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Study of Turbine and Guide Vanes Integration to Enhance the Performance of Cross flow Vertical Axis Wind Turbine

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Abstract. The main purpose of this study is to investigate the best configuration between guide vanes and cross flow vertical axis wind turbine with variation of several parameters including guide vanes tilt angle and the number of turbine and guide vane blades. The experimental test were conducted under various wind speed and directions for testing cross flow wind turbine, consisted of 8, 12 and 16 blades. Two types of guide vane were developed in this study, employing 20^0 and 60^0 tilt angle. Both of the two types of guide vane had three variations of blade numbers which had same blade numbers variations as the turbines. The result showed that the configurations between 60^0 guide vane with 16 blade numbers and turbine with 16 blade numbers had the best configurations. The result also showed that for certain configuration, guide vane was able to increase the power generated by the turbine significantly by 271.39% compared to the baseline configuration without using of guide vane.

Keywords: Wind energy, Wind turbine, Vertical axis wind turbine, Cross flow, Guide vanes

INTRODUCTION

Wind energy is a source of renewable and pollution-free energy that can be utilized to meet daily energy needs. Indonesia has wind speeds between 2 m/s and 5 m/s, with most of region in Indonesia's having wind speeds between 2 m/s to 3 m/s. While the area with highest wind speed in Indonesia is located only in a small part of eastern Indonesia [1]. In order to be able to harvest wind energy under these conditions, it needed turbines that able to self-rotating at low wind speeds conditions and not affected by the wind direction. VAWT will be the right solution to solve this problem, since VAWT is able to rotate in low wind speed and can catch wind from any direction.

The cross flow wind turbine is a vertical axis wind turbine with a design application of a banki water turbine. Existing research indicates that the cross flow wind turbine has good initial torque and high power efficiency at low wind speeds. As a vertical axis wind turbines, cross flow wind turbine also has the advantage against fluctuating wind direction. In addition, cross flow type wind turbines also have advantages in terms of simple design so that this type of turbine can be easily fabricated using simple materials such as metal plates [2][3].

Many research has been conducted to increase the performance of VAWTs. These research include modifications of some turbine design factors. One factor that can affect turbine performance is the number of blades. With more blades attached to the turbine, the amount of torque generated by the turbine will increase. In general with the extra amount of the blade, the available kinetic energy of the stream will be more efficiently converted into mechanical energy by the blade [4]. In addition to modifications on the turbine design factor, turbine performance improvements can also done by using a power augmented devices such as stator, guide vanes and nozzle. These power augmented device use to increase the incoming wind velocity before it enter the turbine inlet section and concentrate the incoming wind direct to the turbine blades. Since the power produced

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by the turbine is proportional to the incoming wind speed, therefore increased incoming wind velocity will significantly improve the performance of a wind turbine [5].

Shigemitsu *et al*. proposed symmetrical casing for cross flow wind turbine to increase turbine performance, their results showed that the power coefficient of the turbine increased at air speed at 20m/s using symmetrical casing [6]. Takao *et al*. proposed a directed guide vane row to improve of a straight-blade VAWT performance, the results showed that the power coefficient was increased by 150% [7]. Pope *et al.* conducted experimental and simulation analysis on a zephyr wind turbine. The turbine design comprises of nine stator vanes around the VAWT with reverse winglets. The results showed that the power coefficient increased from 0.098 to 0.12 or increased by 81.6% compared to the bare turbine [8]. Chong *et al.* designed an omni directional guide vanes (ODGV) as a flow augmented devices for vertical axis H-rotor wind turbines. The results showed that the use of ODGV improved wind turbine performance with an increased rotational speed of the rotor by 125% in experimental experiments and 206% with numerical simulations [9]. Korprasertsak and Leephakpreeda proposed a wind booster on a drag-type Savonius VAWT. The wind booster design consists of curve-sided triangle shape stator vanes evenly distributed around the VAWT to able to capture wind from all direction. The result showed that the angular rotational speed was increased greater than 50% with the wind booster under no load condition [10].

In this study, an omni directional type guide vanes is proposed to improve vertical axis cross flow wind turbine. Several design variations consisted of turbine and guide vanes blade number and tilt angle was also conducted to investigate the effect on the maximum power generation. The optimal design of the turbine and guide vanes lead to the best configuration between guide vanes and the turbine.

EXPERIMENTAL SET UP

The geometry of the rotor and Guide vanes used in this experiment are presented in figure 1. The rotor used in this experiment is a cross flow type rotor with a number of blades consisting of 8, 12 and 16 blades. The guide vanes used in this experiment are an omni directional type guide vanes with vanes blade shaped as two segments with equal length and bend at certain angle. The guide vanes also had three variations of blade numbers which same as the blade numbers variations for the turbines.

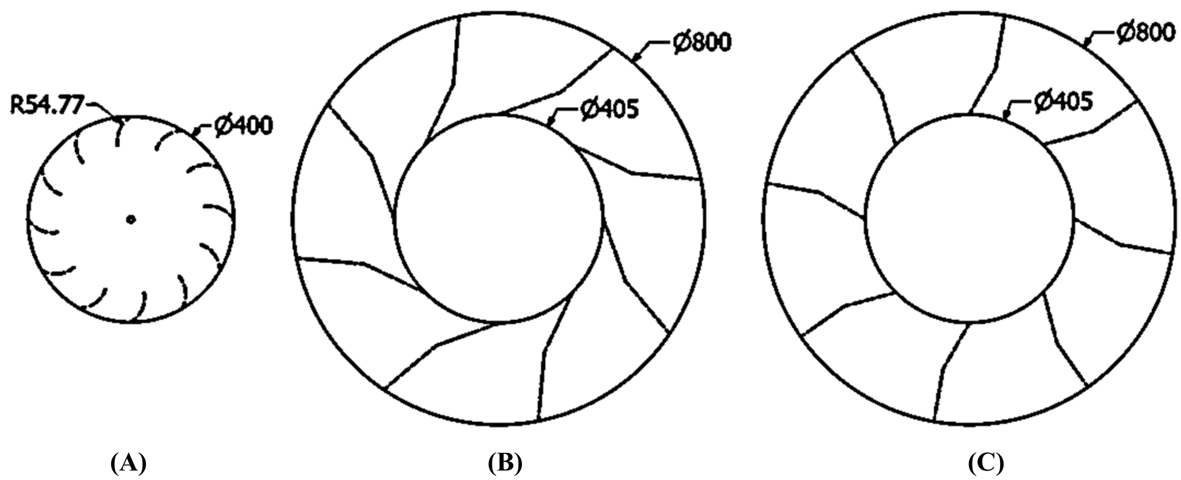


FIGURE 1. Turbine and Guide vanes geometry (A) Cross flow turbine, (B) Guide vanes with tilt angle 20^0, (C) Guide vanes with tilt angle 60^0

The research done by Chong et.al showed that blades with geometric designs in the form of two segments of equal length that bent at the center can improve turbine performance better than straight plate-shaped blades [11]. Two types of guide vane were developed in this study, employing of two tilt angle variations which consisted of 20^0 and 60^0 tilt angle. Both of the two types of guide vane had three variations of blade numbers which had same blade numbers variations as the turbines. To find out the best configuration between turbine and guide vanes, the turbine and guide vanes set to several configuration with the guide vanes tilt angle and blade number of the turbine and guide vanes as the main parameter. The configuration between turbine and guide vanes are presented in the table 1.

TABLE 1. Turbine and guide vanes configuration

Turbine and Guide Vanes Configuration					
16 Blade Turbine		**12 Blade Turbine**		**8 Blade Turbine**	
Guide Vanes 60^0	**Guide Vanes 20^0**	**Guide Vanes 60^0**	**Guide Vanes 20^0**	**Guide Vanes 60^0**	**Guide Vanes 20^0**
16 blade Guide Vanes	16 blade Guide Vanes	16 blade Guide Vanes	16 blade Guide Vanes	16 blade Guide Vanes	16 blade Guide Vanes
12 blade Guide Vanes	12 blade Guide Vanes	12 blade Guide Vanes	12 blade Guide Vanes	12 blade Guide Vanes	12 blade Guide Vanes
8 blade Guide Vanes	8 blade Guide Vanes	8 blade Guide Vanes	8 blade Guide Vanes	8 blade Guide Vanes	8 blade Guide Vanes

The experimental set-up for this study is presented in Figure 2. In the experiment wind flow is generated using wind generator which consisted of two industrial fan to simulated ambient wind condition where the wind flow is turbulent. Rotational speed of the turbine is measure using laser tachometer and wind speed is measure using vanes anemometer. the torque measurement was done using rope brake dynamometer where the rotors were allowed to rotate from no load condition, and then loaded gradually by adding 50 g of mass for ten times. The spring balance readings and the dead weights were recorded and used to calculate the brake torque of the turbines.

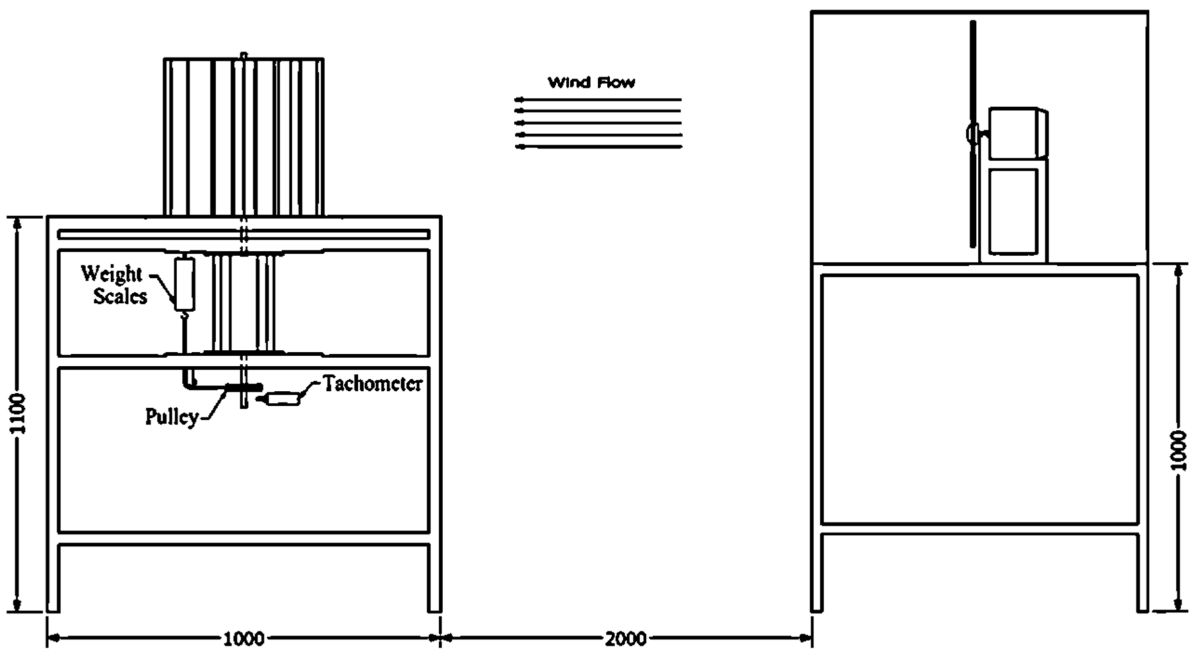


FIGURE 2. Experimental testing apparatus

The wind speed measurement is taken at several measurement point downstream the wind generator and repeated for several times to ensure the air flow uniformity. Wind speed measurement is taken to determine the location of the turbine testing apparatus where the wind flow is much more uniform compare to the outlet of the wind generator and to reduce the greater vortex created by the wind generator. Based on the wind speed measurement location, the wind turbine testing apparatus is placed at 2000 mm downstream of the wind generator. The wind speed was set at 3.56 m/s with center point at the center of the turbine to simulate the wind speed in Surakarta city area which ranged between 2 and 4 m/s.

RESULT AND DISCUSSION

Several experimental test was conducted over several turbine and guide vanes configuration to compare the performance of the turbine without and with the use of the guide vanes. The performance of the turbines was evaluated based on the maximum Cp and TSR (λ). Figure 3 shows the coefficient of power against the tip speed ratio for bare turbine. As shown in figure 3, all of the turbine shows a similar trend where the coefficient of performance increase until the peak performance is reached at certain TSR and then decrease along with the increase of TSR value. The highest Cp in all of the turbine blade number variations occurred between TSR Value 0.2 and 0.3 with performance enhancement about 1.5 times for all the blade variation. The result also shows that the 16 blade number produce the highest Cp compare to the 12 and 8 blade turbine with Cp value of 0.051.

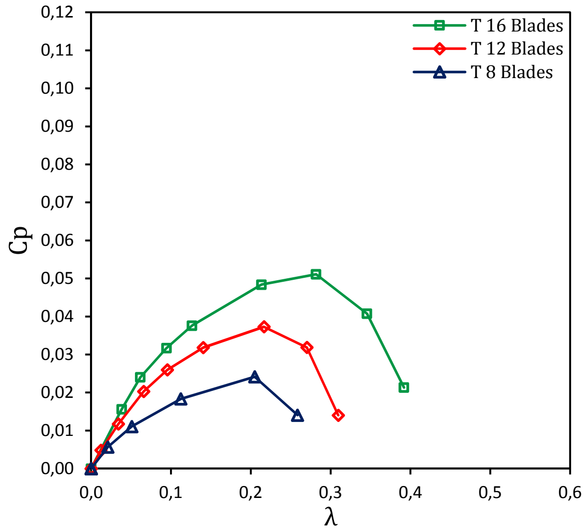


FIGURE 3. Coefficient of power against tip speed ratio for bare turbine

To find out how much guide vanes could improve the turbines performance, the performance of the bare turbine will be compared to the performance of the turbine integrated with guide vanes. The configuration between turbine and guide vanes was set that each variation of turbine blade will be tested using all of the guide vanes blades variation. The result will categorized based on the turbine blade and the guide vanes blade variations to find out the guide vanes influence to the bare turbine performance. Figure 4 compared the coefficient of power value between 2 types of guide vanes on the 16 blade turbine.

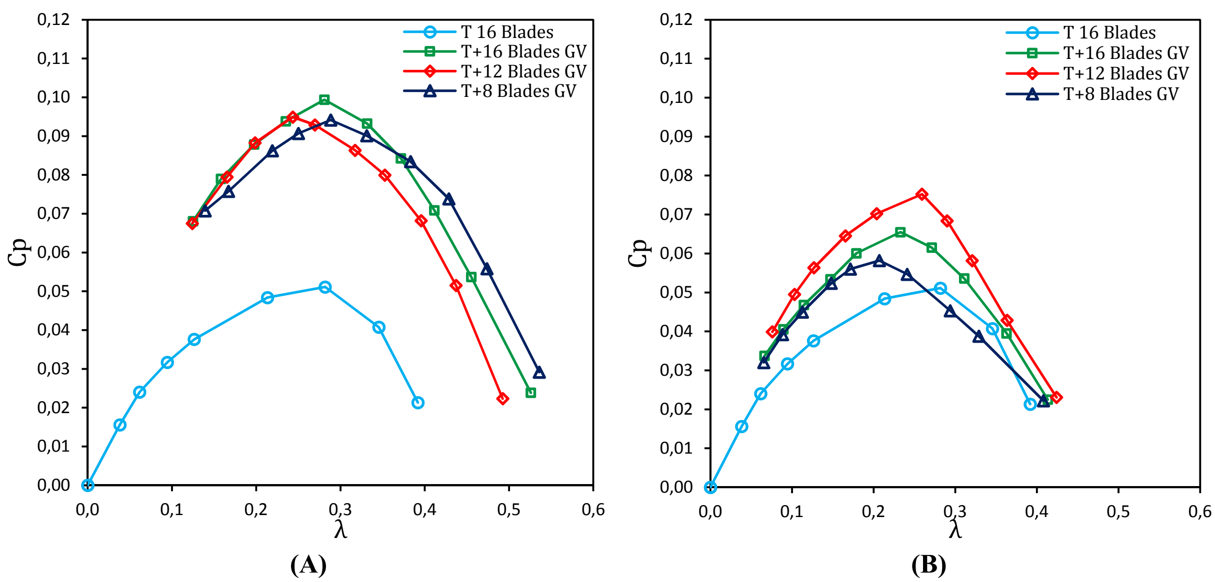
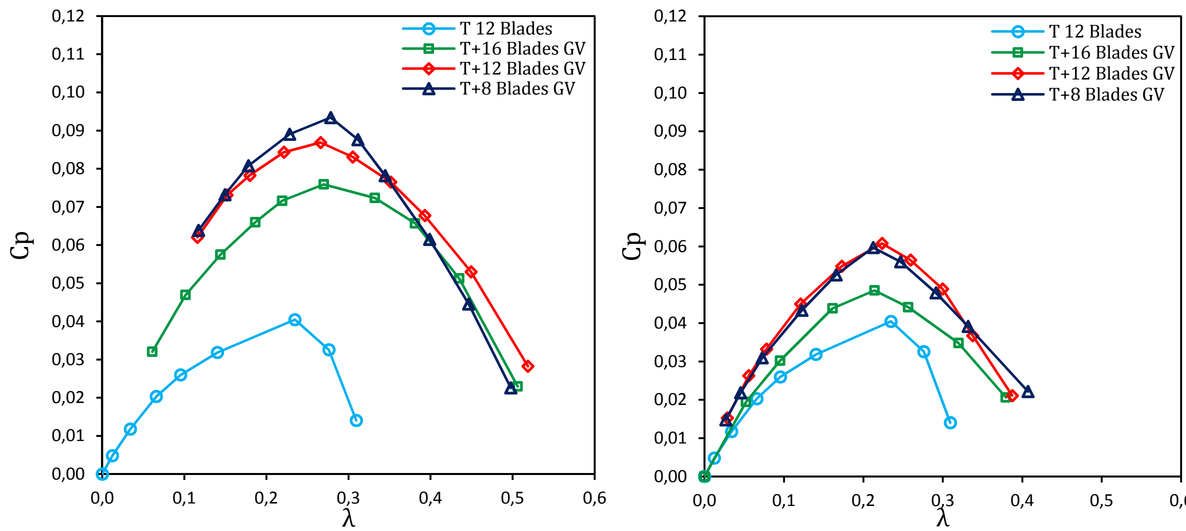


FIGURE 4. Coefficient of power against tip speed ratio for 16 blades turbine: (A) Guide vanes with 60^0 blade angle and (B) Guide vanes with 20^0 blade angle

Based on the result shown in the figure 4, the highest Coefficient of power value of the guide vanes integration to the 16 blade wind turbine is increased about 94.418% for the 60^0 guide vanes and 47.154% for the 20^0 guide vanes with the highest Cp value 0.099 and 0.075 for 60^0 and 20^0 guide vanes. The Cp_{max} of 16 blades turbine is generated by the configuration with 16 blades guide vanes for 60^0 guide vanes type while the configuration with 12 blades guide vanes generated the Cp_{max} for the 20^0 guide vanes type. The result shows that the 60^0 guide vanes integrated turbines generated the Cp_{max} 32% higher compared to the Cp_{max} generated by 20^0 guide vanes type. The lowest performance occurred in the turbine configuration with 8 blade 20^0 guide vanes type with maximum Cp generated about 13.842% higher than bare turbine performance.

The result of the configuration between 12 blade turbine and the guide vanes are presented in the figure 5. The result shows some differences with the result of the 16 blade turbine where the highest Cp value is generated by configuration between 12 blades turbine with 8 blades guide vanes for the 60^0 guide vanes type. However, the 12 blades turbine configuration with 20^0 type guide vanes shows similarity with the result of the previous guide vanes configuration with 16 blades turbine where the $C_{p\ max}$ generated by the turbines configuration with 12 blades guide vanes.



(A) **(B)**

FIGURE 5. Coefficient of power against tip speed ratio for 12 blades turbine: (A) Guide vanes with 60^0 blade angle and (B) Guide vanes with 20^0 blade angle

As shown in the figure 5, the 12 blades turbine performance improved significantly with Cp_{max} increased from 0.037 to the 0.093 or increased about 150.4% for the 60^0 type guide vanes while for for the 20^0 type guide vanes Cp_{max} is increased about 62.96% with Cp_{max} value 0.061. The result comparison between 60^0 and 20^0 guide vanes shows that 60^0 guide vanes integrated turbines generated Cp_{max} 52.971% higher compared to the Cp_{max} generated by 20^0 guide vanes with the lowest Cp_{max} value occurred in the turbine configuration with 16 blade 20^0 guide vanes type with maximum Cp generated about 30.081% higher than bare turbine performance.

Figure 6 presented the Cp value of the configuration between 8 blade turbine and the guide vanes. Compared to both of the previous result this configuration shows another different trend for the turbine configuration with 60^0 guide vanes type where the highest Cp value is generated by turbine configuration with 12 blade guide vanes.

All of the turbine configuration with 60^0 guide vanes shows different trend and result for the configuration that generates the highest Cp value. As an example, 16 blade guide vanes generated highest Cp for the configuration with 16 blade turbine while at the same time generate lowest Cp in the configuration with 12 blades turbine and for the configuration with 8 blades turbine, 16 blades guide vanes generated the second highest Cp compared to the result from another guide vane blades configuration. Both of another turbine blades variation also reported to have similar behavior for the configuration with 60^0 guide vanes where there are no single contributors that generate highest Cp value for the entire turbine configuration with 60^0 guide vanes. However, the entire turbine configuration with 20^0 guide vanes shows similar trend where the Cp_{max} generated by the turbines configuration with 12 blades guide vanes.

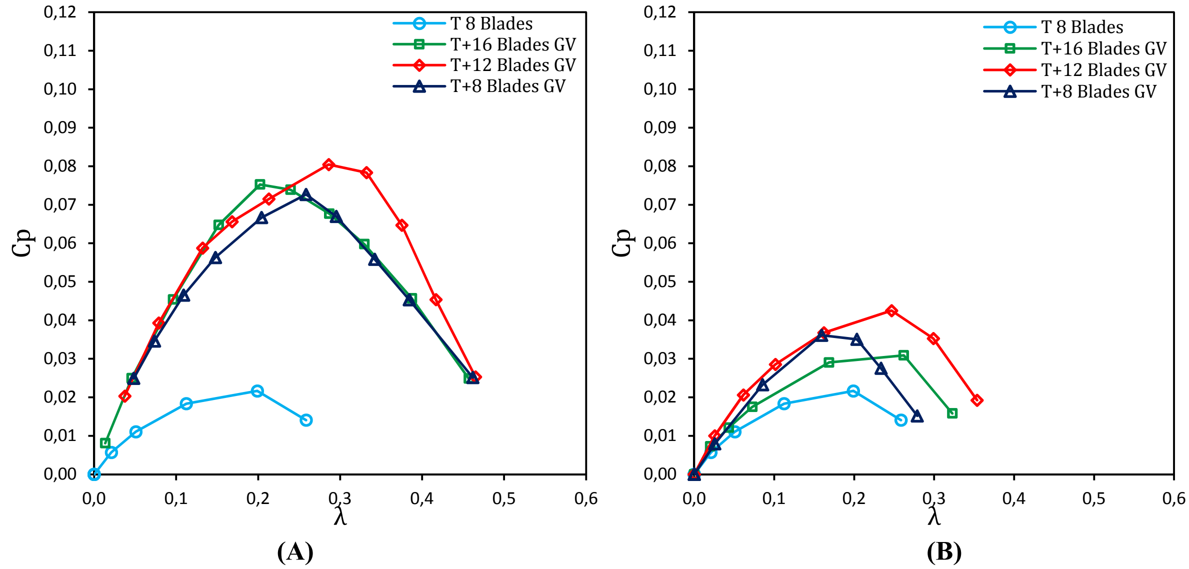


FIGURE 6. Coefficient of power against tip speed ratio for 8 blades turbine: (A) Guide vanes with 60^0 blade angle and (B) Guide vanes with 20^0 blade angle

As shown in the figure 6 the turbine highest Cp_{max} value is increased from only 0.22 to the value of 0.080 or increased about 271.39% for the turbine configuration with 60^0 guide vanes, while Cp_{max} value is increased to the value of 0.043 or increased about 96.326% for the turbine configuration with 200 guide vanes. The result comparison between 60^0 and 20^0 guide vanes shows that 60^0 guide vanes integrated turbines generated Cp_{max} 158.83% higher compared to the Cp_{max} generated by 20^0 guide vanes with the lowest Cp_{max} value occurred in the turbine configuration with 16 blade 20^0 guide vanes type with maximum Cp generated about 42.7% higher than bare turbine performance.

From the experiment result, it can be concluded that configurations between 60^0 guide vane with 16 blade numbers and 16 blade turbine as the best configurations. The result shows that turbine configuration with guide vanes augmented the performance of the bare turbine with the lowest Cp_{max} value increased by 13.842%. The integration between turbine and the guide vanes also indicated significant performance improvement to the bare turbine with an example of integration between 12 blades turbine and 8 blade 60^0 guide vanes. The Cp_{max} that bare 12 blades turbine could generate is value 0.037 or about 1.37 times smaller than Cp_{max} that generated by the bare 16 blades turbine. The integration between 12 blades turbine and 8 blade 60^0 guide vanes augmented the turbine performance by 150.4% with Cp_{max} value 0.093, or only 6.45% less than the highest Cp_{max} generated by 16 blades turbine after integration with guide vanes. The highest Cp for all of the turbine and guide vanes configurations occurred in the same tip speed ratio range wich value between TSR 0.2 and 0.3.

All of the experiment result also shows that the 60^0 guide vanes augmented the turbine performance better than the 20^0 guide vanes. The difference is caused by difference of the guide vanes outlet area between both of the guide vanes. Because guide vanes work with the same principle with venture tube where the flow enters the duct with the initial velocity which in this case same with wind velocity generated by the wind generator, then velocity increases along the guide vanes section which act as flow concentrator and reaching a maximum value at the minimum area of the duct in the outlet section of the guide vanes.

The results shows that the configuration between guide vanes and turbines with the same number of blades do not always generate the highest Cp_{max} values. For some configurations, the highest Cp_{max} value is generated by the configuration between guide vanes and turbines with different number of blades. The results also shows for some configuration, the highest Cp_{max} value is generated by the configuration of the guide vanes and turbines with the number of the guide vanes blades more than the number of turbine blades. However, this phenomenon only occur if the number of the turbine blades is close to the number of the guide vanes blade

CONCLUSION

In this study, the configuration between guide vanes and cross flow vertical axis wind turbine has been investigated using experimental method. The result indicated that the turbine configuration with guide vanes is proven to be able to augment the performance of the bare turbine in terms of coefficient of power. The result of the study can be summarized as follows:

1. The configurations between 60^0 guide vane with 16 blade numbers and turbine with 16 blade numbers is the best guide vanes and turbine configurations
2. The highest Cp_{max} value generated by the best turbine and guide vanes configuration value 0.99
3. The highest Cp_{max} improvement occurs in the configuration between 60^0 guide vane with 12 blade numbers and turbine with 8 blade
4. The configuration between guide vanes and turbines with the same number of blades do not always generate the highest Cp_{max} values

   The highest Cp_{max} value will be generated by the configuration of the guide vanes and turbines with the number of the guide vanes blades more than the number of turbine blades if the number of the turbine blades is close to the number of the guide vanes blade

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REFERENCES

1 Martosaputro. A, Murti. N, Blowing the Wind Energy in Indonesia, Energy Procedia 47, 2014, pp. 273-282

2 Dragomirescu. A, Performance assessment of a small wind turbine with crossflow runner by numerical simulations, Renewable Energy 36, 2011, pp. 957 – 965.

3 Al-Maaitah. A. A, The design of the Banki wind turbine and its testing in real wind conditions, Renewable Energy 3, 1993, pp. 781-786 .

4 S. Mathew, Wind Energy: Fundamentals, Resource Analysis and Economics (Springer, Berlin, 2006), pp. 18.

5 W. T. Chong, Y. Shiah, K. H. Wong, N. L. Sukiman, S. C. Poh, C. T. Wang, Performance enhancements on vertical axis wind turbines using flow augmentation systems: A review, Renewable and Sustainable Energy Reviews 73, 2017, pp. 904–921.

6 T. Shigemitsu, J. Fukutomi, M. Toyohara, Performance and flow condition of cross-flow wind turbine with a symmetrical casing having side boards, International Journal of Fluid Machinery and System 9, 2016, pp. 169-174.

7 M. Takao, T. Maeda and Y. Kamada, A Straight-blades Vertical Axis Wind Turbine with a Directed Guide Vane Row, Journal of Fluid Science and Technology 3, 2008, pp. 379-386.

8 K. Pope, V. Rodrigues, R. Doyle, A. Tsopelas, R. Gravelsins, G. F. Naterer, et al, Effects of stator vanes on power coefficients of a zephyr vertical axis wind turbine. Renewable Energy, 2010, pp.43–51.

9 W. T. Chong, S. C. Poh, A. Fazlizan, K. C. Pan, Vertical axis wind turbine with omni directional guide vane for urban high rise building, Journal of Central South University, 19, 2012, pp. 727-732.

10 N. Korprasertsak and T. Leephakpreeda, Analysis and optimal design of wind boosters for Vertical Axis wind Turbines at low wind speed, Journal of Wind Engineering and Industrial Aerodynamics, 159, 2016, pp. 9–18.

11 K. H. Wong, W. T. Chong, H. T. Yap, A. Fazlizan, W. Z. W. Omar, S. C. Poh, F. B. Hsiao, The design and flow simulation of a power-augmented shroud for urban wind turbine system, Energy Procedia 61, 2014, pp. 1275 – 1278