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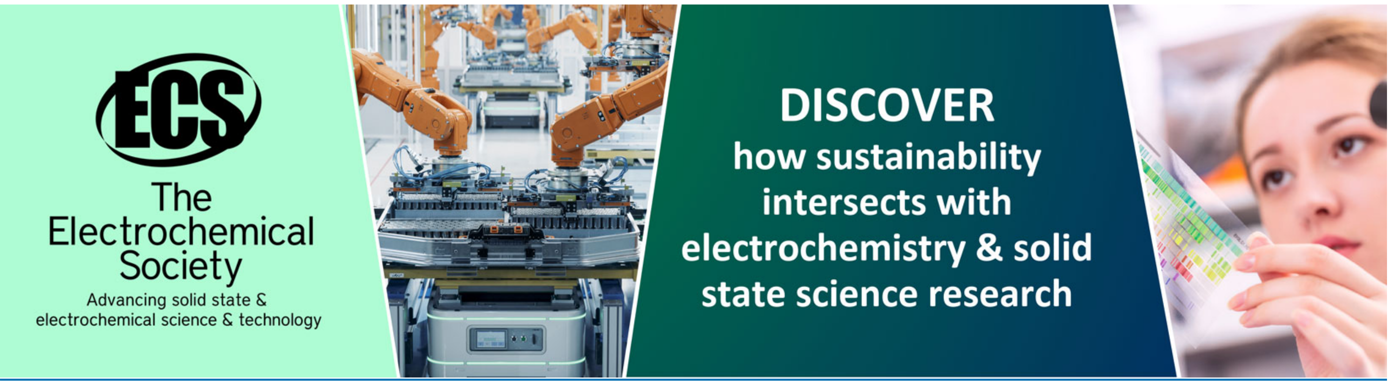

Shrouded wind turbine for low wind speed

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Abstract. The problem of electrification in Indonesia for remote areas is difficult to access and far away from the grid of PLN, so an alternative is needed to overcome this problem. One alternative to this problem is to build off-grid power plants by utilizing natural potential in an area such as wind energy, but not all regions have sufficient wind speed to use wind turbines, so the wind turbine must operate at low wind speeds with good efficiency. Shrouded can be used to increase the efficiency of conventional wind turbines, even at low wind speeds. In this study, the shrouded wind turbine can increase power output by up to 92.71%, with an average of 62.91% compared to conventional wind turbines under wind speed conditions of 2 m s^{-1} - 6 m s^{-1}.

Keywords: power; shrouded; wind speed; wind turbine.

1. Introduction

Electrical energy is the main focus in Indonesia, which will increase every year. Based on data from the Ministry of Energy and Mineral Resources (ESDM), in 2020 there are still 433 regions that have not yet been electrified [1]. One of the constraints in Indonesia is difficult access and far away from grid of PLN, so an alternative is needed to overcome this problem. The alternative is by building off-grid power plants by utilizing the natural potential in an area both macro and micro scale. Some of the off-grid model that are commonly used such as PV and wind turbine, even a hybrid of both. One example of the application of micro-scale wind turbines in Indonesia is in Sumba, Nusa Tenggara Timur which has 100 micro-scale wind turbines which can produce up to 500 Watt per unit with the name The Sky Dancer.

Indonesia has many potentials for renewable energy resources, especially wind energy. Indonesia has 60.6 GW wind energy potential with 4 m s^{-1} wind speed and above [2], where the capacity has been installed is 154.3 MW on 2019 [3]. The kind of wind turbine type that has high efficiency is a horizontal axis wind turbine (HAWT) that is commonly used as a power plant both macro and micro scale. Micro-scale wind turbines have some advantages where there is easier installation and the cost to manufacture is also relatively cheaper which can also be designed according to the potential wind speed in certain areas. However, this type of wind turbine has a disadvantage where its efficiency will drop when operated at low wind speed because it has a relatively high cut-in speed then to vertical axis wind turbines (VAWT) that commonly applied to low wind speed condition. Based on the Beauford scale, wind with a speed of 4 m s^{-1} is categorized as low wind speed [4].

One example of the development of HAWT is the addition of shrouded which known as diffuser-augmented wind turbine (DAWT) that can focus and increase mass flow in the rotor [5]-[17]. The power generated from this wind turbine type can reach 4-5 times than the conventional HAWT [5]. Many factors can affect the shrouded performance, including the length of the shrouded and the geometric shape of the inlet and outlet. In general, the use of shrouded in the form of a diffuser has better results than the shape of the nozzle, so that the combination is done by using the nozzle shape at the inlet and the form of the diffuser at the outlet. Shrouded design also developed in the form of geometry by adding flange or brim to the outlet with the aim of producing vortex behind the turbine that has a low pressure, so that the flow velocity of any time increases, this phenomenon is also known as the wind-lens effect [5]. The use of shrouded can be a solution to improve the performance of horizontal wind turbine, especially in the application of micro scale with low to medium wind speed, which can overcome for some places that are still difficult in the distribution of electricity, especially areas that are still difficult to get access by grid of PLN.

2. Research methodology

The methodology of this research used experimental research. This experiment involves designing dan experimental measurements. The designing process involves rotor and shrouded which adjusted to the conventional wind turbine's specification and geometry. The conventional wind turbine that used, can generate electric power up to 500 Watt. The experiment was carried out at PT Lentera Bumi Nusantara.

2.1 Rotor design

The rotor is a component that captures the power from the wind and converts it to kinetic mechanical power. The rotor on a wind turbine is mainly made up of a hub and blades, with the latter attached to the hub by mechanical [18]. The rotor design is needed to adjust how much power want to generate from wind energy. The wind turbine used on the experiment have rotor diameter of 1.6 m with 3 blades. The blade type that used is a taperless blade that has a lower cut-in speed than the taper blade, because at low wind speeds condition, there is not enough torque applied by the wind to generate electricity. Cut-in speed is the minimum wind speed at which electricity can be generated, the speed at which the rotor of the wind turbine begins turning [18]. The specifications of the rotor and blade are shown in **Table 1**.

Table 1. Rotor and blade specification

Specification	Unit
Rotor Diameter	1.6 m
Hub Diameter	0.34 m
Blade Number	3
Blade Type	Taperless
Airfoil	NACA 4412
Chord	120 mm
Twist Angle	7.5° – 10.1°
Material	Mahogany wood

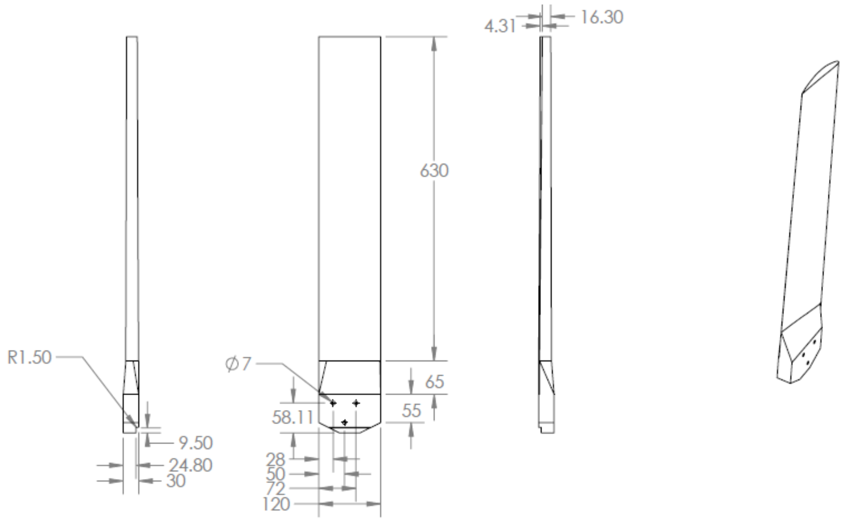


Figure 1. Design of blade

2.2 Shrouded design

Shrouded is the component which focusing the mass flow of wind which can increase wind power to generate [5-17]. Shrouded designed is using the Compact Brimmed Diffuser [5] which is modified according to the geometry of the conventional wind turbine that used on the experiment. The dimension specification of shrouded is shown in **Table 2** and **Figure 2**.

Table 2. Shrouded specification

Specification	Unit
Throat Diameter (D)	1632 mm
Inlet Diameter (D_{in})	1639 mm
Outlet Diameter (D_{out})	1750.44 mm
Brim Diameter (D_{brim})	2076.84 mm
Shrouded Length (L_t)	204 mm (0.125*D*)
Nozzle Length (L_{in})	81 mm
Diffuser Length (L)	123 mm
Flange Hight (h)	163.2 mm (0,1*D*)
Nozzle angle	2.5°
Diffuser angle	25.7°
Brim angle	90°
Tip Clearance (s)	16 mm
Material	Fiber glass

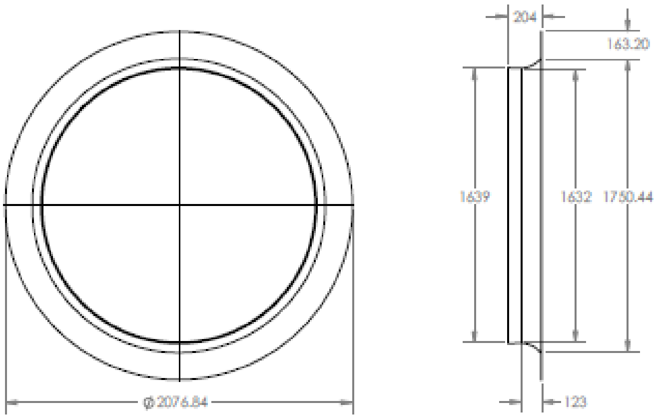
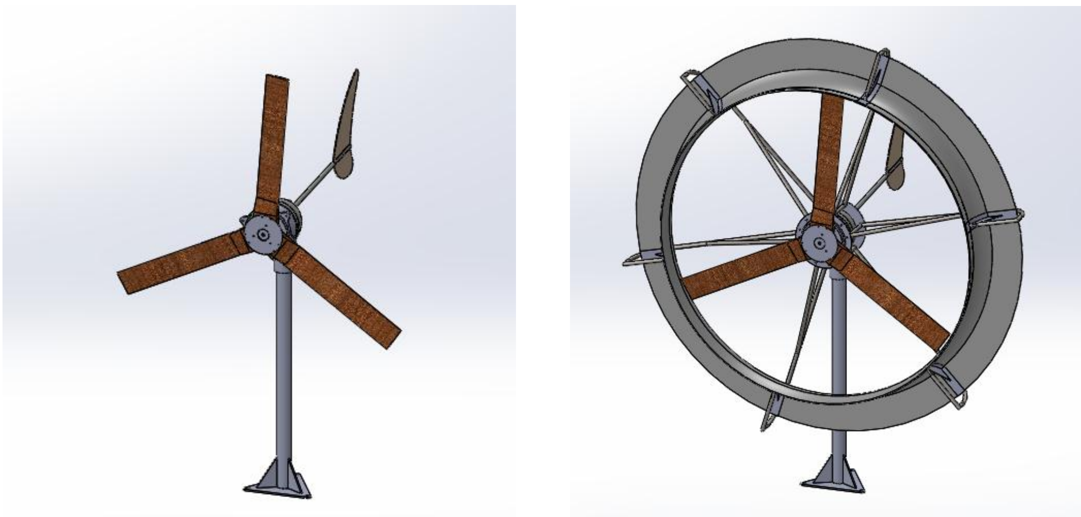


Figure 2. Design of shrouded



(a) (b)

Figure 3. Wind turbine: a) Conventional wind turbine, b) Shrouded wind turbine

2.3 Experimental setup and data measurement

The Experiment purpose to compare the output power of a conventional wind turbine with a shrouded wind turbine at low wind speed conditions. Measurements were using a data logger at the wind speed range are 2 m s^{-1} – 6 m s^{-1}. However, in this research the data used are sorted according to wind speed at each change of 1 m s^{-1}. The data taken from the experiment involves wind speed, voltage, and current.

Figure 4. Shrouded wind turbine experiment

3. Result and discussion

The data that have been collected from the experiment were processed to obtain generated power and efficiency from the wind turbine. The calculation result shown in **Table 3** and **Figure 5**. From the experiment results, the Shrouded wind turbine generated higher output power than a conventional wind turbine in every wind condition.

Table 3. Experiment results

	Wind Speed ($m\ s^{-1}$)	Output Power (Watt)	Efficiency (%)
Conventional Wind Turbine	2	2.21	22.39
	3	7.28	21.89
	4	15.24	19.33
	5	22.74	14.77
	6	30.37	11.42
Shrouded Wind Turbine	2	4.25	43.15
	3	13.79	41.48
	4	25.44	32.27
	5	31.56	20.50
	6	37.35	14.04

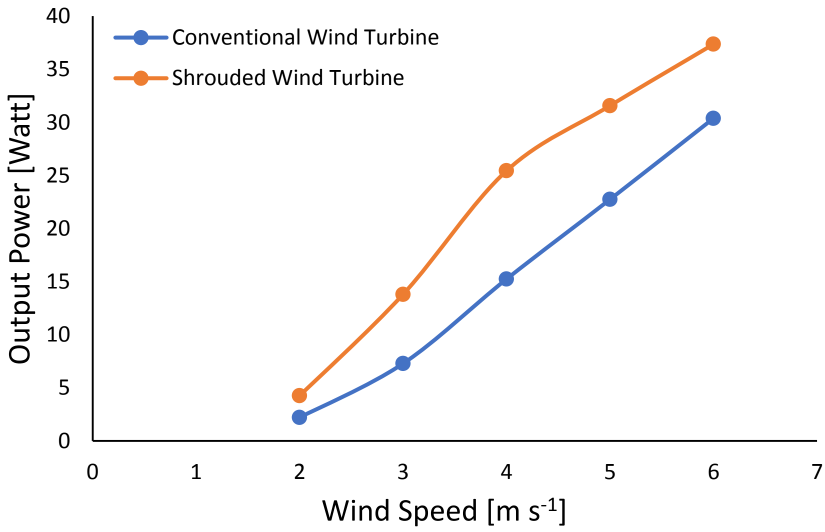


Figure 5. Comparison of wind turbine's output power

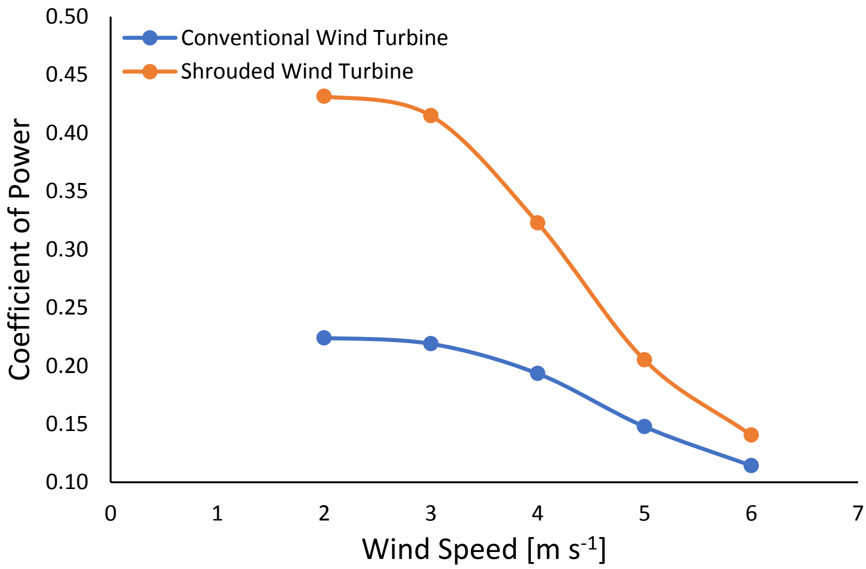


Figure 6. Comparison of wind turbine's power coefficient with wind speed

Table 4. Increasing power by using shrouded

Wind Speed ($m\ s^{-1}$)	Output Power of Conventional Wind Turbine (Watt)	Output Power of Shrouded Wind Turbine (Watt)	Power Increase Percentage (%)
2	2.21	4.25	92.71
3	7.28	13.79	89.51
4	15.24	25.44	66.93
5	22.74	31.56	38.82
6	30.37	37.35	22.98
Average	15.57	22.48	62.19

Figure 6 depicts about relation between coefficient of power (Cp) and wind speed. The coefficient of power is important in a wind turbine since it shows how much wind energy can be extracted from the kinetic energy of the wind through the rotor. Coefficient of power can be said as a measure that signifies a power efficiency in a wind turbine and dimensionless.

The shrouded wind turbine can generate greater power than conventional wind turbines at the same wind speed condition. That is because the shrouded focusing the airflow on the rotor which makes the mass flow that hits the rotor increase, where the flow velocity around the rotor will be higher than the flow before entering the shrouded. In addition, the use of brim can produce vortex behind the rotor, so that the pressure behind the rotor becomes lower than the initial pressure in front of the rotor which can increasing mass flow. This causes the shrouded wind turbine to produce higher power than the conventional wind turbine at the same wind speed.

Based on the experimental results, the shrouded wind turbine produces higher output power than conventional wind turbines in every wind speed condition. But the efficiency decreases when the wind speed increase for both types of wind turbines, where the shrouded wind turbine has a significant reduction. This is caused by the frequencies of data at measured and collected data, where on the collected data process, frequencies of wind speed 1 - 3 m s^{-1} is relatively many than frequencies of wind speed above 3 m s^{-1} which caused the result of average generating power at wind speed 4 - 6 m s^{-1}. Another thing that affects the generated power on the experiment is the yawing mechanism on the shrouded wind turbine which is not optimal due to the addition of structural loads.

Generally, the results show the use of shrouded on the wind turbine can increase power output by up to 92.71%, with an average of 62.91%. This shows that the use of shrouded on micro-scale wind turbines for HAWT can improve performance even in low wind conditions, which is one of the disadvantages of HAWT. The use of shrouded can increase the mass flow rate on the rotor so that the resulting force is greater than conventional wind turbines at the same wind speed, so the cut-in speed of the wind turbine with shrouded is lower than the cut-in speed of conventional wind turbines. Shrouded wind turbine, can be an alternative micro-scale power plant for micro-scaled areas that have low wind potential with better efficiency.

4. Conclusion

The results of this experiment show that the use of shrouded can increase the power generated and efficiency compared to conventional wind turbines at low wind speeds. Based on this research shows the shrouded wind turbine can increase power output by up to 92.71%, with an average of 62.91%.

5. Acknowledgement

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