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**Research Article**

# Simulation and Wind Tunnel Test on a Straight-Bladed Vertical Axis Wind Turbine

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**Abstract:** In this study, we research and develop a program by using single stream-tube theory combined with vortex model which can simulate the torque and power characteristics in this study. To check the efficiency of this program, a model of SB-VAWT was designed and made which had 2 KW capacities at wind speed 12 m/s. Wind tunnel tests were carried out on this model and the test data were analyzed and compared with the simulation results.

**Keywords:** Aerodynamic performance, simulation, VAWT, wind energy, wind tunnel test

## INTRODUCTION

Wind energy as a kind of renewable and green energy has got rapid development in recent years (Hansen *et al*., 2006; Xiaojing *et al*., 2012; Jianzhong *et al*., 2010; Díaz-González *et al*., 2012). There are two main kinds of wind turbines, the Horizontal Axis Wind Turbine (HAWT) and the Vertical Axis Wind Turbine (VAWT) (Chaoqi and Qiang, 2007). Based on the progress of aerodynamic theory of aircraft, the HAWT becomes the most popular wind turbine. Nevertheless, the VAWT has not been paid so much attention (Yan *et al*., 2010; Solum and Leijon, 2007; Riegler, 2003). In this modern time, with the rapid progress of small-scale wind power market, there is resurgence of interests regarding VAWT by some university and research institutions again. Among them, the straight-bladed vertical axis wind turbine (SB-VAWT, shown in Fig. 1) as a kind of lift type VAWT with the main advantages of simple design, low cost and good efficiency (Paraschivoiu, 2002) is one of the most researched and studied VAWT. Past studies show that the VAWT has more advantages when it serves to the small scale wind power (Wilson, 1978; Healy, 1978; Seki, 1991). For optimum design parameters and predicting the performance before fabricating the SB-VAWT, several aerodynamic computational models have been researched. According to the literature survey, the most studied and best validated models can be generally classified into four types shown in Fig. 2 (Islam *et al*., 2002). The streamtube models equate the forces on the rotor blades to a change in streamwise momentum through the rotor of the wind turbine. Therefore, the momentum model can predict well the overall performance of the wind turbine when the rotor blades lightly loaded and for small and low tip speed ratios. However, for the condition of high tip speed ratio and high rotor solidity, the momentum model is inadequate, which needs another model, the vortex model. The vortex models are basically potential flow models based on the calculation of the velocity field of the turbine through the influence of vorticity in the wake of the blades. In the modern time, the researchers have tried to combine these models together to simulate the aerodynamic performance of SB-VAWT.

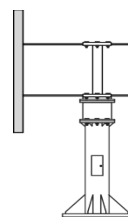

Fig. 1: SB-VAWT

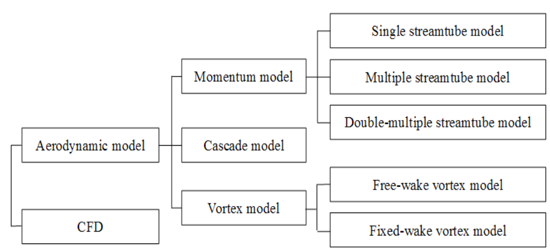


Fig. 2: Ways for simulating aerodynamic performance of the SB-VAWT

In this study, a program was researched and developed by using the single streamtube model combined with vortex model which can simulate the torque and power characteristics of the SB-VAWT. At the same time, a small model of the SB-VAWT which had 4 blades with NACA0018 aerofoil was made for wind tunnel test to invest correctness of the program.

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Wind tunnel tests were carried out on this model and the test data were analyzed and compared with the simulation results.

## MODELS FOR PROGRAM DESIGN

The aerodynamic models used in the program are based on the single stream tube model and vortex model. Wilson (1978) and walker developed the fixed-wake model which is a combination of vortex theory and momentum method for a single stream tube. Paraschivoiu (2002) introduced this model in his book named "Wind turbine design-with emphasis on Darrieus concept. The explanations of this model used in this study below are quoted from this book. Riegler (2003) discuss the HAWT versus VAWT. Paraschivoiu (2002) analyze the wind turbine design with emphasis on darrieus concept. Islam *et al*. (2002) study the aerodynamic models for darrieus-type straight-bladed vertical axis wind turbines. Wilson (1978) have a vortex sheet analysis of the giromill. Healy (1978) study the influence of blade thickness on the output of vertical axis wind turbines. Seki (1991) make a research and development of high-performance airfoil sections for vertical axis wind turbine at low-Reynolds number.

Figure 3 shows the model of an airfoil traversing in a single streamtube. The airfoil moves parallel to the free stream between A and B. At this time there is no force generated. However, both the lift and the circulation $\Gamma u$ are generated when the airfoil changes direction at point B and moves through the wind. Then, the direction of motion is changed at point C and the velocity with an opposite sign is shed again.

Figure 4 shows the wake system. The vortex sheets are convected downstream with a constant value of velocity Vs. The following equations can be obtained:

$$\Gamma_u = V_S \gamma_u / f$$
$$\Gamma_u = -V_S \gamma_D / f \qquad (1)$$
$$\Gamma_u / \Gamma_D = -\gamma_u / \gamma_D$$

where, $\Gamma_u$ and $\Gamma_D$ are the bound circulation, $\gamma_u$ and $\gamma_D$ are the vortex sheet strengths, f is the frequency of the airfoil during a cycle of motion.

We assume that the width of streamtube is enough small (BC<<AB), the velocity jump in the upstream region due to the two semi-infinite vortex sheets AB and CD can be expressed as below:

$$U - V_u = \frac{\gamma_u}{2} = a_u U \qquad (2)$$

The velocity jump in the downstream region due to two semi-infinite vortex sheets of strength ($\gamma_u + \gamma_D$) can be obtained by:

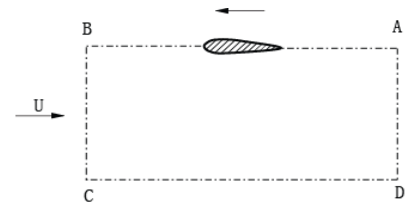


Fig. 3: The moving airfoil in stream tube

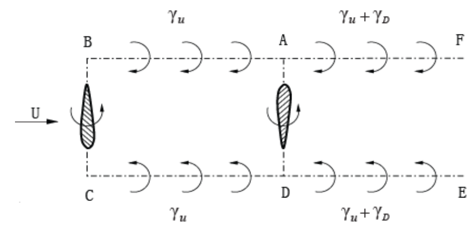


Fig. 4: Wake system

$$U - V_D = \frac{\gamma_u}{2} + \frac{\gamma_u + \gamma_D}{2} = a_D U \qquad (3)$$

The velocity jump in the far wake due to two infinite wakes of strength ($\gamma u + \gamma_D$) is given by:

$$U - V_\omega = \gamma_u + \gamma_D = 2\alpha U \qquad (4)$$

From Eq. (1-4), two relation equations can be obtained as below:

$$\alpha_D - \alpha_u = \alpha \qquad (5)$$

$$\frac{a_D}{a_u} = 2 - \frac{\Gamma_D}{\Gamma_u} \qquad (6)$$

First, "a" is the interference factor which can be calculated with simple momentum theory. Then, the upwind and downwind interference factors can be obtained by using the Eq. (1, 4, 5 and 6).

## PROCESS OF COMPUTER SIMULATION

Figure 5 shows the processes of computer simulation. All data of SB-VAWT can be inputted in windows of the program. The program can automatically calculate the swept area, wind energy, rotor solidity, revolutions, etc after input original geometric parameters of wind turbine. Then the flow field and other computational conditions can be set. After calculations, the aerodynamic performance parameters such as torque and power curves of wind turbines can be obtained.

## EXPERIMENTAL SYSTEM

**Model for simulation test:** Figure 6 shows the computational and test model in this study. The SB-

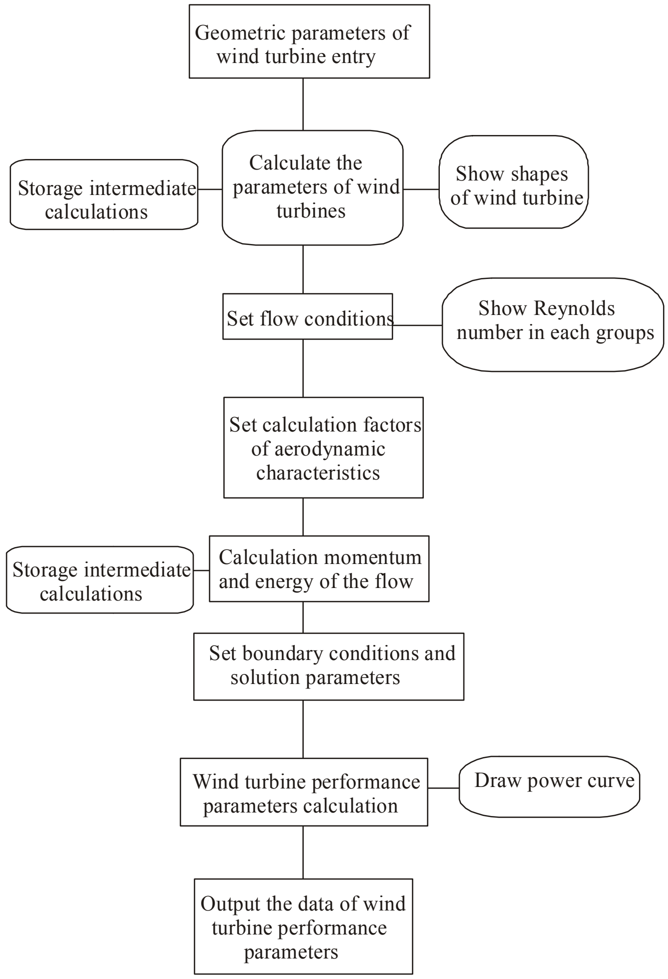


Fig. 5: Process of computer simulation

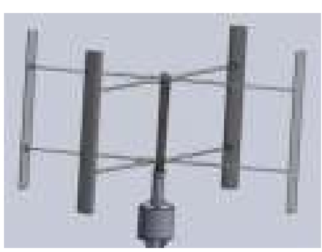

Fig. 6: Model of SB-VAWT designed

VAWT has 4 blades with NACA0018 airfoil. The rotor radius is 1.5 m and the rotor height is 2.2 m. The blade chord is 0.18 m.

**Experimental system and methods:** The system of wind tunnel test is showed in Fig. 7. The system is combined with 4 main parts, wind tunnel, SB-VAWT, control system and test system. The wind tunnel can provide stable wind speed with the test section of 4m×6m. The wind speed is range from 3 to 12 m/s. The control system is mainly consisted by a computer with

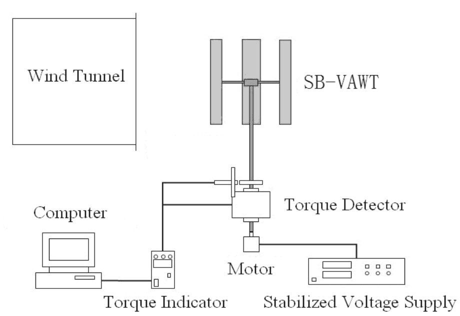


Fig. 7: System of wind tunnel test

data acquisition card and wind speed sensor. The wind speed can be controlled by a computer. The test system contains a torque detector, a motor and a stabilized voltage supply. The test model can be droved to a rated speed by the motor, then data can be obtained by the torque detector. The rotational speed, torque coefficient and power can be obtained by aerodynamic data analysis program. The tip speed ratio tape is range from 0.25-5 and every ratio tape match with a rotational speed. From the software power at different rotational speeds and power coefficient at different wind speeds can be obtained.

## RESULTS AND DISCUSSION

Figure 8 and 9 show the output power performance at different rotational speed while the wind speed was 5 and 9 m/s.

It can be seen that when the wind speed range from 5 to 9 m/s, the maximum output power range from 80w to 800w. According to Fig. 8, from 90 rpm to 130 rpm, the simulation results are similar to the test results; the maximum power was obtained at 120 rpm. Similarly, the simulation curve is similar with the test curve both in trend and value at wind speed 9m/s in Fig. 9. The simulation results are a little higher than the data of wind tunnel test at some rotational speeds. The main reasons can be explained that there is some experimental mechanic loses, such as friction in wind tunnel test. Therefore, it can conclude that the program is effective for the aerodynamic simulation on the SB-VAWT. Furthermore, the negative values of the simulation results mean that the turbine can not start rotation, which indicate that the starting performance of SB-VAWT is not good .

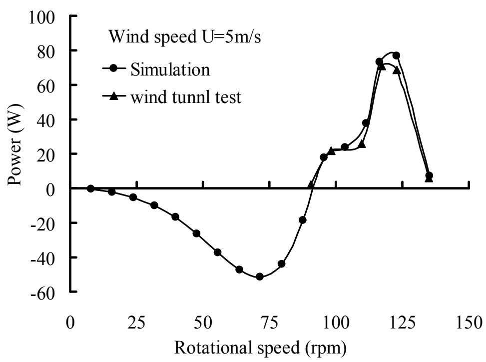


Fig. 8: Power output at U = 5 m/s

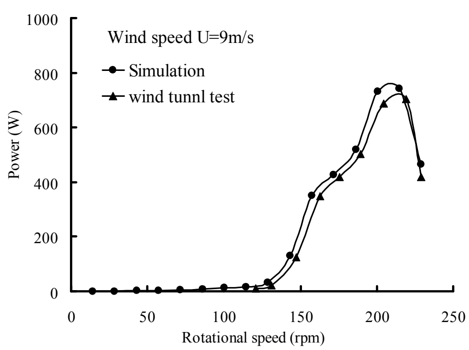


Fig. 9: Power output at U = 9 m/s

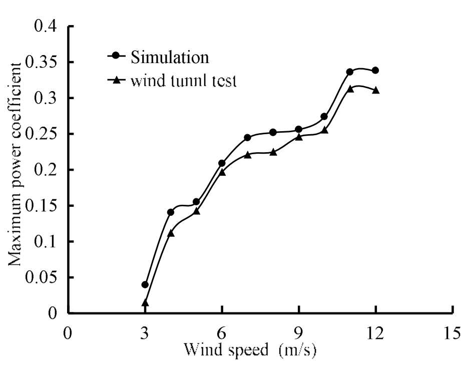


Fig. 10: Maximum power coefficients

Figure 10 shows the maximum power coefficients at different wind speed test in this study. The maximum power coefficients of SB-VAWT increase with the increasing of wind speed from 3 to 11 m/s. There is a maximum power coefficient 0.35 when the wind speed is 11 m/s. Similarly with the power output performance, the maximum power coefficient simulated is also larger than the values obtained are wind tunnel test. However, the difference is limited in 10% when the wind speed is higher than 9m/s. Therefore, it can say that the program is effective for the design of SB-VAWT.

## CONCLUSION

A program which can simulate the torque and power characteristics was researched and developed. Wind tunnel tests were also carried out and the test data were analyzed and compared with the simulation results. Conclusions are inferred as follows.

- According to the wind tunnel test results, the aerodynamic performance of the straight-bladed vertical axis wind turbine can been simulated well by using single stream-tube model combined with vortex model
- It is feasible to use the program developed in this study to compute the output power of the straight-bladed vertical axis wind turbine
- The aerodynamic performance of the straight-bladed vertical axis wind turbine designed in this study has good power performance at high wind speed. However, the starting performance should be improved at low wind speed

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