EXPERIMENTAL PERFORMANCE OF A MODIFIED SAVONIUS TURBINE FOR SMALL SCALE PORTABLE WIND POWER GENERATION

by I Gede Bawa Susana

International Journal of Mechanical Engineering and Technology (IJMET)
Volume 9, Issue 6, June 2018, pp. 1166–1173, Article ID: IJMET_09_06_128
Available online at http://www.iaeme.com/ijmet/issues.asp?JType=IJMET&VType=9&IType=6
ISSN Print: 0976-6340 and ISSN Online: 0976-6359

EXPERIMENTAL PERFORMANCE OF A MODIFIED SAVONIUS TURBINE FOR SMALL SCALE PORTABLE WIND POWER GENERATION

Ida Bagus Alit, Mirmanto, Ida Ayu Sri Adnyani, Arif Mulyanto, I Gede Bawa Susana
Mechanical Engineering Department, Engineering Faculty, Mataram University,
Jl. Majapahit no. 62, Mataram, NTB, 83125, Indonesia

ABSTRACT

Small scale portable wind turbine has the main criteria such as simple, easy to make, strong, and it can be operated at ground level at low wind speed. This modified Savonius rotor is chosen because it meets the criteria. This study was performed to know the performance of the modified Savonius wind turbine such as the tip speed ratio, power and the efficiency. The aspect ratio, overlap ratio, blade arch angle and the blade shape factor used were 1.5, 0.0, 110° and 0.5 respectively. The overall size of the turbine was 1.2 m in diameter, 1.8 m in height. The transmission utilized used a pulley with a ratio of 1:5. The results indicate that the cut in speed obtained in this study is 2.5 m/s, and the maximum power attained is 24.5 watt at the wind speed of 6.06 m/s. Meanwhile, the maximum efficiency found is 11.6%. An additional data such as an occurrence of the prevailing wind speed observed is also provided to see the wind characteristics.

Key word: Wind Speed Occurrence, Tip Speed Ratio, Turbine Power, Efficiency.

Cite this Article: Ida Bagus Alit, Mirmanto, Ida Ayu Sri Adnyani, Arif Mulyanto and I Gede Bawa Susana, Experimental Performance of A Modified Savonius Turbine For Small Scale Portable Wind Power Generation, International Journal of Mechanical Engineering and Technology, 9(6), 2018, pp. 1166–1173.
http://www.iaeme.com/ijmet/issues.asp?JType=IJMET&VType=9&IType=6

1. INTRODUCTION

Wind turbine is a device that can be used to convert the wind energy into the mechanic or electrical energy. There are two types of the wind turbines: horizontal axis wind turbine (HAWT) and vertical axis wind turbine (VAWT). Generally, the HAWT type is more widely used because it has better efficiency. However, recently the VAWT is also developed because it has several advantages, i.e. simple blade construction, no wind directional influence, placement of generator on the ground, and low wind speed Dhote [1].

Nevertheless, recently the VAWT is also developed due to some advantages; e.g. easy to make, easy to utilize, low tip speed ratio, no high tower, simple maintenance and cheap, Akshay and Narayana [2]. The Savonius turbine is one of the turbines run with drag forces. The drag force is the difference force of the positive and negative forces acting on the blade. It usually consists of two or three blades arranged in an S shape viewed from the top, Vaishali et al. [3]. Some studies of the increasing the Savonius turbine performance have been conducted, [4-9]. Wenehenubun et al. [4] studied the effect of the blade number on the turbine performance. The results of their study showed that a number of blades influence the performance of wind turbine. Savonius model with three blades has the best performance at high tip speed ratio. The highest tip speed ratio obtained in [4] was 0.555 for a wind speed of 7 m/s. Previously, Akwa et a. [5] performed a numerical study on the effect of an overlap ratio on the wind flow characteristics. Deb et al. [6] tried to increase the Savonius turbine performance using CFD. Recently, Damak et al. [7] had also performed an experimental investigation to increase the Savonius turbine performance by applying a twist of 180° on the blade. Ged, et.al., [8] conducted a numerical study using fluent software to modify the blades to be V-blade and polynomial blade in order to increase the performance of the turbine. They concluded that high aerodynamic torque and power could be expected when the rotor was positioned at 45º & 90º with respect to incoming flow. Widodo, et. al.[9] made a design and performed an analysis of the Savonius turbine power with the output power of 5 kW. The size of their turbine was 3.5 m in diameter and 7 in height. The blade model was designed using SolidWorks software and analyzed using CFD.

In this study, the modified Savonius rotor is tested on the beach so that the actual performance of the rotor can be obtained. The differences between this study and the previous studies are the size of the rotor, the material of the rotor, the tip speed ratio and the transmission. Therefore, from the tests, the performance of the rotor with actual conditions can be attained. Some important variables are also tested such as the tip speed ratio, the wind speed frequency, the power and the efficiency.

MODIFIED SAVONIUS ROTOR

Basic geometry parameters of modified Savonius rotor include aspect ratio (H/D), overlap ratio (m/D), blade arc angle (Ψ) and blade shape factor (p/q) as shown in Figure 1. Figure 1 is taken from [10]. H is the rotor height (m), D indicates the rotor diameter (m), m is the arm distance or gap (m), q is the blade radius (m), ψ denotes the angle of the blade arch, and p is the arm length (m).

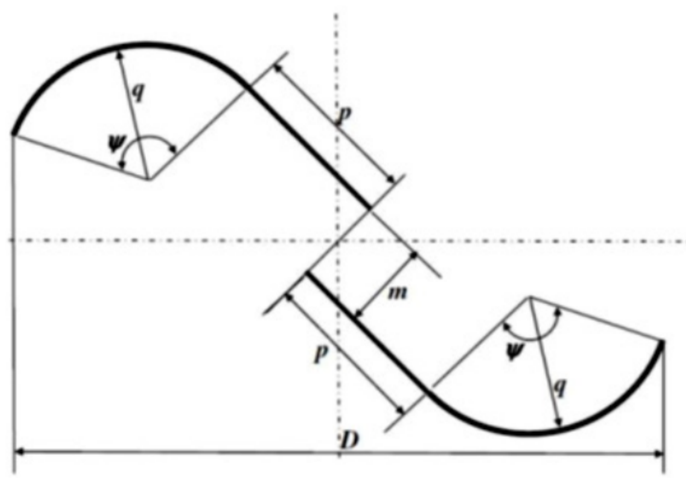

Figure 1 Basic modified Savonius rotor [10]

$$Ar = H / D \quad (1)$$

$$Or = m / D \quad (2)$$

$$BSF = p / q \quad (3)$$

Ar is the aspect ratio, and *Or* is the overlap ratio, and BSF is the blade shape factor. Wind energy conversion is aimed at converting the kinetic wind energy into the mechanic energy done by the turbine and further, the energy is converted into electrical power. The kinetic energy per second can be predicted using an equation that was also used in [9-11].

$$Ek = 0.5\dot{m}v^2 \quad (4)$$

Ek is the kinetic energy per second (W) and *v* is the wind velocity (speed). Meanwhile, the energy of the wind per second also can be calculated as

$$P = 0.5\rho DHv^3 \quad (5)$$

$$As = DH \quad (6)$$

P is the power (W), ρ is the wind/air density (kg/m³), and *As* is the swept area (m²).

Equation (5) is the wind power, while the output power, *Po* is resulted from the wind turbine system. It is equal to the efficiency, η multiplied by the wind power. The turbine system efficiency includes the rotor efficiency, η_r, transmission efficiency, η_t, and generator efficiency, η_g [11].

$$\eta = \frac{Po}{P} = \frac{Po}{0.5\rho DHv^3} \quad (8)$$

The performance of the wind turbine is indicated by the *tip speed ratio* (*Tsr*) relating to the power coefficient or turbine system efficiency. *Tsr* is the ratio of the rotor end velocity to the wind velocity. The rotor end velocity has a nominal value that fluctuates with the wind velocity. Mathematically, *Tsr* can be estimated by:

$$Tsr = \frac{\pi Dn}{60v} \quad (9)$$

n is the rotation per minute (rpm). Every turbine rotor has a different power coefficient at the tip speed ratio. Figure 2 shows the relationship of the tip speed ratio and the power coefficient for several turbine rotor types.

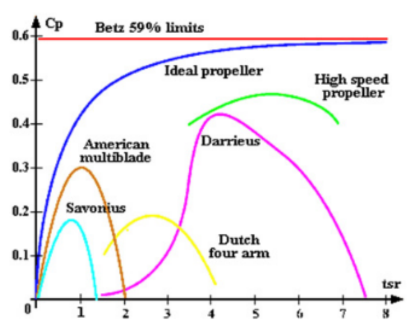

Figure 2 Relationship of Cp-Tsr for several rotor types [10, 12]

2. EXPERIMENTAL SETUP

The testing was performed on the beach named "Loang Baloq", Tanjung Karang, NTB, as shown in Figure 4. It was done to see the synchronization of the modified Savonius rotor design with the natural wind characteristic. The aspect ratio, overlap ratio, blade arch angle and blade shape factor of the tested turbine are 1.5, 0, 110° and 0.5 respectively. The number of the turbine blades was two constructed from the aluminum thin plate with a thickness of 1 mm, a diameter of 1.2 m and the height of 1.8 m. To increase the rotation of the shaft, a V belt transmission with a pulley ratio of 1:5 was employed. The rotating shaft was connected to a generator model PMG 165-0.05 KW 300 RPM. The rotor rotation was measured using a digital laser tachometer DT-2234C.

The generator used was an AC three-phase generator and the AC electric voltage output of the generator is converted into DC electric using a rectifier. Coming out from the rectifier the voltage was measured using a Wattmeter and connected to lamps as the load. The DC voltage and current were directly recorded and saved using a data logger. The Wattmeter has the voltage range measurements of 0-48 V with a resolution of 0.1 V, while the current measurements range from 0 to 30 A with a resolution of 0.01 A. The wind velocity was tested and read using an anemometer JL-FS2 with the measurements ranging from 0.5 m/s to 50 m/s and a resolution of 0.1 m/s.

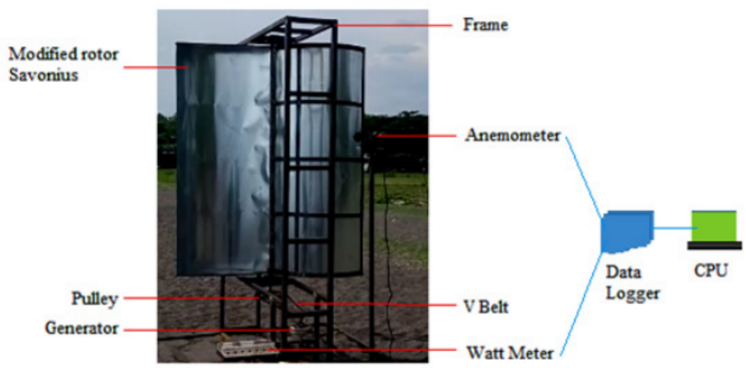

Figure 4 The modified Savonius turbine testing

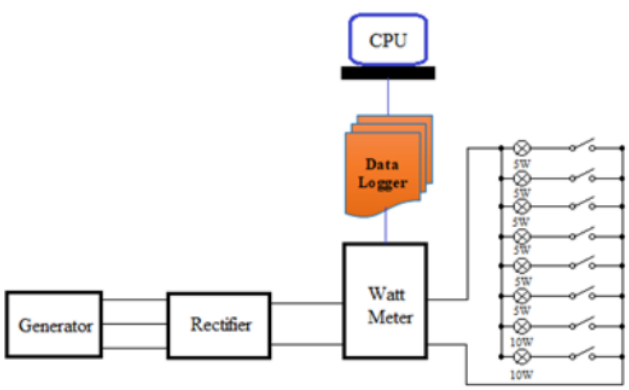

Figure 5 The circuit of the load testing

3. RESULTS AND DISCUSSION

Figure 6 shows the wind speed distribution at the Loang Baloq beach, Tanjung Karang. The wind speed recorded ranges from 1.0 to 6.06 m/s with the wind average speed of 4.2 m/s, while the lowest wind speed indicating the rotor starting to rotate is 2.5 m/s. This wind speed is called cut in speed. It is obtained at the modified Savonius rotor testing in this study. This cut in speed was also found by several previous researchers [13-14]. They elucidated that the cut in speed of 2-2.5 m/s was found in their investigations. Figure 6 shows the occurrence of wind speed. The dominant wind speed occurrence is 4-5 m/s. It has an occurrence of 31%.

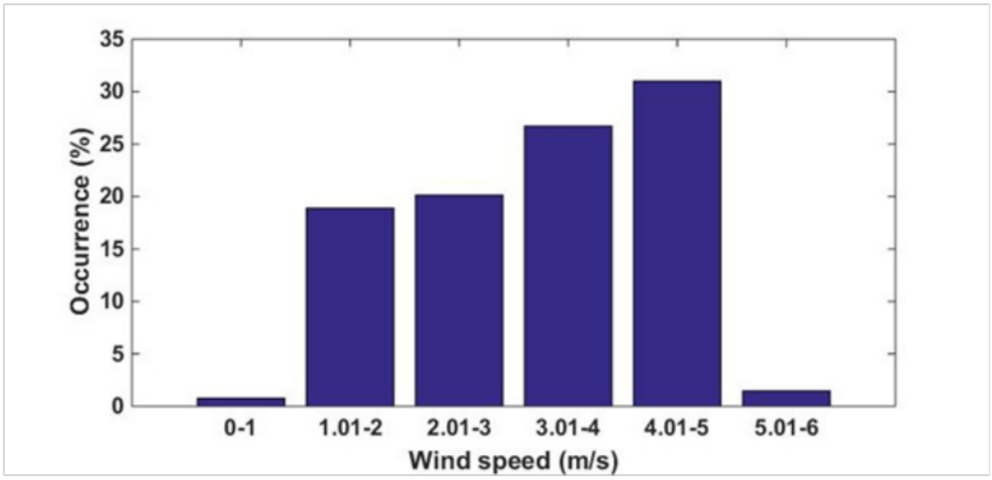

Figure 6. Relationship of the wind speed and its occurrence obtained in the observation

The wind speed influences the tip speed ratio. It indicates the capability of the turbine rotor to convert the kinetic wind energy into the mechanic energy. It also correlates with the rotation of the turbine rotor. The experimental *Tsr* obtained using the modified Savonius rotor is various as shown in Figure 7. Increasing the wind speed up to 6.06 m/s elevates the *Tsr*. This phenomenon was also observed by Wenehenubun [4] using a Savonius turbine rotor with two blades.

Figure 9 demonstrates the relationship of the power, energy and the observation time found in the modified Savonius rotor tests. Increasing the wind speed elevates the force-torque of the blade so that the drag force also increases. Due to the increased drag force, the turbine power raises. The wind speed in the tests fluctuates of between 1.0 to 6.06 m/s. The fluctuation causes the power fluctuation with the time. The highest power obtained in the experiments is 24.5 watt at the wind speed of 6.06 m/s, while the lowest power attained is 1.5 watt at the wind speed of 2.5 m/s. The lowest power is generated because the turbine is just about starting to rotate. Consequently, the generator power output is low. Increasing the wind speed and the observation time boosts the output energy because the energy is equal to the power multiplied by the time.

Figure 10 illustrates the relationship of the *Tsr* and the efficiency of the examined turbine. Elevating the *Tsr* causes the increase in the efficiency. At the *Tsr* of about 0.46, the efficiency reaches the maximum value of 11.6%. Above the *Tsr* of 0.46, the efficiency decreases. The trend of the efficiency was also obtained by Schubel et al. [15]. Schubel et al. [15] also elucidated that the maximum efficiency of the VAWT with the cup shape blades was around 8%, while for the Savonius blades, the maximum efficiency produced was up to 16%.

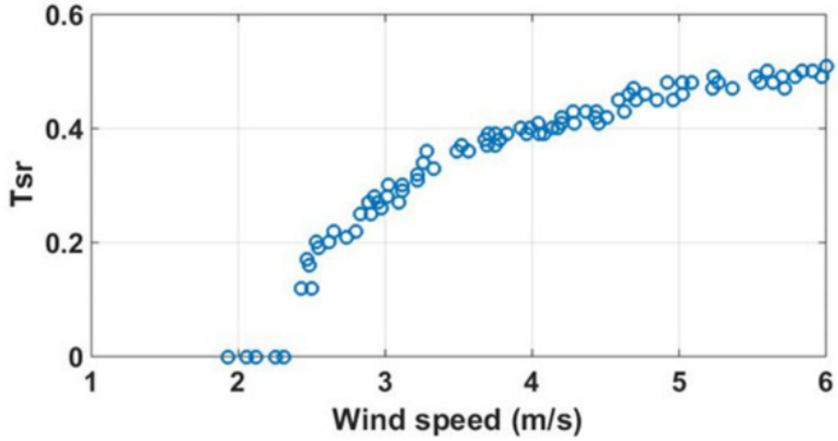

Figure 7 Relationship of the wind speed and *Tsr*

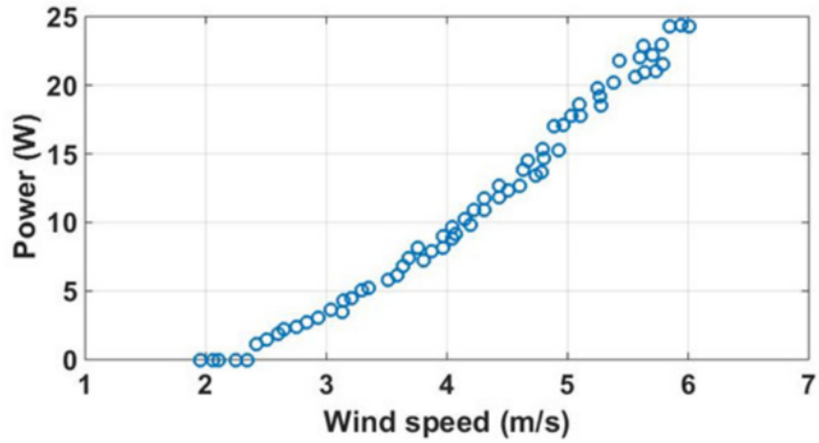

Figure 8 Relationship of the wind speed and the power

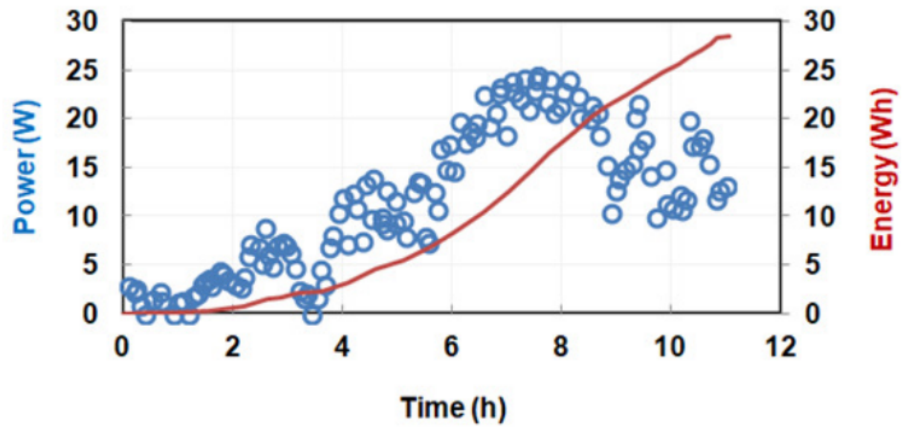

Figure 9 Relationship of the power, energy, and the observation time

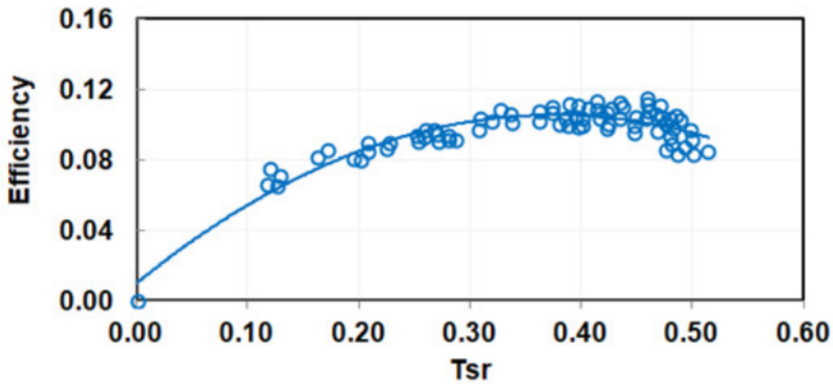

Figure 10. *Tsr* versus efficiency

4. CONCLUSION

An experimental study to examine the modified Savonius turbine with actual conditions has been conducted. The Savonius turbine is chosen because it has a simple construction and it can be operated at low wind speeds. Therefore, this turbine type is suitable to be used in the area where the wind speed is low such as Indonesia. The modified Savonius examined has an aspect ratio of 1.5, an overlap ratio of 0.0, blade arc angle of 110^{O}, and a blade shape factor of 0.5. The turbine has 2 blades with the rotor diameter and height of 1.2 m and 1.8 m respectively. The system uses a pulley transmission with the pulley ratio 1:5 to transfer the energy from the blade to the generator. The cut in speed obtained in the current study is 2.5 m/s. The maximum power attained is 24.5 watt at the maximum wind speed of 6.06 m/s. The maximum efficiency achieved is 11.6%. From the experiment, it can be inferred that although the wind speed is low, the modified Savonius wind turbine examined still works properly and produces reasonable electrical power. Therefore, this modified Savonius wind turbine is recommended to be installed in the low wind speed areas.

ACKNOWLEDGMENT

The authors would like to acknowledge the Ministry of Research, Technology and Higher Education for the funding through the STRANAS research grant. Also, the authors thank the Department of Mechanical Engineering for some facilities and everybody who has helped us in conducting the research and writing the manuscript.

REFERENCES

[1] Dhote, A. Design, Analysis and Fabrication of Savonius Vertical Axis Wind Turbine, *International Research Journal of Engineering and Technology*, **2**(3), 2015, pp. 2048-2054.

[2] Akshay, P. and Narayana, K. Low-Cost Vertical Axis Wind Turbine Project, Proceedings of the 2013 Annual Conference of the American Society for Engineering Education, 2013.

[3] Vaishali, A., Patil, S.A. and Thakur, A.G. Optimization of Savonius Rotor For Wind Turbine, *International Journal of Advances in Engineering & Technology*, **7**(4), 2014, pp. 1294-1299.

[4] Wenehenubun, F., Saputra, A. and Sutanto, H. An Experimental Study on The Performance of Savonius Wind Turbine Related The Number of Blades, 2nd International Conference on Sustainable Energy Engineering and Application, ICSSEA, 2014.

[5] Akwa, J.V., Da Silva, G.A. and Petry, A.P. Verification of The Overlap Ratio Influence on Power and Moment Coefficients of A Savonius Wind Rotor Using Computational Fluids Dynamics, Proceedings of COBEM, 2011.

[6] Deb, B., Gupta, R. and Misra, R.D. Performance Analysis of A Helical Savonius Rotor Without Shaft At 45^{O} Twist Angle Using CFD, *Journal of Urban and Environmental Engineering*, **7**(1), 2013, pp.126-133.

[7] Damak, A., Driss, Z. and Abid, M.S. Experimental Investigation of Helical Savonius Rotor With A Twist Of 180°, *Renewable Energy*, 2013, pp.136-142.

[8] Ged, H.E., El-Hamid, A.A., El-Askary, W.A. and Nasef, M.H. A New Design of Savonius Wind Turbine: Numerical Study, *CFD Letters*, **6**(4), 2014, pp.144-158.

[9] Widodo, W.S., Chin, H., Sihombing and Yuhasri, M.Y. Design and Analysis Of 5 KW Savonius Rotor Blade, *Global Engineers Technologists Review*, **2**(8), 2012.

[10] Alit, I.B., Adnyani, I.A.S. and Mirmanto. Effect of Overlapping Ratio, Blade Shape Factor, and Blade Arc Angle to modified Rotor Savonius performances, *International Journal of Applied Engineering Research*, **13**(1), 2018, pp. 411-416.

[11] Albani, A. and Ibrahim, M.Z. Preliminary Development of Prototype of Savonius Wind Turbine for Application in Low Wind Speed In Kuala Terengganu, Malaysia, *International Journal of Scientific & Technology Research*, **2**(3), 2013, pp. 102-108.

[12] M. D'Ambrosio and M. Medaglia, Vertical axis wind turbines, History, Technology and Applications, Högskolan Halmstad, 2010

[13] Ali, M.A. Experimental Comparison Study for Savonius Wind Turbine of Two & Three Blades At Low Wind Speed, *International Journal Modern Research IJMER*, **3**(5), 2013, pp. 2978-2986.

[14] Pamungkas, S.F., Wijayanto, D.S., Saputro, H. and Widiastuti, I. Performance 'S' Type Savonius Wind Turbine with Variation of Fin Addition on Blade, The 2nd Annual Applied Science and Engineering Conference, 2017.

[15] Nadiya G. Mohammed, "Application of Crowbar Protection on DFIG-Based Wind Turbine Connected to Grid", International Journal of Electrical Engineering & Technology (IJEET), Volume 4, Issue 2, 2013, pp. 81 - 92, ISSN Print : 0976-6545, ISSN Online: 0976-6553.

[16] Sujit Datta, Tanushree Deb, Champa Nandi and A.K. Chakraborty, Modelling and Simulation of Wind Power Plants –Framed with Self-Excited Induction Generator As Well As D.F.I.G. And A Comparative Performance Study Thereof In Pscad/Emtdc Environment, Volume 3, Issue 2, July – September (2012), pp. 123-139, International Journal of Electrical Engineering and Technology (IJEET).

[17] Kokila Ramesh and R.N. Iyengar, Forecasting Indian Monsoon Rainfall Including Within Year Seasonal Variability. International Journal of Civil Engineering and Technology, 8(2), 2017, pp. 390–399

[18] Schubel, P.J. and Crossley, R.J. Wind Turbine Blade Design, *Journal Energies*, **5**, 2012, pp. 3425-3449.

EXPERIMENTAL PERFORMANCE OF A MODIFIED SAVONIUS TURBINE FOR SMALL SCALE PORTABLE WIND POWER GENERATION

ORIGINALITY REPORT

14%	15%	12%	7%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	www.iaeme.com Internet Source	7%
2	ajouronline.com Internet Source	3%
3	Submitted to Universitas Mataram Student Paper	2%
4	eprints.unram.ac.id Internet Source	2%

Exclude quotes	On	Exclude matches	< 2%
Exclude bibliography	On		

EXPERIMENTAL PERFORMANCE OF A MODIFIED SAVONIUS TURBINE FOR SMALL SCALE PORTABLE WIND POWER GENERATION

GRADEMARK REPORT

FINAL GRADE

/0

GENERAL COMMENTS

Instructor

PAGE 1

PAGE 2

PAGE 3

PAGE 4

PAGE 5

PAGE 6

PAGE 7

PAGE 8

Turnitin Originality Report

Processed on: 03-Dec-2022 09:47 WIB
ID: 1969821796
Word Count: 3003
Submitted: 1

EXPERIMENTAL PERFORMANCE OF A MODIFIED SAVONIUS TURBINE FOR SMALL SCALE PORTABLE WIND POWER GENERATION By I Gede Bawa Susana

Similarity Index	Similarity by Source
14%	Internet Sources: 15% Publications: 12% Student Papers: 7%

4% match (Internet from 09-Apr-2020)
http://www.iaeme.com/IJMET/issues.asp?ITType=6&JType=IJMET&PageNumber=3&VType=9

3% match (Internet from 17-Oct-2017)
https://ajouronline.com/index.php/AJAS/article/download/4610/2433

2% match (Internet from 16-Apr-2021)
http://www.iaeme.com/MasterAdmin/Journal_uploads/IJMET/VOLUME_9_ISSUE_6/IJMET_09_06_084.pc

2% match (student papers from 18-Oct-2021)
Class: Sujita
Assignment: Paper
Paper ID: 1677168035

2% match (Internet from 11-Nov-2022)
http://eprints.unram.ac.id/17582/1/C-70.pdf

International Journal of Mechanical Engineering and Technology (IJMET) Volume 9, Issue 6, June 2018, pp. 1166–1173, Article ID: IJMET_09_06_128 Available online at http://www.iaeme.com/ijmet/issues.asp?JType=IJMET&VType=9&IType=6 ISSN Print: 0976-6340 and ISSN Online: 0976-6359 © IAEME Publication Scopus Indexed EXPERIMENTAL PERFORMANCE OF A MODIFIED SAVONIUS TURBINE FOR SMALL SCALE PORTABLE WIND POWER GENERATION Ida Bagus Alit, Mirmanto, Ida Ayu Sri Adnyani, Arif Mulyanto, I Gede Bawa Susana Mechanical Engineering Department, Engineering Faculty, Mataram University, Jl. Majapahit no. 62, Mataram, NTB, 83125, Indonesia ABSTRACT Small scale portable wind turbine has the main criteria such as simple, easy to make, strong, and it can be operated at ground level at low wind speed. This modified Savonius rotor is chosen because it meets the criteria. This study was performed to know the performance of the modified Savonius wind turbine such as the tip speed ratio, power and the efficiency. The aspect ratio, overlap ratio, blade arch angle and the blade shape factor used were 1.5, 0.0, 110° and 0.5 respectively. The overall size of the turbine was 1.2 m in diameter, 1.8 m in height. The transmission utilized used a pulley with a ratio of 1:5. The results indicate that the cut in speed obtained in this study is 2.5 m/s, and the maximum power attained is 24.5 watt at the wind speed of 6.06 m/s. Meanwhile, the maximum efficiency found is 11.6%. An additional data such as an occurrence of the prevailing wind speed observed is also provided to see the wind characteristics. Key word: Wind Speed Occurrence, Tip Speed Ratio, Turbine Power, Efficiency. Cite this Article: Ida Bagus Alit, Mirmanto, Ida Ayu Sri Adnyani, Arif Mulyanto and I Gede Bawa Susana, Experimental Performance of A Modified Savonius Turbine For Small Scale Portable Wind Power Generation, International Journal of Mechanical Engineering and Technology, 9(6), 2018, pp. 1166–1173. http://www.iaeme.com/ijmet/issues.asp?JType=IJMET&VType=9&IType=6 1. INTRODUCTION Wind turbine is a device that can be used to convert the wind energy into the mechanic or electrical energy. There are two types of the wind turbines: horizontal axis wind turbine (HAWT) and vertical axis wind turbine (VAWT). Generally, the HAWT type is more widely used because it has better efficiency. However, recently the VAWT is also developed because it has several advantages, i.e. simple blade construction, no wind directional influence, placement of generator on the ground, and low wind speed Dhote [1]. Nevertheless, recently the VAWT is also developed due to some advantages; e.g. easy to make, easy to utilize, low tip speed ratio, no high tower, simple maintenance and cheap, Akshay and Narayana [2]. The Savonius turbine is one of the turbines run with drag forces. The drag force is the difference force of the positive and negative forces acting on the blade. It usually consists of two or three blades arranged in an S shape viewed from the top, Vaishali et al. [3]. Some studies of the increasing the Savonius turbine performance have been conducted, [4-9]. Wenehenubun et al. [4] studied the effect of the blade number on the turbine performance. The results of their study showed that a number of blades influence the performance of wind turbine. Savonius model with three blades has the best performance at high tip speed ratio. The highest tip speed ratio obtained in [4] was 0.555 for a wind speed of 7 m/s. Previously, Akwa et a. [5] performed a numerical study on the effect of an overlap ratio on the wind flow characteristics. Deb et al. [6] tried to increase the Savonius turbine performance using CFD. Recently, Damak et al. [7] had also performed an experimental investigation to increase the Savonius turbine performance by applying a twist of 180° on the blade. Ged, et.al., [8] conducted a numerical study using fluent software to modify the blades to be V-blade and polynomial blade in order to increase the performance of the turbine. They concluded that high aerodynamic torque and power could be expected when the rotor was positioned at 45º & 90º with respect to incoming flow. Widodo, et. al.[9] made a design and performed an analysis of the Savonius turbine power with the output power of 5 kW. The size of their turbine was 3.5 m in diameter and 7 in height. The blade model was designed using SolidWorks software and analyzed using CFD. In this study, the modified Savonius rotor is tested on the beach so that the actual performance of the rotor can be obtained. The differences between this study and the previous studies are the size of the rotor, the material of the rotor, the tip speed ratio and the transmission. Therefore, from the tests, the performance of the rotor with actual conditions can be attained. Some important variables are also tested such as the tip speed ratio, the wind speed frequency, the power and the efficiency. MODIFIED SAVONIUS ROTOR Basic geometry parameters of modified Savonius rotor include aspect ratio (H/D), overlap ratio (m/D), blade arc angle (Ψ) and blade shape factor (p/q) as shown in Figure 1. Figure 1 is taken from [10]. H is the rotor height (m), D indicates the rotor diameter (m), m is the arm distance or gap (m), q is the blade radius (m), ψ denotes the angle of the blade arch, and p is the arm length (m). Figure 1 Basic modified Savonius rotor [10] Ida Bagus Alit, Mirmanto, Ida Ayu Sri Adnyani, Arif Mulyanto and I Gede Bawa Susana Ar=H /D Or =m/D (1) (2) BSF = p / q (3) Ar is the aspect ratio, and Or is the overlap ratio, and BSF is the blade shape factor. Wind energy conversion is aimed at converting the kinetic wind energy into the mechanic energy done by the turbine and further, the energy is converted into electrical power. The kinetic energy per second can be predicted using an equation that was also used in [9-11]. Ek = 0.5m&v2 (4) Ek is the kinetic energy per second (W) and v is the wind velocity (speed). Meanwhile, the energy of the wind per second also can be calculated as P = 0.5ρ DHv3 (5) As = DH (6) P is the power (W), ρ is the wind/air density (kg/m³), and As is the swept area (m²). Equation (5) is the wind power, while the output power, Po is resulted from the wind turbine system. It is equal to the efficiency, η multiplied by the wind power. The turbine system efficiency includes the rotor efficiency, ηr, transmission efficiency, ηt, and generator efficiency, ηg [11]. Po = Po η = P 0.5ρ DHv3 (8) The performance of the wind turbine is indicated by the tip speed ratio (Tsr) relating to the power coefficient or turbine system efficiency. Tsr is the ratio of the rotor end velocity to the wind velocity. The rotor end velocity has a nominal value that fluctuates with the wind velocity. Mathematically, Tsr can be estimated by: Tsr = π Dn 60v (9) n is the rotation per minute (rpm). Every turbine rotor has a different power coefficient at the tip speed ratio. Figure 2 shows the relationship of the tip speed ratio and the power coefficient for several turbine rotor types. Figure 2 Relationship of Cp-Tsr for several rotor types [10, 12] 2. EXPERIMENTAL SETUP The testing was performed on the beach named "Loang Baloq", Tanjung Karang, NTB, as shown in Figure 4. It was done to see the synchronization of the modified Savonius rotor design with the natural wind characteristic. The aspect ratio, overlap ratio, blade arch angle and blade shape factor of the tested turbine are 1.5, 0, 110° and 0.5 respectively. The number of the turbine blades was two constructed from the aluminum thin plate with a thickness of 1 mm, a diameter of 1.2 m and the height of 1.8 m. To increase the rotation of the shaft, a V belt transmission with a pulley ratio of 1:5 was employed. The rotating shaft was connected to a generator model PMG 165-0.05 KW 300 RPM. The rotor rotation was measured using a digital laser tachometer DT-2234C. The generator used was an AC three-phase generator and the AC electric voltage output of the generator is converted into DC electric using a rectifier. Coming out from the rectifier the voltage was measured using a Wattmeter and connected to lamps as the load. The DC voltage and current were directly recorded and saved using a data logger. The Wattmeter has the voltage range measurements of 0-48 V with a resolution of 0.1 V, while the current measurements range from 0 to 30 A with a resolution of 0.01 A. The wind velocity was tested and read using an anemometer JL-FS2 with the measurements ranging from 0.5 m/s to 50 m/s and a resolution of 0.1 m/s. Figure 4 The modified Savonius turbine testing Figure 5 The circuit of the load testing Ida Bagus Alit, Mirmanto, Ida Ayu Sri Adnyani, Arif Mulyanto and I Gede Bawa Susana 3. RESULTS AND DISCUSSION Figure 6 shows the wind speed distribution at the Loang Baloq beach, Tanjung Karang. The wind speed recorded ranges from 1.0 to 6.06 m/s with the wind average speed of 4.2 m/s, while the lowest wind speed indicating the rotor starting to rotate is 2.5 m/s. This wind speed is called cut in speed. It is obtained at the modified Savonius rotor testing in this study. This cut in speed was also found by several previous researchers [13-14]. They elucidated that the cut in speed of 2-2.5 m/s was found in their investigations. Figure 6 shows the occurrence of wind speed. The dominant wind speed occurrence is 4-5 m/s. It has an occurrence of 31%. Figure 6. Relationship of the wind speed and its occurrence obtained in the observation The wind speed influences the tip speed ratio. It indicates the capability of the turbine rotor to convert the kinetic wind energy into the mechanic energy. It also correlates with the rotation of the turbine rotor. The experimental Tsr obtained using the modified Savonius rotor is various as shown in Figure 7. Increasing the wind speed up to 6.06 m/s elevates the Tsr. This phenomenon was also observed by Wenehenubun [4] using a Savonius turbine rotor with two blades. Figure 9 demonstrates the relationship of the power, energy and the observation time found in the modified Savonius rotor tests. Increasing the wind speed elevates the force-torque of the blade so that the drag force also increases. Due to the increased drag force, the turbine power raises. The wind speed in the tests fluctuates of between 1.0 to 6.06 m/s. The fluctuation causes the power fluctuation with the time. The highest power obtained in the experiments is 24.5 watt at the wind speed of 6.06 m/s, while the lowest power attained is 1.5 watt at the wind speed of 2.5 m/s. The lowest power is generated because the turbine is just about starting to rotate. Consequently, the generator power output is low. Increasing the wind speed and the observation time boosts the output energy because the energy is equal to the power multiplied by the time. Figure 10 illustrates the relationship of the Tsr and the efficiency of the examined turbine. Elevating the Tsr causes the increase in the efficiency. At the Tsr of about 0.46, the efficiency reaches the maximum value of 11.6%. Above the Tsr of 0.46, the efficiency decreases. The trend of the efficiency was also obtained by Schubel et al. [15]. Schubel et al. [15] also elucidated that the maximum efficiency of the VAWT with the cup shape blades was around 8%, while for the Savonius blades, the maximum efficiency produced was up to 16%. Figure 7 Relationship of the wind speed and Tsr Figure 8 Relationship of the wind speed and the power Figure 9 Relationship of the power, energy, and the observation time Ida Bagus Alit, Mirmanto, Ida Ayu Sri Adnyani, Arif Mulyanto and I Gede Bawa Susana Figure 10. Tsr versus efficiency 4. CONCLUSION An experimental study to examine the modified Savonius turbine with actual conditions has been conducted. The Savonius turbine is chosen because it has a simple construction and it can be operated at low wind speeds. Therefore, this turbine type is suitable to be used in the area where the wind speed is low such as Indonesia. The modified Savonius examined has an aspect ratio of 1.5, an overlap ratio of 0.0, blade arc angle of 110O, and a blade shape factor of 0.5. The turbine has 2 blades with the rotor diameter and height of 1.2 m and 1.8 m respectively. The system uses a pulley transmission with the pulley ratio 1:5 to transfer the energy from the blade to the generator. The cut in speed obtained in the current study is 2.5 m/s. The maximum power attained is 24.5 watt at the maximum wind speed of 6.06 m/s. The maximum efficiency achieved is 11.6%. From the experiment, it can be inferred that although the wind speed is low, the modified Savonius wind turbine examined still works properly and produces reasonable electrical power. Therefore, this modified Savonius wind turbine is recommended to be installed in the low wind speed areas. ACKNOWLEDGMENT The authors would like to acknowledge the Ministry of Research, Technology and Higher Education for the funding through the STRANAS research grant. Also, the authors thank the Department of Mechanical Engineering for some facilities and everybody who has helped us in conducting the research and writing the manuscript. REFERENCES [1] [2] [3] Dhote, A. Design, Analysis and Fabrication of Savonius Vertical Axis Wind Turbine, International Research Journal of Engineering and Technology, 2(3), 2015, pp. 2048-2054. Akshay, P. and Narayana, K. Low-Cost Vertical Axis Wind Turbine Project, Proceedings of the 2013 Annual Conference of the American Society for Engineering Education, 2013. Vaishali, A., Patil, S.A. and Thakur, A.G. Optimization of Savonius Rotor For Wind Turbine, International Journal of Advances in Engineering & Technology, 7(4), 2014, pp. 1294-1299. [4] Wenehenubun, F., Saputra, A. and Sutanto, H. An Experimental Study on The Performance of Savonius Wind Turbine Related The Number of Blades, 2nd International Conference on Sustainable Energy Engineering and Application, ICSSEA, 2014. [5] Akwa, J.V., Da Silva, G.A. and Petry, A.P. Verification of The Overlap Ratio Influence on Power and Moment Coefficients of A Savonius Wind Rotor Using Computational Fluids Dynamics, Proceedings of COBEM, 2011. [6] Deb, B., Gupta, R. and Misra, R.D. Performance Analysis of A Helical Savonius Rotor Without Shaft At 45O Twist Angle Using CFD, Journal of Urban and Environmental Engineering, 7(1), 2013, pp.126-133. [7] Damak, A., Driss, Z. and Abid, M.S. Experimental Investigation of Helical Savonius Rotor With A Twist Of 180°, Renewable Energy, 2013, pp.136-142. [8] Ged, H.E., El-Hamid, A.A., El-Askary, W.A. and Nasef, M.H. A New Design of Savonius Wind Turbine: Numerical Study, CFD Letters, 6(4), 2014, pp.144-158. [9] Widodo, W.S., Chin, H., Sihombing and Yuhasri, M.Y. Design and Analysis Of 5 KW Savonius Rotor Blade, Global Engineers Technologists Review, 2(8), 2012. [10] Alit, I.B., Adnyani, I.A.S. and Mirmanto. Effect of Overlapping Ratio, Blade Shape Factor, and Blade Arc Angle to modified Rotor Savonius performances, International Journal of Applied Engineering Research, 13(1), 2018, pp. 411-416. [11] Albani, A. and Ibrahim,

M.Z. Preliminary Development of Prototype of Savonius Wind Turbine for Application in Low Wind Speed In Kuala Terengganu, Malaysia, International Journal of Scientific & Technology Research, 2(3), 2013, pp. 102-108. [12] M. D'Ambrosio and M. Medaglia, Vertical axis wind turbines, History, Technology and Applications, Högskolan Halmstad, 2010 [13] Ali, M.A. Experimental Comparison Study for Savonius Wind Turbine of Two & Three Blades At Low Wind Speed, International Journal Modern Research IJMER, 3(5), 2013, pp. 2978-2986. [14] Pamungkas, S.F., Wijayanto, D.S., Saputro, H. and Widiastuti, I. Performance 'S' Type Savonius Wind Turbine with Variation of Fin Addition on Blade, The 2nd Annual Applied Science and Engineering Conference, 2017. [15] Nadiya G. Mohammed, "Application of Crowbar Protection on DFIG-Based Wind Turbine Connected to Grid", International Journal of Electrical Engineering & Technology (IJEET), Volume 4, Issue 2, 2013, pp. 81 - 92, ISSN Print : 0976-6545, ISSN Online: 0976-6553. [16] Sujit Datta, Tanushree Deb, Champa Nandi and A.K. Chakraborty, Modelling and Simulation of Wind Power Plants –Framed with Self-Excited Induction Generator As Well As D.F.I.G. And A Comparative Performance Study Thereof In Pscad/Emtdc Environment, Volume 3, Issue 2, July – September (2012), pp. 123-139, International Journal of Electrical Engineering and Technology (IJEET). [17] Kokila Ramesh and R.N. Iyengar, Forecasting Indian Monsoon Rainfall Including Within Year Seasonal Variability. International Journal of Civil Engineering and Technology, 8(2), 2017, pp. 390–399 [18] Schubel, P.J. and Crossley, R.J. Wind Turbine Blade Design, Journal Energies, 5, 2012, pp. 3425-3449. Experimental Performance of A Modified Savonius Turbine For Small Scale Portable Wind Power Generation Experimental Performance of A Modified Savonius Turbine For Small Scale Portable Wind Power Generation Experimental Performance of A Modified Savonius Turbine For Small Scale Portable Wind Power Generation Experimental Performance of A Modified Savonius Turbine For Small Scale Portable Wind Power Generation http://www.iaeme.com/IJMET/index.asp 1166 editor@iaeme.com http://www.iaeme.com/IJMET/index.asp 1167 editor@iaeme.com http://www.iaeme.com/IJMET/index.asp 1168 editor@iaeme.com http://www.iaeme.com/IJMET/index.asp 1169 editor@iaeme.com http://www.iaeme.com/IJMET/index.asp 1170 editor@iaeme.com http://www.iaeme.com/IJMET/index.asp 1171 editor@iaeme.com http://www.iaeme.com/IJMET/index.asp 1172 editor@iaeme.com http://www.iaeme.com/IJMET/index.asp 1173 editor@iaeme.com