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Experimental investigation of the area ratio of double-layer blades as obstacle blades on swirling savonius rotor performance

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Abstract. The effect of the area ratio of the double layer obstacle blades to the performance of the swirling savonius rotor model has been identified. There are 4 studied ratios of 1: 6, 2: 6, 3: 6 and 4: 6 which are equivalent to 30° , 60° , 90° and 120° of the double layer obstacle blades arc angles in wind tunnels with wind speeds between 3 m s^{-1} to 6 m s^{-1} which is equivalent to Reynolds number 323 to 112645. The results of the study show that a small ratio of 30° and 60° blades arc angles can improve the performance of swirling savonius rotor, especially at Reynolds number 112645. Besides that, the existence of double-layer obstacle blades can increase the resistance of swirling savonius rotor toward the load.

Keywords: area ratio, double layer obstacle blades, arc angles, Reynolds number, swirling savonius rotor

1. Introduction

In recent times the world's energy supply today is dominated by non-renewable fossil energy. Apart from this the use of fossil energy also impacts the environment and human health. A serious impact on the environment is the occurrence of weather changes caused when fossil energy is converted into energy that is useful for humans will release carbon dioxide into the atmosphere which causes the formation of the greenhouse effect which will ultimately change the weather [1]. Emissions released by fossil energy also pollute the air which has a serious impact on human health [2].

To overcome the impact of the use and non-renewable nature of fossil energy, researchers have recently looking for alternative energy supplies that are environmentally friendly and renewable. Wind energy is one of the most promising renewable energy sources, many countries have explored and used wind energy because of pollution-free and the availability of abundant sources of wind energy for conversion to electricity and the other energy form [3].

The technology that can convert wind energy into energy that can be utilized by humans is a wind turbine, where the wind turbine is divided into two kinds of vertical axis wind turbine and



horizontal axis wind turbine. In general, vertical axis wind turbines have simple construction, are low cost, have better start capability than horizontal axis wind turbines, and do not require yaws and the turbine orientation always faces the wind direction [4].

Vertical axis wind turbines are divided into two kinds of Savonius rotor wind turbines that work due to differences in drag forces that arise on the sides of concave and convex blades, while Darrieus wind turbines work based on lift forces acting on the blades [5]. Savonius rotor wind turbines have the ability to self-starting at low wind speeds better than darrieus wind turbines but in terms of efficiency lower than darrieus wind turbines [6].

Indonesia's geographical position in the equator causes its wind characteristics to vary and the average wind speed is also low with an average of 3 m s^{-1} to 7 m s^{-1} . However, Indonesia based on PEU has a wind energy potential of 9 GW, so that with a large enough energy potential and low average wind speed, the development of savoniusrotor wind turbine is very appropriate.

There are many experimental studies concerning to improve the performance of Savonius rotor wind turbine has been carried out, starting from the effect of the number of blades [7-9], the results show that the number of blades in Savonius rotor wind turbine has an impact on turbine performance which is the number of blades 2 gives the best performance.

The development of the geometric shape of savoniusrotor wind turbine blades have been carried out by many researchers, including Modi and Fernando [10]. Then Kamoji et al. [11] modified the savonius blade with the geometric shape of the J-shaped blade, where the concave blades were separated, this modification received a C_p value of 0.2 while Kacprzak [12] modified the blade developed by Kamoji by reducing the plane of the geometric blade, the resulting C_p value was better than the blades developed by Kamoji et al. [11] and Tartuferi [13] developed new blades for savonius rotor wind turbines based on drag named SR 3345 and SR 5050, but the resulting C_p value is no better than the blades developed by kamoji however, the maximum C_p value is achieved at a lower tip speed ratio.

Besides, to increase the performance of the savonius rotor wind turbine, the researchers also conducted research related to controlling the flow on the surface of the blade by adding horizontal plate [14,15] and vertical plate [16] on the surface of the main blade and adding multiple quarter blades [17,18].

The recent study is focusing on the effect ratio of the double-layer blade as an obstacle to the main blade to improve the performance of the savonius rotor wind turbine in the wind tunnel.

2. Research Methods

In this study, the model of savonius rotorwind turbine is swirling savonius rotor wind turbine because of any overlapping each blade. The model made from PVC withthe aspect ratio (H/D) = 1, where the height of model (H) = 300 mm, the diameter of the model (D) = 300 mm, and overlapping ratio (m/d) = 20%, where m is the distance between the blades, the number of blades is 2 blades, diameter of each blade (d) = 180 mm. The savonius rotor wind turbine modelis made from PE for more details see figure 1.

The swirling Savoniusrotor wind turbine model was tested in an open-type subsonic wind tunnel with an area of 2025 cm^2 with a blower diameter specification of 16 "blades integrated with a speed inverter that can produce wind speeds ranging from 0 to 15 m s^{-1} . The swirling Savonius rotor wind turbine model setup in the wind tunnel can be seen in Figure 2.2.

The instrument used in this study to measure the rotation of the wind turbine model is a laser tachometer DT-1236L with a measurement range of 10-99999 rpm and accuracy: $\pm (0.05\% + 1 \text{ digit})$, wind speed measurement with a flexible anemometer KW0600562 with a measurement range of $0.6 - 30 \text{ m s}^{-1}$.

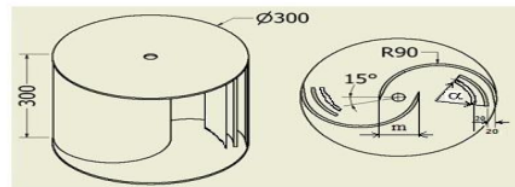


Figure 1. Dimensions of model swirling Savonius wind turbine

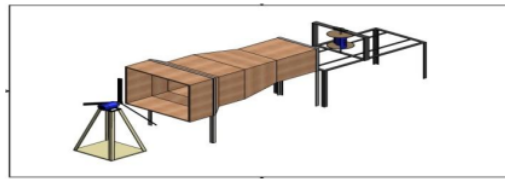


Figure 2. Set up of swirling Savonius rotor wind turbine model in the wind tunnel

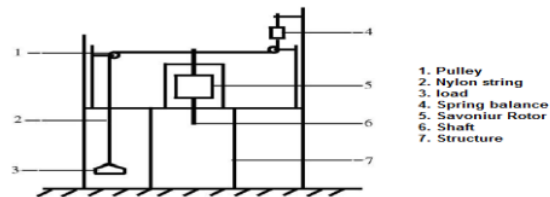


Figure 3. Prony brake scheme for torque measurement

Torque measured by the Prony brake method proposed by Kamoji et.al [11] with load every 250 gr till the wind turbine model stops, the scheme can be seen in Figure 3. The main variable of the study is the ratio of the area of the double blade as an obstacle ($\alpha/180^\circ \times$ circumference of the blade \times height of the blade) to the area of the main blade ($180^\circ/360^\circ \times$ circumference of the blade \times height of the blade). The ratio is $\alpha = 0^\circ$ (only main blades), $\alpha = 30^\circ$ (1:6), $\alpha = 60^\circ$ (2:6), $\alpha = 90^\circ$ (3:6) and $\alpha = 120^\circ$ (4:6). While the control variable is the speed of the wind coming out of the wind tunnel from 3 to 6 m s^{-1} adjusting the range of Indonesian average wind speeds.

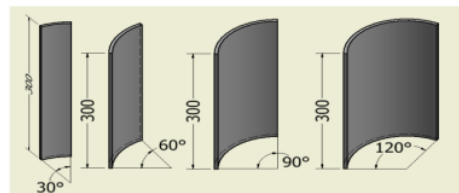


Figure 4. Design of obstacle blade

The swirling Savonius rotor wind turbine model performance parameters can be calculated using three non-dimensional equations and a dimensional equation in the form of power density,

tip speed ratio, power coefficient, and Reynolds number. The density of the power is determined from the measurement of torque (T) and angular speed (ω) divided by the sweep of turbine area (A), as in the following equation

$$\text{Power Density} = \frac{T\omega}{A} \quad (1)$$

The tip speed ratio (TSR) is the ratio of the wind speed at the tip of the blade which is determined based on the measurement of the angular velocity (ω) and the radius of the turbine shaft (R) with the wind speed entering the turbine V_w as in the following equation

$$TSR = \frac{\omega R}{V_w} \quad (2)$$

While the power coefficient is defined as the ratio of the power generated by the wind turbine rotor to the wind power entering the turbine which is formulated with the following equation

$$C_p = \frac{T\omega}{0.5 \rho A V_w^3} \quad (3)$$

Reynolds number is the ratio between inertial force and viscous force what is used to determine whether the fluid flow is laminar or turbulent.

$$Re = \frac{\rho V D}{\mu} \quad (4)$$

3. Results and discussion

The swirling savonius rotor wind turbine model is made of PVC sheet and tested in an open wind tunnel with performance parameters such as power density and power coefficient. Figures 5 and 6 show that the maximum power density of The swirling savonius rotor wind turbine model is obtained at a ratio of 2: 6 or at the arc angle of the double layer blades as an obstacle 60° at Reynolds 112645 at 30.62 W m^{-2} , under this condition the resulting power coefficient is 25.25 %, while the maximum power coefficient obtained at the Reynolds number 93871 is 27.73% with the power density under this condition 19.46 W m^{-2} .

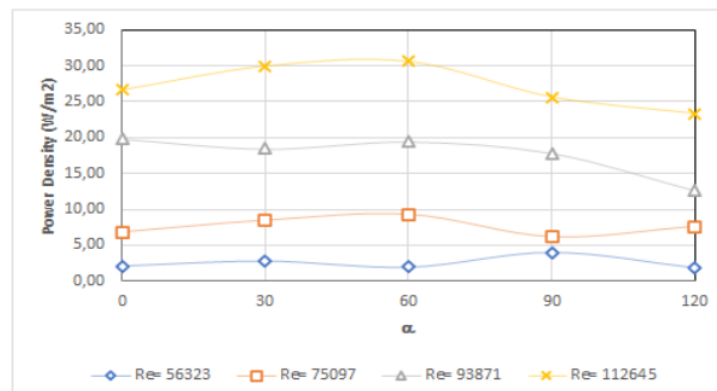


Figure 5. Power Density max in the variation of the ratio of obstacle blades to main blades and different Reynolds number

The existence of the double layer blades as an obstacle in front of the main blade able to increase the performance of the swirling savonius rotorwind turbine model both the power density and the power coefficient. This is suspected by the existence of the double-layer blades as an obstacle at a certain position the obstacle blade can increase the flow thrust in the overlap area so that it pushes the convex blades in the direction of the concave blades which results in the negative torque produced by the convex blades decreasing (see figure 7) which causes the positive torque difference generated by the concave blade with the negative torque produced by the convex blade, the fact that there is an increase in torque from The swirling savonius rotor wind turbine model with the obstacle blade than without the obstacle blades see Figure 8.

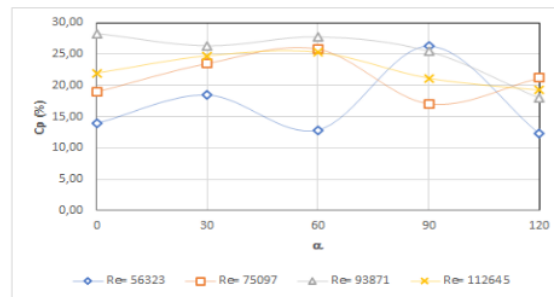


Figure 6. Power coefficientmax in the variation of the ratio of obstacle blades to main blades and different Reynolds number

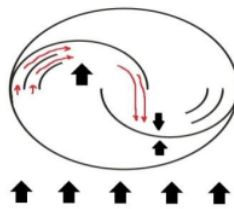


Figure 7. Illustration of flow in an overlap area

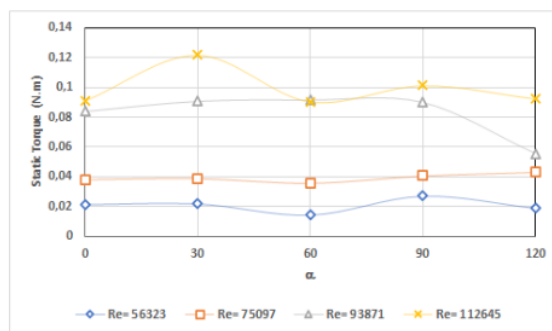


Figure 8. Static torque max in the variation of the ratio of obstacle blades to main blades and different Reynolds number

Figure 8 also shows that at the arc angle of the double layer blades as an obstacle of 300 and 600 the presence of the disturbing blade able to improve the static torque capability of The swirling savonius rotor wind turbine model , where the increase in static torque is correlated with the increased self-starting capability of The swirling savonius rotor wind turbine model [7].

Figures 9 to 12 show that the addition of the double-layer blades as an obstacle is able to increase the power coefficient of The swirling savonius rotorwind turbine model in the small ratio of the area of the double-layer blades as an obstacle to the area of the main blade, this is represented by the arc angle of the double-layer blades as an obstacle 30° and 60° . The greater area ratios represented by arc angles 90° and 120° have an impact on the decreasing power coefficient of The swirling savonius rotor wind turbine model . This is because the presence of the double-layer blades as an obstacle in this condition causes the flow that will enter the overlap area to be distortion by the free stream but also causes the focus point on the concave side main blade (f) to be obstructed so that both of these causes the thrust produced by the concave side blade to decrease which in finally the positive torque produced is also reduced see figure 13.

In addition, figures 9 to 12 also show that the existence of the double-layer blades as an obstacle increases the resistance of swirling savonius rotors to the load, which is shown by the extent of the graph produced by swirling savonius rotors with the double-layer blades as an obstacle which are wider than swirling savonius rotors without the double-layer blades as an obstacle.

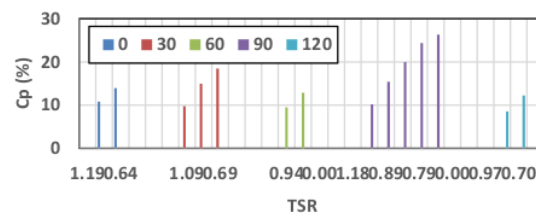


Figure 9. Power coefficient in the variation of the ratio of obstacle blades to main blades at Re = 56323

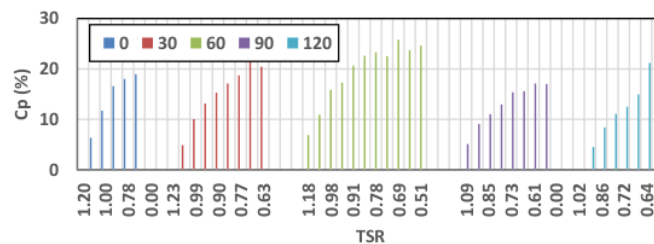


Figure 10. Power coefficient in the variation of the ratio of obstacle blades to main blades at Re = 75097

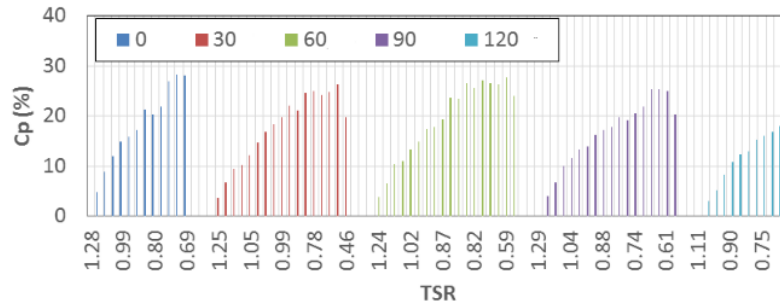


Figure 11. Power coefficient in the variation of the ratio of obstacle blades to main blades at $Re = 93871$

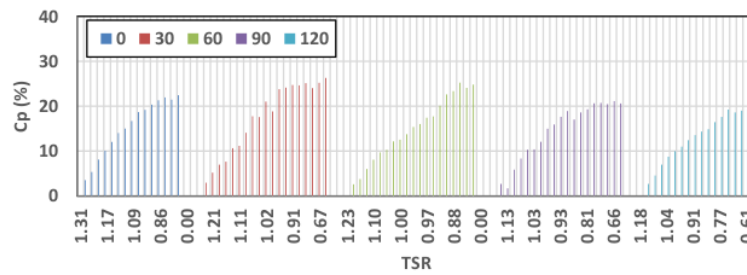


Figure 12. Power coefficient in the variation of the ratio of obstacle blades to main blades at $Re = 112645$

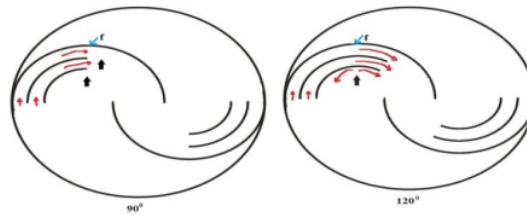


Figure 13. Illustration of flow over overlap area for 90° and 120° the double-layer blades as an obstacle arc angles

4. Conclusions

The addition of the double-layer blades as an obstacle able to work up the durability of the swirling savonius rotor wind turbine model against loading and is able to increase the performance and ability of the self-starting model in the small ratio of the area the double-layer blades as an obstacle with the main blade.

Acknowledgments

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