Effects of Tip Vanes on Aerodynamic Performance of H-Type VAWT

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Abstract. In order to investigate the effect of the tip vanes on the aerodynamic performance of H-type vertical axis wind turbines (H-VAWTs), adopting the method of the CFD numerical simulation to analysis blade surface pressure distribution, tip vortex and power coefficient of H-VAWTs that are installed two different kinds of tip vanes on both ends of the blade and not installed. The result showed that the tip vanes can weaken the tip vortex, increase the blade surface pressure difference and improve the power coefficient of the H-VAWT. In addition, the power coefficient of the rotor with V type tip vane was greater than that of the rotor with S type tip vane. The maximum improvement achieved was a 37.5 percent increase in power coefficient with V type tip vane and a 33 percent increase in power coefficient with S type tip vane, the tip vanes made the power augmentation of the H-VAWT.

1. Introduction
Increasing awareness of the issues of climate change and sustainable energy use has led to growing levels of interest in small-scale, decentralised power generation. Wind power is a source of clean and renewable energy, and its application technology is becoming increasingly mature [1]. With current developments in the wind turbine industry, interest in the H-VAWT is increasing due to their low vibration, high safety, simple structure, ease of installation and convenience of control and repair. An H-VAWT is a typical small wind turbine, investigating the effect of different tip vanes on its aerodynamic performance has a certain theoretical significance and practical value. The idea of augmenting the power output of a horizontal axis wind turbine (HAWT) by installing a tip vane on the blade tip was proposed by Van Bussel (1986) and Von Holten (1976) ten years ago[2, 3]. Then Van Bussel and G J W analyzed and proved this idea [3, 4]. In the 1990s, Shimizu et al. installed the Mie-Type tip vane on a HAWT and conducted a large number of systematic studies using wind tunnel tests. The results showed that the Mie-Tip tip vane could increase the output power of a HAWT [5-8]. When the air passes through the blades of a VAWT will produce a lift, the tangential component of the lift makes the VAWT rotate, and the tangential component is generated by the pressure difference on the surface of the blades. While due to the presence of the pressure difference, the airflow on the high pressure surface will flow around the tip to the low pressure surface, and then form the tip vortex [9]. The generation of the tip vortex leads to a decrease in pressure difference near the tip of the blades. Tip vortex is one of the main reasons for the reduction in efficiency of the blades [10]. In order to reduce the tip vortex, the large aircrafts generally used the method of installing tip vanes to reduce this adverse effect. Refer to the method used on aircraft wings and HAWTs, this paper adopted the method
of the CFD numerical simulation to analysis blade surface pressure distribution, tip vortex and power coefficient of H-VAWTs that are installed two different kinds of tip vanes on both ends of the blade and not installed. The result showed that the tip vanes can weaken the tip vortex, increase the blade surface pressure difference and improve the power coefficient of the H-VAWT. The tip vanes made the power augmentation of the H-VAWT.

2. Parameters of the H-VAWT and tip vanes

2.1. Parameters of the H-VAWT
In order to verify the accuracy of the computation, the reference H-type VAWT is founded in literature [11]. The blade profile of the rotor is NACA4518 airfoil, the chord length is 100mm, the blades number is 3, the radius of the rotor is 300mm, the height of the blade is 700mm.

2.2. Parameters of tip vanes
According to the experimental results of Shimizu et al. [5-8] and Wang J W [12], the structural parameters of the V and S type tip vanes are shown in table 1.

| Table 1. Dimensions of tip vanes |
|----------------------------------|
| Parameter | value | Parameter | value |
| α (°) | 15 | α (°) | 39 |
| β (°) | 20 | β (°) | 50 |
| A/mm | 88 | B/mm | 80 |
| B/mm | 80 | L/mm | 104 |
| C/mm | 45 | R/mm | 52 |
| D/mm | 25 | E/mm | 18 |

The shape of the tip vanes are shown in Figure 1:

![Figure 1. Definitions of V and S type tip vanes](image)

The V type tip vane is shown in figure 1(a): the tip vane is of flat shape, the width is A, the length is B, α is the camber angle of leading edge, and β is the camber angle of trailing edge. The S type tip vane is shown in figure 1(b): L is the straight edge, B is the flap in mounting surface, α is the arc design angle, β is the angle of trailing edge, R is the arc radius and r is the transition radius. The arc center point 3 is the midpoint of the two points 1 and 2, where point 1 is the intersection point of the
arc design angle line and the sideline of the tip vane, point 2 is the intersection point of the arc design angle line and the arc that is centered on the point O and with the width B as the radius.

3. CFD methodology

The CFD simulation of an H-Durrieus VAWT is difficult due to the flow field around the rotor is highly time-independent. In recent years, Ansys Fluent is becoming the leading commercial supplier of CFD software and services. This paper carries out a three-dimensional unsteady CFD simulation of an H-Durrieus VAWT with the CFD solver, Ansys Fluent 14.5. The instantaneous turbulence flow field is obtained by using URANS approach with k-ω SST model, the URANS equations are resolved using the SIMPLE algorithm. Discretization is preceded using the second order upwind scheme with finite volume method for all variables. In order to compute the rotational zone with respect to the stationary zone, the sliding meshing model (MMS) is used between both zones. For better accuracy simulation, boundary layer mesh is used on the blade surface, and the height of the first layer is set to be 10-5 m which ensures \( y^+ < 1 \) for cells near the blade surface. The inlet boundary is retained as a constant velocity of 8 m/s, the outlet is set to a constant pressure of 1 atm, the side and top surfaces are set as the standard no-slip wall condition and the bottom surface is set as the symmetry. The boundary conditions are shown in figure 2.

![Figure 2. Boundary conditions](image)

4. Result and discussion

4.1. Model reliability verification

To verify the accuracy of the computation, the torque coefficients of different tip speed ratio (\( \lambda \)) are compared with experimental data of literature [11]. The torque coefficient and tip speed ratio can be defined as follows:

\[
C_t = \frac{T}{\frac{1}{2} \rho u^2 \cdot A \cdot R} \quad (1) \\
\lambda = \frac{\omega R}{V} \quad (2)
\]

Where \( T \) is the torque, \( A \) is the swept area of the rotor, \( R \) is the rotor radius, \( \omega \) is the rotor speed and \( V \) is the wind speed. The instantaneous torque coefficient vs. time is shown in Fig. 3(a) and (b). The mean torque coefficient can be written as Ct, mean, we can see that the Ct, mean=0.04 for \( \lambda=0.4 \) and Ct, mean=0.055 for \( \lambda=2 \) in figure 4, while Takao et al. [11] achieved Ct, mean=0.035 for \( \lambda=0.4 \) and Ct, mean=0.05 for \( \lambda=2 \). The comparison between the three-dimensional unsteady CFD computation and the experiment data shows this simulation is accurate.
4.2. Effects of tip vanes on blade pressure distribution

Define the dimensionless coefficient—the pressure difference coefficient $\Delta P$ between the pressure and the suction surface of the blade:

$$\Delta P = \frac{(P_1 - P_2)}{(0.5 \rho V^2)}$$

(3)

Where $P_1$ is the pressure of the pressure surface, $P_2$ is pressure of the suction surface, $\rho$ is the air density, $V$ is the flow velocity, the dimensionless radius position $r/0.5H = 0.3, 0.7, 0.9$, the dimensionless chord length position $x/C = 0.3, 0.5, 0.7, 0.9$.

Figure 3. The instantaneous torque coefficient vs. time (a): $\lambda = 0.4$, (b): $\lambda = 2$

Figure 4. Pressure difference coefficient at different locations
As shown in figure 4, the horizontal axis is the relative chord length and the vertical axis is the pressure difference coefficient. It can be seen from figure 4 that with the relative radius increases, the pressure difference coefficient gradually increased. At $r/0.5H=0.9$, the tip vanes have the greatest effect on the pressure distribution of the blades, and the pressure difference coefficient reaches the maximum between the pressure surface and the suction surface. With the relative radius decreases, the effects of the tip vanes are gradually reduced. In addition, two types of tip vanes both can improve the pressure difference coefficient of the blade surface, while the pressure difference coefficient of the blade with V type tip vane is slightly higher than that of the blade with S type tip vane.

4.3. Effects of tip vanes on power coefficient

Figure 5.

Figure 5 is the curve of tip speed ratio and power coefficient of the rotor with tip vanes and without tip vanes. It can be seen from figure 5 that V and S type tip vanes can increase the power coefficient of the rotor of a VAWT, and the power coefficient increases significantly when the tip speed ratio is high. In addition, the power coefficient of the rotor with V type tip vane is greater than that of the rotor with S type tip vane. The maximum improvement achieved is a 37.5 percent increase in power coefficient with V type tip vane and a 33 percent increase in power coefficient with S type tip vane.

5. Conclusion
This paper investigated the effect of the tip vanes on the aerodynamic performance of H-type vertical axis wind turbines (H-VAWTs) and applied the method of the CFD numerical simulation to analyze the blade surface pressure distribution, tip vortex and power coefficient of H-VAWTs that were installed two different kinds of tip vanes on both ends of the blade and not installed. The result showed that two types of tip vanes both could improve the pressure difference coefficient of the blade surface, while the pressure difference coefficient of the blade with V type tip vane was slightly higher than that of the blade with S type tip vane. Moreover, the tip vanes could improve the velocity distribution of the blade surface and the velocity distribution in front of the rotor, weaken the formation of the tip vortex, and make the rotor absorb more wind energy. Additionally, the power coefficient of the rotor with V type tip vane was greater than that of the rotor with S type tip vane. The maximum improvement achieved was a 37.5 percent increase in power coefficient with V type tip vane and a 33 percent increase in power coefficient with S type tip vane. Therefore, the two types of tip vanes have the effect of power amplification to the rotors, effectively improve the aerodynamic performance of an H-VAWT, while the effects of V type tip vane is better than S type tip vane.

6. Conflict of Interest
The authors declare there is no conflict of interest.
Reference

[1] World Wind Energy Association. World Wind Energy Report 2008 [R]. 2008.

[2] Van Holten. Windmill with diffuser effect induced by small tip vanes [A] .Proc Int System [C], Wind Energy Syst, Camdridge, U K, 1976.

[3] Van Bussel, G J W. Status report on tip vane research [A].EWEA Conference [C], Rome, 1986, 691—695.

[4] Van Bussel, G J W. Use of the asymptotic acceleration potential method for horizontal axis wind turbine rotor aerodynamics [J] .Journal of Wind Engineering and Industrial Aerodynamics, 1992, 39 (3): 161—172.

[5] Shimizu Y, Ismaili E, Kamada Y, et al. Rotor configuration effects on the performance of a HAWT with tip-mounted Mie-Type vanes[J]. Journal of Solar Energy Engineering, 2003, 125 (4): 441—447.

[6] Shimizu Y, Yoshikawa T, Matsumura S. Power augmentation effects of a horizontal axis wind turbine with a tip vane-Part 1: Turbine performance and tip vane configuration. Journal of Fluids Engineering, 1994, 116 (2): 287—292.

[7] Shimizu Y, Yoshikawa T, Matsumur S. Power augmentation effects of a horizontal axis wind turbine with a tip vane-Part 2: Flow visualization [J].Journal of Fluids Engineering, 1994, 112 (2): 293—297.

[8] Shimizu Y, Imamura H, Matsumura S. et al. Power augmentation of a horizontal axis wind turbine using a Mie-Type tip vane: Velocity distribution around the tip of a HAWT blade with and without a Mie-Type tip vane [J].Journal of Solar Energy Engineering, 1995, 117 (4): 297—303.

[9] Zhong W, Wang T G. Numerical analysis of the wind turbine blade-tip vortex [J]. Journal of Nanjing University of Aeronautics & Astronautics, 2011 (10): 640

[10] Hansen M O L. Wind turbine aerodynamics [J]. 2009

[11] Takao M, Kuma H, Maeda T, Kamada Y, Oki M, Minoda A. A straight-bladed vertical axis wind turbine with a directed guide vane row-Effect of guide vane geometry on the performance. J Therm Sci 2009; 18 (1): 54-7.

[12] Wang Jian Wen, Gao Z Y, Han X L, et al. The horizontal axis wind turbine with S tip vane [P]. China: 20082005522612008-11-26.