# Experimental Study On Improvement The Performance Of Savonius Windmill With Ventilated Blade

Rudi Hariyanto*, Sudjito Soeparman**, Denny W**, Mega N S**

*Department of Mechanical Engineering, Merdeka University, Malang – Indonesia. Jl. Terusan Raya Dieng 62-64, Malang, Indonesia 65146

**Department of Mechanical Engineering, Brawijaya University, Malang – Indonesia, Jl. MT Haryono 167, Malang, Indonesia 65145

(ui_masrudi@yahoo.com, sudjitospn@yahoo.com, denny_malang2000@yahoo.com, megasasongko@yahoo.com)

‡ Corresponding Author; Rudi Hariyanto, Jl. Bunga Merak 51 RT 08 RW 02 Kec. Lowokwaru Malang Indonesia 65141, Tel: +62-85755612303, ui_masrudi@yahoo.com

*Received: 27.06.2016 Accepted:24.08.2016*

**Abstract-** This study aims to determine how much influence the use of fixed ventilation on the blade towards improvements in performance Savonius windmill. Ventilation is made in the form of a reflection on the letter C. The ventilation opens into the concave side of the blade. There are one model of the conventional Savonius windmill and six models of the ventilated Savonius windmill that tested in the wind tunnels. Experimental variables are variations for the clearence width of the ventilation, variations for the wind speed and variations for the rotor rotation. The ventilated Savonius windmill have the average power coefficient (Cp) higher than the conventional Savonius windmill. Especially for the clearance width of ventilation is 0.05 of the diameter of the blade, the ventilated Savonius gives the Cp improvement of 132%.

**Keywords :** Savonius windmill , ventilation, the clearance width of ventilation, the useful power, coefficient of performance

## 1. Introduction

Savonius windmill is a vertical axis windmill developed by Sigurd Savonius in 1925 [1]. Savonius windmill has good starting torque even at low wind speeds. The weakness of Savonius is a low efficiency. Efficiency or Cp (power coefficient) of the conventional Savonius windmill is about 15% [2].

Many researchers have tried to improve the efficiency of Savonius windmill. Altan [3] has been testing the use of directional curtain to prevent the negative torque on the blade Savonius. The results showed that Savonius rotor performance can be improved by setting the curtains. The best position of the curtains could increase Cp of Savonius rotor approximately 38.5%. Mohamed et al [4] also were done the research ideas such as Altan. But Mohamed investigated the use of the obstacle plate in front of the convex side of the Savonius blade. The obstacle plate assembled with a different tilt angle. Thus, the obstacle plate is able to reduce the negative moment on the convex side of the blade. The obstacle plate also is able to direct the wind toward the concave side of the Savonius rotor blade. The use of obstacle plate is able to increase the performance of Savonius windmills up to 27%. On the development of further research, Mohamed et al [5] done a study of computational numerical simulations to optimize the geometry of the Savonius turbine with deflector blade. Performance of Savonius windmill increased of at least 30% for $0.3<TSR<1.4$. However, Saha and Rajkumar [6] have investigated the use of the twisted blade on Savonius windmill. The results showed the maximum Cp of the twisted blade of 13,99%, and Cp of the semicircular blade showed improvement by 11,04%. But in its application, the new modification of the blade such as the twisted blade is likely to make the shape of the Savonius blade more complicated and difficult to produce it. Likewise, the use of the wind curtains that permanently outside the Savonius rotor is very difficult to apply in the field because the wind coming from any direction, unlike the testing in a wind tunnel.

Some researchers were also making efforts to improve efficiency but remain concentrated on the standard shape of the conventional Savonius rotor. Use of overlap between 10% - 30% of the blade diameter was able to increase the efficiency of conventional Savonius rotor by 5% to 20% [7]-[9]. The use of end plates are also able to improve the performance of Savonius rotor [10]-[12]. Research on the effect of aspect ratio on Savonius rotor shows that the best performance is generated when the high of rotor is made twice the diameter of rotor [7, 11, 12].

There were also researches that presented the simulation results on the value of torque generated at each position on the rotation angle of the rotor [13]-[17]. Gavalda [18] presents the results of research on the value of the drag at each position of the rotation angle of the Savonius rotor. The lowest torque and the lowest drag occur at the same of rotation angle of $165^{o}$. This is very interesting because the maximum torque and maximum drag generated at the different positions of the rotation angle. Rudi Hariyanto, et al. [19] describes the rotation angle of $165^{o}$, the position of the concave side of the blade is covered by the back of the blade, thereby acting on the rotor blade purely negative torque. Thus the position of rotation angle of $165^{o}$ is a critical position for conventional Savonius windmill because it is in a negative working position. This is one reason why the Savonius windmill efficiency becomes low, due to the vortex formation and the negative force generated the convex side of the blade.

Based on this study, we can confirm that the performance of conventional Savonius rotor can be improved. In this research, we investigate the effect of the use of a fixed ventilation in the blade to improve the Savonius rotor efficiency. Research on fixed ventilation of the Savonius blade has not been investigated before. The axis of symmetry of the ventilation long side placed right at 15° angle from the outer end of the blade of Savonius rotor. With the manufacture of the ventilation, the lift force is already working when a rotor blade is in the rotation angle $165^{o}$. Ventilation will make the lift force work early on the blade, add the mass flow rate of air that worked rotating blade and eliminate a critical position on the Savonius rotor. With the manufacture of the ventilation, the lift force is already working when a rotor blade is in the rotation angle around $165^{o}$ position. Ventilation will make the lift force work early on the blade, add the mass flow rate of air that worked on the rotating blade and eliminate a critical position on the conventional Savonius rotor. In this study, we experimentally investigated the influence of the clearance width of ventilation and variations in wind speed to rotor performance. Then the experimental results are compared with the conventional Savonius rotor. Another important point in this research is the construction of the blade modifications still do not change the basic shape of the rotor Savonius, keep it simple, easy to make, inexpensive and flexible against the wind coming from any direction.

## 2. Material and Methods

### *2.1 Spesification of Models*

Fig. 1 illustrates geometry of permanent ventilated blade of Savonius rotor. The permanent ventilation on the blades shape like the inverted letter C on a plate with a blade width of 15 mm and a length of 140 mm. The axis of symmetry of the ventilation long side placed right at 15° from the outer end of the blade Savonius. The long side of the ventilation further pushed towards the blade so as to form a gap where the clearance width can be varied. The following is geometry of the ventilated Savonius rotor that used in this study:

- Disk diameter of rotor (D) = 200 mm
- The rotor height of the rotor (H) = D
- The diameter of the blades (d) = 0,5.D
- The width of overlap (e) = 0.2.d
- The diameter stainless steel shaft (ds) = 0,03.d
- The clearance width of ventilation ( s ) = (0,02 – 0,2).d. Selection of s = (0,02 to 0,2).d is identical to the slope angle of the ventilation from 7,5o to 53o. These slope angle of ventilation are expected to flow along the concave surface of the blade and direct the wind towards the buckets overlap
- The width of ventilation (L) = 0,15.d
- Lenght of ventilation (h) = 0,7.H
- Lenght of t = (H-h)/2

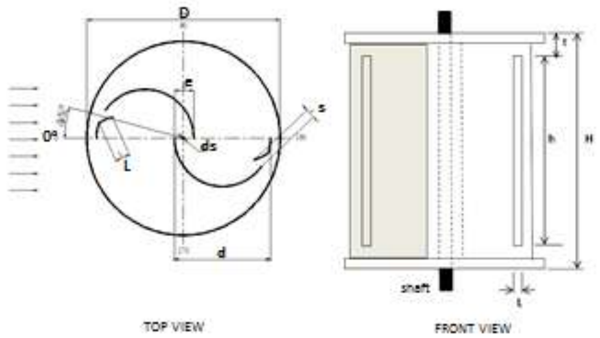



**Fig. 1.** Schematic description and main parameter a ventilated Savonius rotor

In this research, there are six models studied. Table 1 shows six models studied and its codification. Six models are five models the ventilated Savonius rotor and one model the conventional Savonius rotor. The variables that varied from the ventilation on the blade is the clearance width of ventilation. All models are made from the same material so that it has the same weight. The rotor blade is made of stainless steel plate of 0.5 mm. While the disc rotor made transparent mica with a thickness of 3 mm. The disc rotor is useful to bind the rotor blades.

Table 1. The Savonius rotor models and its codification

| No | Type Windmill | The Clearance Width of Ventilation (s) | Codification |
|---|---|---|---|
| 1 | Conventional Savonius | 0 | SC |
| 2 | Ventilated Savonius | 0,02*d | SV02 |
| 3 | Ventilated Savonius | 0,05*d | SV05 |
| 4 | Ventilated Savonius | 0,1*d | SV10 |
| 5 | Ventilated Savonius | 0,15*d | SV15 |
| 6 | Ventilated Savonius | 0,2.*d | SV20 |

*2.2 Testing Methods*

There were three methods of testing in this study:

1. The first test is testing the performance of the models in the wind tunnel with variations in wind speed of 1-7 m/s. Testing data that taken is rotor rotation (rpm). Then the testing data is used to calculate tip speed ratio (TSR) of each model.
   TSR is calculated from
   $$TSR = \frac{U}{v} = \frac{\omega.R}{v} \quad (1)$$
   Where R is radius of rotor (m) , v is wind speed (m/s), and ω is the angular speed ( rad/s).
   $$\omega = \frac{2\pi n}{60} \quad (2)$$

2. The second test is testing the torque of the rotor with a small dynamometer. Testing data that taken are variations of rotor rotation (rpm) to get the braking load against the shaft of rotor.The controlled variable is the wind speed constant at 5 m/s. Then the testing data are used to calculate the Ct (torque coefficient) and Cp as follows:
   The static torque coefficient is calculated from
   $$Ct = \frac{4T}{\rho D^2 v^2 H} \quad (3)$$

Where T is the mechanical torque in (Nm), ρ is air density (kg/m$^3$), D is rotor diameter (m), and H is rotor height.
The mechanical torque is calculated by:
$$T = F \,.\, l \quad (4)$$
Where F is braking load that acting on the rotor shaft in (N) and $l$ is the length of the arm between the shaft and stick brake dynamometer in (m).
The power coefficient Cp can be determined from the following equations:
$$C_p = \frac{P_m}{P_w} \quad (5)$$
Where Pm is the mechanical power and Pw is the wind power.
The mechanical power can be calcilated from
$$P_m = T.\omega \quad (6)$$
The wind power can be calcilated from
$$P_w = \frac{1}{2}\rho A v^3 \quad (7)$$
Where A is the projected area of the rotor in (m$^2$)

Fig. 2 shows the schematic diagram used in the present work. It consists mainly of the following components: (1) a subsonic wind tunnel, (2) Savonius rotor, (3) steel shaft, (4) and the brake arm (5) dynamometer.

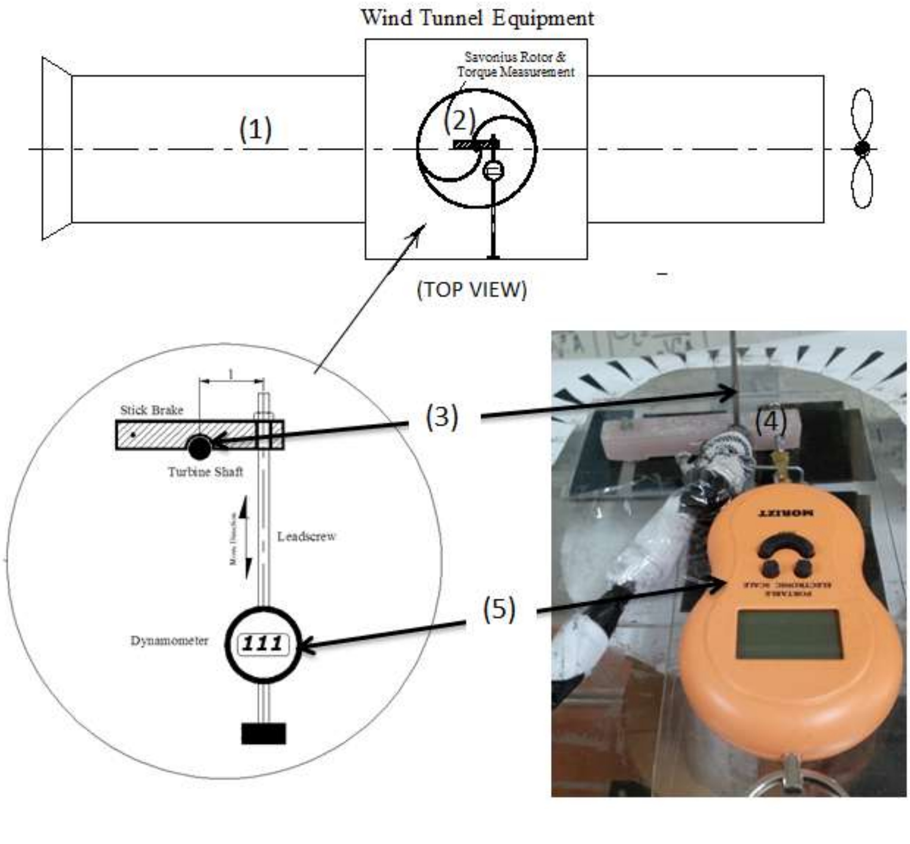



**Fig. 2.** Mechanical torque measurement of the Savonius rotor shaft

3. The third testing was the investigation of ventilation effectiveness. The method used is the same as reported in Hariyanto et al. [19]. But in this test, the investigations were made by recording the experiments using video recorder at 30 fps. Recording results will provide data on the effectiveness of the use of ventilation in the blade especially at the critical position on the rotation angle of 165°. The wind speed that selected in the recording process is 5 m/s. This is in accordance with the controlled variable that used in the testing of torque. The controlled variable is the wind speed at 5 m/s.

In order to obtain valid research data, the testing is done by minimizing the friction losses on the shaft and the bearing. The rotor shaft rotates at the holes of thin stainless steel plate with a thickness of 0.8 mm as replacement bearings. The hole works as the bearing, and has diameter of 3 mm, the same as shaft diameter with clearance. In order to minimize the friction the hole is lubricated. The bottom end of the rotor shaft sharpened like a nail tip, and rotates on the lubricated ceramic tiles.

## 3. Results and Discussion

### *3.1. Comparison of the rotor rotation*

Fig. 3, 4 and 5 show if the ventilation in the blade can improve performance of Savonius windmill. This is indicated by the rotation of the rotor and the TSR value of Savonius rotor with ventilated blade is higher than the conventional Savonius on almost all variations of wind speed. Ventilation on the blade of Savonius able to increase the mass flow rate of air that drives the concave side of the blade and increase the positive torque. This is shown by the high value of rotor rotation at the same wind speed, as shown in figure 3. This means, the rotor rotation shows the magnitude of the change in momentum of wind that occurs on the concave side of the blade. Rotation also shows the magnitude of the kinetic energy of the wind that can be absorbed and converted into a positive torque. Ideally widening gap ventilation openings or clearance of ventilation will increase mass flow rate of air. However, the results showed if the best clearance width of ventilation is 0.05 to 0.10 of the blade diameter (d), at all range of wind speed from 1-7 m/s.

Fig. 4 shows if model SV15 has a rotation higher than others for wind speeds between 1 m/s to 2.5 m/s. Rotation of SV 15 is 6% higher than the conventional Savonius model. It shows the model SV15 able to provide a better starting torque at low wind speeds. As for the wind speed from 2.5-7 m/s, SV05 and SV10 models have the highest rotation. So the model that has a clearance width of (0.05 to 0.1).d most effective work at wind speeds from 2.5-7 m/s. The worst performance of ventilated Savonius is model SV20. Ventilation effectiveness in directing the wind to rotate the rotor only occur at wind speeds above 2 m/s.

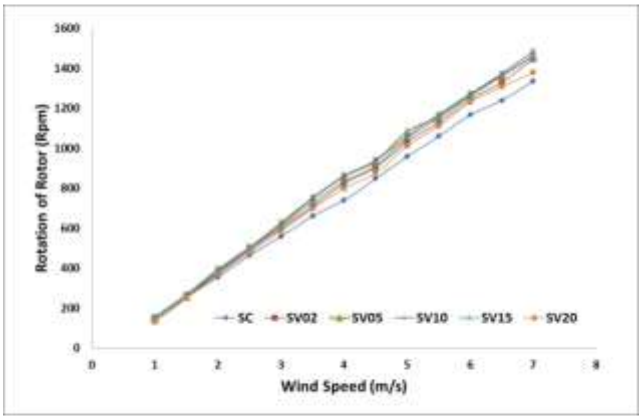



**Fig. 3.** Comparison of the rotor rotation changes with the ventilated blade Savonius and the conventional Savonius

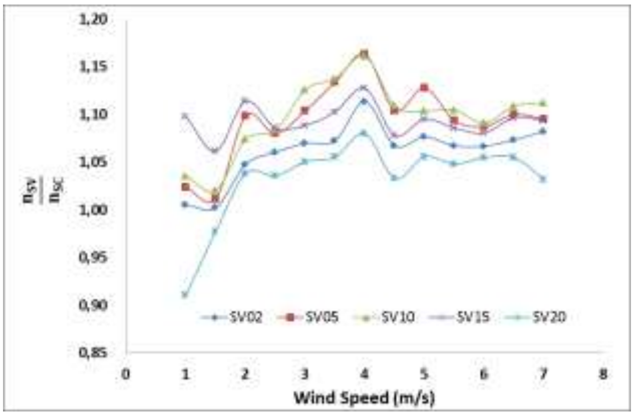



**Fig. 4.** Comparison index of the rotor rotation changes with the ventilated blade Savonius and the conventional Savonius

### *3.2. Comparison of tip speed ratio (TSR)*

TSR is the ratio between the peripheral speed of the rotor of the wind speed. At the same wind speed, rotor has TSR larger than the others that indicates if the rotor is capable of greater convert a wind energy into torque. Rotor with a higher TSR also explain that the rotor is able to work at lower wind speeds to produce the same useful power. Fig. 5 shows if the general TSR of the ventilated Savonius better than conventional Savonius. At wind speeds of less than 2 m/s, the model SV15 has the highest TSR and model SV20 has TSR worse than conventional Savonius. For wind speeds above 2 m/s, SV05 and SV10 models have the highest TSR. TSR value of SV05 and SV10 models are 111% higher than the conventional Savonius.

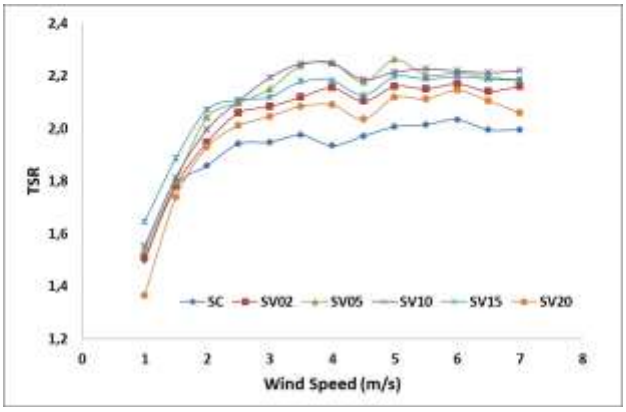



**Fig. 5.** Comparison of TSR changes with the ventilated blade Savonius and the conventional Savonius

*3.3. Comparison of torque coefficient ($C_t$)*

Fig. 6 shows if $C_t$ of all ventilated Savonius are higher than conventional Savonius. $C_t$ of model SV05 has the highest value for all variation of TSR. $C_t$ is directly proportional to torque. Thus, the torque generated of model SV05 will also be higher compared to other models in the same angular velocity values. Average $C_t$ value of model SV05 is 1,64 higher than the conventional Savonius model. This proves if the ventilation in the blade, especially model SV05 able to convert wind energy into more torque at the same TSR.

Fig. 6 also shows if the $C_t$ value of all models will decrease if TSR value is higher. The explanation is all torque testing performed on a constant wind speed of 5 m/s. Then the rotor blade will convert wind speed into the rotor rotation. Braking load will cause shaft rotation slowed. The greater the braking load is given, it will cause slower rotation. Braking load is directly proportional to the torque and rotor rotation is directly proportional to the TSR. Therefore, the Ct value will decrease if TSR value is higher.

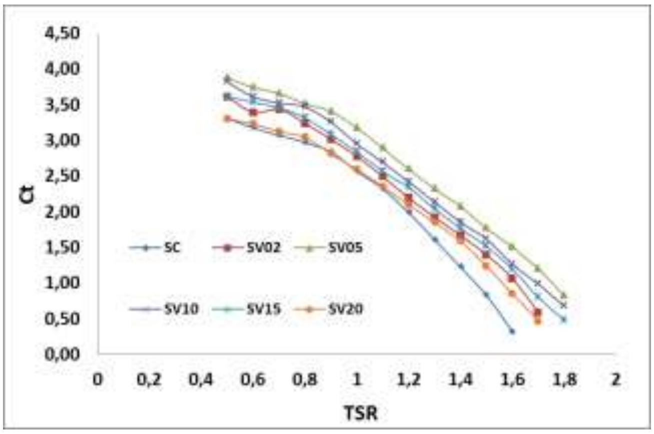



**Fig. 6**. Comparison of the torque coefficient ($C_t$) changes with the ventilated blade Savonius and the conventional Savonius

*3.4. Comparison of power coefficient ($C_p$)*

Fig. 7 shows if the graph of all models increased and peaked at TSR between 1 to 1,1 and after that the graph has decreased Cp value is determined by the useful power because the testing is done on a constant wind speed of 5 m/s. The constant wind speed will produce the constant wind power. Useful power is determined by the magnitude of the braking load to generate torque and rotor angular velocity. As for the wind speed constant, the value of the braking load is inversely proportional to the angular velocity. Based on testing, the optimum value between braking load and angular velocity of all the models obtained in TSR between 1 to 1.1. Fig. 7 shows if model SV05 has the highest Cp. Cp value of model SV05 is 125% higher than conventional Savonius on TSR = 1.1. Model SV20 has the lowest Cp among all ventilated Savonius models. Whereas for Cp value of model SV20 is 101.5% higher than conventional Savonius on TSR = 1.1.

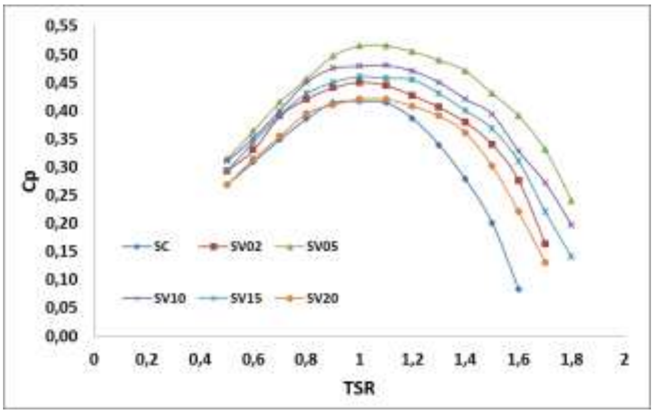
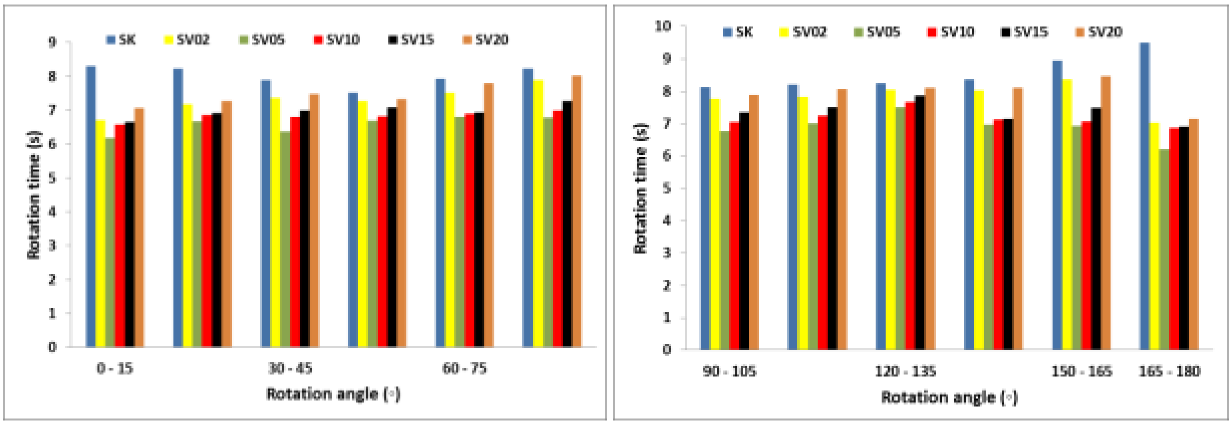



**Fig. 7.** Comparison of the power coefficient (Cp) changes with the ventilated blade Savonius and the conventional Savonius

*3.5. Effectiveness of ventilation*

Fig. 8 shows if the most superior models are SV05 and SV 10 or models that have ventilation with s/d = 0.05 to 0.10. Fig. 8 also shows the making of ventilation in blade Savonius able to improvement the lack of the conventional Savonius windmill. The ventilated Savonius shows the running time is faster and more stable in taking every rotation angle of 15°. Ventilation effectively make the lift force work early on the blade. So that, when the ventilated Savonius rotor is in a position at rotation angle of 165°, as if the blade is already in the position of 0° or 180°. This is showed by the running time at rotation angle of 165° is almost equal to rotation angle of 0°. Thus, it does not happen again a critical condition as occurs in conventional Savonius rotor when blades rotate at an angle of 165°. As is known, when the rotor rotates, there is a critical condition at an angle of 165° where the blade need a inertia moment to rotate past the critical position. Ventilation position that placed right at 15° from the outer end of the blade Savonius is able to overcome these problems. Ventilation were able to eliminate a critical position as in the conventional Savonius rotor.




**A** **B**

**Fig. 8.** Comparison of the rotation time changes with the ventilated blade Savonius and the conventional Savonius

## 4. Conclusion

The use of ventilation in the Savonius blade as in this study verifying the capability to improving the performance of conventional Savonius windmill. Ventilation in the blade able to improve the work of lift force. Ventilation in the blade also able to eliminate the critical condition as seen in the conventional Savonius rotor. Cp of ventilated Savonius is 1,5-25% better than conventional Savonius at a wind speed of 5 m/s. The clearance width of the ventilation openings that produce the best performance are 0.05 to 0.10 of the blade diameter, in term of TSR between 0,5 to 1,8.

## References

[1] Sukanta Roy, Saha, UK., Computational study to assess the influence of overlap ratio on static torque characteristics of a vertical axis wind turbine, Elsevier Journals, Procedia Engineering 51, p.694-702, 2013.

[2] J.W. Twidwell, A.D. Weir, Renewable Energy Resources, The University Press Cambridge, Britain, p. 411,1985.

[3] Altan BD, Atılgan M. An experimental and numerical study on the improvement of the performance of Savonius wind rotor. Energy Convers Manage, p:3425–32, 2008.

[4] Mohamed MH, Janiga G, Pap E, Thevenin D. Optimization of Savonius turbines using an obstacle shielding the returning blade. Renew Energy 2010;35:2618-26

[5] Mohamed MH, Janiga G, Pap E, Thevenin D.. Optimal blade shape of a modified Savonius turbine using an obstacle shielding the returning blade. Energy Convers Manage 2011;52:236-42.

[6] Saha UK, Rajkumar MJ. On the performance analysis of Savonius rotor with twisted blades. Renew Energy, p:1776–88, 2006.

[7] Fujisawa, N., Gontoh, F., Pressure Measurements and Flow Visualization Study of a Savonius Rotor, Journal of Wind Engineering and Industrial Aerodynamics 39, pp. 51-60, 1992.

[8] Blackwell BF, Sheldahl RE, Feltz LV. Wind tunnel performance data for two- and three-bucket Savonius rotors. Sandia Laboratories, USA, Sand 76-0131 under act AT/29-11; p. 789, 1978.

[9] Alexander AJ, Holownia BP. Wind tunnel tests on a Savonius rotor. J Ind Aerod; p:343–51, 1978.

[10] Mojola OO. On the aerodynamic design of the Savonius windmill rotor. J Wind Eng Ind Aerod, p:223–31, 1985.

[11] Ushiyama I, Nagai H. Optimum design configurations and performance of Savonius rotors. Wind Eng, p:59–75, 1988.

[12] Vance W. Vertical axis wind rotors – status and potential. In: Proceedings of the conference on wind energy conversion systems, p. 96–102, 1973.

[13] Saha UK, Thotla S, Maity D. Optimum design configuration of Savonius rotor through wind tunnel experiments. J Wind Eng Ind Aerod, p: 1359–75, 2008.

[14] V. D'Alessandro, Unsteady Aerodynamics of a Savonius wind rotor: a new computational approach for the simulation of energy performance, Elsevier Journals, p.3349 -3363, 2010.

[15] Nakajima, M., Lio, S., Ikeda, T., Performance of Savonius Rotor for Environmentally Friendly Hydraulic Turbine, Journal of Fluid Science and Technology, vol. 3 no. 3, 2008.

[16] Kamoji, MA., Kedare, SB., Prabhu, SV., Experiments Investigations on Single Stage Modified Savonius Rotor, Applied Energy 86, pp. 1064-1073, 2009.

[17] Akwa JV . Stators Use Influence On The Performance Of A Savonius Wind Rotor Using Computational Fluid Dynamics. Engenharia Térmica (Thermal Engineering), Vol. 10 • No. 01 - 02 • June and December 2011 • p. 63-72.

[18] Gavalda, Jna., Massons, J., Diaz, F., Drag and Lift Coefficients of the Savonius Wind Machine, Wind Engineering vol. 15 no. 5, 1991

[19] Rudi Hariyanto, Sudjito S., Denny W., Mega N.S., Analysis the vortex effect on the performance of Savonius Windmill based on CFD (Computational Fluid Dynamics) Simulation and Video Recording, International Journal of Renewable Energy Resources, Vol.6, No.3, p. 931-937, 2016.