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Original Paper

Characteristics of the Savonius Wind Turbine Using Multiple Guide Vanes

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Abstract

This paper aims at identifying the characteristics of the Savonius Wind Turbine using a guide vane, which functions as the steering mechanism and reduces the negative torsion on the returning blade. The addition of the guide vane did not influence the turbine's capacity in receiving wind direction. The number of guide vanes varied from 4, 8, and 16 with an angle of 45°. The testing was conducted in a wind tunnel at the wind speeds of 4 m/s, 5 m/s and 6 m/s. The turbine with the additional 16 guide vanes gave the best result. The static torsion increased by 84%, dynamic torsion increased by 57%, and the coefficient of power increased by 58% at the speed of 4 m/s.

Keywords: Savonius wind turbine, Guide vane, Negative torsion, Coefficient of power.

1. Introduction

The Savonius wind turbine was one of the instruments to transform the kinetic energy of wind into moving energy using a vertical axis. The strengths of turbines are there simple design, the ability to take in the wind from all directions and the high static torsion. The weakness of this turbine was that it has a low coefficient of power at only 15%. Nakajima et al. [1, 2], Fujisawa and Gotoh [3] described the stream of the Savonius wind turbine. The stream was differentiated into six types, namely, I the stream that pulled the convex side of the advancing blade, II the stream at the backside of the advancing blade toward the concave side of the returning blade, III the stream that occurred from the concave side of the advancing blade toward the concave side of returning blade, IV the stream that occurred in front of the convex side of the returning blade, V the stream that created the vortex in the advancing blade, and VI the stream that caused the vortex in the returning blade. The streams I, II, and III are the streams that gave a positive impact, while the streams IV, V, and VI gave a negative effect on the turbine performance. Some researchers have tried to increase the coefficient of power by modifications to reduce the quantity of the streams IV, V, and VI.

Ogawa and Yoshida [4] published that the Savonius turbine with the additional deflector plate increased the coefficient of power to 24 %. Irabu and Roy [5] observed the turbine in a tunnel that was shaped as a guide-box. It caused the increment of the coefficient of power to increase 1.23 times compared with those without the guide-box. Mohamed et al. [6] added an obstacle shielding in front of the returning blade with the intention to omit the negative torsion. It resulted in an increase in the coefficient of power to the amount of 40% compared to the conventional turbine. The obstacle shielding was the additional apparatus that functioned to reduce the streams causing the negative performance of the turbine. The addition of the curtain was done by Altan et al. [7, 8, 9] with the testing of variations of the curtain lengths and curtaining angles. The best result was that at the lengths l_1 = 45 cm and l_2 = 52 cm and the curtaining angles of α = 15° and β = 45°; it reached the coefficient of power at 0.385. In this condition, the biggest static torsion occurred in the position of the turbine on the turbine angle of 60° namely 2.2 Nm. Sharma et al. [10] in their study stated that the Savonius turbine with the concentrator increased the coefficient of power to be 0.47. Sugiharto et al. [11] tested the turbine with the guide vane in the wind speed of 5 m/s and found that the coefficient of power increased 33% compared with the conventional turbine. Shigemitsu et al. [12] published the power coefficient of Cross-Flow wind turbine with symmetrical casing higher than the turbine without a casing.

All the research above was only conducted in the laboratory because if conducted in the field, it would require special construction so that the wind always blows from the front side. This study discussed the performance of the Savonius turbine using the guide vane with variations of guide vane number. The guide vane aimed to direct the flow to the turbine and reduce the negative torque at the returning blade. The testing was done at the wind speed of 4 m/s, 5 m/s, and 6 m/s. In addition, the Savonius turbine was able to receive the wind from any direction. The guide vane was made of simple and cheap acrylic.

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2. Methodology

The Savonius wind turbine was made from two parts of a half-cylinder shaped just like letter S. The turbine design and parameter were adopted from Fujisawa and Gotoh [3] and Gupta et al. [13, 14]; the overlap ratio was e (=a/2R) = 0.15 (a = overlap) = 30 mm, endplate diameter D_0 = 1.1 D and aspect ratio A_s (=H/D) = 1, with the D as the turbine diameter and H as the turbine height. Geometric parameter wind turbine as seen in Fig. 1.a and wind turbine with the guide vane in Fig. 1.b. The size of the turbine was D = H = 370 mm, and the blade thickness was 4 mm. The blade was made of a PVC pipe with a diameter of 200 mm which was split. The guide vane was made of acrylic at the length L = 1.5 R (R = blade radius = 100 mm). In the Savonius turbine testing, the observations were conducted on the performance of the turbine without the guide vane (conventional) and the performance of the turbine with the guide vanes numbering of 4, 8 and 16. The slope angle of the guide vane was at 45° and was at the distance 0.2 R from the edge of the endplate. The guide vanes were placed around the turbine, as seen in Fig. 2.

The testing was conducted in the wind tunnel at the dimension of 120 cm x 120 cm x 240 cm. The power of the fan blower was 7.5 HP at the rotation speed of 960 rpm. Adjust the wind speed using the inverter by adjusting the frequency of electricity entering the fan. The wind speed in the testing varied namely 4 m/s, 5 m/s and 6 m/s. The conventional turbine performance was compared with the turbine performance using the guide vanes numbering 4, 8, and 16. The preparation of the turbine experiment is shown in the Fig. 3.a, by placing the turbine in Fig. 3.b in the middle of the wind tunnel.

The calculation of the torsion, either the static or dynamic one, employed the braking system such as in Fig. 3.c. The rotation speed measurement utilized the tachometer DT 2236, which provided the resolution at 0.1 rpm with the range of measurement of 5 – 99.999 rpm, and the display specification was in 5 digits. The performance of the wind turbine was based on Sanusi equation [15] with modification, namely:

Turbine torque

$$T = F\,r \tag{1}$$

Input power

$$P_i = 1/2\,\rho\,A\,v^3 \tag{2}$$

Output (Tubine) power

$$P_o = T\,\pi\,n/30 \tag{3}$$

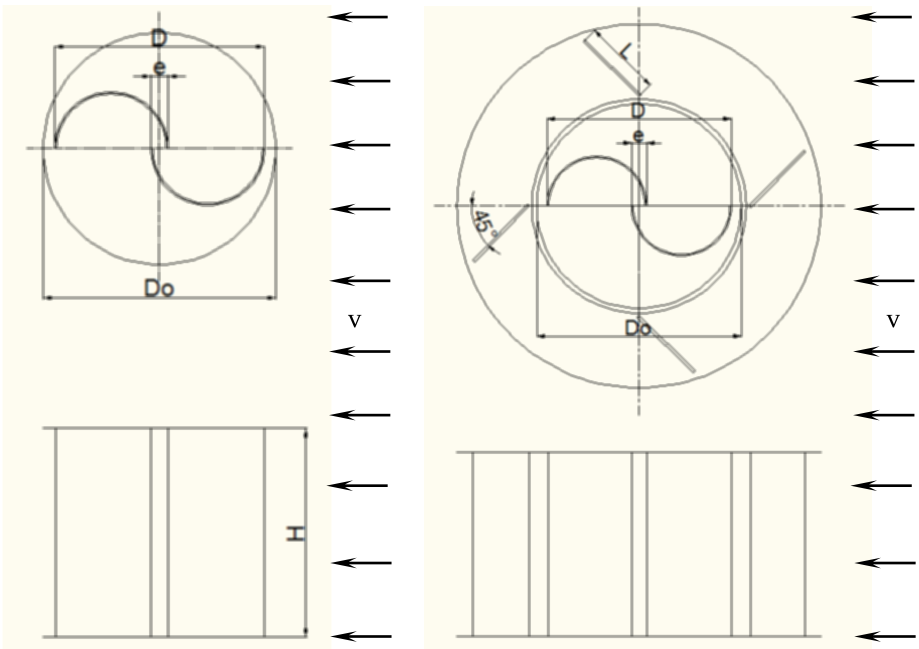
Coefficient of power

$$Cp = P_o / P_i \tag{4}$$

Tip speed ratio (tsr)

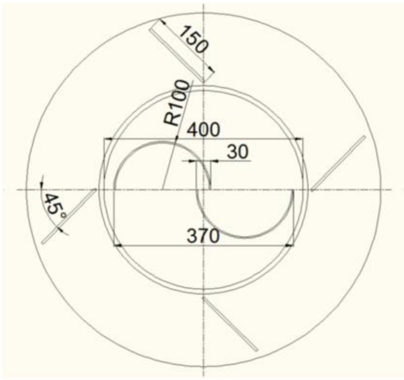
$$\lambda = \pi\,D\,n / (60\,v) \tag{5}$$

λ was the comparison of the turbine tip speed with the wind speed.



a. b.

Fig. 1 The configuration of the Savonius turbine and the geometric parameter
a. Conventional, b. With Guide Vane



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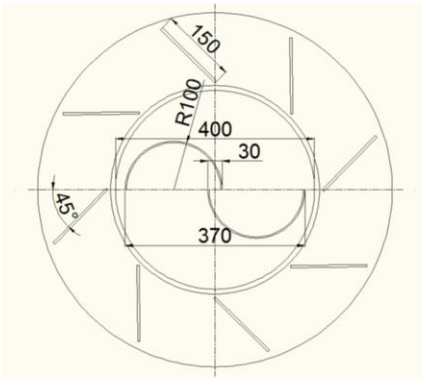

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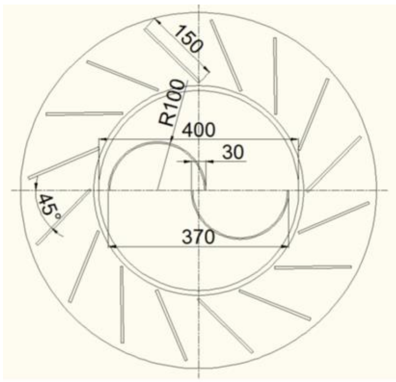
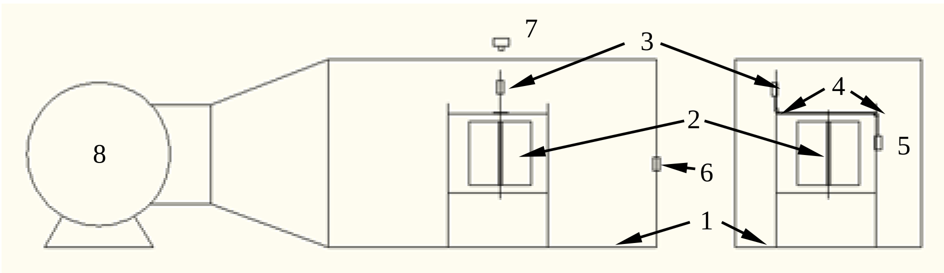


c.

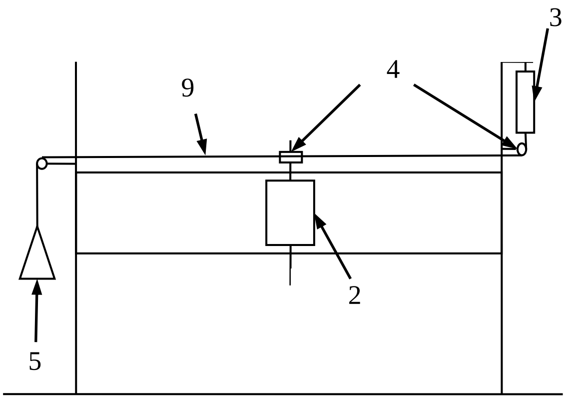
Fig. 2 Number of guide vane on Savonius turbine a. 4, b. 8, and c. 16



a.

Description:
1. Wind tunnel
2. Savonius turbine
3. Scales
4. Pulley
5. Balancer load
6. Anemometer
7. Camera
8. Fan blower
9. Nylon yarn

b.



c.

Fig. 3 Preparation the turbine experiment
a. Experiment setup
b. Savonius turbine
c. The braking schematic diagram

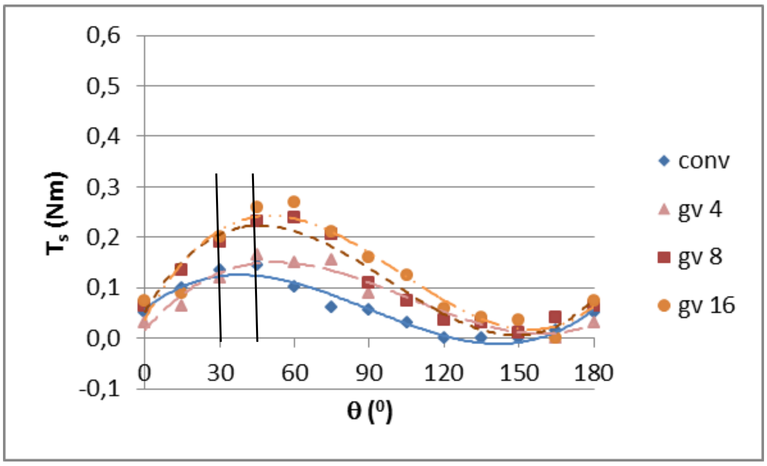
The air stream in the turbine was observed by putting on the 15 cm yarn in the front part and at the back part of the blade. The position of the yarn was in the middle of the turbine height, as seen in Fig. 3.b. Taking photos was done using the D 700 camera with f 3.5 aperture specifications, shutter speed 1/125 and Auto ISO, which was placed above the wind tunnel (Fig. 3.a). Visualization was done to see the change in flow at 45 ° and 135 ° positions marked by changes in the position of the separation point. Changing the separation point changed the turbine performance.

3. The Results and Discussion

The results of the experiment are displayed in the correlational graphic of the static torsion with the angle position in Fig. 4, in the correlational graphic of dynamic torsion with the rotation in Fig. 5, and in the correlational graphic of the coefficient of power with the tip speed ratio in Fig. 6.

3.1 The Static Torsion (Ts)

The correlation between the static torsion and the position of the turbine angle were shown in Fig. 4.a-c. The static torsion was the torsion that occurs in the turbine when it is idle. The static torsion indicated the turbine capacity in initiating the operation. The bigger the static torsion that occurs, the easier it is for the turbine to start rotating and vice versa. At the wind speed of 4 m/s (Fig. 4.a), the conventional turbine was difficult to initiate rotation when it stopped at the position of 120° – 150°. It was because the static torsion was under zero. The condition of the turbine with the guide vane has no problem starting the rotation at any position. In Figure 4.a-c, the static torsion of the turbine followed the sinusoidal function and had the highest value in the position of 45°. The turbine with the guide vane number 4 in the positions of 0° - 30° had more difficulty to start rotation, hence it is not recommended to use guide vane numbering 4. The more guide vanes there were, the static torsion experienced was incrementally bigger. The turbine with the guide vane numbering 16 experienced static torsion increment by 84% at the wind speed of 4 m/s and by 59% at the wind speed of 6 m/s. When the wind speed increased, the static torsion changed proportionally. Maximum torque on conventional turbines occurred at position 30 ° while the turbine with maximum torque guide vane shifted at position 45 °. This was supported also by the visualization in Fig. 8, the separation that occurred in the turbine with the guide vane is displaced close to the turbine axis. It is also possible regarding the angle of the guide vane used so that the drag force on the blade of the thrust increases.



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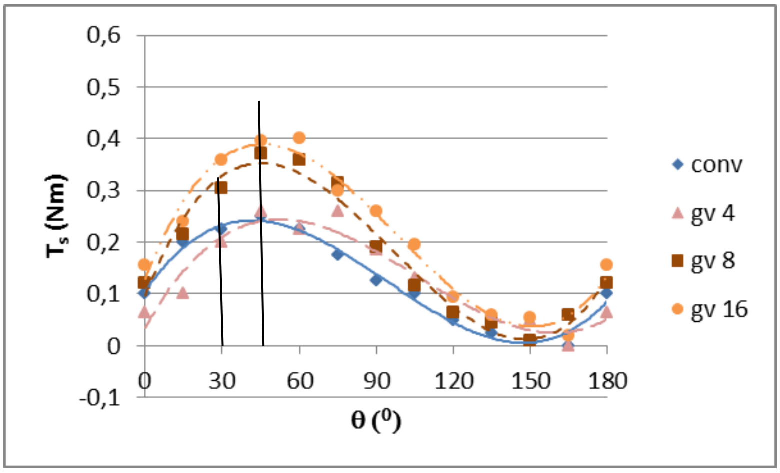

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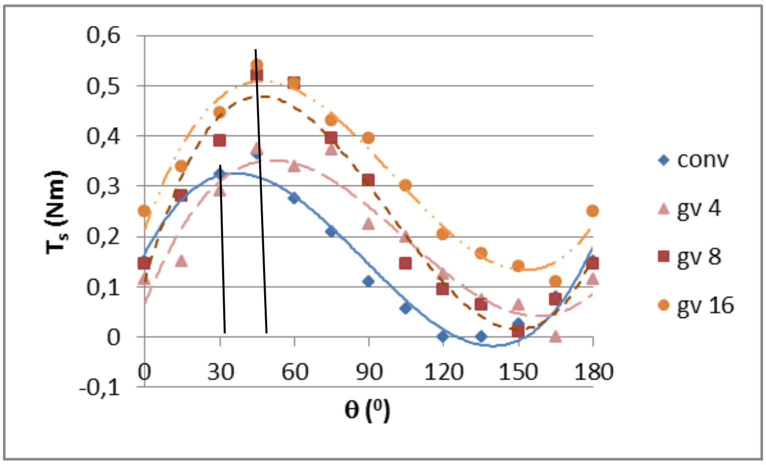
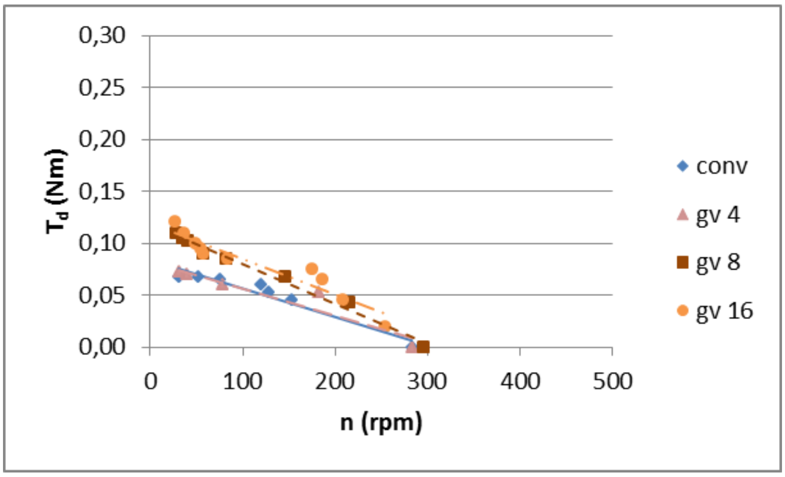


c.

Fig. 4 The correlation between the angle position and the static torsion (T_s) on wind speed a. 4 m/s, b. 5 m/s, c. 6 m/s

3.2 The Dynamic Torsion (Td)

The correlation between the dynamic torsion and the rotation is shown in Fig. 5. The dynamic torsion became smaller when the rotation increased and vice versa. When the wind speed increased, the achieved value of the dynamic torsion and the rotation were bigger. The turbine with the additional guide vane increased the dynamic torsion. At the wind speeds of 5 m/s (Fig. 5.b) and 6.m/s (Fig. 5.c), the turbine with 4 additional guide vanes had lower dynamic torsion compared to the conventional turbine. In this condition, the guide vane exactly executed the braking in the turbine. The dynamic torsion in the turbine with 16 additional guide vanes experienced increment up to 57% at the wind speeds of 4 m/s and up to 37% at the wind speed of 6 m/s compared with the conventional turbine. The maximum dynamic torsion was only 50% of the maximum static torsion.



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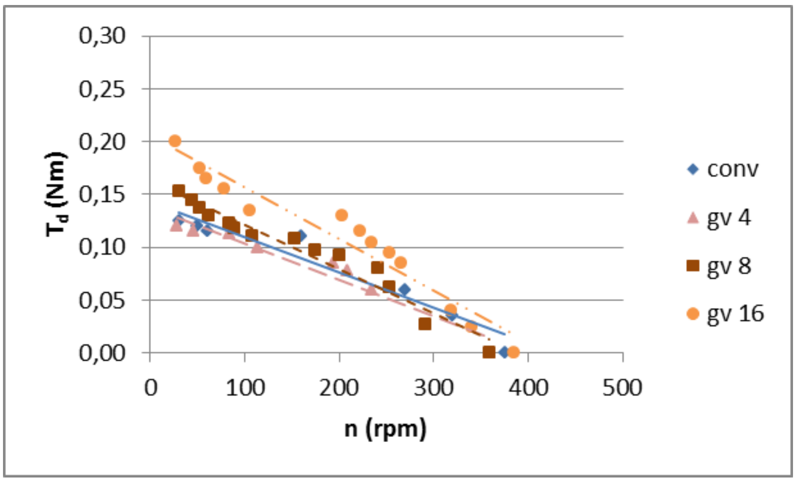

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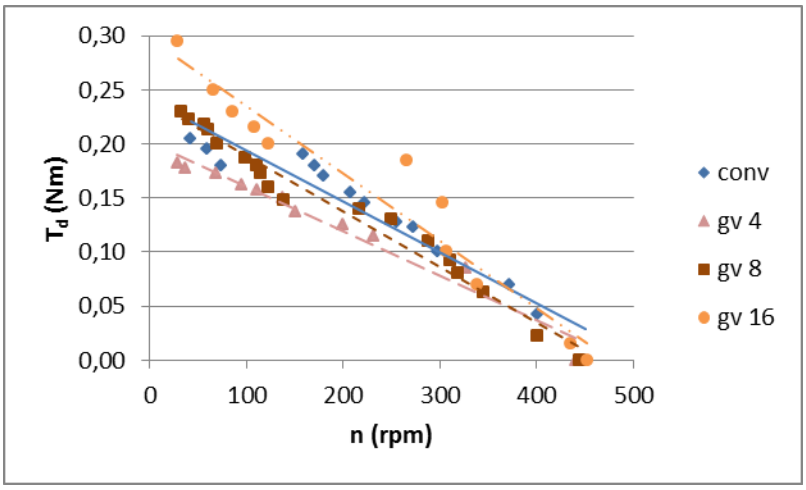
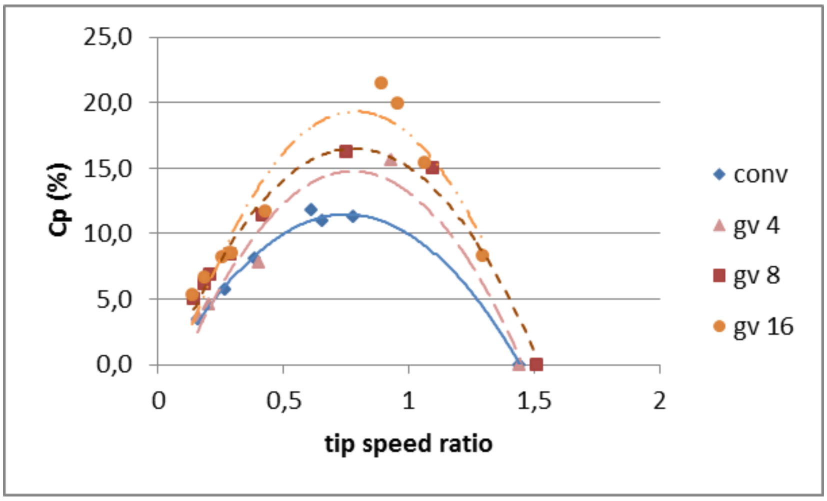


c.

Fig. 5 The correlation between the dynamic torsion (T_d) and the rotation on wind speed a. 4 m/s, b. 5 m/s c. 6 m/s

3.3 The Coefficient of Power (Cp)

Figure 6.a) indicates the correlation between the coefficient of power and the tip speed ratio at the wind speed of 4 m/s, and the coefficient of power of the turbine with the guide vane increased compared with the conventional turbine. The increase of the coefficient of the turbine power with 4 additional guide vanes was up to 17%, with 8 additional guide vanes it raised up to 42%, and with 16 additional guide vanes it increased up to 58%. In Figure 6.b) the increase of the coefficient of power occurred up to 40% in the Savonius turbines with the guide vane numbering 16 compared to the conventional turbine. In contrast, the turbines with 4 and 8 additional guide vanes experienced a decrease of the coefficient of power. Figure 6.c) shows the correlation of the coefficient of power with the tip speed ratio at the speed of 6 m/s. The turbine with 16 additional guide vanes increased the coefficient of power to 12% compared with the conventional turbine. While the turbine with 8 additional guide vanes decreased to 18.75%, the turbine with the 4 additional guide vanes experienced the decrease at 23%. The increase of the coefficient of power of the turbine with 16 additional guide vanes was caused by the effectiveness of the stream hogging to the blade in every position. In contrast, the turbines with the 4 and 8 additional guide vanes at the wind speed of 5 m/s and 6 m/s acted as barriers even it created the braking in the turbines. The optimum coefficient of power of either the conventional turbine or the turbine with guide vane occurred at the tip speed ratio of 0.8.



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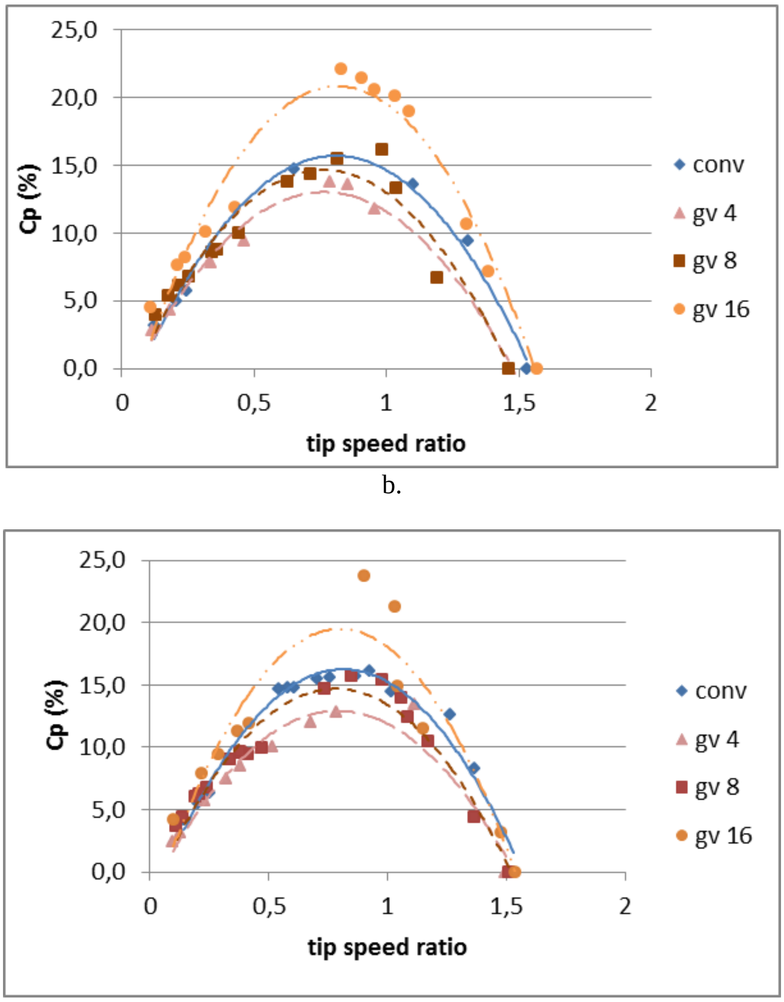

b.

c.

Fig. 6 The effect of the coefficient of power on the tip speed ratio on wind speed a. 4 m/s, b. 5 m/s, c. 6m/s

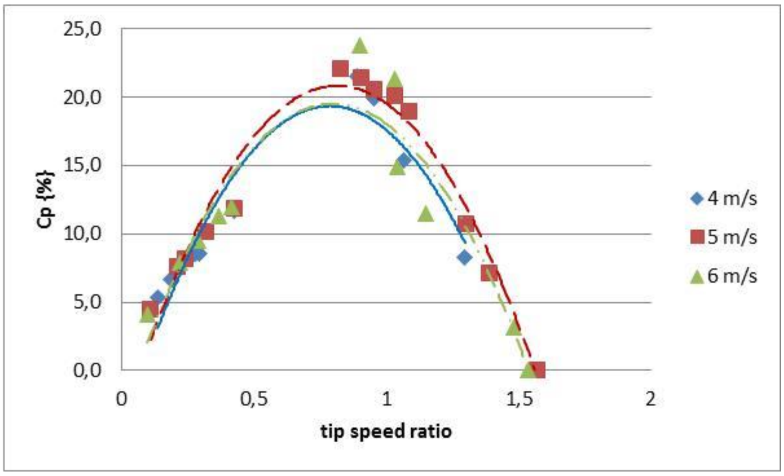

Fig. 7 The effect of the coefficient of power on wind speed at turbine with 16 guide vanes.

Figure 7 shows the comparison of the coefficient of power to wind speed in savonius turbines with an additional 16 guide vanes. Turbines with 16 guide vanes work most effectively at wind speeds of 5 m/s which produce the largest coefficient of power. The highest power coefficient of 21% at tsr 0.8. When the wind speed increased, braking will occur so that the coefficient of power decreased.

3.4 Visualization

The visualization of the stream in the Savonius turbine was conducted at the wind speed of 5 m/s and in the condition of being idle which is shown in Fig. 8. The visualization was conducted in the positions of the turbine at 45° and 135°. At the position of

45°, the Coanda stream at the back of the convex side of the advancing blade and the stream in the concave side of the advancing blade increased due to the existence of the guide vane, and this became one of the causes of the increase of the static torsion. The guide vane addition on to the turbine, other than increasing the static torsion, also became the controller of the turbine rotation speed. This was useful to avoid excessive rotation speed. The stream changes at the back of the convex side of the advancing blade, with the additional guide vane at the position of 45°, replaced the separation point more to the backside (shown by the arrow). Meanwhile, the separation point in the convex side of the returning blade experienced the shift more to the front. The changes in the separation point altered the value of static torsion to be bigger. At position 135°, there was no change in the point of separation in the turbine with a guide vane or in a conventional turbine. This proves that static torque at this position did not experience a shift in the minimum torque value.

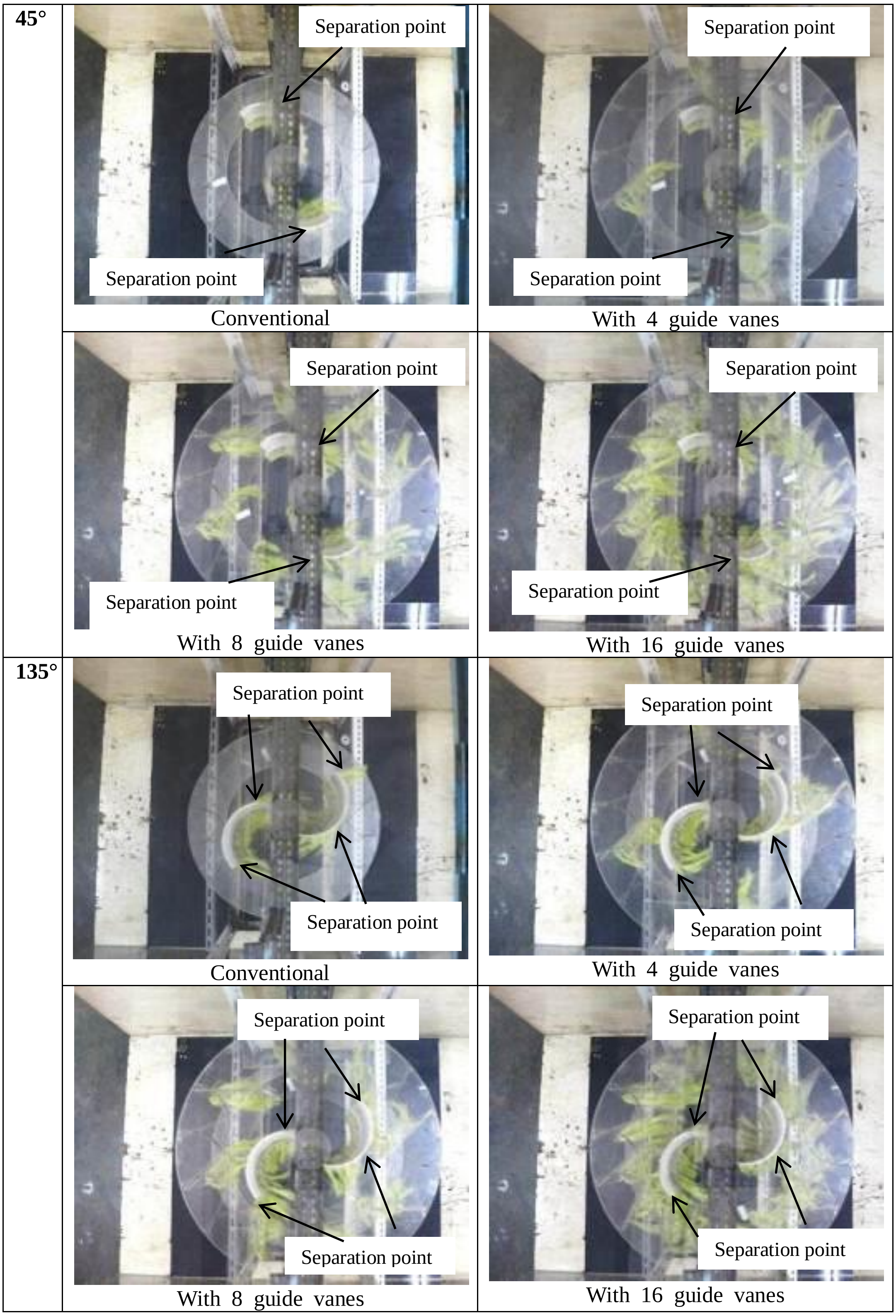

Fig. 8 The visualization of the stream in the Savonius turbine

4. Conclusion

Adding guide vanes to the Savonius turbine to direct the flow to the advancing blade and thus result in increased static torque values. The increased static torque makes turbines easier to start rotating. The turbine with the addition of guide vanes 16 at wind speeds of 4 m/s has the highest increase on static torque (84%) and coefficient of power (58%) compared to the conventional turbine. Furthermore, the maximum point of static torque in the Savonius turbine with the addition of a guide vane shifts to an angle of 45 ° from 30 ° in a conventional turbine. The addition of a guide vanes to the Savonius turbine does not affect the value of the tip speed ratio at the maximum coefficient of power.

Nomenclature

A	Cross-section area of rotor (m^2)	P_i	Input power (watt)
A_s	Aspect ratio	P_o	Output power (watt)
a	Overlap (mm)	R	Blade radius (mm)
Conv Cp	Conventional	r	Pulley radisu (mm)
D	Coefficient of power	T_d	Dynamic torsion (Nm)
D_o	Turbine diameter (mm)	T_s	Static torsion (Nm)
e	End plate diameter (mm)	v	Speed (m/s)
F	Overlap ratio	α	Curtaining angle 1 (°)
Gv	Force (N)	β	Curtaining angle 2 (°)
H	Number of guide vane	λ	Tip speed ratio (tsr)
n	Turbine height (mm)	ρ	Air density
	Rotation (rpm)	ω	Angular speed (rad/s)

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