The Implementation of Low RPM Generator on Small Scale Savonius Vertical Axis Wind Turbine (VAWT)

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***Abstract*— Fossil energy, especially petroleum, is the main energy source and a source of foreign exchange. Indonesia has a limited amount of fossil energy. Meanwhile, energy consumption continues to increase along with the economic and population growth. Thus natural resources such as oil, gas, and coal are becoming more depleted, because they are not renewable energy. Indonesia is a tropical country located on the equator, as an archipelago with varied geological contours, more than 100 mountains, and also beaches. One of the energies that might be utilized is wind energy with an affordable cost and free pollutant output. Wind Turbines have become one of the feasible power plants to replace fossil energy. The mechanism of wind turbine is that the wind blows against the blades of the wind turbine, and allows the blades to rotate as the axis and produces a valuable source of renewable energy by repetitive rotational motion. This research was focused on finding a suitable generator for Savonius Vertical Axis Wind Turbine (VAWT) that can produce a high voltage at low RPM. In this research, to replicate the real wind blow, two different fans are used: a. 71 cm diameter industrial fan with range of wind speed from 1 to 6 m/s; b. 31 cm fan with a range of wind speed from 1 to 4,5 m/s. From the result, it can be concluded that the direction of the wind affects the rotation of the rotor, so it must be ensured that the wind touches the tip of the blade to maximize the rotational speed. The maximum voltage output produced by VAWT is 4,8 V at 67 RPM on wind speed 6 m/s using the 1st Generator. For further development, the Vertical Axis Wind Turbine (VAWT) have to be remodelled so the ratio between rotor radius and rotor height is 1,2.**

Keywords*—*Vertical Axis Wind Turbine, Savonius, Low RPM Generator, Toll Road, Flow Simulation

I. Introduction

Fossil energy, especially petroleum, is the main energy source and a source of foreign exchange. Indonesia has a limited amount of fossil energy. Meanwhile, energy consumption continues to increase along with the rate of economic and population growth. Thus the natural energy resources are increasingly depleted. because most of the energy sources come from sources that are not renewable, such as oil, gas and coal [1].

Energy is a basic human need that must be fulfilled, it continues to increase as time passes, it is directly proportional to human life. Fuel oil holds a very dominant position in meeting national energy needs. The current composition of energy consumptions are fuel oil: 52,50%; gas: 19,04%; coal: 21,52%; water: 3,73%; geothermal: 3,01%; and renewable energy: 0,2% [2].

Indonesia is a tropical country located on the equator, as an archipelago with varied geological contours, more than 100 mountains, and also beaches. One of the energies that might be utilized is wind. The movement of wind from the mountains which has high air pressure towards the coast with low air pressure can be utilized in the implementation of wind turbines, which convert mechanical energy into electrical energy. Few advantages of this wind energy are inexpensive production cost, and free of pollutant [2].

Wind power is the future form of power generation. Basically, the kinetic energy of the wind is converted into mechanical energy for the production of electricity. The most common and familiar machine for generating wind power is the horizontal axis, which consists of a number of blades rotating around a central axis [3].

The blades of the wind turbine are driven by the wind, allowing the blades to rotate their axis, which is produced a very valuable source of renewable energy with repeated rotational motion. The wind turbine produces rotational motion, and the component which rotates to produce wind energy is called rotor. The conversion of wind energy into electrical energy is done by connecting a turbine to an electric generator [3].

An alternate form of producing wind energy, which is a modified version of the Horizontal Axis Wind Turbine (HAWT), is the Vertical Axis Wind Turbine (VAWT) model. An advantage of the VAWT model over its counterpart is that it operates independent of the direction of the wind. A key component of the Horizontal Axis Wind Turbine is that it requires a Yaw system. Yaw system is required in order to guide the turbine towards the direction of the wind, however this is not required for the vertical axis wind turbines. VAWT blades will rotate regardless of wind direction, this allows for cost efficiency during the manufacturing process. All Vertical Axis Wind Turbines are functioning by lift or drag principles [4].

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This research has been conducted to demonstrate the efficiency and productivity of a VAWT, with a Savonius Rotor using 3 different kind of low RPM generator for producing voltage.

II. Methodology

This research was conducted following based on flow of research as illustrated in Figure II.1.

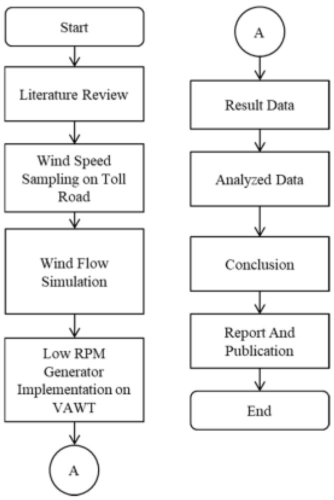

Fig. II.1 Flow of research

Figure II.1 demonstrates the Flow of Research. First, a review of various literatures as a reference for conducting this research is carried out. Then the wind speed measurement was carried out on the Tanjung Priok Toll Road as a reference for wind speed in the field. After that, 3D modeling was carried out for digital analysis using wind flow simulation on Solidworks. If the modeling is in accordance with the real specifications of the VAWT, Then proceed with the implementation of 3 generators on the VAWT. Then, the output power is calculated at the wind speed data that had been obtained using power equation. Then conclusions can be drawn from the results of the analysis.

III. Result and Analysis

A. *Wind Speed Sampling*

The source of the wind data used in the calculations were the same as the actual wind data obtained using anemometer in Tanjung Priok Toll Road location as shown in Figure III.1.

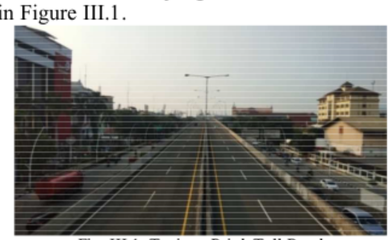

Fig. III.1. Tanjung Priok Toll Road

The selection of the location was based on wind data from the Global Wind Atlas web based [5]. On the wind speed map in North Jakarta [5], it can be seen that the North Jakarta was potential to get higher wind speed, especially Tanjung Priok. Figure III.2 shows the wind speed data sample for 3 days in a row.

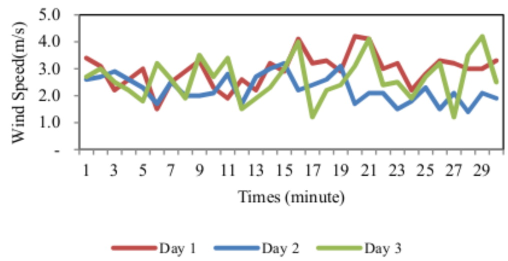

Fig. III.2 Wind speed sample on Tanjung Priok Toll Road

From the wind speed data collection, it is known that the average of wind speed on Tanjung Priok Toll Road is 2,6 m/s and the maximum wind speed is 4,2 m/s.

B. *Wind Flow Simulation*

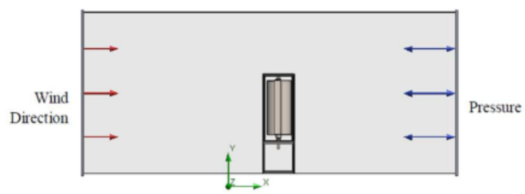

Fig. III.3. Determine the boundary conditions

Figure III.3 shows the condition of the wind direction and the enviromental pressure of the wind tunnel. It can be seen if on the left, there is an arrow showing a red line to indicate the direction of the wind of 8 m/s which will move in the direction of the X axis.

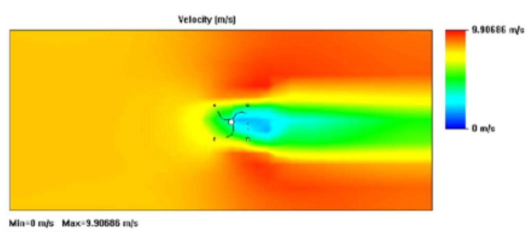

Fig. III.4. Velocity contour in wind tunnel visualization (top view)

Figure III.4 shows the contour of the wind speed that rotates the wind turbine. It can be seen that the wind source moving from the left wall at a speed of 8 m/s, but approaching the wind turbine, the speed decreases to yellow, green to blue. This refers to Betz's Law, which states that wind turbines can only utilize 59,3% of the kinetic energy of the wind speed. More details can also be seen in Figure 4.8 where the contour is shown from the top side of the wind turbine. It can be seen clearly, on the advancing blade, the wind speed is decrease to green contour, this means that the distance from the wind speed source can affect the wind speed received by the wind turbine blades. Figure III.5 shows how envireomental pressure affects the blade of the turbine.

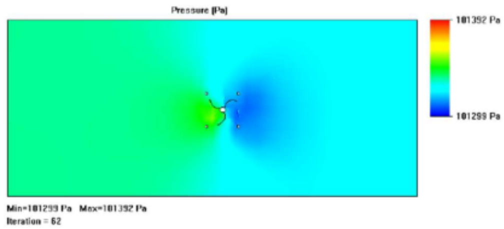

Fig. III.5. Pressure Contour in wind tunnel visualization (top view)

The above simulation results will be used as a reference material for measuring voltage, RPM, and wind speed in the electrical laboratory. The distance between the wind source and the VAWT affects how much wind speed will be received by the turbine blades.

C. Small Scale VAWT Product

All VAWT specification data was taken from the existing Savonius VAWT model from latest project of Electrical Machinary Course on 2018 at the Indonesia Al-Azhar University [6-9]. The low RPM generator will be implemented on the base part of VAWT as shown in Figure III.6. This Table III.1 shows the detail of specifications of the VAWT.

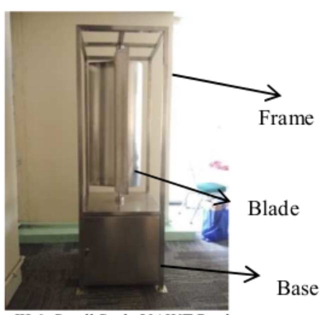

Fig. III.6. Small Scale VAWT Product

Table III.1. Small Scale VAWT Dimension

VAWT Type	Savonius Vertical Axis Wind Turbine (VAWT)
Total Height (m)	1,81
Base Height (m)	0,58
Base Width (m)	0,60
Blade Thickness (m)	0,008
Rotor Length (m)	1
Rotor Radius (m)	0,24
Total Blade	3
Blade Material	Stainless Steel

From the generator implemented below, it can be seen the performance of the voltage output, RPM and wind speed from the existing VAWT.

D. Generator Implementation

Low RPM Generator was used as a converter of mechanical energy generated from the rotation of the turbine rotor into electrical energy. This wind turbine was driven by low wind speeds and the assumption that the rotational speed of the rotor was low. So, it needs a generator that could generate electricity at low rotations.

Fig. III.7. 1st Generator Implementation

The first generator implemented as shown in Figure III.7 is labeled as the 1st generator and the specification for the 1st generator is shown at Table III.2.

Table III.2 Specification of 1st Generator

1st Generator Specifications		
Voltage		180
Speed (R.P.M)		2400 +- 5%
Frequency (Hz)		50/60 Hz

Figure III.8 shows the implementation of the 2nd and 3rd generator with width of 150 mm and a height of 75 mm and the following at Table III.3 shows the specifications of the 2nd and 3rd generator.

Fig. III.8. 2nd and 3rd Generator Implementation

Table III.3 Low RPM Generator 12V and 24V Specification

Rated Voltage	12/24 V
Speed (R.P.M)	600 rpm
Maximum Resistance	0.5NM
Power Rating	400 W
Maximum Power	410 W
Control System	Electromagnetics

From Figure III.9, it can be stated that with low wind speeds (1~4 m/s), the 3rd generator has the highest voltage value. However, when the wind speed is more than 4 m/s, the output voltage value on 1st generator is higher than 3rd generator. While on 2nd generator, the resulted voltage is not greater than 1st and 3rd generator. The data obtained were consistent with the result obtained by Musawir stating that the greater the wind was obtained, the greater the voltage obtained [10].

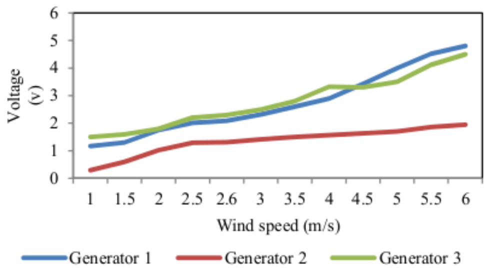

Fig. III.9. Wind Speed vs Voltage for 3 Generators

But, before giving conclusions, it is necessary to know the RPM output values at the same wind speed condition. It can be seen that at the average wind speed in the field, namely, 2,6 m/s, the RPM values of the three generators namely from 1st, 2nd and 3rd generator are 28, 69,1, and 80,1 respectively. An easier comparison of the RPM versus wind speed is shown in Figure III.10.

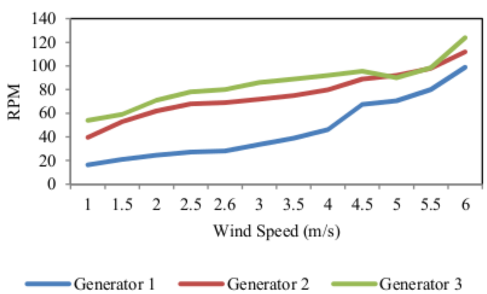

Fig. III.10 Wind Speed vs RPM for 3 Generators

One of the objective of this research was to find a suitable generator that can produce high voltage at low RPM. Figure III.10 shows that the one with lowest RPM is 1st generator, and in Figure III.9, the 1st generator also has a higher voltage.

The result was consistent with mathematical correlations in Eq (1) [11], showing that the wind speed increases with increasing the power output. Then, the correlations between Power to Voltage is linear. So the correlations between wind speed and voltage is linear.

$$P = VI = \frac{1}{2}\rho A v^3 \quad (1)$$

Where :

P = power generated from the savonius wind turbine (watts)
ρ = wind density (1,225 kg/m³)
v = wind speed (m/s)
A = the swept area of the rotor (m²)

The same phenomenon happens between the wind speed and RPM or ω, it shows in Eq (2) [12], when wind speed (v) is moved to the Tip Speed Ratio section, then the correlations between v and ω is linear.

$$\text{TSR } (\lambda) = \frac{\omega R}{v} \quad (2)$$

Where :

λ = Tip Speed Ratio
ω = Rotational Speed (RPM)
v = Wind Speed (m/s)

The recapitulation of generator implementation is shown at Table III.4

Table III.4 Implementation Recapitulation for 3 Generator

Parameter	**G1**	**G2**	**G3**
Voltage Output on Wind Speed 6 m/s	4,8 V	1,95 V	4,5 V
Voltage Output on Wind Speed Average 2.6 m/s	2,09	1,31	2,3
RPM Output on Wind Speed Average 2.6 m/s	28	69,1	80,1
Driven By 31 cm Diameter Fan	YES	NO	NO
Driven By 71 cm Diameter Fan	YES	YES	YES
$V_{desired}$ = 13,7V	182,7 rpm	685 rpm (not possible)	342,5 rpm

From the results of the implementation of the three generators above as shown at Table III.4, it is hereby decided that 1st generator has good performance on this Small Scale Vertical Axis Wind Turbine (VAWT). With the advantage that the shaft can rotate with a fan with a diameter of 31 cm, meaning that it can move at lower wind speeds. Considering that the implementation of this low RPM generator were not added by a voltage multiplier component such as a gearbox or step up transformer, it can be said that 1st generator is good enough to be implemented on this VAWT.

IV. Conclusion

From the research, resulting that the 1st generator produced higher voltage at low RPM than the other 2 generators. When the 1st generator is implemented, it can be turned using 31 diameter fan as a wind blow source. But it must be ensured that the wind touches the tip of the blade, positioning the wind direction also affects the rotational speed of the rotor. It is also known that VAWT needed larger force, wind speed, and pressure to be turned initially, if the wind speed is too low and does not collect at the tip point of the blade turbine, the turbine will not rotate.

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