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An Experiment on Horizontal and Vertical Wind Turbines with Incorporation of Rounded Shroud Device Using Wind Simulation in a Vehicle

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ABSTRACT: The detrimental impact on the environment over the utilization of the conventional energy based fossil fuel is obvious. Thus, the effort on the reduction on the dependency on this unclean fuel is salient. The application of the clean renewable wind power can be one of the appropriate measures in supporting the effort in reducing the dependency on the unclean fuel. Performance is one of the essential aspects in determining the economic attractiveness on the technology application. One of the factors responsible to the performance of the power technology is the wind velocity acting on the rotor blade. The addition of a shroud element is believed to have a great promise to increase the velocity at rotor, thus possibly improving the performance of the wind turbine. This study presents an experiment on horizontal and vertical wind turbines incorporated with rounded shroud devices. The experiment is conducted in a vehicle to simulate the effect of the flow of wind. The results on this experiment indicate that the addition of the shroud device with geometry of diffuser improves the performance of the horizontal axis wind turbine. For the nozzle shroud geometry, it seems to less significantly improve the performance of the horizontal axis wind turbine. For the vertical turbine, the incorporation of the shroud devices, both nozzle and diffuser, has almost no effect to increase the performance. This study also presents the discussion for the reasons behind the experimental results by relating to the condition of the turbine rotation and the wind velocity inside the shroud devices.

KEYWORDS: Wind turbine, shroud, performance, experiment, vehicle.

1 INTRODUCTION

Energy plays an essential role in the social and economic development. It is inevitably that currently the major sources of energy worldwide come from fossil fuel. Relying merely on the energy based fossil to support the social and economic development seems to be less appropriate option as the limitation and, importantly the detrimental environmental impact of the greenhouse gas carbon emission.

The application of the clean renewable wind power can be one of the appropriate options in reducing the dependency on this exhaustible and unclean fuel. The wind technology has been developed rapidly and are about to play an important role in a new energy field [1]. All wind turbines installed by the end of 2010 worldwide can generate 430 TWH per annum, which is equal to more than 2 percent of the global electricity consumption [2].

There are two main classes of wind turbines; horizontal and vertical axis turbines. Each of which has advantages and disadvantages. The horizontal turbines offer higher efficiency, easier starting, less torque fluctuation and higher speed rotation than the vertical machines [3-4]. The vertical turbines offer some beneficial features including no requirement for a constant yaw mechanism in the local wind direction, less noise than the horizontal turbine due to low rotational operation, lower manufacturing cost for a very large vertical turbine than that of the equivalent horizontal turbine due to the simpler

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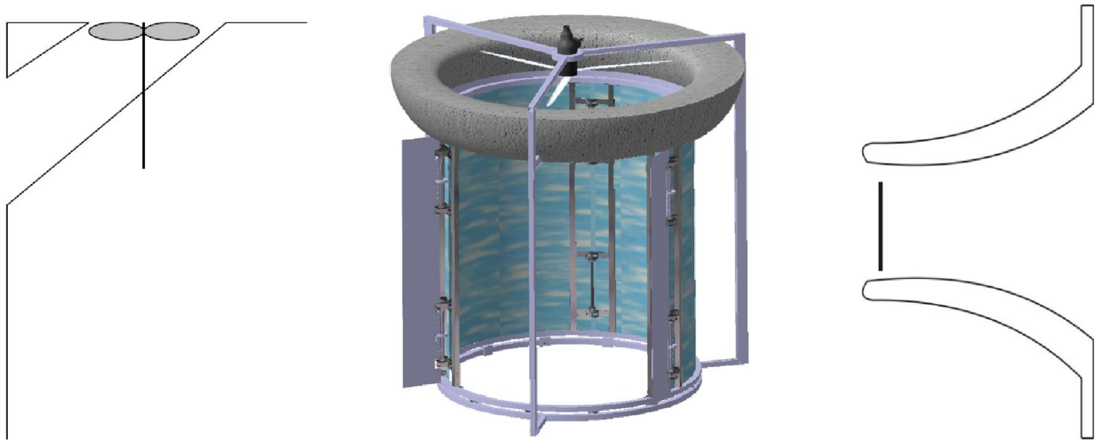
straight constant section blades and mechanically better able to withstand higher winds through changing stalling behavior and better operational safety during gust conditions than those of the horizontal turbine [5].

Performance is one of the essential aspects in the design phase of the wind technology. This is because that the aspect can determine the economic feasibility on the wind technology application. The high performance possibly makes the wind technology posing economical senses when it is put into application, while the low performance effortlessly brings the technology less favorable for application. The performance of the wind technology can be determined by the dimension of the turbine and the wind velocity [6]. The bigger a wind rotor, the more wind energy is obtained. The more wind speed, the more force acting on the rotor, making the higher torque generated as well as the higher performance. The idea of increasing the wind speed becomes the main scope in this study.

It seems to be impossible to create the nature of windy condition. However, by, one of the alternative methods, incorporating a shroud device into the wind machine, it seems to be highly possible to create a local environment where the wind speed can be higher than the ambient velocity, thus it can enhance the wind machine performance.



(a) **(b)** **(c)**

Fig. 1 (a) The shrouded wind turbine in a building section
(b) The bucket shape wind turbine (c) The diffuser shroud wind turbine

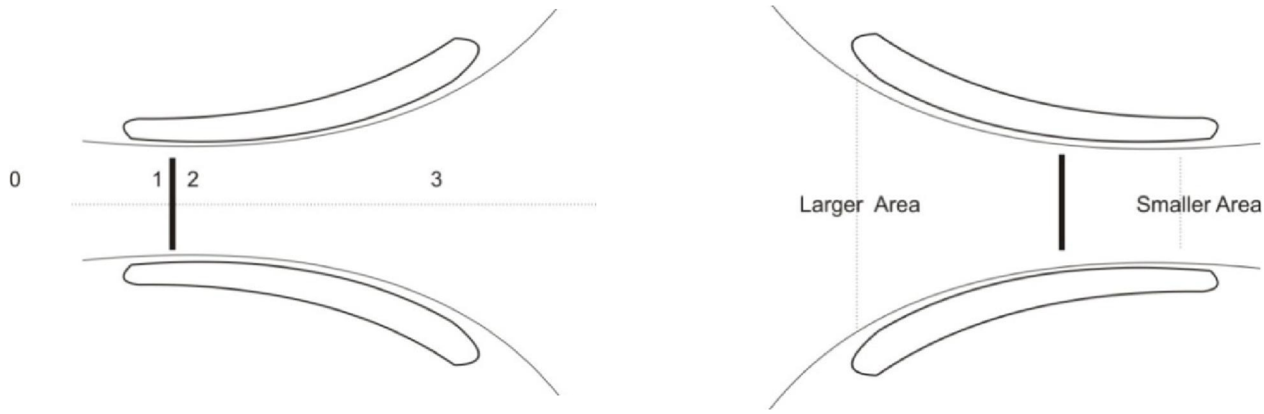
A reference [7] shows an investigation on a placement of a shrouded wind turbine in a building section [Figure 1a]. The idea of this configuration is to harnesses the pressure difference of the air flow between the front facade and the roof of the building in order to increase the velocity. Using a wind tunnel test and a *Computational Fluid Dynamic* (CFD) simulation, it is shown the wind velocity through the shroud can increase by the factor around 1.5.

A reference [8] shows a study on an improvement of a wind machine performance by incorporating a shroud with the geometry of a bucket-shape which is partially hollowed on its cylindrical surface [Figure 1b].The configuration of the bucket shroud is to guide the airflow into the inlet (the hollowed surface) and across the outlet (the other hollow) simultaneously so that a low-pressure zone develops alongside the outlet to create a suction effect which accelerates the airflow inside the shroud. Using a *Computational Fluid Dynamic* (CFD) analysis and a field experiment, it is found that the wind speed inside the shroud can increase by the factor almost two.

A grounded shrouded wind turbine is studied in [9]. The idea of the grounded shroud turbine is that the rotor and the supporting electrical equipment may just as well be positioned on the ground (or even underground). The configuration also enables the structure to be much easier to be built, assembled and maintained. Using a one-dimensional momentum analysis, it is indicated that the coefficient of performance (CP) can possibly exceed the Betz limits (the maximum efficiency of the bare turbine) when the pressure difference along the shroud is high.

Turbines incorporated with a flanged diffuser shroud are investigated in [1,10,11] using a wind tunnel analysis, a *Computational Fluid Dynamic* (CFD) analysis and a field experiment [Figure 1c]. It is shown that the wind speed in the diffuser can be higher than the ambient wind speed. The addition of the diffuser generates a low-pressure zone in the region behind the turbine, thus it can absorb more wind from the outside, as a results it increases the wind speed inside the shroud [1].

A reference [12] shows an experiment on the effect of adding a rounded diffuser on the performance on models of three–bladed horizontal axis wind turbines. The effect of the wind flow is simulated by a standing-fan. The results of this experiment show the addition of the diffuser improves the rotation and the torque of the turbine shaft.



(a) (b)

Fig. 2 (a) Model of diffuser shroud wind turbine (b) Nozzle shroud wind turbine

A one-dimensional mathematical model to analyze the turbine with the incorporation of diffuser shroud is developed in [13]. The Bernoulli equation is applied to develop the model. The induced velocity (V_1) (m/s) derived from the model is formulated by

$$V_1 = V_0\sqrt{\frac{\eta_{01} - C_{pb}}{\eta_{01} + K - C_{P23}}} \quad (1)$$

where, V_0 is the free-stream velocity (ambient velocity) (m/s), C_{pb} is the base pressure coefficient, defined as

$$C_{pb} = \frac{P_3 - P_0}{\frac{1}{2}\rho V_0^2} \quad (2)$$

P_0 is the static pressure at the free-stream region (ambient pressure) (N/m^2) and P_3 is the static pressure at the rear part of diffuser (N/m^2).

Parameter of K is the resistance coefficient defined as

$$K = \frac{P_1 - P_2}{\frac{1}{2}\rho V_1^2} \quad (3)$$

where P_1 is the static pressure in region immediately before the turbine (N/m^2) and P_2 is the static pressure in region immediately after the turbine (N/m^2).

Parameter of C_{P23} is the diffuser coefficient formulated by

$$C_{P23} = \frac{P_3 - P_2}{\frac{1}{2}\rho V_1^2} = \left(1 - \left(\frac{V_3}{V_1}\right)^2\right) \quad (4)$$

where V_3 is the velocity at the rear region (downstream) (m/s).

Parameter of η_{01} is the inlet diffusion efficiency, formulated by

$$\eta_{01} = \frac{(P_1 - P_0)}{\frac{1}{2}\rho V_0^2 - \frac{1}{2}\rho V_1^2} \quad (5)$$

From the model, one of the approaches to make the velocity enhancement ($V_1 > V_0$) is that the base pressure (C_{pb}) should be negative. This means that the static pressure at the rear region of the shroud (P_3) must be lower than the ambient pressure (P_0) (see Equation 2). Another option to obtain the velocity enhancement is to make the high amount of the diffuser coefficient (C_{P23}). This can be obtained when the velocity at the rear region of the diffuser (V_3) is lower than the induced velocity (V_1) (see Equation 4). The shape of the diffuser can contribute to make the velocity at the rear (V_3) lower than the induced velocity (V_1). This is because that the area of the diffuser at the rear is higher than the area where the induced velocity is generated (at inlet). Based on the continuity law, when fluid passes into a higher cross sectional area, the velocity reduces. The low resistance coefficient (K) also enables the velocity enhancement (see equation 1).

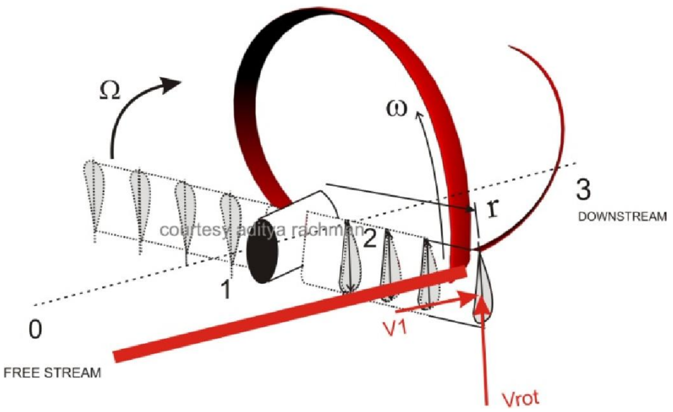
Instead of the studies on the shroud geometry, there is a study [14] on the shrouded wind turbine considering the effect of blade number. A *Computational Fluid Dynamic* (CFD) analysis is employed in this study. The result of this study shows that the high blade number into a shrouded diffuser wind turbine can result in the reduction of the mass flow rate to reduce the performance.

From previous references, the addition of the shroud devices shows a potential to improve the wind velocity. The diffuser shrouded arrangement seems to be favorably utilized in some of the references. Theoretically, nozzle, which is geometrically opposite to diffuser, can also potentially enhance the velocity. This is because that nozzle has the shape of the lower cross sectional area at the rear part which can make the increasing on the wind velocity (see Figure 2 (b)). The aim of this study is to present an experiment on the horizontal and vertical axis wind turbines incorporated with shroud devices of nozzle and diffuser in order to increase the performance. The methodology of generating this study is a simulation on models of the wind turbines incorporated with the shroud devices in a vehicle in order to provide the effect of wind flow.

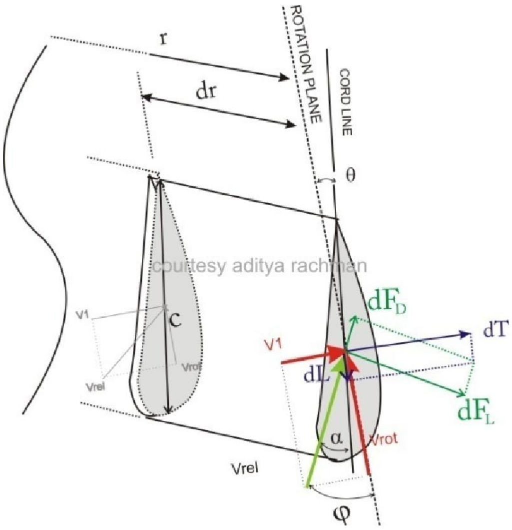
2 METODOLOGY

2.1 MODEL OF TURBINE

The model of the horizontal turbine is designed with three blades with the radius of 0.30 m. The blade shape is a plate with the width at hub of 0.05 m and the width at tip of 0.13 m.



(a)



(b)

Fig. 3. (a) The model of Blade Element Momentum (b) The detail of the forces on a blade element Illustrated by Rachman, adopted from [6 and 15]

To obtain an optimum design of the blade pitch angle, this study conducts a parametric study using the Blade Element Momentum (BEM) model. According to [16], this model can be utilized in designing the wind turbine blade and in evaluating the wind turbine performance. The formula to find the power (P) in the BEM model is

$$P = \int_{rh}^{R_T} \frac{TL\, 8\, \Omega\, B\, c\, \rho\, V_0^2}{(\sin\varphi)^2 (K+4)^2} \left(C_L \sin\varphi - C_D \cos\varphi\right) r\, dr \quad (6)$$

where, TL is the tip loss factor, V_o is the ambient wind velocity (m/s), B is the blade number, ρ is the specific mass of air (kg/m^3), c is the cord length (m), Ω is the blade rotational speed (RPM), r is the elemental radius (m), dr is the elemental length (m), R_T is the turbine radius (m) and rh is the hub radius (m). Parameter of φ is the wind relative angle following the relation of $\varphi = \alpha + \theta$, where θ is the blade pitch angle and α is the attack angle. Parameter of C_L is the lift coefficient and C_D is the drag coefficient of the blade cross sectional shape. In this model, the input velocity (V_0) is 17 m/s. The computer program of MATLAB is employed in the calculation using the BEM model. The result of this parametric study shows that at the pitch angle of 20 °, the power will be a maximum. Thus in the horizontal turbine model, the pitch angle is set to be 20°.

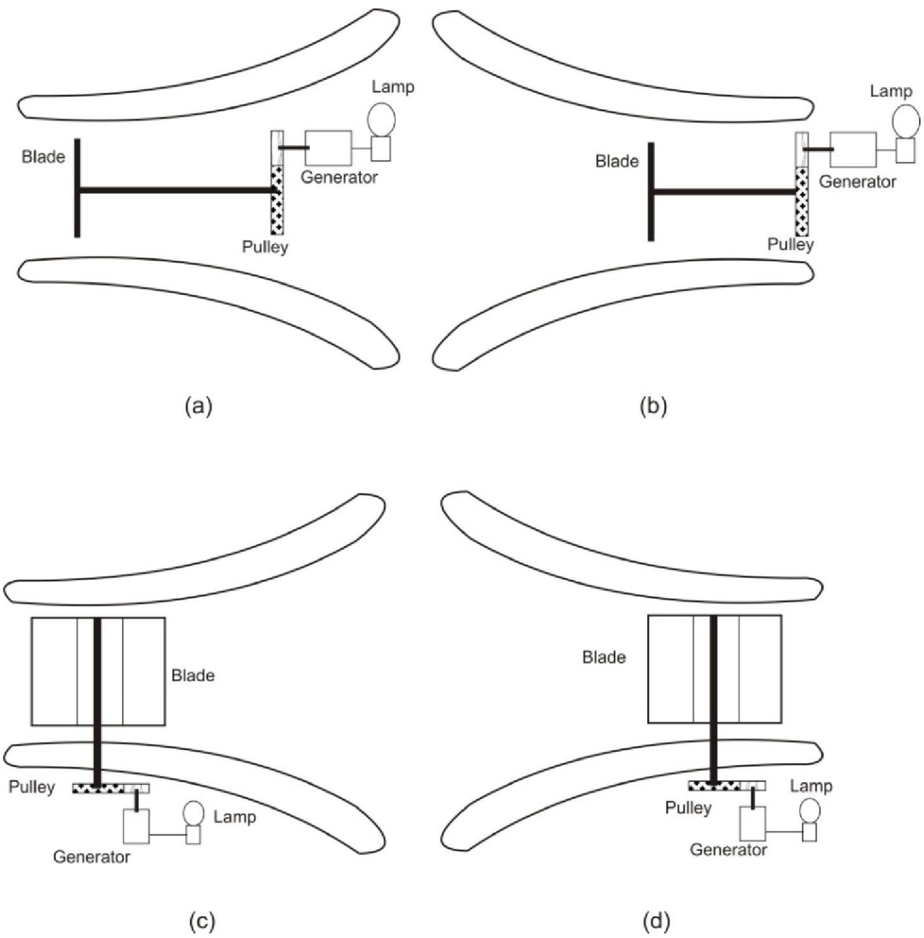


Fig. 4. Models of the wind turbine (a) Horizontal turbine with diffuser (b) Horizontal turbine with nozzle (c) Vertical turbine with diffuser (d) Vertical turbine with nozzle

The model of the vertical turbine is designed with three blades with the height of 0.6 m. The blade shape is a *S-Rotor* (Savonius Type) with the width of 0.15 m. Both models (horizontal and vertical turbines) are designed as such they can be modified for the placement of a rounded shroud device with the geometry of diffuser and nozzle. The shroud has the ratio of the smaller diameter to the length of 0.33 with the incline angle of 4 ° [adopted from a study [1]). The shaft of the turbines is connected to a pulley which is linked into a generator where lamps are connected.

2.2 EXPERIMENT METHOD

The models are placed in the rear part of a van. The vehicle is moved and the velocity in the opposite direction becomes the wind operating velocity for the turbines. The wind speed is measured by an anemometer. In this experiment, the operating wind speed is set to be 10 m/s. For each model tested, it measures the electricity current in the lamps in order to obtain the coefficient of performance (CP), a ratio of the energy generated by the wind turbine to the available wind energy, formulated by

$$CP = \frac{R\,[I]^2}{0.5\,\rho\,[V_0]^2\,A} \qquad (7)$$

where I is the measured electricity current in the lamps (Ampere), A is the turbine swept area (m^2) and R is the resistance of the lamps (ohm).

Fig. 5. The method of experiment

To provide the explanations on the experimental results, the data of the turbine blade rotation and the wind speed inside the shroud when the turbine is omitted will be measured by tachometer and anemometer respectively.

3 Results and Discussion

The results indicate that the horizontal axis wind turbine with the diffuser has the highest coefficient of performance (CP) (around 0.4), the horizontal turbine incorporated with the nozzle has CP of 0.26, and the horizontal turbine without the diffuser and the nozzle (bare) has CP of 0.20 (see Figure 6). The horizontal turbine with the diffuser has the rotation of 808 RPM, the horizontal turbine using nozzle has the rotation of 620 RPM and the bare horizontal turbine has the rotation of 560 RPM (Figure 7). For the vertical turbines, the coefficient of performance (CP) is almost similar in all arrangements (CP around 0.1) (Figure 6). The vertical turbine with the diffuser has the rotation of 400 RPM, the vertical turbine with the nozzle has the rotation of 390 RPM and the bare vertical turbine has the rotation of 398 RPM (Figure 7).

The turbine performance, theoretically, is the function of torque and rotation. Thus, the high rotation possibly results in the high performance. This could be one of the reasons for the highest performance of the horizontal turbine with the diffuser as the rotation is the highest among the turbines tested. The high rotation of this turbine can be caused by the high wind speed inside the shroud (Figure 8).

For the horizontal turbine with the nozzle configuration, although the wind speed inside the shroud is higher than the ambient velocity, the rotation is not significantly different to that of the bare turbine. This may be due to the losses on the contribution of the wind velocity in the tip region (near the inner shroud surface). The airflow in the middle would be at a high speed. However, in the region near the inner surface of the nozzle, it will be very low due to the air friction (see Figure 9). As the contribution of the velocity at the tip is less, the turbine rotation is not too high; as a result the torque generated would be not too high, thus the performance will be not significantly improved.

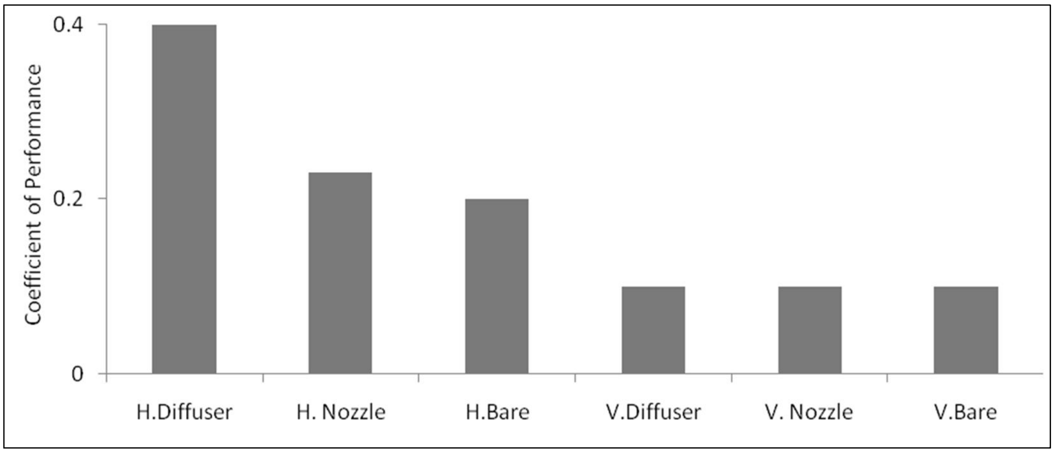


Fig. 6. The Coefficient of performance in the wind models tested

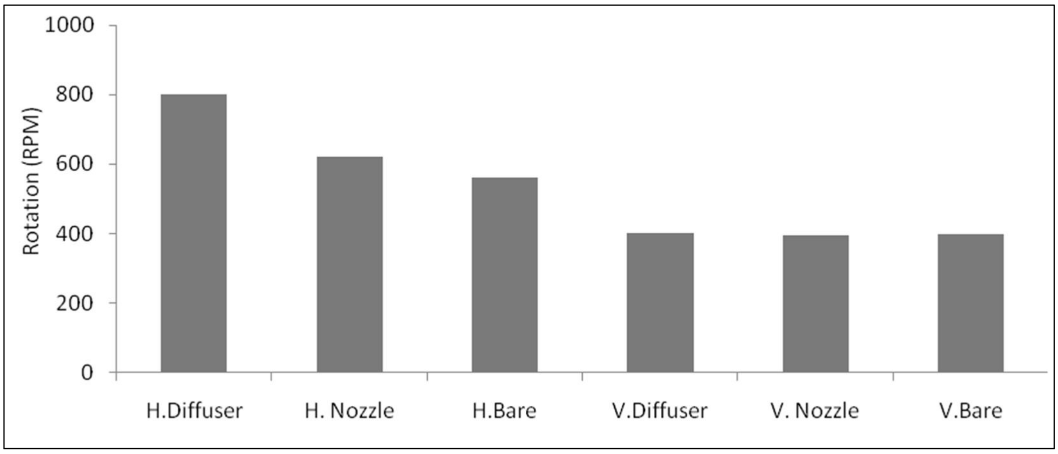


Fig. 7. The rotation in the wind models tested

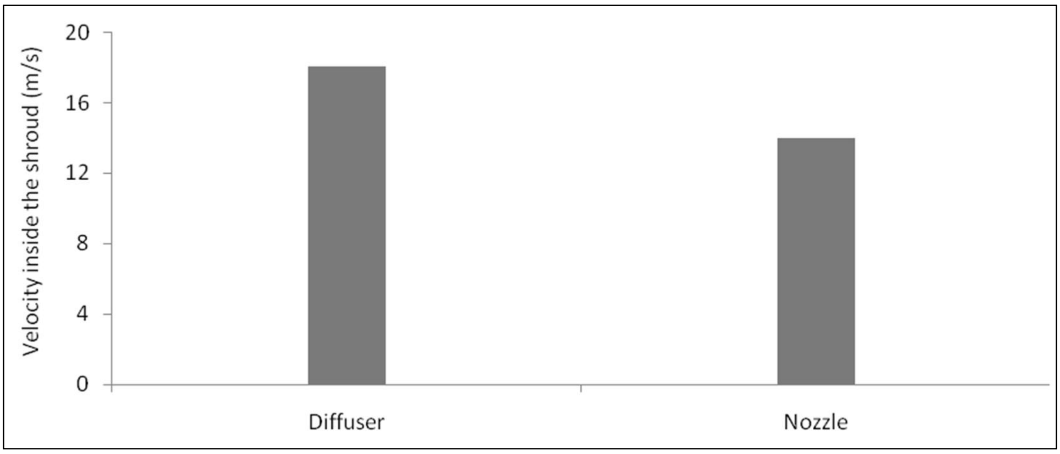


Fig. 8. The velocity inside shroud (omission of turbines)

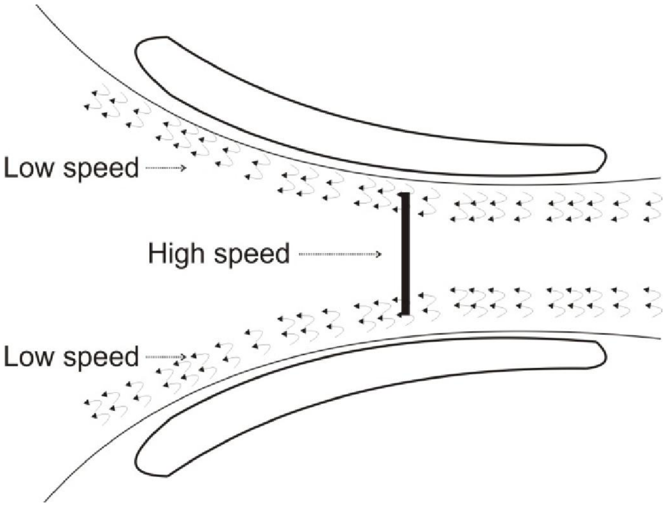


Fig. 9. Velocity profile inside the nozzle

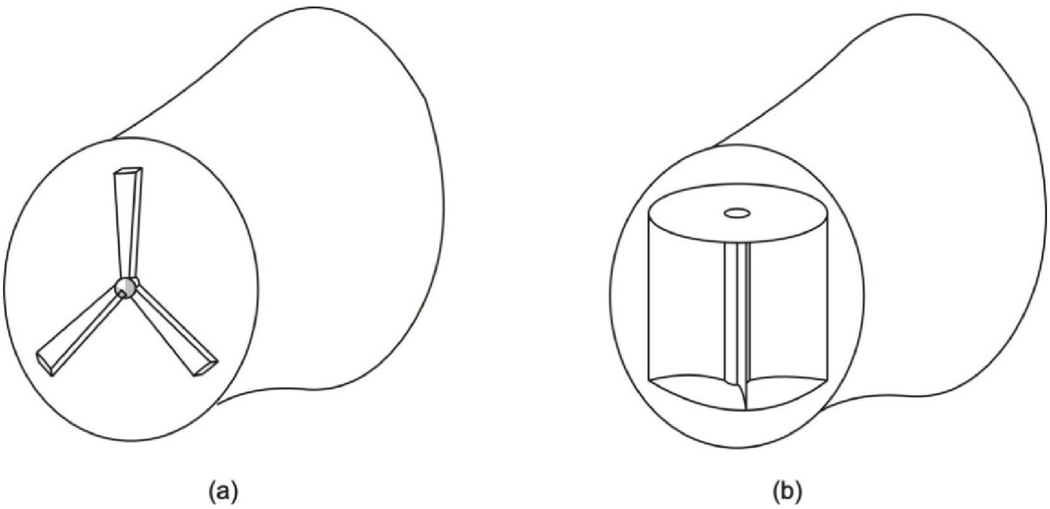


Fig. 10. The condition of the blade area facing the approaching wind in the shroud device
(a) The horizontal turbine (less blade area) (b) The vertical turbine (more blade area)

For the vertical turbine, the addition of the shroud devices almost has no impact on the change on the rotation and the performance. For the diffuser shrouded arrangement, the resistance aspect can be one of the factors responsible. As the vertical turbine has more blade area compared to the horizontal turbine (see Figure 10), it creates more blockage effect, reducing the wind flow into the turbine. This condition can be explained by using the mathematical model for the turbine with the diffuser in section I. The resistance coefficient (K) can represent the existence of the turbine. This is because that the turbine can act as a porous disk which allows only some air faction to pass. This condition makes the pressure difference of the region immediately before the turbine and the region immediately after the turbine (P_1-P_2). When a turbine has more blade area, the pressure difference can be high; as a result the resistance coefficient is high, thus the induced velocity will be low (see equation 1). As a vertical turbine has the higher blade area (60 cm x 30 cm x 2) compared to the horizontal turbine (the maximum of 13 cm x 30 cm x 3), the resistance coefficient for the vertical turbine will be higher.

For the vertical turbine with the nozzle shrouded arrangement, both the resistance effect of the blade area and the air resistance inside the shroud can contribute for the almost zero impact on the power enhancement.

4 CONCLUSION

This study presents the experiment on the models of the horizontal and vertical wind turbines equipped with the shroud devices with the geometry of nozzle and diffuser in order to increase the performance. Following paragraph is conclusions that can be drawn.

The addition of the diffuser on the horizontal axis turbine model seems to be effective to enhance the performance. The effect of the wind velocity enhancement inside the shroud can be one of the factors responsible for the increase in the performance. The addition of the nozzle seems to have less effective to enhance the performance of the horizontal axis turbine. For the vertical turbine, the incorporation of the shroud devices almost has no contribution to enhance the performance. The blockade effect created by the high blade area of the vertical turbine can be one of the factors responsible for this phenomenon.

In further study, for the vertical arrangement case, it is very important to choose the turbine with less blade area in order to gain the high induced velocity. The selection of the Daerius type–vertical turbine can be one of the potential alternative options as the blade area facing the approaching wind in this vertical type turbine is typically low.

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REFERENCES

[1] Y. Ohya, K.I. Abea, “An investigation of flow fields around flanged diffusers using CFD”. Wind Engineering and Industrial Aerodynamics. Vol 92, pp. 315–330, 2004.
[2] World Wind Energy Association (WWEA), “World Wind Energy Report 2010”, Date of publication: April, 2011.
[3] M. Anyi, B. Kirke, “Evaluation of small axial flow hydrokinetic turbines for remote communities”. Energy for Sustainable Development, Vol 14, pp. 110–116, 2010.
[4] M.J. Khan, G. Bhuyan, M.T. Iqbal, J.E. Quaicoe, “Hydrokinetic energy conversion systems and assessment of horizontal and vertical axis turbines for river and tidal applications : technology status review” . Applied Energy. Vol 86, pp. 823–1835, 2009.
[5] R. Howell, N. Qin, J. Edwards, N. Durrani , “Wind tunnel and numerical study of a small vertical axis wind turbine”, Renewable Energy, Vol 35 ,pp. 412–422, 2010.
[6] J.F. Manwell, J.G. McGowan, A.L. Rogers, “Wind Energy Explained; Theory, Design and Application. University of Massachusetts”, USA John Wley & Sons, LTD, 2002.
[7] A. Grant, R. K.W. Dannecker , “Investigations of a building-integrated shrouded wind turbine module”. Wind Energy. Vol 5, pp. 53–71, 2002.
[8] S.Y. Hua, J.H. Cheng, “Innovatory designs for shrouded wind turbines”. Renewable Energy. Vol 33,pp. 1491–1498, 2007
[9] D.P. Georgiou, N.G. Theodoropoulos, “Grounding and the influence of the total pressure losses in shrouded wind turbines “. Wind Energy. DOI: 10.1002/we.373, 2009.

[10] T. Matsushima, S. Takagi, S. Muroyama, "Characteristics of a highly efficient propeller type small wind turbine with a diffuser". Renewable Energy. Vol. 31. pp. 1343–1354, 2006.
[11] Y. Ohya, T. Karasudani, "A shrouded wind turbine generating high output power with wind-lens technology". Energies, Vol 3. pp. 634–649, 2010.
[12] Hermawan, "Studi eksperimental penggaruh penambahan difuser terhadap unjuk kerja turbin angin sumbu horizontal tiga sudu dengan variabel bentuk dan panjang difuser", Prosiding Seminar Nasional Perkembangan Riset dan Teknologi di Bidang Industri ke 18 Universitas Gadjah Mada, 18, MF 8, 2012.
[13] C.J. Lawn, "Optimization of the power output from shrouded turbines ", Proceedings of the Institution of Mechanical Engineers. 217, 1; ProQuest Science Journals, 107, 2003.
[14] S.H. Wang, S.H. Cheng, "Blade number effect for a ducted wind turbine", Journal Mechanical Science Technology, vol. 22, pp 1984-1992, 2008.
[15] T. Burton, D. Sharpe, N. Jenkins, E. Bossanyi, "Wind Energy Handbook", John Wiley & Sons, Ltd. Baffins Lane, Chichester West Sussex, PO19 1UD, England, 2001.
[16] R. Lanzafame, M. Messina, "Horizontal axis wind turbine working at maximum power coefficient continuously", Renewable Energy, Vol 35, pp 301–306, 2010.