Performance of a 90°-Bent Bladed Vertical Axis Wind Turbine Model with Various Numbers of Blades

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Abstract. This study aims to design a vertical axis wind turbine that can effectively harness the power of wind. This was performed by designing and testing a vertical axis wind turbine with 2, 3 and 4 blades bent at 90° angles in wind speeds between 1.6 m/s and 4.2 m/s for every type of wind turbine. The results show that 2-blade vertical axis wind turbines coefficient of power \( C_P \) = 0.28 is most capable of converting wind power into electricity with wind speeds of 3.4 m/s and 3-blade wind turbines \( C_P \) = 0.40 in wind speeds of 2.2 m/s, and 4 blade wind turbines \( C_P \) = 0.25 performed best in wind speeds of 2.4 m/s. The \( C_P \) of all three wind turbines decreased as wind speeds increased to 4.2 m/s. The examination and calculation analysis results indicate that 3-blade wind turbines work more effectively than 2-blade and 4-blade wind turbines due to the asymmetric positioning creating a relatively small drag, and the distance between each blade and the shaft of the wind turbine creates a rift allowing for wind to flow which results in the blades hitting other. This increases the blades momentum leading to less turbulence for 3-blade wind turbines.

Keywords: wind turbines, wind speeds, blades bent, blades momentum, number of blades, coefficient of power

1. Introduction
Humans have been harnessing wind energy for 5,500 years[1]. As technology develops, so do the potential uses of wind energy[2]. Humans have been using wind energy to support their activity for long time ago. Currently, wind energy potential has attracted the attention of researchers to invent a form of energy utilization in the form of turbines and wind turbines during this era of global warming.

Based on data by National Meteorological Agency of Indonesia (BMKG), the average of annual wind speeds in Indonesia is 4-5 m/s[3]. Therefore, an appropriate wind energy conversion system (SKEA) capable of harnessing wind energy in Indonesia is needed.

Generally, wind turbines were used to generate electricity by harnessing wind energy. In the beginning, wind turbines were made to accommodate the needs of farmers in digging paddies and irrigation among others. The basic work principle of electricity-producing wind turbines is converting the mechanical energy of wind into rotation energy by the turbines[4,5]. This rotation is then used to run an electricity-producing generator.

One type of wind turbine is a vertical axis with a shaft or a perpendicular main rotary axis[6–8]. The main advantage of this type of build is that the turbine does not need to be aimed towards wind direction to produce electricity[5,9]. This is useful in places where wind direction varies greatly. Vertical axis wind turbines are able to harness wind from different directions, as well as having a good
self-starting mechanism which allows for the rotary to rotate with little wind[6]. In addition, the resulting torque from this wind turbine is relatively high.

![Figure 1. Vertical Axis Wind Turbine Model with 2, 3, and 4 of 90° Bent Blades](image)

![Figure 2 Scheme of axis turbine A1-A3 and vertical axis wind turbine with 2,3, and 4 of 90° bent blades B1-B3](image)
This study focuses on vertical axis wind turbines due to their ability to better utilize lower and fluctuating wind speeds in Indonesia. Although this type of wind turbine is less efficient than other builds, this turbine has other advantages such as its simplistic build, ability to utilize wind from all directions, and independence from over speed rotation protection components. In addition, it also has good starting torque and a self-starting mechanism that can perform well in producing electricity in small-scaled generators. In order to be efficient, some modifications have been made on the wind turbines. Additional fins, geometric alterations and blade shape, additional stages, and use of valves are some changes made. This study employs the use of 90°-bent blade vertical axis wind turbines.

2. Research methodology

The type of research used in this study is experimental research which involves observing and measuring predetermined variables to assess 90°-bent blade vertical axis wind turbines with varying number of fans (2, 3 and 4). A stand fan is placed in a vary distance from the front of blade due to define a speed of wind.

2.1. Research variable

Two types of research variables used in this study: independent and dependent variables. Firstly, independent variables give a variation of treatment to the wind turbines in this study. In this study, the variables are the varying wind speeds starting from 1.6 to 4.2 m/s, as well as the use of multiple fan blades (2, 3 and 4). Secondly, dependent variables are the results of the study. In this research, the dependent variables has some circumstances i.e., shaft power of 90°-bent blades vertical axis wind turbines, torque resulting from the 90°-bent blades vertical axis wind turbines, and efficiency level.

2.2. Experimental setup

Prepare the study tools and materials. Set/make a series of savonius wind turbine bent blades. Prepare various bent blades in sets of 2, 3 and 4. Make a series of savonius wind turbines with 2, 3 and 4 blades as shown in Figure 1. Design savonius wind turbines with 2, 3 and 4 bent blades is shown in Figure 2.
Figure 3 and Figure 4 shows the vertical axis wind turbine with dimension and position experimental device. The blower fan is turned on due to gain wind energy. Then, the wind speed of the fan is adjust in order to arrange the wind power into the axis turbine. Measure and record the rotation of the wind turbine axis with a digital tachometer, tachometer sensor attached to the wind turbine axis below the pulley. The wind speed of air flow into the turbine blades is measured by using an anemometer that installed between the fan and the turbine blades. Measure voltage and current outflow of the DC generator with a multimeter. Procedure step is repeated for each different blade (2, 3 and 4).

2.3. Collected data

Collected data was conducted by measuring wind speeds using an anemometer. The wind speeds gauged by the blowers for each experiment ranged from 1.6 to 4.2 m/s. A tachometer was used to measure the shaft’s rotations per minute (rpm) for each experiment with varying wind speeds. A multimeter was used to compute generator output by assessing DC current and voltage.

3. Result and discussions

Data processing was done by calculating the results with certain formulas and presenting them through tables and graphics. Figure 5 shows the relationship between wind speed and coefficient power where higher lead to a greater increase of break horse power (BHP). This increase is because the coefficient power is the ratio between BHP and wind force. This can be seen from the formula

\[
\text{Coefficient Power} = \frac{\text{BHP}}{\text{Wind Force}}
\]

Figure 4. Scheme of frame and shaft savonius wind turbine using 90° of bent blades

It can be seen from Figure 5 that wind turbines with 3 blades has a greater coefficient power than turbines with 2 and 4 blades. Wind turbines with 2 blades have an optimum coefficient power of 0.28 for wind speeds of 3.4 m/s which decreases as wind speeds increase to a maximum of 4.2 m/s.

The 3-blade turbines have an optimum coefficient power of 0.40 in wind speeds of 2.2 m/s which decreases as wind speeds increase to 4.2 m/s. 4-blade wind turbines have an optimum coefficient
power of 0.25 when wind speed reaches 2.4 m/s which decreases as wind speed increases to 4.2 m/s. This decrease in coefficient power is caused by an imbalance between increase in axis force and wind increase in wind speeds. Higher wind speeds lead to greater losses which cause the coefficient power value to decline.

\[ C_p = \frac{\text{BHP}}{P_{\text{wind}}} \] (1)

Figure 5 shows that 3 of 90° bent blade wind turbines have a greater rpm number compared to 2- and 4-blade turbines. This is because an odd number of fan blades experiences the least amount of wind draft which results in a smaller negative torque. This allows optimum turbine rotation. 2-blade turbines have a greater rpm number than turbines with 4 blades. This is due to the greater mass belonging to 4-blade turbines compared to that of 2-blade turbines which allows for faster rpm in the latter.

Figure 6 shows that 3 of 90° bent blades are optimal in turning wind power into generator power than tubines with 2 and 4 of 90° bent blade. This is due to the higher rpm for 3-blade turbines with 90° bends in wind speeds of 4.2 m/s (wind power of 2.99 watts) than 2- and 4-blade turbines. The 2 of 90°
bent blades have a generator power of 0.537 watts, the 3 of 90° bent blades have 0.774 watt generator output value, while 4-blade 90° bends only generate 0.395 watts.

Figure 7 Curve of wind power as input power and generator power

Figure 8 shows 3-blade wind turbines have a far greater coefficient power value than that of 2- and 4-blade turbines. This is due to the 3-blade turbine’s ability to capture wind power due to less wind friction on returning blades which leads to less negative torque allowing for the turbine to spin at a maximum rate. These result in a greater output compared to 2- and 4-blade turbines. The highest coefficient power reached by the 2-blade wind turbine is 0.28 in wind speeds of 3.4 m/s. 3-blade wind turbines reached a coefficient power of 0.4 in wind speeds of 2.2 m/s. The 4-blade wind turbines reached a coefficient power of 0.25 in wind speeds of 2.4 m/s.

Figure 8 Curve of tip speed ratio and coefficient power

Figure 9 shows that tip speed ratio (TSR) has a trend similar to that of rpm. In this case, TSR shows the comparison between output speed (rotor) and input speed (wind). In other words, TSR was parallel. The peak of graph for TSR is caused by the savonius characteristic that is unable to convert in high wind speeds. The graph and data shows that the TSR value for 3-blade wind turbines are far better than for 2 and 4-blade turbines. 2-blade turbines reached a TSR 0.1, 3-blade turbines reached 0.11 and 4-blade turbines reached a TSR of 0.8.
From Figure 10 and Figure 11, it can be concluded that the coefficient power value for savonius wind turbines is far better in comparison to 2 90° bent blade vertical axis wind turbines and America multiblade wind turbines. 2 90° bent blade vertical axis wind turbines have a greater coefficient power when compared to American multiblade wind turbines. However, the TSR value for the 2-blade wind turbine is lowest compared to that of the savonius and American multiblade turbines.

**Figure 9** Curve of wind speed and tip speed ratio

**Figure 10.** Relation between Tip Speed Ratio and Coefficient Power for 2 of 90° Bent Blade Vertical Axis Wind Turbines
Figure 11. comparison between tip speed ratio and coefficient power for 2 of 90° bend blade vertical axis wind turbine, savonius wind turbine, and American multiblade wind turbine

Figure 12 and Figure 13 show that the coefficient power of the 3 of 90° bent blade vertical axis wind turbine is far greater in comparison to that of the savonius and American multiblade wind turbines. However, the TSR value for the 3 of 90° bent blade vertical axis wind turbine is lowest in comparison to that of the savonius and American multiblade turbines.

Figure 12. Relation between Tip Speed Ratio and Coefficient Power for 3 of 90° Bent Blade Vertical Axis Wind Turbines
Figure 13. Comparison between tip speed ratio and coefficient power for 3 of 90° bent blade vertical axis wind turbines, savonius wind turbines, and American multiblade wind turbines.

Figure 14 and Figure 15 indicate that the coefficient power of the savonius wind turbine is greater than that of the 4 90° bent blade vertical axis wind turbine and the American multiblade wind turbine. The 4 of 90° bent blade wind turbine has a better coefficient power than that of the American multiblade, but the TSR value of this wind turbine is lowest in comparison to the savonius and American multiblade turbines.

Figure 14. Relation between tip speed ratio and coefficient power for 4 90° bent blade vertical axis wind turbines.
Conclusions
The three 90° bent blade of vertical axis wind turbine is the best design compared to the Savonius and American multiblade wind turbines. It can be utilized in wind speeds starting from 1 m/s.

The design of the 90° bent blade of vertical axis wind turbine has an aspect ratio \((h / R)\) of 2.8, making it able to reach higher coefficient powers when compared to Savonius and American multiblade turbines. The three 90° bent blade of vertical axis wind turbine is able to reach coefficient powers of approximately 0.4 greater than the Savonius design which can reach a coefficient power of 0.3.

The 90° bent blade of vertical axis wind turbines are able to convert wind energy in electricity. 2-blade models can reach a maximum capacity of 28 percent in winds of 3.4 m/s, 3-blade models has a maximum capacity of 40 percent in winds of 2.2 m/s, and 4-blade turbines have a maximum capacity of 25 percent in wind speeds of 2.4 m/s. The 3-blade vertical axis wind turbine model is the most effective model among the three designs made for this research.

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