the following.

Flexible scalable blade plays an important role in the new type of vertical axis wind turbine. At low tip speed ratio, flexible auxiliary blade will open, with by-blade together assembling into the resistant wind wheel, to solve the straight-blade vertical axis wind turbine startup problems. At high tip speed ratio, flexible auxiliary blade retracted into by-blades, lift characteristics of a wind turbine is recovered then, which can improve the utilization of wind energy to some extent.

Acknowledgments

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