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Analyzing The Wind Energy Potential Using Vertical Axis Wind Turbine (VAWT)

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Abstract - Wind is a renewable energy that has the potential to be utilized in Indonesia. Wind can be obtained in the Budiarto Curug airport area. This study analyzes the potential of wind energy that can be utilized for Vertical Axis Wind Turbine. Measurements were made using a weather station for 7 days and data was recorded every 30 minutes. Weibull distribution method is used to characterize wind energy potential. The Weibull distribution has 2 parameters, namely the shape parameter and the scale parameter. The result of each parameter is. 3 types of VAWT are suitable to be installed in the Budiarto Curug airport area, namely SRM 300 W, SRM 500 W, and SRM 1000 W. With the specifications of each VAWT, the amount of energy produced is the amount of energy produced by SRM 300 W VAWT, SRM 500 W VAWT, SRM 1000 W VAWT during the observation time (168 hours) were 0.75 kWh, 1.49 kWh, and 1.7 kWh. Meanwhile, the energy produced by each wind turbine for 1 year (8760 hours) is 39 kWh, 77,741 kWh, and 88,847 kWh.

Keywords—Wind, Renewable, Energy, Airport, Indonesia.

I. Introduction

Entering the 21st century, the demand for energy sources continues to increase along with population growth, economic growth and the pattern of energy consumption itself. In line with the increase in energy demand, the supply of primary energy has also increased. This increase in primary energy supply is a problem because fossil fuels such as oil, natural gas and coal will run out.

Petroleum is still often used, especially in the transportation sector, because gas and electricity-fueled transportation have not yet shifted the dominance of fuel oil technology. Energy supply has increased from 2017 by 8.4% and 1,504 million Barrel Equivalent Oil (SBM) in 2018. Despite the increase in energy supply, wind and solar energy have yet to contribute to energy supply.

One of the solutions to overcome the energy supply is the utilization and development of new and renewable energy (EBT). Renewable energy is experiencing the fastest growth in supply at 6.5% to substitute the decline in petroleum. The potential of renewable energy continues to be developed to overcome concerns about rising fossil energy prices. Renewable energy is energy that can be renewed and will not run out of its source. Renewable energy includes water, wind, biomass, solar and biogas.

The data in Figure 1.1 shows that renewable energy sources in Indonesia are very diverse, but have not been optimally utilized. This is due to several factors, such as the geographical gap between the location of energy sources and the location of energy needs as well as the high investment cost of renewable-based technology.

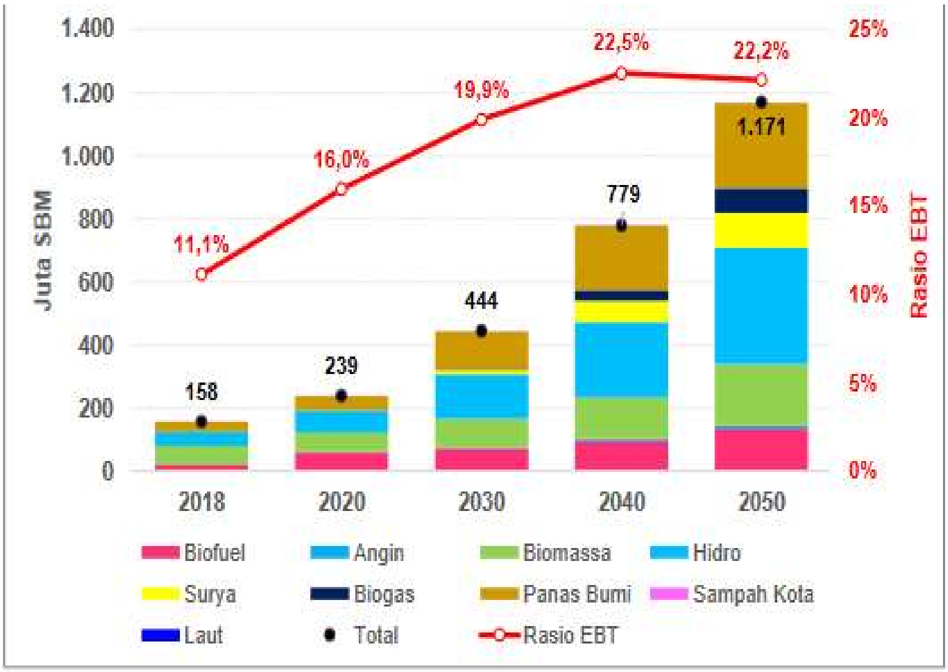

Figure 1.1. Renewable energy potential in Indonesia 2020 [1].

Wind is one of the renewable energies that has the potential to be utilized in Indonesia. Airports are one of the places to utilize wind energy. The open area produces wind with high speed and frequency. The available wind can rotate the Vertical Axis Wind Turbine (VAWT) installed in the airport area. VAWT is one of the types of wind turbines that convert wind kinetic energy into electrical energy.

The VAWT can accept wind from any direction and has a low cut-in speed. Budiarto Airport is an airport located in Curug sub-district, Tangerang district, Banten. The 360 ha airport is located at an altitude of 46 meters above sea level and has 2 runways, 1,602 meters and 1,821 meters long. Budiarto Airport has a large open area, which can be utilized to generate electricity from wind energy.

II. CONCEPTUAL FRAMEWORK AND LITERATURE REVIEW

2.1 Wind

Wind is air that moves due to differences in air pressure and moves from high pressure areas to low pressure areas. The difference in air pressure is due to the different density of air. this is due to the different solar radiation power in each region. This different radiation also causes different air temperatures in each place. Areas that are more exposed to solar radiation will have higher air temperatures than areas that are less exposed to solar radiation. The relationship between air density, air temperature and air pressure is expressed in equation below

$$\rho = \frac{P \, x \, Mr}{R \, x \, T}$$

ρ = density (kg/m^3)

P = air pressure (atm)

Mr = relative mass of air

R = $\frac{Latm.K}{K.mol}$

The available wind has power, which is energy per unit time. Wind power is directly proportional to air density and the third power of wind speed, as stated in equation below

$$P = \frac{1}{2} A\rho v^3$$

The power possessed by the wind is influenced by two variables, namely air density and wind speed. The amount of wind power per unit cross-sectional area of the turbine or commonly referred to as wind power density is determined by equation

$$\frac{P}{A} = \frac{1}{2} \rho v^3$$

In addition, the wind also has a direction. Wind direction is determined by the direction from which the wind comes. Wind direction is expressed in 8 compass directions or by degrees. The grouping of wind directions can be seen in Table 2.1.

Table 1. Wind direction grouping.

Wind Direction	Symbol	Class
North	U	337,6° – 22,5°
Northeast	TL	22,6° – 67,5°
East	T	67,6° – 112,5°
Southeast	TG	112,6° – 157,5°
South	S	157,6° – 202,5°
Southwest	BD	202,6° – 247,5°
West	B	247,6° – 292,5°
Northwest	BL	292,6° – 337,5°

2.2 Weibull Distribution

The Weibull distribution was first introduced by a Swedish physicist named Walodi Weibull in 1939. Weibull distribution is the most accurate distribution to determine the potential of wind energy in a region than other distributions, such as, Gamma, Exponential, Normal, Log-logistic, Lognormal, Pearson V, Pearson VI, Uniform. Weibull distribution is represented through probability density function (PDF) and cummulative density function (CDF). The PDF indicates the probability that the wind speed (v) will occur, while the CDF indicates the probability that the wind speed is equal to or smaller than the reference v value. The Weibull PDF can be expressed in equation below :

$$f(v) = \frac{k}{c} \left(\frac{v}{c}\right)^{k-1} \exp\left(-\left(\frac{v}{c}\right)^k\right)$$

Meanwhile the Weibull CDF is expressed in equation :

$$F(v) = 1 - \exp\left(-\left(\frac{v}{c}\right)\right)^k$$

Where k is the shape parameter (dimensionless), c is the scale parameter (m/s), and v is the wind speed (m/s). The value of parameter k is obtained with a value based on actual wind speed data in the field. To determine the value of the shape parameter k, equation is used,

$$k = \left(\frac{\sigma}{v} \right)^{-1,086}$$

while equation is used to obtain the scale parameter c.

$$c = \frac{v}{\Gamma(1+\frac{1}{k})}$$

To find the value of wind speed (and standard deviation), we can use equations

$$v = \left(\frac{\sum_{i=1}^{n} fi\, Vi^3}{\sum_{i=1}^{n} fi} \right)^{\frac{1}{3}}$$

$$\sigma v = \sqrt{\frac{\sum_{i=1}^{n} fi\,(Vi-Vm)^2}{\sum_{i=1}^{n} fi}} \sigma v = \sqrt{\frac{\sum_{i=1}^{n} fi\,(Vi-Vm)^2}{\sum_{i=1}^{n} fi}}$$

2.3 Wind Turbine

A wind turbine is a machine that converts wind kinetic energy into other forms of energy, such as mechanical energy and electrical energy. Mechanical energy converted into electrical energy is called a wind turbine or Wind Energy Conversion System (SKEA). The main principle of wind turbine work is to change the kinetic energy of the wind that will rotate the turbine, then forwarded by rotating the rotor on the generator, thus producing electricity. VAWT has a rotation axis perpendicular to the ground surface, so VAWT can receive wind from any direction. VAWTs can self-start at low speeds and have lower installation costs and easier construction than Horizontal Axis Wind Turbines (HAWTs). To calculate the energy produced by a wind turbine over a period of time (T) can use equation

$$E = P \ x \ T$$

E = Wind Turbine Energy (Wh)

P = Wind Turbine Power (W)

T = Time Period (h)

III. METHODOLOGY

The method used in this research is a descriptive method with a quantitative approach. The data in this research is taken using a measuring instrument that will produce data on wind speed, wind direction, and air temperature. The data will be the basis for explaining how much wind energy potential is available, for the selection of VAWT and the resulting energy production. The variables involved in this research are :

1. Wind

   Wind is air that moves due to differences in air pressure. Air moves from an area of high pressure to an area of low pressure. Air pressure differences are caused by different air densities.

2. Wind Power

   Power is energy per unit time. Wind power is directly proportional to air density and the third power of wind speed.

3. Weibull Distribution

   The Weibull distribution is represented through the probability density function (PDF) and cumulative density function (CDF). The PDF indicates the probability that the wind speed (v) will occur, while the CDF indicates the probability that the wind speed is equal to or greater than the reference wind speed (v).

4. Vertical Axis Wind Turbine (VAWT)

VAWTs have a rotation axis perpendicular to the ground, so they can receive wind in all directions. VAWTs can self-start at low speeds, cost less to install and are easier to construct than Horizontal Axis Wind Turbines (HAWTs).

5. Wind Turbine Energy

The power generated by a wind turbine over a certain period of time multiplied by the Capacity Factor.

The tool used is a weather station. The weather station measures wind speed, wind direction, and temperature. Data is taken every 30 minutes for 7 days and stored in the data storage memory. The weather station in this study was placed on top of the Flight Operation (Flop) building of Budiarto Airport, with a height of 5 meters.

The purposive sampling technique in this study is based on certain characteristics, namely the data measured are wind speed, wind direction, temperature, and data taken every 30 minutes for 7 days and the presence of a measurement tool at a height of 5 meters.

Data processing techniques in this study are divided into 3, namely data analysis of wind speed, wind direction, and air temperature, namely :

1. Wind speed data analysis

Wind speed data processing uses the Weibull distribution method. The scale parameter and shape parameter of the Weibull distribution are calculated using empirical methods. In the Weibull distribution, wind speed variations are characterized by PDF and CDF curves. PDF and CDF curves were created using Minitab software.

2. Wind direction data analysis

In addition to speed, wind also has different directions. Wind direction with a certain speed can be represented through the Wind Rose diagram. Processing wind direction data using WRPLOT View software.

3. Air temperature data analysis

Air temperature data is used to calculate the air density at the measurement location.

The research is conducted upon these steps:

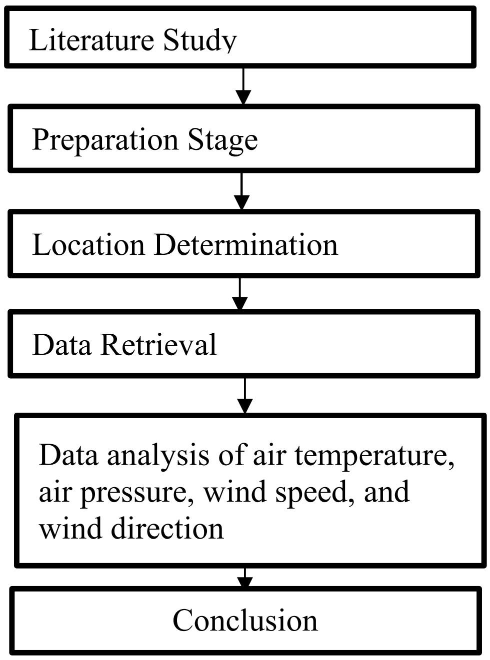

Figure 3.1. Research flowchart.

IV. RESULT

The measurement location is carried out on the roof of the Flop building of the Indonesian Aviation Polytechnic Curug Aviation study program using the Weather Station measuring instrument. Figure 4.1 is a measurement tool installed at the measurement location taken using a cellphone camera.

Figure 4.1. Weather station at the measurement location.

Wind speed, wind direction, and temperature measurements were taken on November 25, 2021-December 1, 2021. Data collection was carried out every 30 minutes. The data is stored in the weather station storage memory, which is then recorded manually by the researcher. Every day, the wind speed at the measurement location has a different maximum value and minimum value. The following is the wind speed data in the Budiarto Airport area on November 28, 2021 and November 30, 2021 at the observation time shown in Figure 4.2 and Figure 4.3. On November 28, 2021 the wind speed had a maximum value of 11.1 m/s, while on November 30, 2021 it had a maximum wind speed of 3.9 m/s.

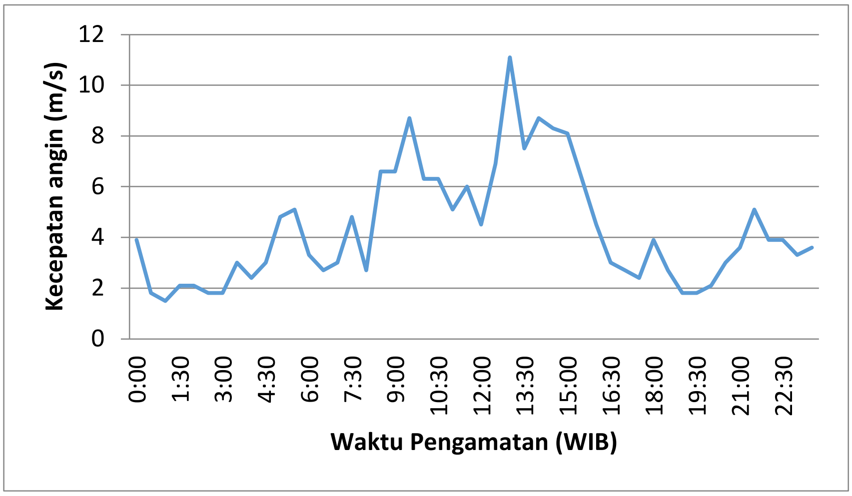

Figure 4.2. Graph of November 28, 2022 wind speed against observation time.

Figure 4.2 shows that on November 28, 2021, the maximum wind speed was at 13:00 WIB with a speed of 11.1 m/s, the minimum wind speed occurred at 01:00 WIB with a wind speed of 1.5 m/s. Meanwhile, Figure 4.3. shows that on November 30, 2021, the maximum wind speed is at 01:00 WIB with a speed of 3.9 m/s and the minimum wind speed occurs at 04:30 WIB with a speed of 0.3 m/s.

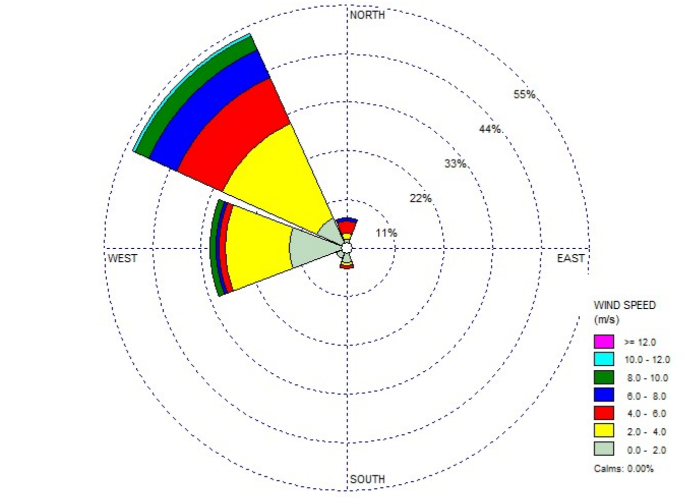

Figure 4.3. Wind speed graph of November 28, 2022 against observation time.

The amount of wind power density is influenced by air density and air speed. Air density is affected by air temperature and air pressure. Air density will get smaller as air temperature increases. The average air density during the observation time was 1.14 kg/m3. This value will be used to calculate wind power density.

The wind direction at the study site blows from various directions. The wind direction measured by the weather station is divided into 8 wind classes, namely north, northeast, east, southeast, south, southwest, west, and northwest. The distribution of the wind direction can be represented in the wind rose shown in Figure 4.5.

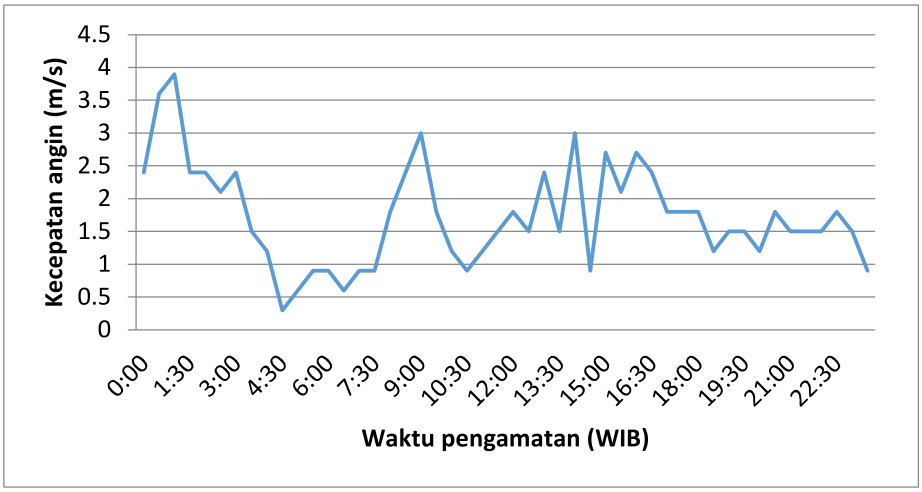

Figure 4.5. Wind rose

The wind rose classification in Figure 4.5. is divided into 7 wind classes, namely winds with speeds of 0-2 m/s, 2-4 m/s, 4-6 m/s, 6-8 m/s, 8-10 m/s, 10-12 m/s, and above 12 m/s. The wind speed is represented by each color, namely 0-2 m/s in gray, 2-4 m/s in yellow, 4-6 m/s in red, 6-8 m/s in blue, 8-10 m/s in dark green, 10-12 m/s in tosca green, and above 12 m/s in pink. The wind with the highest frequency comes from the northwest with a percentage of almost 55% of the total data. Meanwhile, the smallest frequency of wind comes from the east and northeast, which is about 0.7% of the total data. Then the wind speed that has the largest frequency is yellow, namely the speed of 2-4 m/s, while the frequency with the smallest speed is above 12 m/s.

The distribution used to model wind speed data is the Weibull distribution. The Weibull distribution uses 2 parameters, namely the shape parameter (k) and the scale parameter (c). To find the value and use equations (2.8) and (2.9). By using equations (2.8) and (2.9), the values = 3.37 m/s and 2.17 are obtained. Meanwhile, to find the value of k and c using equations (2.6) and (2.7). By using equations (2.6) and (2.7), the values of k = 1.965 and c = 3.103 are obtained. The Weibull distribution can be represented using PDF and CDF curves. PDF and CDF curves are created using minitab software. The PDF and CDF curves are shown in Figure 4.6 and Figure 4.7.

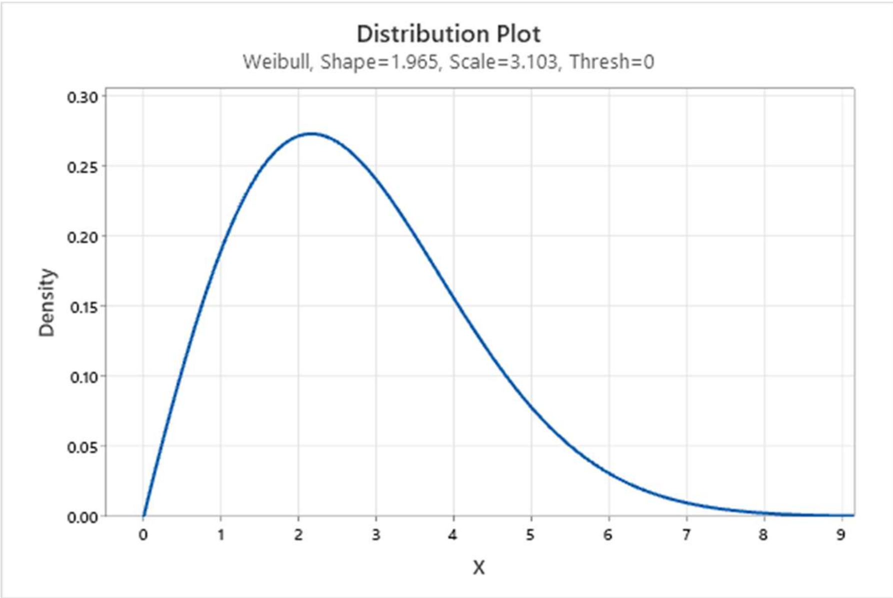

Figure 4.6. PDF curve

Figure 4.6 is the PDF curve. The PDF curve has a peak, which represents the most frequent wind speed in the Budiarto Airport area. The most frequent wind speed is 2.3 m/s with a frequency presentation of 27% of the total data. The total wind speed data during the observation time was 289. In addition, the pdf curve can represent that the higher the wind speed, the lower the frequency of the wind speed.

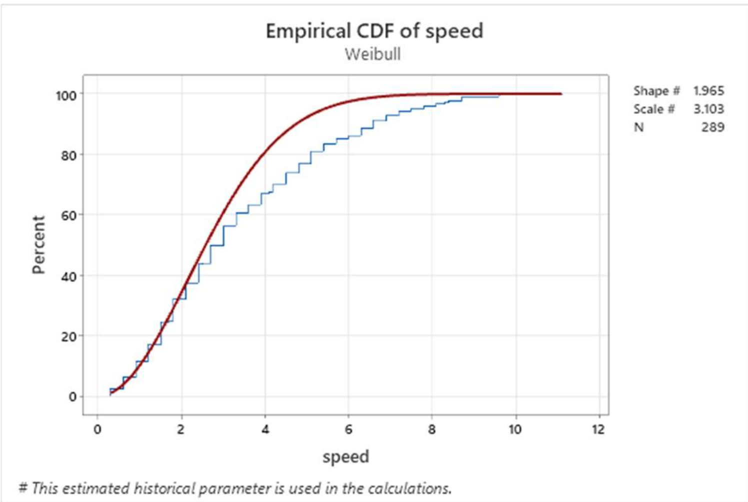

Figure 4.7. CDF curve

Figure 4.7 is the CDF curve. The CDF curve shows that the wind speed is equal to or greater than the wind speed which is the reference wind speed in the study. The reference wind speed in this study is 1.8 m/s. It can be said that the wind speed is equal to or greater which has a frequency of about 25% or has a total of about 217 data.

The statistical distribution of wind speed data is not only used to determine the potential of wind energy, but also affects the performance of wind turbines. The criteria for wind turbines suitable for application in the Budiarto Curug Airport area is to have a low cut-in. The three types of wind turbines selected are SRM 300 W Vertical Axis Wind Turbine, SRM 500 W Vertical Axis Wind Turbine, Aeolos 300 W Vertical Axis Wind Turbine.

The SRM 300 W is a type of vertical axis wind turbine made by the SRM Wind Power company. The SRM 300 W has the specifications shown in Table 4.1.

Table 2 Spesification SRM 300 W.

Cut-in speed	1.8 m/s
Rated speed	8 m/s
Rated power	300 W
Daya maksimum	350 W
Diameter rotor	1 m
Swept Area	0,6 m^2
Blade Number	5 pcs

The SRM 300 W is the smallest capacity vertical wind turbine owned by the SRM W company. Meanwhile, the power curve of the SRM 300 W can be seen below.

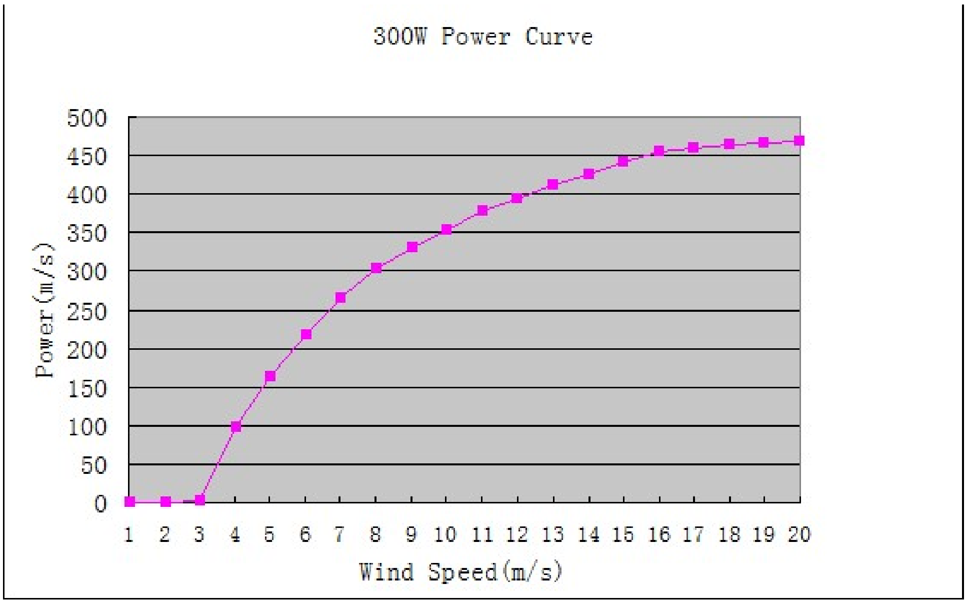

Figure 4.8. Power curve of 300 W SRM.

SRM 500 W Vertical Axis Wind Turbine

The SRM 500 W is a vertical wind turbine manufactured by the same company as the SRM 300 W. This wind turbine has specifications as shown in Table 4.2.

Table 3 Specification SRM 500 W.

Cut-in speed	1.8 m/s
Rated speed	8 m/s
Rated power	500 W
Daya maksimum	600 W
Diameter rotor	1,4 m
Swept Area	1,5 m^2
Blade Number	5 pcs

SRM 500 W is a vertical wind turbine with a capacity one level above SRM 300 W. The power curve of SRM 300 W can be seen in Figure 4.9.

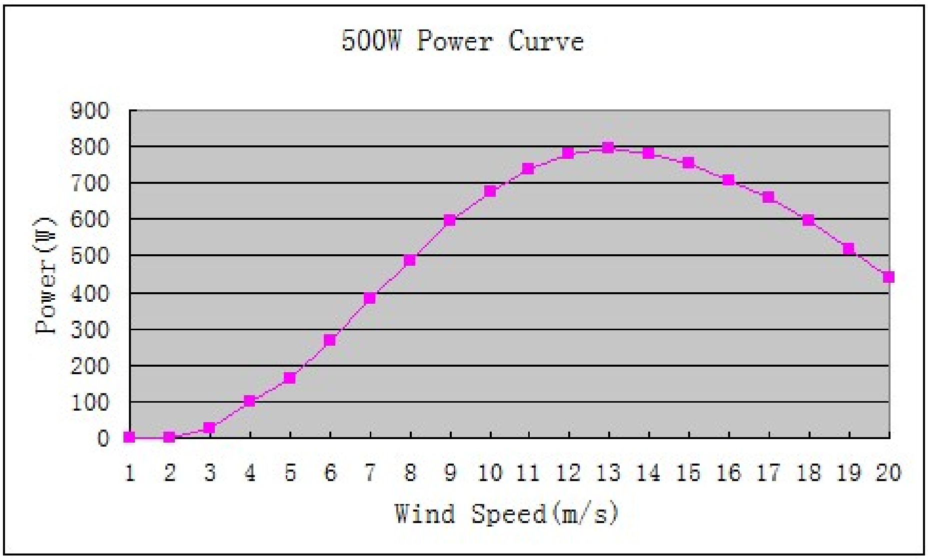

Figure 4.9. Power curve of 500W SRM.

SRM 1000 W Vertical Axis Wind Turbine

The SRM 1000 W is the third type of wind turbine manufactured by SRM Wind Power and has the specifications listed in Table 4.3 and the power curve shown in Figure 4.10.

Table 4. Spesification SRM 1000 W

Cut-in speed	1.8 m/s
Rated speed	10 m/s
Rated power	1000 W
Daya maksimum	1200 W
Diameter rotor	1,5 m
Swept Area	1,5 m^2
Blade Number	5 buah

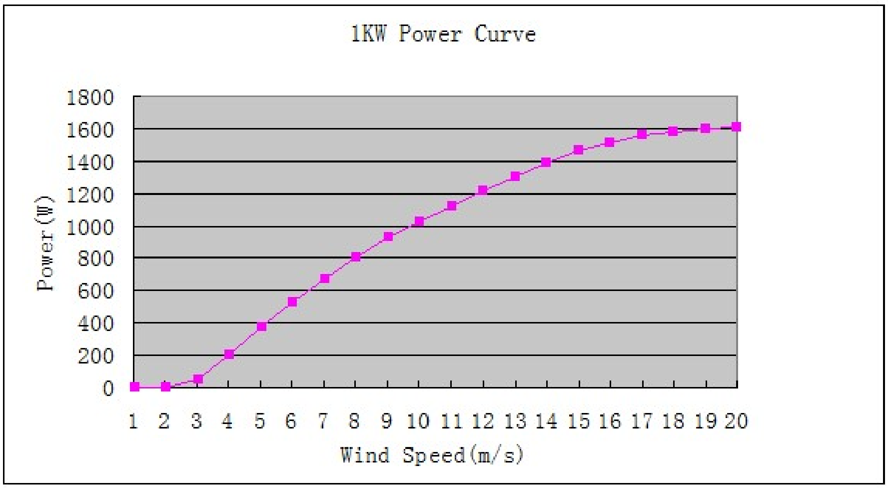

Figure 4.10. 1000W SRM power curve

The power generated by each wind turbine uses equation (2.10). Meanwhile, to calculate the energy produced by wind turbines, equation (3.11) is used. The energy that can be generated by each wind turbine SRM 300 W, SRM 500 W, SRM 1000 W is the multiplication of power multiplied by the observation time period of 168 hours. The energy produced by SRM 300 W, SRM 500 W, and SRM 1000 W is 0.75 kWh, 1.49 kWh, and 1.7 kWh, respectively. While the energy generated by each wind turbine for 1 year (8760 hours) is 39 kWh, 77.741 kWh, and 88847 kWh.

V. Conclusion

Research on the analysis of wind energy potential for VAWT utilization in the Budiarto Curug airport area provides the following conclusions:

1. The wind speed in the Budiarto Curug Airport area ranges from 0.3 m/s to 11.1 m/s with an average wind speed of 3.37 m/s. The Weibull distribution method has a scale parameter of 1.965 and a shape parameter of 3.103. These values can characterize the wind potential in the Budiarto Curug airport area.
2. There are 3 VAWT options suitable for installation in the Budiarto Curug Airport area based on wind potential with low cut-in speed, namely SRM 300 W VAWT, SRM 500 W VAWT, SRM 1000W VAWT.
3. The amount of energy generated by SRM 300 W VAWT, SRM 500 W VAWT, SRM 1000 W VAWT during the observation time (168 hours) is 0.75 kWh, 1.49 kWh, and 1.7 kWh. Meanwhile, the energy generated by each wind turbine for 1 year (8760 hours) is 39 kWh, 77,741 kWh, and 88,847 kWh.

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