Optimization Research on Lift-Type Vertical Axis Wind Turbine Airfoil by CFD

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Abstract. The blade airfoil has an important effect on the performance of a lift-type vertical axis wind turbine (VAWT). In this paper, a research has been carried out based on CFD numerical technology to compare the effects of 4 kinds of S series airfoil (S1012, S1016, S1046, S1048) and traditional airfoil NACA0015 on lift-type VAWT. The turbulence model is used \( k-\omega \) SST model. The simulation results indicate that: The airfoil NACA0015 has the highest torque coefficient and power coefficient. In terms of S series airfoils, the airfoil S1012 has the best performance and airfoil S1016 performs worst. The airfoil S1016 has the largest static torque coefficient. And the airfoil which has higher power coefficient would have a lower static torque coefficient for S series airfoil. The static torque coefficient of airfoil NACA0015 is lower than airfoil S1016 and S1046.

1. Introduction

In recent years, the continuous consumption of fossil energy brought serious environmental pollution, and it has become the biggest threat to human development. The wind, as a kind of clean and sustainable energy, has great prospects for development. The global wind power generation had reached 468.99 GW by 2016 [1]. The lift-type VAWT is a normal wind power equipment. Compared to the horizontal axis wind turbine (HAWT), it has the following advantages: without upwind devices, no requirement for flow direction, simpler structure, simpler installation, simpler maintenance and lower cost.

The blade airfoil has an important effect on the performance of lift-type VAWT. A suitable airfoil can effectively improve the wind energy utilization rate of wind turbine. At present, the airfoil NACA0015 is one of the most widely used airfoils in lift-type VAWTs [2]. In recent years, many new airfoils have gradually attracted the attention of investigators. Mohamed M.H. compared the performances of 20 airfoils such as NACA0010, NACA0015, and NACA63418 and so on using Realizable \( k-\omega \) turbulence model [3]. His results shows that the airfoil S1046 has the maximum wind energy efficiency 0.4051, 10.87% higher than the traditional NACA airfoil. Singh M.A. studied the self-initiation of H-type VAWT with airfoil S1210 and the effect of the solidity on it by experimental method [4]. The result shows that the maximum power coefficient is reached to 0.32 when the solidity is 1 and the wind speed is 5.7 m/s, it means the wind turbine can have higher static and dynamic torque at the same time. Consequently, it can be seen that the use of S series airfoil has good effect on improving the performance of VAWT.
In this paper, a research has been carried out based on CFD numerical technology to compare the effects of 4 kinds of S series airfoil (S1012, S1016, S1046, S1048) and traditional airfoil NACA0015 on lift-type VAWT. The purpose is to get more suitable airfoil for lift-type VAWT.

2. CFD Model
In this paper, the flow field characteristics and wind energy utilization efficiency of lift-type VAWTs with different airfoils are analyzed by solving the unsteady NS equation, based on the \(k-\omega\) SST turbulence model. And the coupling calculation of pressure and velocity is carried out using SIMPLE algorithm.

2.1. Airfoil Parameter Setting
Figure 1 shows the 5 kinds of airfoil studied in this paper. Obviously, airfoil S1012 is thinner than S1016, while S1046 is thicker than S1048. Comparison between airfoil S1016 and airfoil S1046 shows that the former is thicker than the latter in the middle near the tip of the blade, also the former’s overall outline is more symmetrical. Compared to the airfoil NACA0015, the tail edges of S series airfoil are sharper. A 3-blade lift-type VAMT with diameter of 2.5 m is selected in this paper, the blade height is 3.5 m, airfoil chord length is 0.25 m. so the depth-width ratio (AR) is 14 and the solidity is 0.6.

2.2. Calculation Grid Setting
A two-dimensional model is established according to the characteristics of lift-type VAMT, as Figure 2 shown. The calculation region take a square with a side length of 20D (D is the diameter of wind turbine impeller), and the impeller is located in the center of calculation region to ensure that the air flow can be fully developed when the wind turbine is in operation, and the influence of the boundary on the flow field around the turbine impeller can be minimized to obtain accurate results. The whole calculation region is divided into rotating domain and static domain. During the progress of calculation, the rotating domain revolves around the center of rotation over time.

The calculation grid in this paper is mainly constructed by triangular unstructured meshes. In order to make the calculation results more accurate, the grid near the surface of the airfoil is divided by quadrilateral meshes. The height of the first layer quadrilateral mesh on the surface of the airfoil is 0.01mm. There are 15 layers quadrilateral meshes and the thickness of each layer increases in proportion. Figure 3 shows that the meshes around the airfoil are locally encrypted according to the characteristics of the flow field. And Figure 4 shows that arc processing is done on the tail edge of airfoil to ensure mesh quality. At the same time, the grid density outside the rotating region will gradually decrease along the direction away from the turbine impeller to save calculation time.
2.3. Turbulence Model Selection

At present, the turbulence models used to simulate the running state of VAWT are mainly as follows: Standard k-ε model, RNG k-ε model, Realizable k-ε model, k-ω SST model and Spalart-Allmaras model. The accuracy of Spalart-Allmaras model is the lowest one in these models because it is a kind of one-equation model. Francesco Balduzzi [13] compared Standard k-ε model, RNG k-ε model and k-ω SST model, his result shows that the turbulence models based on ε are difficult to converge and the k-ω SST model has the best stability and reliability, it is also consistent with the experimental results. In this paper, k-ω SST model is used to simulate the running condition of VAWT, and the enhanced wall function is used to improve the accuracy of calculation in boundary layer.

3. Calculation Result Analysis

In this paper, the input wind flow speed is set to 10 m/s, and the operating conditions of the wind turbine under 7 tip speed ratios (0.5, 1, 1.5, 2, 2.5, 3, 4) are simulated and calculated respectively. Figure 5 and Figure 6 show the curves of torque coefficient (C_t) and power coefficient (C_m) of different airfoils with tip speed ratios (TSR) respectively. It can be seen that the maximum C_t and C_m of the airfoil NACA0015 are greater than the coefficients of S series airfoil. During the S series airfoil, the maximum power coefficient of airfoil S1012 is the highest, and the maximum power coefficient of airfoil S1016 is the smallest. All of these airfoils can work normally under TSR=4.

As shown in Figure 5, the torque coefficient C_t of the 5 airfoils have the same trend with TSR. With the increase of TSR, the C_t increase first and then decrease, an obvious peak occurs when TSR=2.5. As shown in Figure 6, the maximum power coefficient C_m of these airfoils increase first and then decrease with the increase of TSR. The C_m of airfoil S1012 and S1048 both have an obvious peak when TSR=3, and the C_m of airfoil NACA0015, S1016, S1046 have an obscure peak when TSR=2.5, the C_m of NACA0015 are almost the same when TSR=2, 2.5, 3.
Figure 7 shows the instantaneous torque coefficients of five airfoils at different azimuths under their optimal TSR. The instantaneous torque coefficients of the five airfoils are higher at the azimuth angle of 110°, 210°, 340° and lower at the azimuth angle of 40°, 160°, and 290°. Figure 7 also shows that the instantaneous torque coefficient of airfoil NACA0015 is in the outer position under most azimuths, and its value is quite different from that of airfoil S1012 and S1048. For the S series airfoils, although the instantaneous torque coefficients of the airfoils S1012 and S1048 are not in the outer circle under most azimuth angles, the optimum TSR is 3 and their instantaneous torque coefficients are not different from those of the airfoil S1016 and S1046. The optimum TSR of S1016 and S1046 is 2.5. Consequently, the optimum $C_m$ of airfoil NACA0015 is the highest, and the $C_m$ of airfoil S1012 and S1048 are bigger than that of other S series airfoil.

![Figure 7. Instantaneous torque coefficient of 5 airfoils at different azimuth angles under optimum TSR](image1)

Figure 7. Instantaneous torque coefficient of 5 airfoils at different azimuth angles under optimum TSR

![Figure 8. Static average torque coefficients of different airfoils](image2)

Figure 8. Static average torque coefficients of different airfoils

Figure 8 shows the static average torque coefficients of VAWT with different airfoils. The static average torque coefficient of airfoil S1016 is the highest, it means its automatic start performance is the best, followed by airfoil S1046, while airfoil NACA0015 is in the third place. The static average torque coefficient of the airfoil with larger maximum power coefficient in S series airfoil is smaller.
4. Conclusion
The performances of the 4 S series airfoils studied in this paper are not as good as the performance of traditional airfoil NACA0015. The maximum torque coefficient and maximum power coefficient of the airfoil NACA0015 are both higher than those of the other 4 S series airfoils. The specific conclusions are as follows:

1) For the torque coefficient, the optimum TSR of 5 airfoils is 2.5, while for the power coefficient, the optimal TSR of the airfoil S1012 and S1048 is 3, and that of the other 3 airfoils is 2.5;
2) All 5 airfoils work properly when the TSR reaches 4;
3) NACA0015 has the maximum power coefficient and torque coefficient;
4) In S series airfoil, the maximum power coefficient of airfoil S1012 is the largest, and the maximum power coefficient of airfoil S1016 is the smallest;
5) The static average torque coefficient of the airfoil S1016 is the highest, and it also have better automatic starting performance. The automatic starting performance of the airfoil NACA0015 is in the middle position;
6) In the S series airfoil, the smaller the maximum power coefficient, the smaller the static average torque coefficient of the airfoil, also the less automatic starting ability.

Compared with the result of Mohamed M.H. [3], there are some discrepancies in the conclusion of this paper. The main reasons for the difference include the different solidities of wind turbine model, different turbulence models and different meshing methods. In addition, the use of new airfoils can enhance VAWT’s performance, such as automatic start up capability. Therefore, it is necessary to continue to strengthen the research on new airfoil in the future.

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