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Effect of the Number of Vanes in the Omnidirectional Guide Vane on Performance of Swirling Savonius Rotor

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Abstract

In this study, an omnidirectional guide vane (ODGV) was developed surrounding a swirling savonius rotor to increase the rotor performance. The ODGV consisted of several vanes which were to guide the air with a 45 deg counter-clockwise direction. The design was to accelerate the flow to increase the positive torque of the advancing blade. An open type wind tunnel is used to test the wind turbine model to investigate how ODGV influences rotor performance. Five ODGV were developed in this study, employing 4, 6, 8, 12, and 16 guide vanes that were 5 cm in width. Results showed that ODGV can substantially increase the rotor performance, depending on the number of guide vanes. The ODGV with 12 blades on produced the largest effect on the rotor performance in Re = 93269 can increase Cp 69,15 % more than a swirling savonius rotor without ODGV. As increase Reynolds number effect ODGV tends to increase the rotor performance significantly.

Keywords: *an omnidirectional guide vane, a swirling savonius rotor, positive torque, advancing blade, Reynolds number*

1. Introduction

Fossil energy is currently the dominant energy source in various countries, its use has a serious impact both in terms of energy sources, where fossil energy is classified as non-renewable energy, and from the environment, where the use of fossil energy causes an increase in carbon emissions which is the main cause of the effect greenhouse in the atmosphere which ultimately causes climate change [1].

Lately, many countries are looking for alternative energy sources that are renewable and environmentally friendly. Wind energy is one of the most promising renewable energy sources, many countries have explored and used wind energy because it is pollution-free and the availability of wind energy sources to be converted is abundant, according to the Danish energy agency the potential of wind energy in Indonesia is 9 GW with an average wind speed of between 3 m/s to 6.3 m/s [2], besides that due to Indonesia's geographical position on the equator, winds in Indonesia have characteristics that always change direction [3] so that the development of an appropriate type of wind turbine is Savonius wind turbine. The difference in the contour of the Savonius wind turbine blades is concave and there is a convex, then there is a difference in the drag force that works on both sides of the Savonius wind turbine blades, this is what causes Savonius wind turbines to spin [4], this type of turbine also has several advantages include simple construction and low cost, receiving wind from all directions in operation, having static and dynamic moments [5].

The influence of the number of blades on the Savonius wind turbine has been thoroughly studied [6-9], the results of their study explained that the increasing number of blades on the Savonius wind turbine has an impact on decreasing turbine performance and

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the number of blades 2 which is the number that produces the best turbine performance. Changes in the geometry of the Savonius wind turbine model that aims to improve the performance of Savonius wind turbines have been carried out by previous researchers including Modi and Fernando [10] modifying blades developed by Savonius, where the new blades can increase the Cp value of the turbine. Kamoji et al. [11] they modified savonius base blades with J-shaped blades which returned the advancing blades apart, this modification received a Cp value of 0.2 while Kacprzak [12] modified the blades developed by Kamoji by reducing the flat plane of the geometric slats the resulting Cp value is better than the blades developed by Kamoji et al. [11] and Tartuferi [13] developed new blades for drag forces based wind turbines named SR3345 and SR 5050, but the Cp values produced were no better than the blades developed by kamoji however, the maximum Cp value is reached at a lower tip speed ratio.

Ushiyama [14] and Al-faruk [15] proposed a new savonius wind turbine design that they swirling savonius rotors (SSR), where overlaps that generate swirl flow from the advanced blade to the returning blade so they can reduce the drag that occurs on returning the blade with the presence of the thrust created by the flow coming from the advance blade, the optimum Cp that can be achieved from this design is 0.22.

In addition to modifying the geometric shape of the blades to improve the performance of the savonius wind turbine, the researchers also conducted research related to controlling the flow in the upstream with augmentation techniques such as the nozzle [16] V-shaped deflector [17], plate-shaped deflector [18], curtain [19], slot ventilation [20].

Previous research related to the addition of guide vane aimed at improving the performance of savonius wind turbines has been carried out. Salim [21] conducted a diffusion guide vane design study with a tilt angle of 15, 30, and 45-degrees while the number of blades 6. The results of the study explained that the diffuser with a 45-degree tilt angle resulted in a maximum turbine performance coefficient of 0.065 at the tip speed ratio 0,55. Sugiharto [22] conducted a numerical simulation related to the influence of the number of blade guide vane and guide vane angle on the performance of the swirling savonius wind turbine. From the simulation results, it was explained that the 45-degree guide vane angle and the number of guide vane 16 produced a maximum performance of 0.22 at a tip speed ratio of 0.8.

In this study, an omnidirectional guide vane is proposed to improve swirling savonius rotor performance with Several designs of omnidirectional guide vanes with variations number of guide vanes.

2. Methodology

In this study, a swirling savonius rotor was made based on the best configuration from Al-faruk et.al design [15], and the ODGV design was made based on sugiharto *et al.*, design [22] with guide vane angle 45 deg. However, there were differences in some design parameters. Some of the variables that distinguished the designs from previous studies include the number of guide vane and dimensions.

The experimental setup of a structured test bench supported the ODGV, a Savonius wind turbine, fan blower, and measurement devices. Figure 1 shows the schematic diagram of the experimental apparatus. In the experiment, a wind tunnel comprised of a fan with an inverter and an exit area of 450 mm x 450 mm was used. The wind velocity adjusted with variable a switch in the range of 3 to 15 m/s. The rotor load used scales and the rotational speed was measured by a digital photo tachometer with range 10 to 99.999 rpm, accuracy 1 rpm. Wind velocity measured by a portable anemometer with range 0,6 to 30 m/s, accuracy 0,01 m/s. The torque is measured by the Prony brake method [23], the scheme can be seen in Figure 2.

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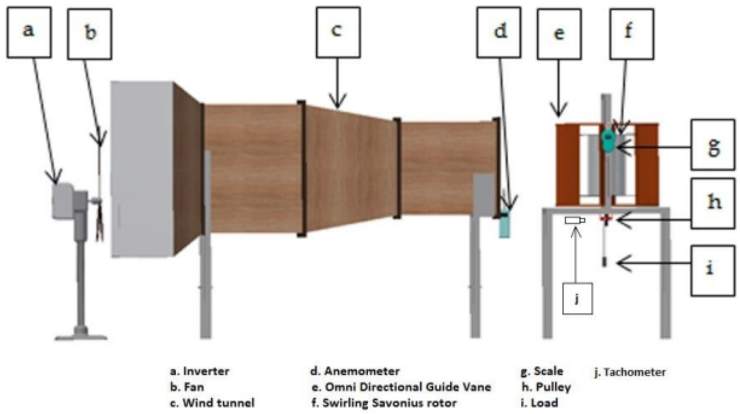

Figure 1. Scheme set up of instruments and test equipment

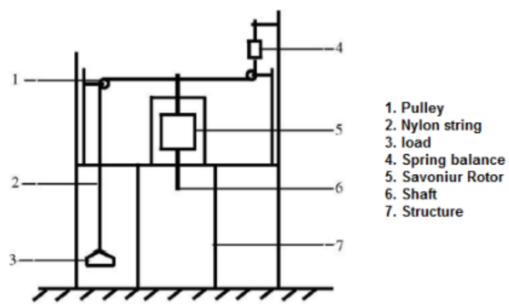

Figure 2. Prony brake scheme for torque measurement

The Savonius type turbines with two semi-circular blades were used in the research. Figure 3 shows the form of the swirling Savonius rotor used in the recent study. The rotor is based on two blades with end plates characterized by the height of H = 300 mm, endplate diameter of D_0 = 300 mm, and overlap gap is 60 mm. These designs corresponded to rotors studied by Al-faruk et.al., [15]. The primary dimension of the Savonius Rotor is shown in Table 1.

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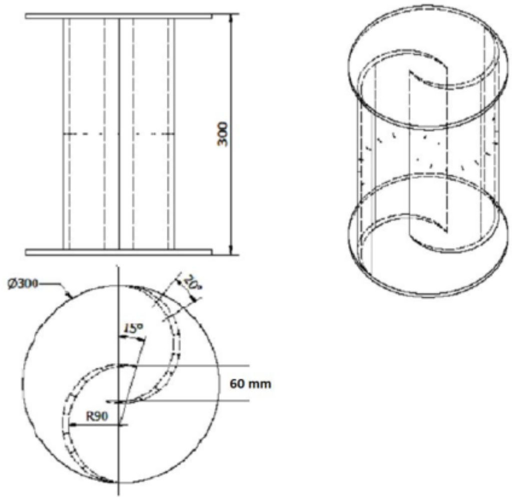

Figure 3. The swirling savonius rotor model tested

Table 1. The dimension of the Swirling Savonius Rotor

Parameters	shape/value/material
The geometry of blades	C
Number of blades	2
Length of the chord , [mm]	180
The diameter of the rotor, [mm]	300
High of the rotor, [mm]	300
Overlap [mm]	60
Material of blades	PVC
The material of the upper disk	PVC
The material of the bottom disk	PVC

Figure 4 shows the geometrical parameter of ODGV. The ODGV has an inner diameter, D_{in} = 400 mm, outer diameter, D_{out}= 500 mm, and guides vane angle of 45-degree to the normal line. The ODGV was set around the Savonius rotor. The experiment, the effect of the number of guide vane from ODGV is to be seen on the performance of the swirling savonius rotor. The main dimensions of the ODGV model are shown in Table 2.

There are several important parameters in determining the performance of a wind turbine, the Reynolds number (Re), tip speed ratio (λ), and power coefficient (C_p). Reynolds number is the ratio between inertial force and viscous force what is used to determine whether the fluid flow is laminar or turbulent.

$$Re = \frac{\rho V D}{\mu} \quad (1)$$

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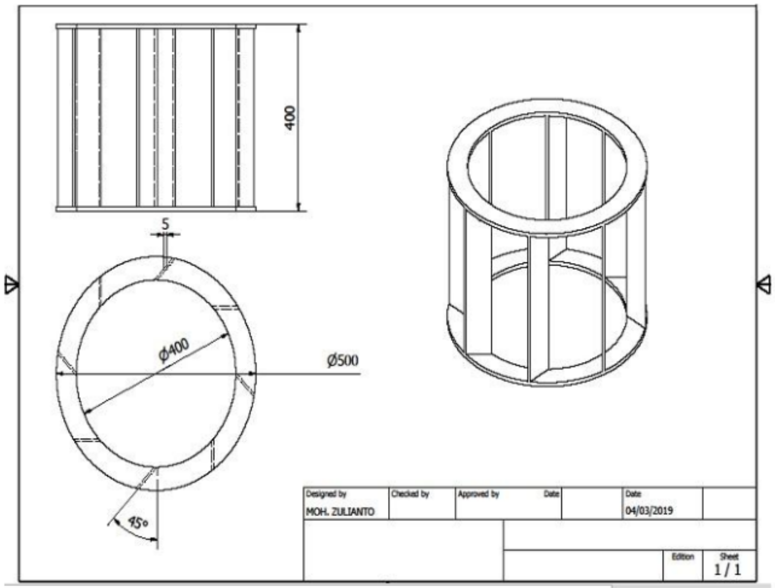

Figure 4. The model of Omni Directional Guide Vane (ODGV) tested

Table 2. Dimension of ODGV

Parameters	Geometric shape/value
Profile of guide vane	Plate
Number of guide vane	4,8,12,16
The outer diameter (D_{out}), [mm]	500
The inner diameter (D_{in}) , [mm]	400
igh, [mm]	400
Material	PVC
Guide vane angle [deg]	45

The Tip speed ratio is the ratio of wind speed at the end of the blade obtained from the rotational speed of the rotor and the radius of the rotor with the wind speed that hits the blades formulated as the following equation.

$$\lambda = \frac{\omega R}{V_w} \qquad (2)$$

While the power coefficient of the rotor shows the ratio of power produced by the rotor with wind power

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

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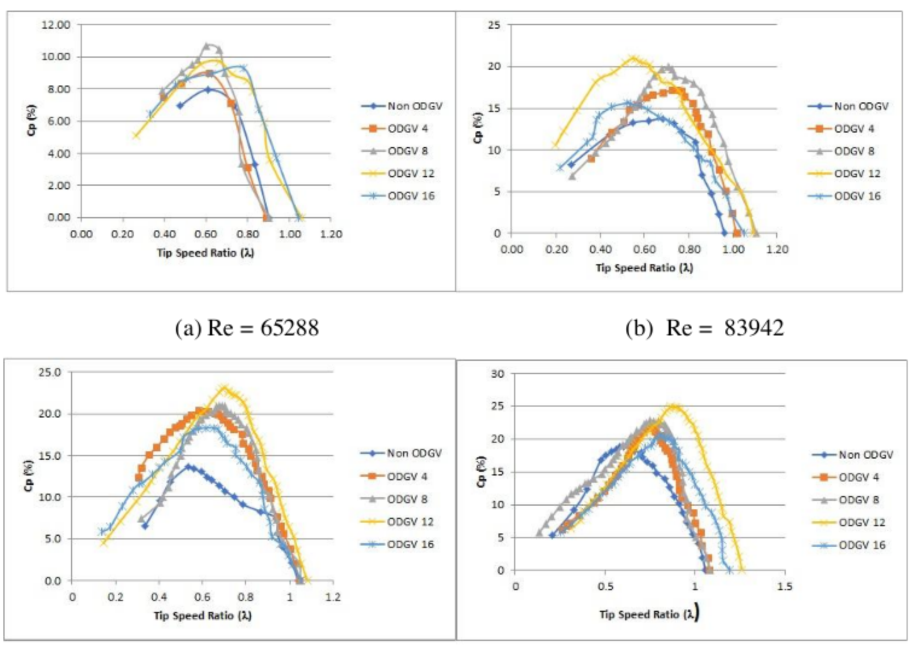
3. Results and Discussion

3.1 Effect number of guide vane and Re to the power coefficient

Figure 5 shows that the omnidirectional guide vane (ODGV) can increase the coefficient of the swirling savonius rotor power. In small Reynolds numbers the number of guide vane 8 (ODGV 8) produces the greatest power coefficient, but as the value of Reynolds increases the number of guide vane 12 (ODGV 12) produces the largest power coefficient.

The increase in the rotor power coefficient on ODGV 12 is greater with increasing Reynolds number, this is due to the increasing number of Reynolds that are correlated with increasing wind speed, the presence of omnidirectional guide vane accelerates the flow of air significantly before hitting the surface of the blades from swirling savonius rotor. Besides the existence of the omnidirectional guide vane can increase the lift coefficient of the rotor marked by the value $\lambda > 1$, the increase in the lift rotor coefficient causes the resultant force to move the rotor to increase which ultimately can increase the torque generated by the rotor. From figure 5 and 6, it can be seen that the value of the power coefficient produced by the omnidirectional guide vane with the smallest number of guide vane 16 (ODGV 16) when compared to the number of another guide vane, this is due to the increasing number of guide vane, the distance between the guide vane is getting narrow so that there is a portion of airflow that flows on the outside of the omnidirectional guide vane so that although it can accelerate the flow the mass of air that hit the surface of the blade of swirling savonius rotor at ODGV 16 is smaller than the number of another guide vane.



(a) Re = 65288

(b) Re = 83942

(c) Re = 93269

(d) Re = 111923

Figure 5. The effect of Reynolds Number (Re) and the number of vanes of various omnidirectional guide vanes to the distribution of power coefficient of the Swirling savonius rotor

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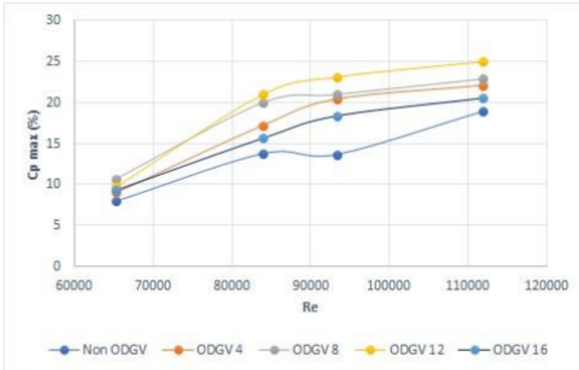

Figure 6. The value of the maximum power coefficient of the swirling savonius rotor on the Reynolds value and the number of vanes of various omnidirectional guide vanes

The effect of the number of blades on the omnidirectional guide vane to the maximum power coefficient (Cp_{max}) of the swirling savonius rotor is shown in Table 3.

Table 3. Comparison of swirling savonius rotors with and without omnidirectional guide vane

Re	Non ODGV	ODGV 4	ODGV 8	ODGV 12	ODGV 16	Δ1 (%)	Δ2 (%)	Δ3 (%)	Δ4 (%)
65288	7,96	8,99	10,70	9,72	9,29	12,94	34,42	22,11	16,71
83942	13,75	17,20	19,97	20,95	15,63	25,09	45,24	52,36	13,67
93269	13,64	20,40	20,97	23,07	18,33	49,54	53,70	69,15	34,38
111923	18,90	22,09	22,85	24,96	20,52	16,89	20,88	32,05	8,56

From table 3 it can be seen that the addition of omnidirectional guide vane with variations in the number of guide vane can increase the value of the power coefficient of swirling savonius rotor for all conditions marked by the value of the percentage difference between swirling savonius rotor without an omnidirectional guide vane (Non-ODGV) with swirling savonius rotor with omnidirectional guide vane with variations in the number of guide vane (ODGV 4, ODGV 8, ODGV 12 and ODGV 16). The biggest increase occurred in swirling savonius rotor with omnidirectional guide vane 12 (ODGV 12) of 69,15% at Reynolds number (Re) 93269.

4. Conclusion

The influence of the number of guide vane from ODGV can improve the performance of the swirling savonius rotor in the form of the power coefficient (Cp) with the greatest increase in ODGV 12 and the Reynolds number 93269 by 69,15%.

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