Improving the Performance of a Small-Scale Wind Turbine System

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Abstract: This research aims to improve the performance of a small-scale wind turbine system. It is done by varying the inertia energy through designing different wights of hubs and blades. One is heavy blades with light hub and the other is a light blade with the heavy hub. The assumption is that the starting point of the blade to run will be at the lower wind speed due to the smaller torsion moment. However, when the blades have run, the turbine gets the power from the centrifugal post stored in the hub. The research result shows that both sets of blades and hubs produce relatively the same power, that is 12 watts. The difference is on the speed of the wind to run the turbine. The one with the lighter blade and heavier hub start running at 3 m/s and the other is that of 4m/s. The conclusion is that the use of the lighter blade and heavier hub is effective to improve the performance of a small-scale turbine system.

1 INTRODUCTION

Indonesia is an archipelago country with 2/3 of its territory is the ocean and has the longest coastline in the world (± 81,000 km), located on the equator line, and has more than 17,000 islands. Under these circumstances, wind energy is a potential that must be developed and utilized. Based on LAPAN data (Daryanto, et al., 2005), wind in Indonesia has varying speeds but generally is categorized as low-speed winds.

The utilization of wind energy sources as a power plant is one of the efforts to meet the needs of electric energy, which is increasing in the number of needs for households, industries, and commercials. Wind power generation can be developed as alternative energy, which is renewable and environmentally friendly. To develop this potential, we need a tool to convert the kinetic energy of the wind into electrical energy in the form of a windmill that works to rotate an electric generator. This research study the performance test of windmill propeller with blade material from wood composite with flax fiber reinforcement. The windmill model used in this study is a propeller type windmill with a comparison of the number of blade 5 which is made of wood as core material (a type of balsa wood) with hemp fiber and the polymer matrix. Data retrieval on the windmill is done in two ways, first from the generator, and the second is mechanical power by measuring the torque and speed of the spinning shaft rotation (rpm)
Wind speeds in Indonesia are not as big as in countries like the Netherlands that have used windmill energy. The wind speed around the southern coast of Yogyakarta ranges from 3-5 meters per second. So it needs to be combined with low-speed generators and solar thermal energy. Alternative energy is acknowledged to be still difficult to replace conventional energy, but at least renewable energy can be a supporting energy, especially for areas that have not been electrified.

Research by Wakui, et al. (2002) compared three types of windmills, namely Savonius-Darius, Darius, and horizontal shaft two winder types of propellers. The results showed that the combination of Savonius Darius had the advantage of being able to start independently compared to Darius even though there was a decrease in the quantity of output power. The propeller horizontal windmills have a large power output, with a note they must have a good Yaw mechanism to respond to wind direction

Research to determine the speeds characteristic range of the wind machines and to make easy the choice of the suitable wind turbine for a given site, in order to maximize the delivered energy for a given amount of available wind energy has done by Bencherif et. al (2014).

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The results of Setiawan's research (2016) show that the change in pitch angle of the two H-type Darrieus wind turbine blades affects the power produced by wind turbines in real wind conditions. The greater the pitch angle, the lower the power produced. Changes in pitch angle also affect the efficiency of wind turbines in real wind conditions. The more pitch angle increases the greater the efficiency. Purwono's research (2016) states that there is a significant difference in the average power produced by NACA 3412 Vertical Axis Windmill (KASV) at 5% real level and there is a tendency that the increased wind speed and number of blades used will increase the power produced by KASV.

The airfoil used for the turbine blade base profile is the airfoil through which low-velocity winds (maximum 10 m/s) flow, so the lift ratio parameter to the maximum drag force becomes the focus of developing airfoil characteristics for wind turbines with a wind speed range of 0-10 m / s (Timmer and Rooij, 2003). Timmer and Rooij (2003) also stated that in the early 1980s to 1990, profiles that were widely used as the basic form of wind turbine blades were airfoils developed by NASA which were given 4-digit NACA codes (NACA 44xx series) and 5-digit NACA (NACA 63xxx series). Parezanovic, et. al (2005) state that the most important aspect of wind turbines is their aerodynamic effectiveness, the base of which is the design of the airfoils forming the blades. It is possible to predict airfoil performance by using commercial CFD programs, and furthermore, to design new airfoils with better performance, based on those predictions.

At present, windmill propellers, which were previously made from metal materials, have begun to be made from GFRP (glass fiber reinforced plastic) skin composite materials. From previous studies, it is known that the Sengon Laut Wood (Albizia falcata) has a high tensile stress and buckling stress. Meanwhile, hemp has a high tensile stress and impact strength as well. The sandwich composite structure has the ability to withstand a greater load than that of the lamina composite (Sudarsono, 2013). The description above shows that the windmill propeller engineering from the GFRP skin composite needs to be developed into a composite structure in order to be able to withstand external loads (collisions) and have a lightweight to easily rotate when blown in the wind. In this study, a composite sandwich with balsa wood and hemp fiber will be developed as a reinforcement for propeller-making raw materials. Testing will also be done to determine the effect of the position /location of the center of gravity (C.G) of blade and hub on the performance of the windmill. The variable of the center of gravity of the windmill is obtained by making the windmill hub and blade different in weights. The first hub was made of Aluminum material whereas the second one used AISI 1030 steel material. While the windmill blade was made from composite using glass fiber while the other was made from composite using balsa wood core and hemp natural fiber, this way the different weight of the hub and blade were obtained.

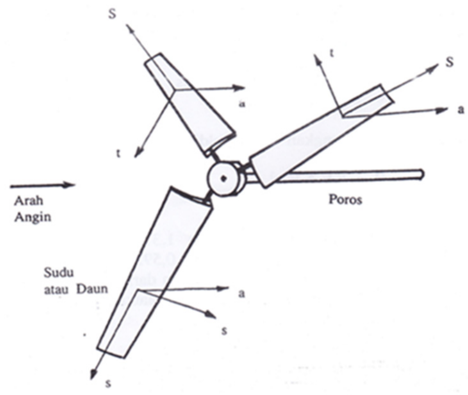
2 METHOD

This research was conducted to determine the effect of the position/location of the center of gravity / C.G blade and hub on the performance of the windmill. This was done by observing the power generated by the windmill and the wind speed needed for the initial round of the windmill. The variable location of the center of the windmill is obtained by making the windmill hub and blade have different weights. The first hub was made of Aluminum, while the second used AISI 1030 steel material. The first windmill blade was made from composite using glass fiber and the second was made from composite using balsa wood core and hemp natural fiber, this way the different weight of the hub and blade were obtained.

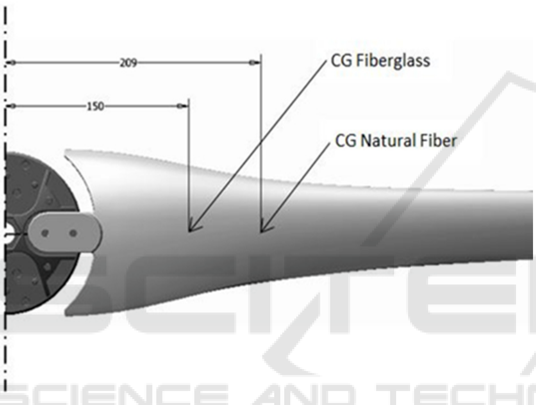
Forces that work on C.G. windmill blades due to wind flow theoretically consist of tangential force t, axial force a and centrifugal force S. The different position of C.G. will result in the different T torque produced by the windmill. This is because the distance of the tangential force t to the axle weight point is different so that a different P Power is produced assuming the windmill shaft rotation is the same. A different T torque will also affect the initial rotation of the windmill in which theoretically for the same wind speeds the torque of C.G. which is farther from the center of the shaft axis will be bigger so that at the farther the CG, the windmill will rotate at a lower wind speed.

The kinetic energy of K rotation is a function of the mass of a rotating object and angular velocity, by making a mass variable from the hub and blade, the rotational kinetic energy produced by the windmill also changes. In this research, a hub made of steel with a weight of 550 g and aluminum with a weight of 320 g was made. The windmill blade is made of fiberglass composite which has a weight of 300 gr and a composite with balsa wood core and hemp fiber that weighs 280 gr. Both are made according to the NACA 4415 standard. The distance between the C.G. and the center of the axis for the blade made of fiberglass is

150 mm while the blade made of natural fiber with a balsa wood core is 209 mm.



(a)



(b)

Figure 1: (a) Forces that work on C.G. and (b) location of C.G on a windmill blade.

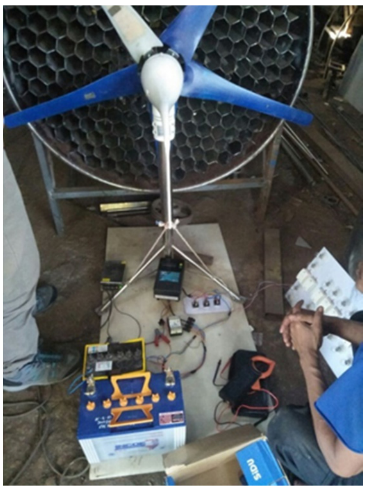


Figure 2: Measurement of electrical power and mechanical power.

In order to find out the power generated by the windmill, electrical power is tested by using an AC generator and mechanical power testing using torque meters. While wind energy is obtained from a simple wind tunnel that is specifically designed (figure 2).

3 RESULTS AND DISCUSSION

The data to determine the performance of the windmill in this research were obtained using two different methods, first, by finding the relationship between wind speed and electrical power produced by windmill generators, while the second is finding the relationship between wind speed and mechanical power produced by the windmill using a torque tester. This is done to determine the possibility of a generator performance that is not optimum. The test results are presented in the following discussion.

3.1 Electrical Power Testing

Figure 3 (a) shows that blades made of natural fibers with lighter weight at 3 m / s wind speed can produce a voltage of 22 V. While heavier blades are only able to produce a voltage of 7 V even though the wind power produced is equal. This is consistent with the following [Yeni Yusuf Tonglolangi, 2014]:

$W = \frac{1}{2} \rho A V^3$ watt ……………………..(1)

Where : W = Wind Energy watt , ρ = Air density (kg / m^3), A = Wind catching area (m^2) and V = Wind Speed (m / s).

This shows that the lighter blade has a better initial rotation because of the tangential force generated by the wind at the beginning of the rotation of the windmill against the smaller blade weight with smaller kinetic energy. This is in accordance with the following equation.

$K = \frac{1}{2} I\, \omega^2 \;\; J$ ……………………………..(2)

$I = \frac{1}{2} m\, R^2 \;\; Kg\, m^2$ ……………………...(3)

Where V is the wind speed m / s, while m is the period of rotating objects in kg. At larger wind speeds with the same air density will produce greater power as the following wind power equation: $P = 0.5\, \rho\, A\, V^3$ watt ……………………...(4)

Where P is wind power (watts), ρ is wind density (Kg / m^3), A is the section of the wind channel (m^2) and V is the wind speed (m / s). With wind density in Yogyakarta [Kifli, 2016] of 1.17 kg / m^3, wind power of W is 157.5 watt, so the power produced as in Figure 3 (c) has very low efficiency, both for the blade made of glass fiber and natural fiber both have

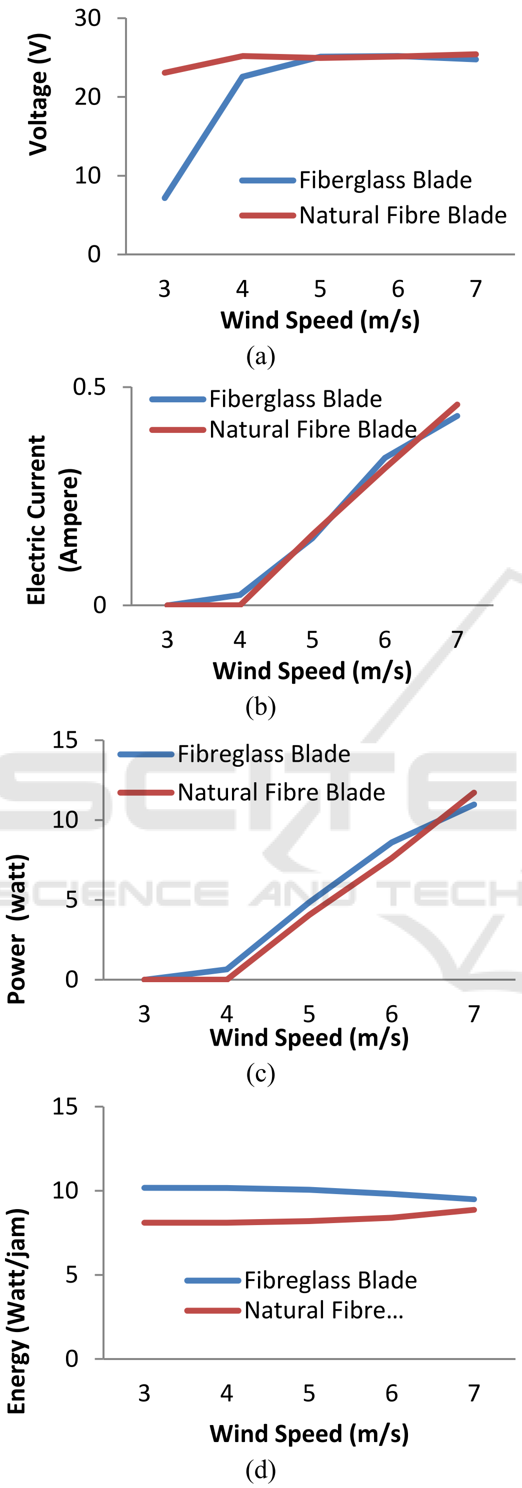


Figure 3: The results of the windmill electrical power test versus (a) Voltage (b) Electric Current (c) Power output (d) Energy.

almost the same performance. The total efficiency of a wind turbine can be calculated using the equation: γ = P / W x 100%; so that for wind speeds of 7 m / s turbine efficiency γ is 8%.

3.2 Mechanical Power

Mechanization factors. In order to know the parts that cause the low efficiency of wind turbines, whether turbine generators or mechanical factors of windmills, mechanical efficiency is calculated by comparing the wind power and the shaft mechanical power produced by the windmill. The mechanical power of the Pm shaft is calculated based on the equation:

$$P = \frac{T\,2\,\pi\,N}{60} \quad \text{watt} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(5)$$

where :
T = Torque N-m
n = Shaft Rotate rpm

Mechanical power on the shaft generated by windmills with blades made of glass fiber and that of made of natural fibers is relatively the same. At a wind speed of 6 m / s glass fiber blade has a power (P) of 40 watt, while the blade of natural fiber has a power of 52 watt. While at wind speeds of 7 m / s fiberglass fiber blades produce 80 watts of power, and natural fiber blades produce 65 watt of power. Wind power at wind speeds of 6 m / s and 7 m / s are 85 watt and 157 watt respectively, so the average mechanical efficiency of windmills is 50.1%, much higher than the efficiency of wind turbines using electric generator windmill. Figure 4 shows the results of mechanical tests of power and wind speed relations.

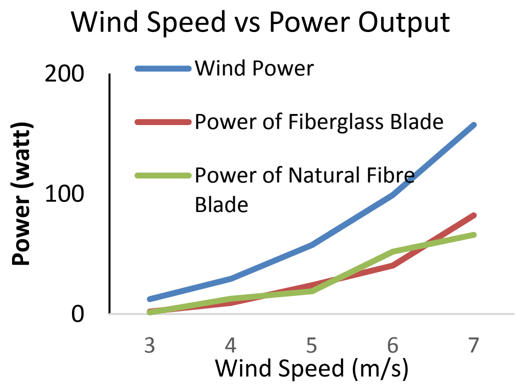
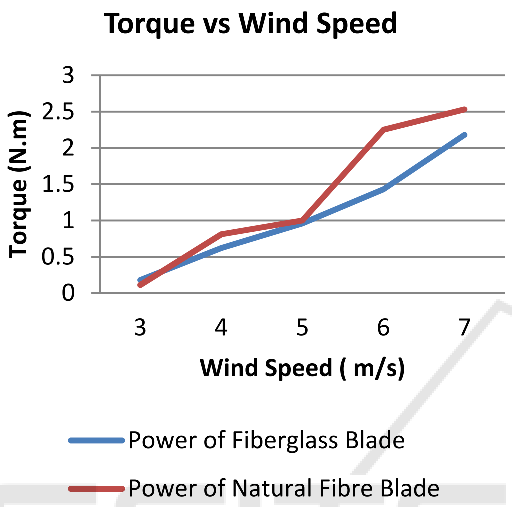


Figure 4: Results of mechanical tests of power and wind speed relations.

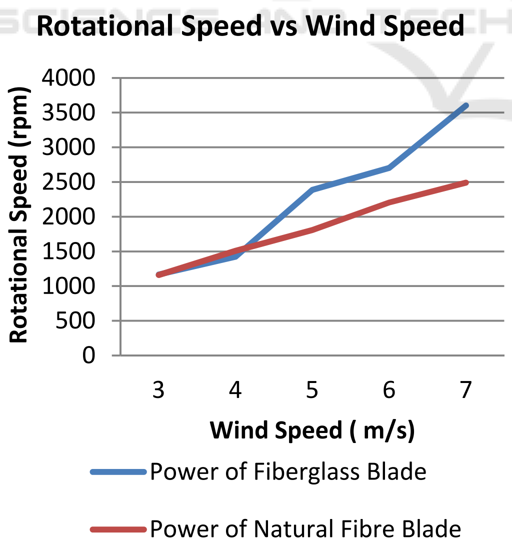
3.3 Torque and Windmill Rotation

The rotational kinetic energy of an object that rotates depends on the angular velocity ω radians / second and the magnitude of the moment of inertia I Kg. m^2 of the object. Rotational kinetic energy can be calculated using the equation:

$$K = \frac{1}{2} \mathrm{I}\, \omega^2 \; J \qquad \text{.................................(6)}$$



(a)



(b)

Figure 5: Results of mechanical tests of rotational speed, torque, and wind speed relations.

Figure 5 (a) and (b) shows that the rotational speed of the glass fiber blade can achieve greater rotation at the same wind speed when compared to blade from natural fiber, this occurs because the blade of glass fiber has a higher weight so that the rotational kinetic energy is greater and more stable at higher speed and wind speed. On the other hand, the torque produced is higher in the blade with natural fiber than the blade using glass fiber.

4 CONCLUSIONS

The test results show that at a wind speed of 3 m / s the blade made of natural fiber produces a voltage of 22 V while the blade of glass fiber produces a voltage of 7 V. This indicates that the lighter blade has a better initial rotation, due to the tangential force the wind was generated at the beginning of the rotation of windmills against the smaller blade weight with less kinetic energy.
The speed of the glass fiber blade can achieve greater rotation at the same wind speed when compared to the blade of natural fiber, at the same wind speed of 7 m / s, RPM of the fiberglass blade is 3.600 rpm. While natural fiber blade is 2.500 rpm. This happens because the blade of glass fiber is heavier so that the rotational kinetic energy is larger and more stable at higher speeds and wind speeds. On the other hand, the torque produced is higher in the blade with natural fiber than that of the blade using glass fiber. From the results of the analysis, a conclusion can be drawn that the blades made of natural fiber have a better performance than the blades made of glass fiber.

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