Performance Investigation of A Mix Wind Turbine Using A Clutch Mechanism At Low Wind Speed Condition

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Abstract. Wind energy is one of the methods that generates energy from sustainable resources. This technology has gained prominence in this era because it produces no harmful product to the society. There is two fundamental type of wind turbine are generally used this day which is Horizontal axis wind turbine (HAWT) and Vertical axis wind turbine (VAWT). The VAWT technology is more preferable compare to HAWT because it gives better efficiency and cost effectiveness as a whole. However, VAWT is known to have distinct disadvantage compared to HAWT; self-start ability and efficiency at low wind speed condition. Different solution has been proposed to solve these issues which includes custom design blades, variable angle of attack mechanism and mix wind turbine. A new type of clutch device was successfully developed in UMS to be used in a mix Savonius-Darrieus wind turbine configuration. The clutch system which barely audible when in operation compared to a ratchet clutch system interconnects the Savonius and Darrieus rotor; allowing the turbine to self-start at low wind speed condition as opposed to a standalone Darrieus turbine. The Savonius height were varied at three different size in order to understand the effect of the Savonius rotor to the mix wind turbine performance. The experimental result shows that the fabricated Savonius rotor show that the height of the Savonius rotor affecting the RPM for the turbine. The swept area (SA), aspect ratio (AR) and tip speed ratio (TSR) also calculated in this paper. The highest RPM recorded in this study is 90 RPM for Savonius rotor 0.22-meter height at 2.75 m/s. The Savonius rotor 0.22-meter also give the highest TSR for each range of speed from 0.75 m/s, 1.75 m/s and 2.75 m/s where it gives 1.03 TSR, 0.76 TSR, and 0.55 TSR.

Keywords: Wind speed performance, Clutch system, Savonius-Darrieus turbine, low wind speed.

1. Introduction
Wind energy is one of energy resources that is available in abundance and can be utilized to produce mechanical work. A wind turbine is used to convert the kinetic energy from air movement to mechanical work, thus a lot of research have been done to increase the efficiency of a wind turbine at different wind condition. The technology has evolved and continually developed throughout the years and now it becomes one of the economically viable and sustainable sources of energy [1].
Wind turbine technology is commonly used in a suitable location that has strong consistent wind speed. In the Malaysian context, studies showed that there is a limited application for wind turbine technology as an electric generator. Generally, a site which has a mean wind speed exceeds 6m/s can be considered as a suitable location for a wind farm. Several locations that have minimum mean wind speed have been identified in Malaysia. Per Jha, 2011 [2], the locations that have a mean speed of 6 m/s in Malaysia includes; Kelantan, Terengganu, Pahang, Sarawak, and Kedah. In the context of Sabah and its immediate shores, Kudat and Labuan is a suitable place for a small-scale wind turbine because it located at the northern site of Sabah that has an average wind speed of 6m/s and meets the requirement for wind farm development [3].

Wind turbines are categorized by two type which is Horizontal Axis Wind Turbine (HAWTs) and Vertical Axis Wind Turbine (VAWTs) [4]. Each of these turbine types has distinct properties; HAWT is much more suitable at low wind speed while VAWT is better suited for a higher wind speed condition [5]. The general different between these two type is the orientation of their axis of rotation. For HAWT, the horizontal axis always pointed in the horizontal direction into the wind or away from the wind to get the maximum efficiency in order to produce power while for VAWT rotational axis is perpendicular to the wind direction [6]. This study focuses on the VAWT which generally have better tolerance to wind direction change compared to the HAWT. A vertical axis wind turbine (VAWT) do not have to be orientated into the wind and can operate in any wind direction [7]. Subsequently, two types of VAWT are available; Savonius and Darrieus turbine [4]. A Savonius turbine is a drag type wind turbine while a Darrieus turbine is a lift type turbine.

The savonius wind turbine has an ability to self-start [8] and able to generate torque due to the drag force of its own geometry, but the efficiency is (20%) lower than darrieus rotor [9]. The ability to self-start is one of the critical factors for wind turbine considering the place that has low wind speed and varied from time to time.

Darrieus turbine has the highest efficiency among the other VAWTs but do not have a self-start ability and has a low starting torque [9]. According to Daut 2012 [4], the darrieus wind turbine normally requires self-starting assist mechanism. To overcome these problem Darrieus- Savonius mix wind turbine were introduced and the starting torque and performance show dramatic improvement [10]. Almotairi 2011 [11] also state that Darrieus- Savonius mix turbine can generate more power and able to self-start in low wind condition. Combining these two type of blade on a single rotor can improve and compliment the disadvantage of each type of blade [12].

2. Methodology
The noise-free clutch system as shown in Figure 1 functioned as a coupling to connect Savonius and Darrieus blade in a single rotor. This clutch allows the Savonius blade to rotate at low wind speed and helps to drive the Darrieus turbine. At higher wind speed, the Darrieus turbine realizes higher rotation speed and the clutch will mechanically disconnect the Savonius blade from the Darrieus rotor. At this stage, the Darrieus turbine drives the turbine while the Savonius blade rotates freely. To investigate the effectiveness of the design Savonius rotor the performance of the turbine will be compared with stand-alone Darrieus turbine.
Figure 1. (a) Schematic of the design clutch, (b) photograph of fabricate noise-free clutch, considered in this work it consists of; 1 - shaft, 2 - c-clip, 3 - top plate, 4 - top cover, 5 - top base, 6 - base, 7 - bottom base.

Figure 2 shows the Savonius blade design that is used in this study. Researchers [8,14] have reported that the Savonius design is more stable when using two blade rotor. The power coefficient for the Savonius rotor increases when the aspect ratio increases and two stage rotor is more efficient compare to single stage rotor. The addition of end plates on a Savonius rotor also increases the overall efficiency and is included in this design.

Figure 2. (a) Savonius rotor, (b) photograph of Savonius rotor.
The Darrieus blade used in this project are as shown in Figure 3. A Darrieus wind turbine powered by the lift force from the vertical axis blade; thus, the shape of the blade is identical to an airfoil [15]. The lift force created from the shape of the blade which is an asymmetric shape. A pressure difference is created from the blade when it cut the air with an angle of attack driven by wind flow creating a lift force. Also, Mohammed 2014 [16] reported that 0° (zero degree) blade pitch angle gave the best efficiency compared to other pitch angle.

![Figure 3. (a) Darrieus turbine, (b) photograph of Darrieus turbine.](image)

A mix wind turbine was designed and fabricated using the three main components; Savonius rotor, Darrieus blade and a clutch. Different Savonius heights were experimented to study the effect of Savonius size to the wind turbine performance. The material used for the clutch must have high yield strength so that it can withstand the weight from Savonius rotor and the wind force from the blower while able to resist weather element. Thus, an Aluminium 5000 series was used as the material as it corrosion resistant, machine-able and attainable in the market. Figure 4 shows the complete CAD model and fabricated model of the mix wind turbine with the clutch system. Table 1 and table 2 below shows the specification of the Darrieus and Savonius rotor used in this study. The design Savonius rotor has a fix diameter for each design which is 0.16 meter.
Table 1. Darrieus Turbine.

| Model               | SAV-75W Wind Turbine Generator |
|---------------------|---------------------------------|
| Weight              | 10.5 kg                         |
| Height              | 0.745 meter                     |
| Rated Power         | 50 Watt                         |
| Rotor Diameter      | 0.56 meter                      |
| Rated RPM           | 260 RPM                         |

Table 2. Savonius rotor.

| Savonius rotor | Savonius 0.16-meter | Savonius 0.19-meter | Savonius 0.22-meter |
|----------------|---------------------|---------------------|---------------------|
| Height (meter) | 0.16                | 0.19                | 0.22                |
| Aspect ratio (H/D) | 1.00                | 1.19                | 1.39                |
| Swept Area (m²)  | 0.026               | 0.030               | 0.035               |

Figure 4. (a) Complete CAD model, (b) photograph of complete model.
3. Experimental Work

To assess the performance of the design blade related to RPM performance using design noise-free clutch for MVAWT, three configurations and three different speed were planned and tested. Each set of the experiment were repeated three times to get an average reading. The rotor rotation speed (RPM) was recorded and swept area (SA), aspect ratio (AR) and tip speed ratio (TSR) was calculated the formula as shown as bellow.

\[ TSR = \frac{\omega R}{v} \]  

\[ \omega = \frac{2 \pi n}{60} \]

\[ SA = H \times D \]

\[ AR = \frac{H}{D} \]

Where, TSR (Tip Speed Ratio), \( \omega \) is angular velocity, R is the radius of the rotor, n is revolution per minutes, H is the height of the rotor and D is the diameter of the rotor.

The performance of the mix wind turbine is measured at three different wind speed; 0.75 m/s, 1.75 m/s and 2.75 m/s. These speeds are chosen because the experiment is designed to investigate the wind turbine performance at low wind speed condition. The Savonius rotor were varied in heights; 0.16 meter, 0.19 meter and 0.22 meter. The low wind speed is generated by a custom-made wind blower as shown in Figure 5. The wind speed is measured using smart sensor AR83 Anemometer Plus while the rotation speed of the wind turbine is measured using a MASTECH MS6208B non-contact Type Digital Tachometer. Three readings were made for each experiment and the average value is used to calculate the TSR.

![Wind Blower](image)

**Figure 5. Wind Blower**
4. Results
The test shows that the highest RPM recorded was at 2.75 m/s which is 90 RPM for Savonius 0.22-meter. Savonius 0.22-meter, has the largest value of swept area which is 0.035 m$^2$ compare to the other design; Savonius 0.16-meter and Savonius 0.19-meter which have 0.026 m$^2$ and 0.030 m$^2$ swept area. As the swept area of the rotor increase, the amount of air which strikes the blades of Savonius rotor also will increases. Thus, the rotation per minutes (RPM) also increases. As shown in Figure 6, Stand-alone Darrieus turbine started to rotate at 1.5 m/s as the RPM recorded for this speed is only 6 RPM, compare to the other configuration shown in Figure 7 that used the clutch system as connecting device for Savonius and Darrieus turbine the turbine started to rotate at 0.75 m/s for each design of Savonius rotor. As shown in Figure 7 as the wind speed of the blower increases from 0.75 m/s to 1.75 m/s and to 2.75 m/s the RPM for each design increases for Savonius 0.22-meter the RPM increases from 46 RPM to 76 RPM to 90 RPM while for Savonius 0.19-meter and Savonius 0.16-meter the RPM increases from 44 RPM to 70 RPM to 86 RPM and 40 RPM to 68 RPM to 82 RPM. It can be concluded that using coupling as the connecting device for Savonius-Darrieus turbine increase its performance and able to self-start at low wind speed. Figure 8 show the highest value for tip speed ratio (TSR) recorded in this experiment which is 1.03 TSR at 0.75 m/s for Savonius 0.22-meter at wind speed 1.75 m/s and 2.75 m/s Savonius 0.22-meter also have the highest value for TSR compare to the other design which is 0.76 TSR and 0.55 TSR. When the RPM of the turbine increase, the TSR also will increases. It can be concluded that the Savonius 0.22-meter has shown good performance in term of RPM and TSR at low wind speed condition. Figure 6, Figure7, and Figure 8 shows more details about the comparison between Savonius 0.16-meter, Savonius 0.19-meter and Savonius 0.22-meter in term of RPM and TSR.

![Figure 6. Data of Revolution per Minutes (RPM) vs Wind Speed (m/s).](image-url)
**Figure 7.** Data of Revolution per Minutes (RPM) vs Wind Speed (m/s).

**Figure 8.** Data of tip speed ratio ($\lambda$) vs wind speed (m/s).
5. Conclusion
In this study, a mix wind turbine with a new coupling system and at various Savonius rotor height were investigated. The results show that when the Savonius rotor has a bigger swept area the TSR of the turbine will increase. As the swept area increase the air which strikes the blades of Savonius rotor also will increase and affecting the performance of the turbine in term of RPM and TSR. Figure 8 show the TSR of each design decrease as the wind speed increases, this due to the weight of the Savonius rotor that affecting the RPM of the turbine. The experiments show that;

- Highest RPM recorded is 90 RPM for Savonius 0.22-meter.
- Highest TSR recorded for this experiment is 1.03 which for Savonius 0.22-meter at 0.75 m/s.
- The addition of a clutch system in a mix wind turbine design have been proven to give the turbine a self-start capability.
- The Savonius rotor main function is to assist the Darrieus blade self-start capability as well as to maintain rotation at low wind speed condition. Thus, Savonius 0.22-meter have shown good rotation speed and TSR at low wind speed compared to another configuration.

Moreover, the design should be able to function normally at high wind speed condition as the clutch system is expected to disengage and allow the Darrieus turbine to rotate faster than the Savonius rotor. Further study needs to focus on better design and a full characterization of the noise-free clutch so it can increase the performance of the turbine. To improve the feasibility of wind turbine as an alternative power, further study like this project need to be conducted so that energy from a wind turbine can be generated at the region where the wind speed is not suitable for wind turbine technology.

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