



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.

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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 45° & 90° 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).

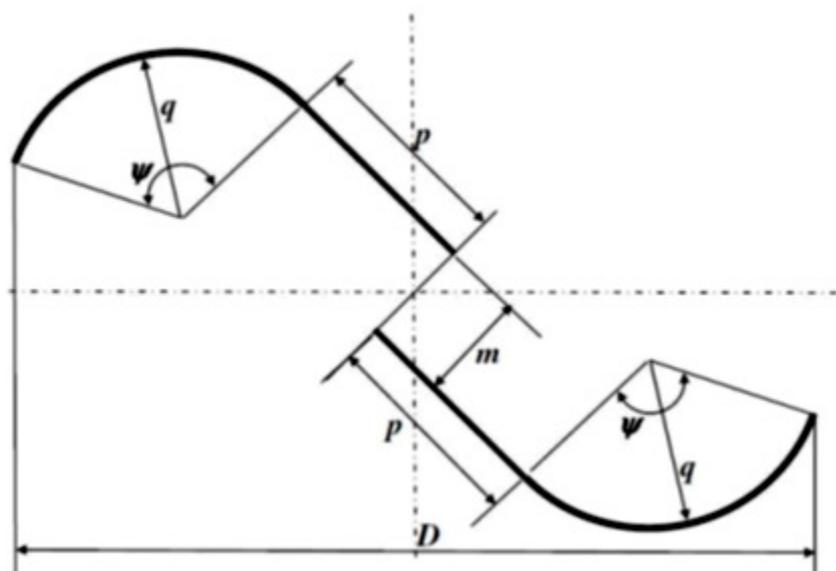


Figure 1 Basic modified Savonius rotor [10]

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

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

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

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/m^3), and As is the swept area (m^2).

Equation (5) is the wind power, while the output power, P_o 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].

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

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.

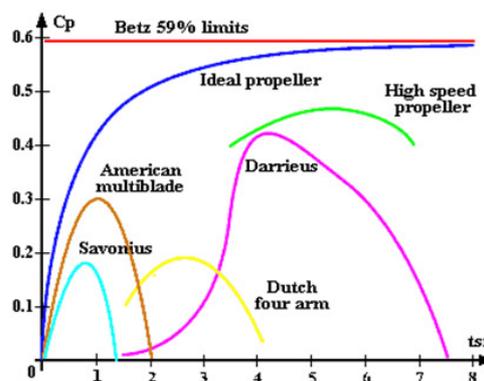


Figure 2 Relationship of C_p - Tsr for several rotor types [10, 12]

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.

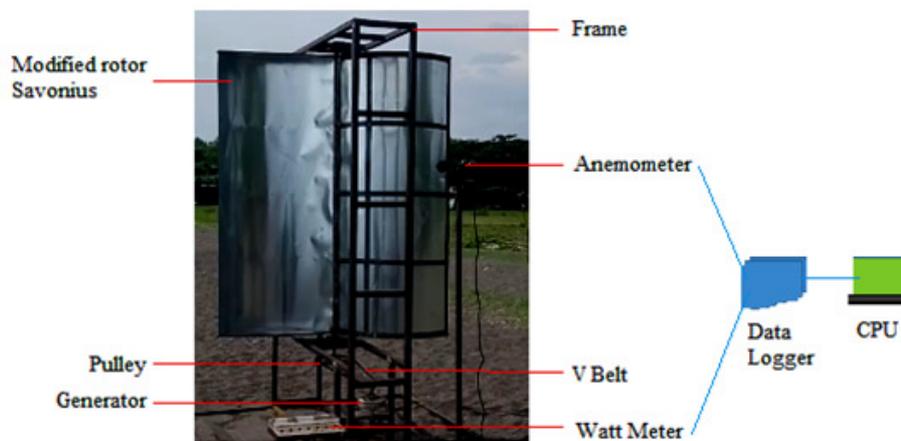


Figure 4 The modified Savonius turbine testing

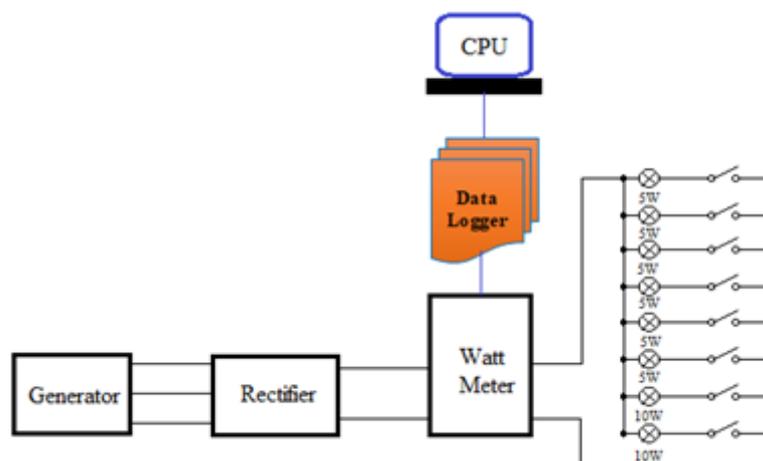


Figure 5 The circuit of the load testing

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%.

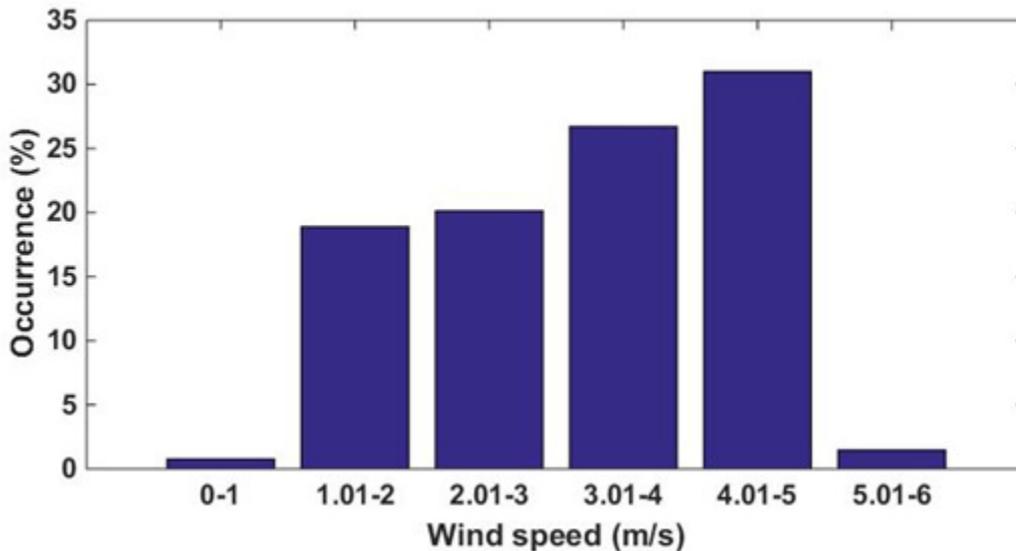


Figure 6. Relationship of the wind speed and its occurrence obtained in the observation

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%.

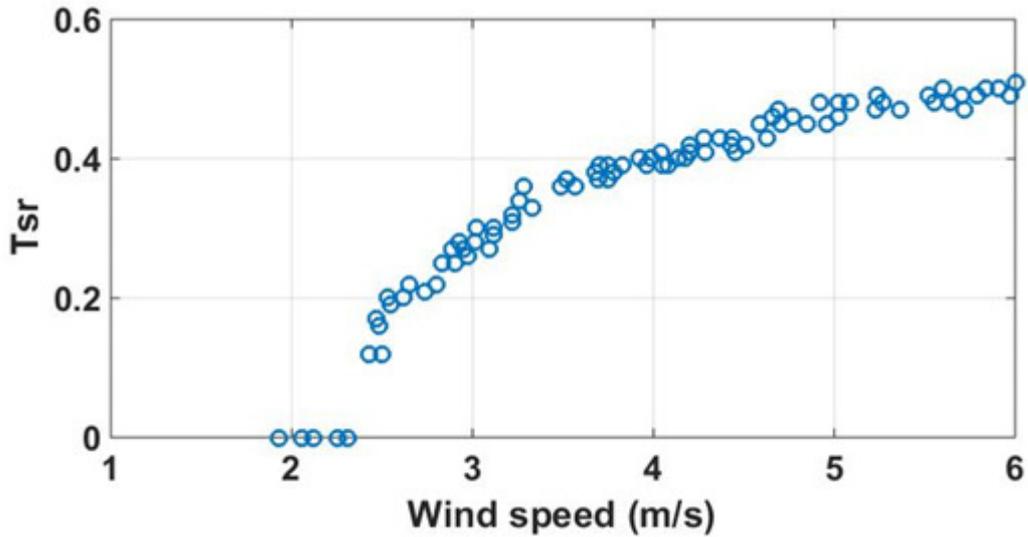


Figure 7 Relationship of the wind speed and Tsr

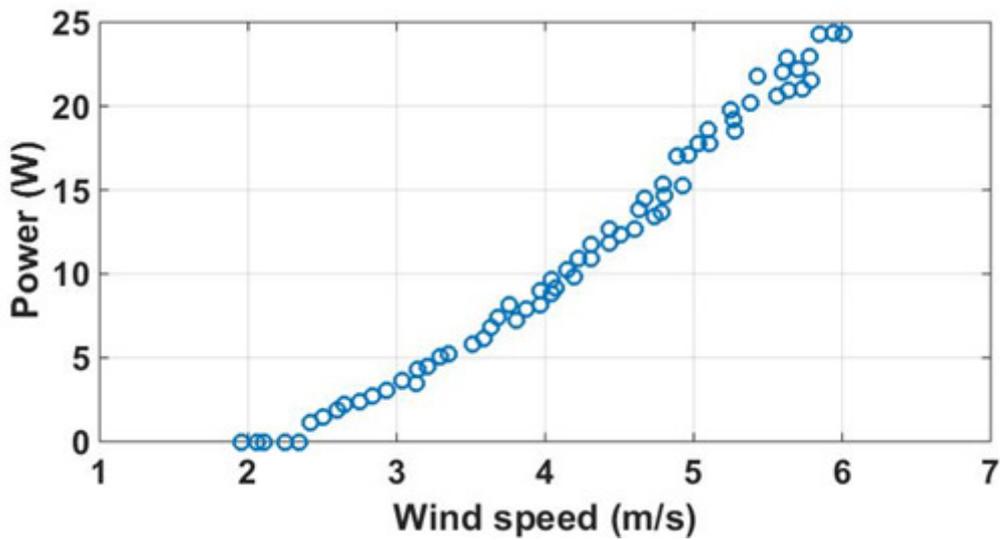


Figure 8 Relationship of the wind speed and the power

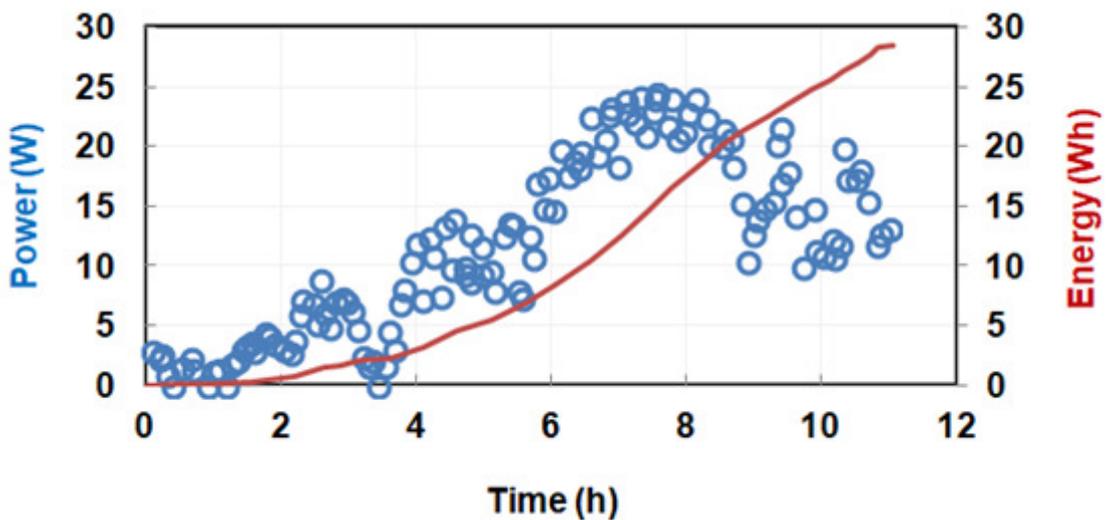


Figure 9 Relationship of the power, energy, and the observation time

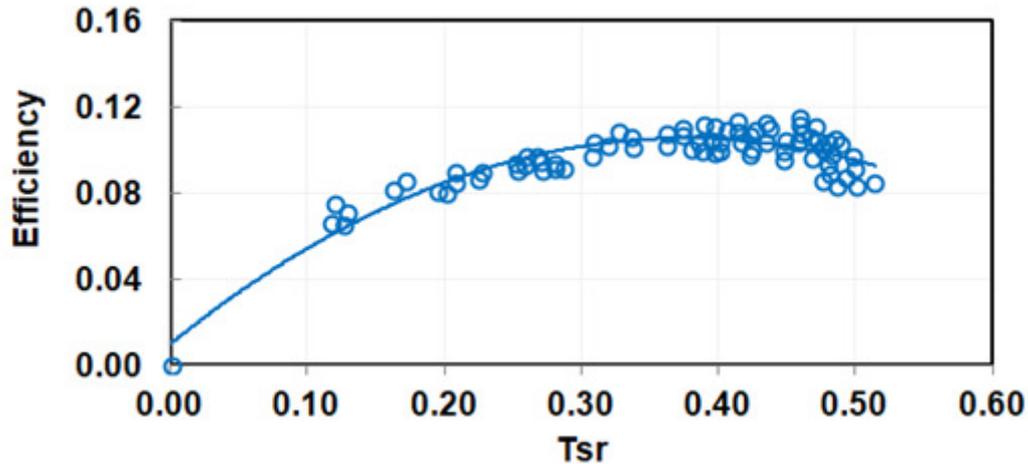


Figure 10. *Tsr* versus efficiency

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° , 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.

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