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Optimization of Accelerated Ducted Design in Wind Turbine System Using Computational Fluid Dynamics (CFD)

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ABSTRACT

A conceptual design of wind accelerating device is developed for small vertical axis wind turbine (VAWT) with the objective of improving incoming wind speed before reaching and subsequently hitting the turbine blades. Two design concepts which are round and square shape are modeled as a wind accelerating device. The working condition is similar to wind vane and venture effect principle. The performance of the device is analyzed using Computational Fluid Dynamic (CFD) method at various wind speed. The performance on wind speed after the device and power density is investigated. The results report that the device has successfully increased the wind flow speed. Besides that, the square shape design show better performance compare to round shape design in term of wind speed and power density.

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INTRODUCTION

The study on vertical axis wind turbine (VAWT) configuration has already conducted and established. The study of VAWT performance is focussing on torque (Gavald, Massons *et al*. 1990; Islam, Ting *et al*. 2008; Chong, Poh *et al*. 2012; Mohamed 2012; Park, Asim *et al*. 2012), power (Gavald, Massons *et al*. 1990; Chong, Poh *et al*. 2012; Greenblatt, Schulman *et al*. 2012; Mohamed 2012; Park, Asim *et al*. 2012) and rotational speed(Chong, Poh *et al*. 2012). Several factors influencing the VAWT performance are discussed such as structural integrity, fluid flow around the blade, and wind turbine design. The efforts were conducted in simulation and experimental method and the VAWT performance was improved.It is reported that wall thickness of the blade can be optimized by reducing weight of the blade but maximum stresses and maximum deflection should be in acceptable range for straight bladed VAWTs by using analytical and numerical techniques (Hameed and Afaq 2013). By increasing the number of blades to four, the performance of wind turbine is significantly increased as compared to two blades (El- Samanoudy, Ghorab *et al*. 2010). On the other hand, drag-type or Savonius VAWT integrated with rectangular guide-box tunnel to adjust the inlet mass flow rate improved the output power of the Savonius rotor (Irabu and Roy 2007). The power coefficient was augmented 2.23 times and 2.5 times for a two-bladed rotor and three-bladed rotor respectively. Another improvement on Savonious turbine, computationally optimized the geometry and position of a flat deflector for both two-blade and three-blade Savonius turbines (Mohamed, Janiga *et al*. 2010). Even though optimal geometries of the deflector are different for both turbines, the performance of both turbines was similarly improved by about 27%. It was also reported that the power output of the lift-type or Darriues straight-bladed VAWTs has increased by placing a deflector in front of the wind turbine(Kim and Gharib 2013).In addition, the guide vane at the outer devices of VAWT system may improves the rotational speed and starting behaviour performance (Takao, Kuma *et al*. 2009; Chong, Naghavi *et al*. 2011; Chong, Fazlizan *et al*. 2012; Chong, Poh *et al*. 2012; Chong, Pan *et al*. 2013).

Although many studies on the deflector effect or additional structure to the wind turbine have been done for drag-based Savonius VAWT, there is little information on the performance of a lift-based VAWT with a deflector or other additional structures. The objective of this work is to study the best accelerated ducted head design to increase the wind flow passed through it before reached the turbine blade.

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Methodology:

The concept idea of the proposed ducted design is based on the wind vane and venture effect work principle. A wind vane works by wind blowing against a large surface to measure the wind direction. The tail end is the larger of the two areas and causes the front end to point in the wind blowing direction. Figure 1 shows the typical shape of the wind vane and the working principle of venture effect.

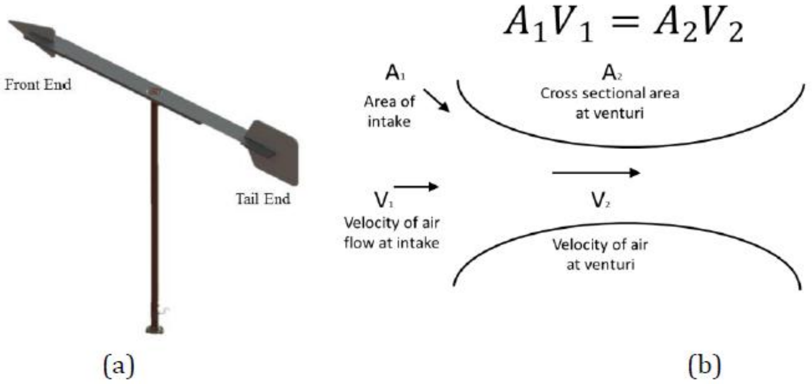


Fig. 1: Typical illustration of (a) wind vane and (b) venture effect.

The acceleration of air flow can be achieved with the use of converging nozzle concept or venture effect. It is performed due to pressure changes hence effect the changes to velocity as well. This is fundamentally identified as Bernoulli's principle, which relates the pressure of a fluid to its velocity. According to the laws of governing fluid dynamics, a fluid's velocity must increase as it passes through a constriction to satisfy the principle of continuity, while its pressure must decrease to satisfy the principle of conservation of mechanical energy. Figure 2 shows the illustration of the overall design where by the wind acceleration device is mounted at the same pole of the wind turbine and consists of square and rounded shape head design. The dimension of the ducted head is summarized in Table 1. The investigation of wind velocity performance output of a wind accelerating device is numerically analyzed using ANSYS CFD package. The appropriate size of the steady computational domain, namely static zone, has been properly proposed. The dimensions of the static zone were set in multiples of the device head, and the boundary conditions adopted for the solution of the governing flow equations are shown in Figure 3. At the inlet of the static zone, a respective velocity value for the wind is proposed which is 2, 4, 6 and 8 m/s, while at the outlet of the zone, the pressure is considered equivalent to atmospheric pressure. The hybrid mesh applied consists of two parts: the mesh of the static zone and the object under study. The finest grids near the object are used in order to improve the assessment of the boundary layer.

Table 1: Dimension of the wind accelerating device head.

Dimension	
Round head	Square head
inlet : 2 m (diameter) outlet : 1 m (diameter) length : 0.5 m	inlet : 2 m x 2 m outlet : 1 m x 1 m length : 0.5 m

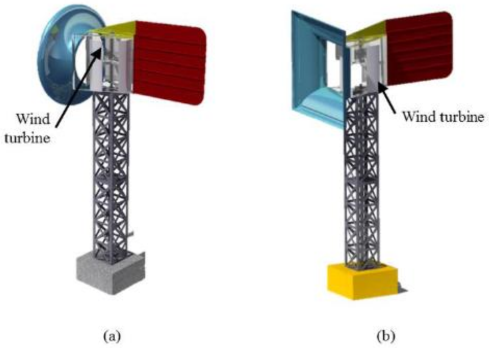


Fig. 2: Wind accelerating device with (a) round head (b) square head.

RESULT AND DISCUSSION

Figure 4 and 5 show the velocity contours for both shapes at different input velocity. The velocity magnitude after passing through the head of the device for both shapes is considerably increased as compared to the input velocity 2, 4, 6 and 8 m/s respectively. Table 2 summarized the comparison of the performance for both shapes after CFD analysis. It clearly shows that the velocity of the incoming wind has increased after passing through the wind accelerating device by 26% and 28% for round and square shape respectively. Besides that, the performance of local wind velocity after passing through the ducted square head is slightly better than round head of the wind accelerating device. This could be due to the size of opening area. The opening area for square and round shape is 4 m2 and 3.14 m2 respectively. The size of square shape is slightly bigger than round shape, thus it able to capture more wind as compared to round shape. Efficiencies of the proposed design can be gained with the ability of accelerating the wind through a convergent path of the head of wind accelerating device. The analysis on power density is conducted as well and tabulated in table 2. The power density is computed by employing equation $P=12\rho Av3$ where P is power in *watt*, ρisdensity in *kg/m3*, A is swept area in *m2*and v is velocity in *m/s*. It shows that the power density has increased tremendously due to the power is directly proportional to the cube of wind velocity. Furthermore, this provides evidence of the increasing in efficiency available from VAWT wind turbine with wind accelerating device. The calculation shows an improvement from as low as 8.2 W/m2 to 515 W/m2 of extra potential energy can be harvested from the incoming wind speed from 2 m/s to 8 m/s respectively if the VAWT wind turbine integrated with wind accelerating device.

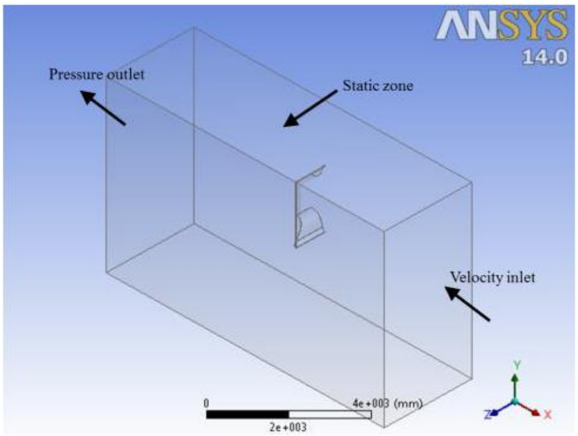
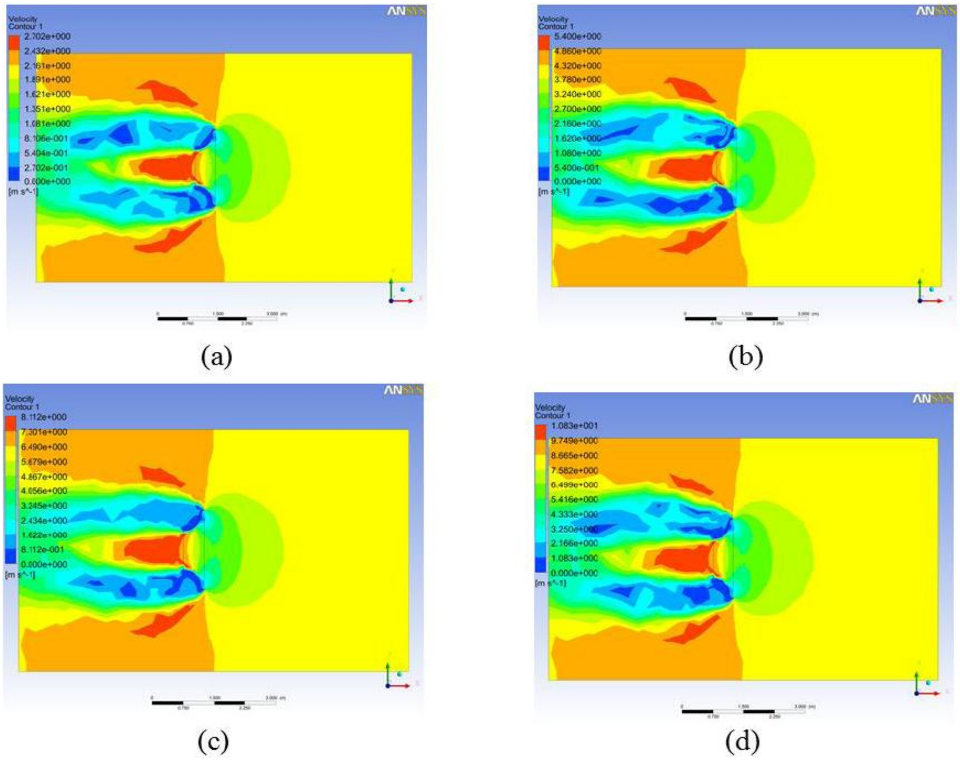


Fig. 3: Boundary conditions and main dimensions of computational domain for square and round head.



(a) (b)
(c) (d)

Fig. 4: Velocity contours for round shape (a) 2m/s, (b) 4 m/s, (c) 6 m/s and (d) 8 m/s.

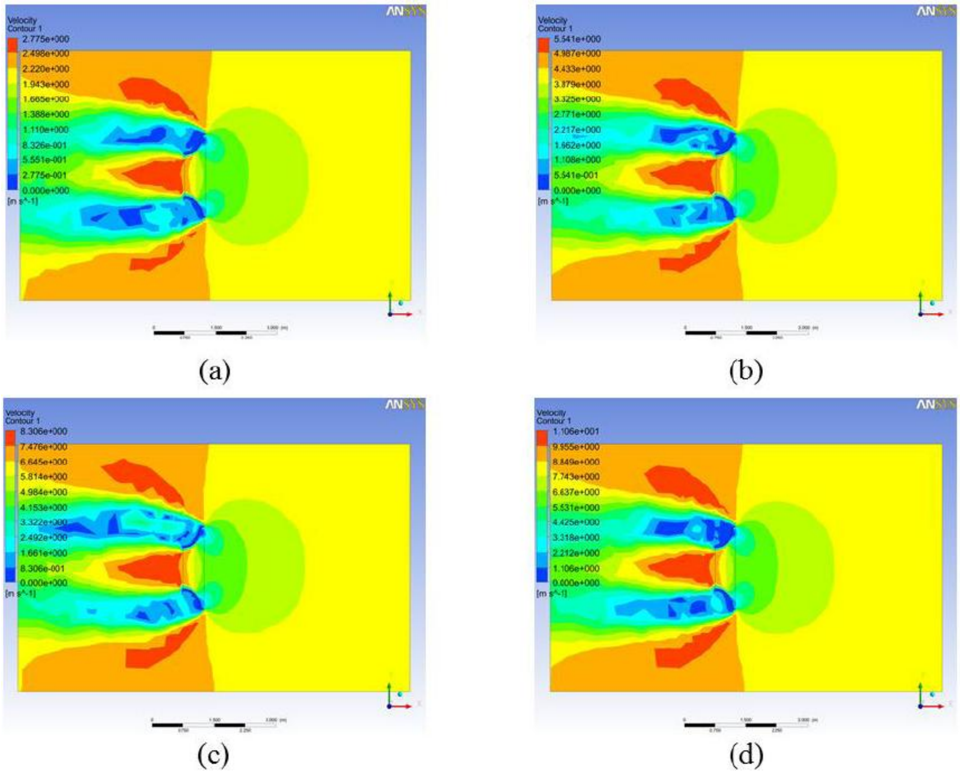


Fig. 5: Velocity contours for square shape (a) 2m/s, (b) 4 m/s, (c) 6 m/s and (d) 8 m/s.

Table 2: Comparison result on velocity performance and theoretical power extracted for round and square shape of wind accelerating deviceand without wind accelerating device.

Wind Turbine without wind accelerating device		Wind Turbine with wind accelerating device						Improvement of power density (comparison between VAWT without wind accelerating device and VAWT with accelerating device – square head) (W/m^2)
		Round head			Square head			
Wind Velocity (m/s)	Power density (W/m^2)	Wind Velocity (m/s)	Power density (W/m^2)	% of Velocity Improvement	Wind Velocity (m/s)	Power density (W/m^2)	% of Velocity Improvement	
2	4.9	2.702	12.1	26	2.775	13.1	28	8.2
4	39.2	5.4	96.5	26	5.541	104.3	28	65.1
6	132.4	8.112	327.1	26	8.306	351.1	28	218.7
8	313.8	10.83	778.4	26	11.06	829.1	28	515.3

Conclusion:

The low wind speed can be increased by utilizing the accelerated ducted devices. The square and round shape design is selected in this study to optimize the performance. It reports that the square shape design perform better in increasing the wind flow speed due to the bigger area of air intake. Besides that, accelerated ducted devices assists in improving the power density generated in wind turbine.

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