The Effect of the Number of Vanes in the Omnidirectional Guide Vane on Aerodynamics Characteristic of Stationary Swirling Savonius Rotor

by Indra Siregar

The Effect of the Number of Vanes in the Omnidirectional Guide Vane on Aerodynamics Characteristic of Stationary Swirling Savonius Rotor

Indra Herlamba Siregar *, Moch Effendy, and Akhmad Hafizh Ainur Rasyid
Department of Mechanical Engineering, Universitas Negeri Surabaya, Surabaya, Indonesia
Email: indrasiregar@unesa.ac.id, m_effendy2001@yahoo.com, akhmadrasyid@unesa.ac.id

***Abstract*— The savonius rotor is a vertical-axis wind turbine which operates according to the drag forces. It is widely used as equipment with the wind as a source of energy and has a simple design, it is easy to install, good starting ability, relatively low operating speed, and independent of wind direction. Several studies have been conducted in the last decade to improve the performance of this equipment with the focus on the aspect ratio, overlap ratio, and installing additional devices such as curtain design, deflector plate, guide box tunnel, and windshields. Swirling savonius rotor is an improvement on the savonius rotor with a gap between the concave and convex blades to reduce the negative torque generated by the convex blade. This present study was conducted to analyze the power coefficients, drag coefficients, and static torque of a swirling savonius rotor with omnidirectional guide vanes by measuring the pressure distribution on the blade surfaces at different rotor angles. The experiments were conducted at a Reynolds number of $1.1x10^5$ with the rotor having two semi-circular blades, an overlap ratio of 0,2, and the number of omnidirectional guide vanes varied at 4, 8, 12, and 16. The results showed all the omnidirectional guide vanes except 16 increased the static torque and drag coefficients of the swirling savonius rotor.**

***Index Terms*— static torque, drag coefficients, swirling savonius rotor, omnidirectional guide vanes**

I. Introduction

The energy being supplied for daily human needs is mainly sourced from fossil energy as indicated by its 84.3% contribution [1]. This source, however, has a negative impact on the environment due to its ability to release CO_2 into the air which reduces the air quality and, subsequently, causes the greenhouse effect and climate change when the gas is in large quantity [2]. Moreover, the availability of fossil energy is decreasing due to the fact that it is non-renewable. This has, therefore, led to the increasing trend of renewable and environmentally friendly sources of energy such as wind [3].

Wind turbines utilize wind as a well-known energy source which is now widely applied to generate electrical energy. These turbines are, however, classified into horizontal axis and vertical axis with the vertical axis observed to be more beneficial due to its better continuity of energy production based on the fact that the blade is usually hit by the wind in all directions. It is also capable of working at much lower wind speed, has lower noise, and lesser investment cost than the horizontal axis [4].

The vertical axis wind turbine is further divided into two based on the dominant moving force and these include the savonius wind turbine which works based on the drag force and the darrieus wind turbine which works on the lift force. The advantages of the savonius type over the darrieus include its self-starting factor which makes it work at lower wind speeds but its disadvantage is that it has a lesser efficiency [5].

Several studies have been conducted on savonius wind turbines and an increment in the aspect ratio was reported to have led to more efficiency of the system [6,7] while some also reported the best configuration of savonius wind turbines is two blades [8,9]. Another study showed the addition of endplates to the turbine improved its performance [6,10] while some also reported the effect of overlap [6,11,12] with an overlap ratio of 0.2-0.3 discovered to have provided the best performance. Moreover, a tool was also added in some studies to direct the free airflow to the savonius wind turbine with overlap blades in order to increase its performance [13,14] and the results showed a significant 33 to 66% increment in efficiency.

The research on savonius overlap or swirling rotor turbine with a wind direction was discovered not to have focused on the pressure distribution and aerodynamic characteristics of the blades due to the wind direction. Therefore, this study was conducted to determine the influence of the number of blades from omnidirectional guide vanes (ODGV) on the aerodynamic characteristics of the swirling savonius rotor.

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Corresponding author : Indra Herlamba Siregar, indrasiregar@unesa.ac.id

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II. Experimental Set-up and Methodology

The research was conducted in an open circuit wind tunnel with the exit area designed to be 45 x 45 mm^2 and the uniform flow generated by the wind tunnel flowed into the Swirling Savonius Rotor model with the omnidirectional guide vanes placed 600 mm from the exit. The schematic of the research configuration is, therefore, shown in Fig. 1.

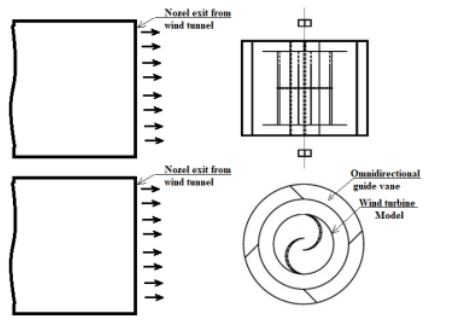

Figure 1. Experimental set-up

The Swirling Savonius Rotor model consists of two halves-cylinder curves with a diameter, d = 180 mm, and a height, H = 300 mm. The cylinders were made of PVC material. Moreover, the overlap distance a was 20% of the rotor diameter which means S = a / D, and the central shaft was removed. The overlap distance selected was the optimum value with respect to the wind power extraction [3]. The pressure distribution was measured on the 18 pressure tappings located at the mid-plane on one side of each blade and connected to a manometer through 2 mm PVC tubes as shown in Fig. 2. The pressures were measured at every 20^0 intervals rotor angle to obtain a detailed picture of the aerodynamic loading and torque characteristics. Furthermore, the rotor blades experienced forces per unit span length at a particular rotor angle (α) due to the pressure difference between the concave and convex surfaces. These forces were resolved into two components, F_t and F_n, which pass through the center of the semicircle since the blade surfaces are circular. The positive direction of F_t and F_n are, therefore, presented in Fig. 3.

The drag coefficients in normal and tangential directions can be written as follows:

$$C_n = \frac{F_n}{0{,}5\rho U_0^2 A}, \; C_t = \frac{F_t}{0{,}5\rho U_0^2 A} \quad (1)$$

The values of F_t and F_n need to be known to obtain the drag coefficients in the normal and tangential direction of the chord. They were, therefore, calculated by integrating the blade pressure as follows:

$$F_n = \int_0^{\Pi} \Delta p \, \frac{d}{2} \cos\phi \, d\phi = \sum_{i=1}^{18} \Delta p_i \, \frac{d}{2} \cos\phi_i \, \Delta\phi_i$$

and similarly,

$$F_t = \int_0^{\Pi} \Delta p \, \frac{d}{2} \sin\phi \, d\phi = \sum_{i=1}^{18} \Delta p_i \, \frac{d}{2} \sin\phi_i \, \Delta\phi_i \quad (2)$$

Where Δp_i is the difference in pressure on the concave and convex surfaces at a particular pressure tapping, i.

Figure 2. Manometer

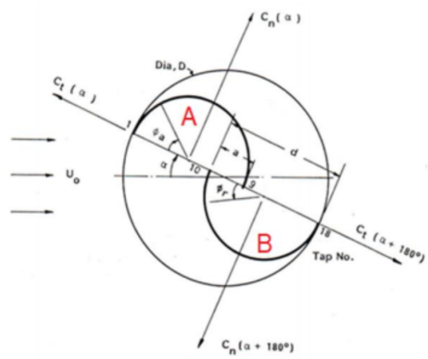

Figure 3. Forces acting on the blade

Force F_n is responsible for the production of torque on the shaft of the rotor which is expressed for a blade as follows :

$$T = F_n * \frac{d}{2} * (1 - s) \quad (3)$$

The net Pressure coefficient (Cpr) can also be expressed as

$$C_{pr} = C_{pri} - C_{pr0} = \frac{\Delta P_i - \Delta P_o}{0{,}5 x \rho x U_\infty^2} \quad (4)$$

Where ΔP_i pressure measurement of the inner surface of the blade and ΔP_o is the pressure measurement at the outer surface of the blade and wind velocity at 6 m/s was correlated with Re = 1,1 x 10^5.

III. Results and Discussion

A. Pressure Distribution

The net pressure distribution on the inside and outside of the blade at a wind speed of 6 m/s with an angle between the taps (ϕ) of 20^0 and an interval of $90^0 \le \alpha \le 270^0$ rotor rotation angle are presented in Figs 4 to 7 for $\alpha = 90^0, 130^0, 170^0$, and 210^0 respectively.

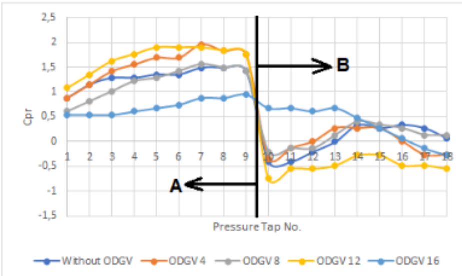

Figure 4. Net pressure distribution over the blade surfaces for $\alpha = 90^0$

Fig. 4 shows the normal airflow conditions towards the rotor and the presence of ODGV was observed to have increased the pressure on the surface of blade A (concave blades) to produce positive torque. An exception was, however, discovered for ODGV with a large number of blades which disturbs the incoming airflow and hits the blade surface.

The presence of overlap was also observed to reduce the pressure on blade B (convex blade) as indicated by the positive value of the pressure on the inside of blade B in the overlap tap area 10,11, and 12 in Fig. 5.

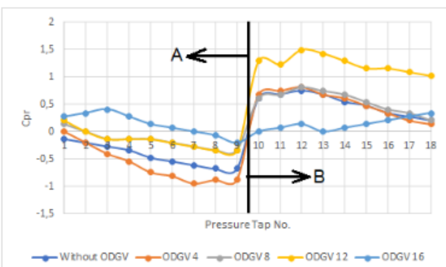

Figure 5. Pressure distribution over the blade surfaces backside $\alpha = 90^0$

An increase in the rotating angle of the rotor up to $\alpha = 170^0$ was also able to increase the pressure distribution on blade A for the rotor with ODGV 12 while the increase was up to $\alpha = 130^0$ for ODGV 4 and ODGV 8 and the pressure distribution is relatively the same for each angle of rotation of the rotor for ODGV 16. Meanwhile, the rotor without OGDV showed an opposite result with a decrease recorded in the pressure distribution as the rotating angle of the rotor increases as indicated in Fig. 6 and 7.

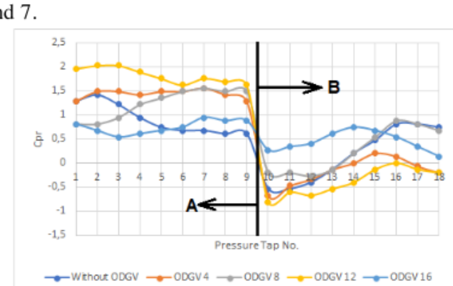

Figure 6. Net pressure distribution over the blade surfaces for $\alpha = 130^0$

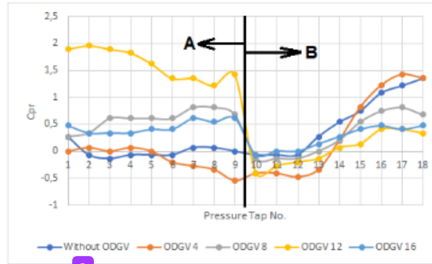

Figure 7. Net pressure distribution over the blade surfaces for $\alpha = 170^0$

The presence of overlap on blade B leads to negative pressure as indicated by the opposite thrust on the area of the blade B or convex blade which directly reduced the negative torque produced as showed in Fig. 4, 6, and 7.

It is also important to note that when the angle of the rotor was increased, blade A which was a concave blade transformed into a convex blade, and blade B which was originally a convex blade transformed into a concave blade as presented in Fig. 8.

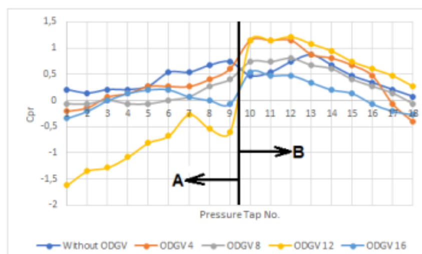

Figure 8. Net pressure distribution over the blade surfaces for $\alpha = 210^0$

In this condition, the rotor with ODGV 12 convex blade (Blade A) produced negative pressure and this automatically reduces the negative torque. Meanwhile, the concave blade (blade B) which produced positive torque has a large pressure. Therefore, the difference between the positive and negative torque caused an increase in the rotation of the rotor and this means the ODGV 12 produced the best performance coefficient (Cp) [14] for all conditions tested as indicated in Fig. 9.

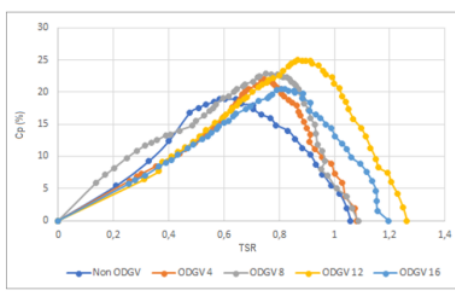

Figure 9. The performance coefficient of the Swirling savonius rotor at Re = $1{,}1 \times 10^5$

B. *Drag and Torque*

The pressure difference between the front and rear surfaces of the blades produced the normal and tangential drag forces as shown in Fig. 10 and 11. Moreover, the ODGV with a guide vane angle of 45^0 was able to increase the difference in the drag forces to the normal direction produced by the concave sidebar and the convex side blade. This was associated with the guide vane which forms an angle of 45^0 and directed the flow of free air towards the concave side while blocking the direct free flow to the convex side. Furthermore, the number of blades of the guide vane is related to the distance of the vane such that a higher number of vanes was observed to cause a smaller gap. This affected the amount of mass flow hitting the blade surface of the wind turbine model, thereby, reducing the normal drag coefficient as confirmed by ODGV 16 in Fig. 10.

The distribution of the normal drag coefficient for Non-ODGV blades is similar to ODGV 4 and ODGV 8. ODGV 12 is also similar to ODGV 16 but ODGV 16 has a lot of mass due to the narrower gap associated with its additional number of guide vanes. Moreover, the blocked air entering the ODGV 16 continued to hit the blade surface of the wind turbine model and this made its normal drag coefficient to be smaller than ODGV 12 which has a larger gap as indicated in Fig. 10.

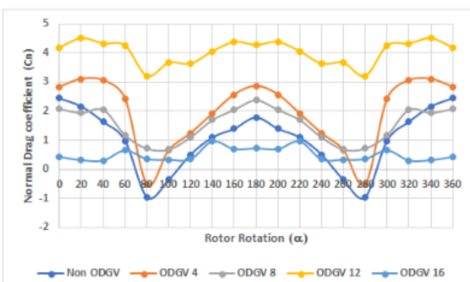

Figure 10. The normal drag coefficient of the Swirling savonius rotor at Re = 1,1x10^5

The ODGV was, therefore, observed not to have a significant effect on tangential drag coefficient except for the ODGV 16 where the gap is getting narrower as observed in Fig. 11.

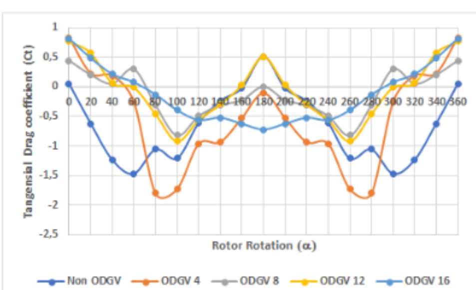

Figure 11. The tangential drag coefficient of the swirling savonius rotor at Re = 1,1x10^5

The ODGV was able to increase the static torque on the swirling savonius rotor as shown in Fig. 12 and this was also confirmed by Sugiharto et al. [15] to be due to its ability to increase the normal drag coefficient which has a direct effect on the static torque. Meanwhile, ODGV 16 decreased the static torque as against the findings of Sugiharto et al. [15].

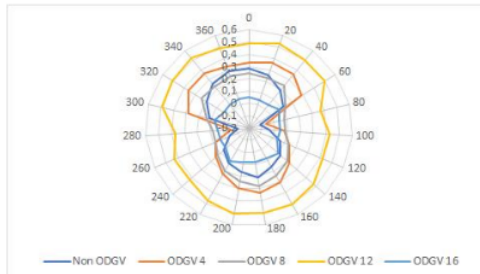

Figure 12. Evolution total static torque of the swirling savonius rotor at Re = 1,1x10^5

IV. Conclusions

The study focused on the pressure distributions over the convex and concave surfaces at different angles of rotation for a swirling savonius rotor with omnidirectional guide vanes. The results showed the presence of ODGV with up to 12 guide vanes was able to increase the normal drag coefficient and, consequently, the static torque. This further improved the performance coefficient of equipment with the best value of 25% at a tip speed ratio of 0.9 recorded in ODGV 12 but the static torque was observed to have reduced when the guide blades were increased to 16 blades (ODGV 16).

Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

Indra Herlamba Siregar conducted the research, prepared the draft manuscript, and approved the final version while Moch Effendy analyzed the data and Akhmad Hafizh Ainur Rasyid collected the data.

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References

[1] Anonymous, Statistical Review of World energy. [Online]. Available: https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2020-full-report.pdf

[2] S. Keleş. (2011). Fossil Energy Sources, Climate Change, and Alternative Solutions, Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 33:12, 1184-119.

[3] C. Zou, Q. Zhao, G. Zhang, and B. Xiong, "Energy revolution: From a fossil energy era to a new energy era," *Natural Gas Industry B*, vol. 3, no. 1, pp. 1-11, 2016.

[4] M. M. M. Saad, and N. Asmuin, "Comparison of horizontal axis wind turbines and vertical axis wind turbines," *IOSR Journal of Engineering (IOSRJEN)*, vol. 4, no. 08, pp. 27-30, 2014.

[5] K. Sahim, D. Santoso, D. Puspitasari, "Investigations on the effect of radius rotor in combined Darrieus-Savonius wind turbine," *International Journal of Rotating Machinery*, pp. 1-7, 2018.

[6] N. H. Mahmoud, A. A. El-Haroun, E. Wahba, M. H. Nasef, "An experimental study on improvement of Savonius rotor performance," *Alexandria Engineering Journal*, vol. 51, no. 1, 19-25, 2012.

[7] U. K. Saha, S. Thotla, and D. Maity, "Optimum design configuration of Savonius rotor through wind tunnel experiments," *Journal of Wind Engineering and Industrial Aerodynamics*, vol. 96, no. (8-9), pp. 1359-1375, 2008.

[8] M. H. Ali, "Experimental comparison study for Savonius wind turbine of two & three blades at low wind speed," *International Journal of Modern Engineering Research (IJMER)*, vol. 3, no. 5, pp. 2978-2986, 2013.

[9] F. Wenehenubun, A. Saputra, and H. Sutanto, "An experimental study on the performance of Savonius wind turbines related with the number of blades," *Energy Procedia*, vol. 68, pp. 297-304, 2015.

[10] I. Ushiyama and H. Nagai, "Optimum design configurations and performance of Savonius rotors," *Wind Engineering*, pp. 59-75, 1988.

[11] R. Sukanta, K. S. Ujjwal, "Review of experimental investigations into the design, performance and optimization of the Savonius turbine," *Journal of Power and Energy*, vol. 227, no. 4, pp. 528–542, 2013.

[12] M. A. Kamoji, S. B. Kedare, S. V. Prabhu, "Experimental investigations on the effect of overlap ratio and blade edge conditions on the performance of conventional Savonius turbine," *Wind Engineering*, vol. 32, no. 2, pp. 163–178, 2008, 2008.

[13] E. Salim, W. Yahya, D. Danardono, D. A. Himawanto, "A study of the influence of guide vane design to increase savonius wind turbine performance, " *Modern Applied Science*, vol. 9, no. 11, p. 222, 2015.

[14] I. H. Siregar, M. Effendy, A. H. A. Rasyid, "Effect of the number of vanes in the omnidirectional guide vane on performance of swirling savonius rotor," *International Journal of Advanced Science and Technology*, vol. 29, no. 3, pp. 12931–12938, 2020.

[15] B. Sugiharto, S. Soeparman, D. Widhiyanuriyawan, and S.Wahyudi, "Performances of savonius rotor with addition guide vane," *International Journal of Renewable Energy Research (IJRER)*, vol. 6, no. 4, pp. 1336-1341, 2016.

Indra Herlamba Siregar is a graduate of Mechanical Engineering from Institut Teknologi Sepuluh Nopember. He has completed his Master's degree from Institut Teknologi Sepuluh Nopembe and presently a senior lecturer in the Department of Mechanical Engineering at Universitas Negeri Surabaya and a licensed energy auditor. His research interests are renewable energy, wind turbine, and combustion.

Moch Effendy is also a graduate of Mechanical Engineering from Institut Teknologi Sepuluh Nopember. He has completed his Master's and Doctor's degree from Institut Teknologi Bandung and presently a senior lecturer in the Department of Mechanical Engineering at Universitas Negeri Surabaya. His research interest is energy.

Akhmad Hafizh Ainur Rasyid is a graduate of Mechanical Engineering from Brawijaya. He has completed his Master's degree from Institut Teknologi Sepuluh Nopember and presently a senior lecturer in the Department of Mechanical Engineering at Universitas Negeri Surabaya. His research interests are heat exchanger and wind turbine.

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