FIELD TEST STUDY ON THE PERFORMANCE OF SIX-BLADE SPIRAL HORIZONTAL AXIS WIND TURBINE RELATED TO THE EFFECT OF SOLIDITY NUMBER

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Abstract-- Fossil fuels are still a daily necessity in the world. Human dependence on fossil fuels has created problems related to pollution and energy security. Wind turbines are renewable energy power plants where their use is expected to be an unlimited alternative energy source. This wind turbine research uses a field test study method with a six-blade spiral horizontal axis wind turbine (TASH) type. TASH performance is assessed by measured parameters such as rated voltage, generator output current and torque value; also non-dimensional parameters such as power coefficient, Cp, torque coefficient, Ct and Tip Speed Ratio, TSR values generated due to TASH rotation at every wind speed from 3.0 m/s to 4.5 m/s wind speed. Field test results obtained: Actual power (experimental) = 5.50 Watt and torque value = 10.7 N.m at a wind speed of 4.5 m/s. Cp = 0.0083, Ct = 1.2180, and TSR = 0.0068 at a wind speed of 3.0 m/sThe solidity value obtained based on the calculation results is 1.627 for a 5-blade wind turbine, while for a 6-blade and 8-blade wind turbine, the solidity values are 1.953 and 2,604. As the turbine solidity value increases, the power coefficient will also increase, inversely proportional to the torque coefficient, that as the turbine solidity value increases, the torque coefficient will decrease.

Keywords: Spiral Blade TASH, Solidity Number, power coefficient Cp, torque coefficient Ct, Tips Speed Ratio

1. INTRODUCTION

The need for energy and electricity has increased globally, and this means more power is needed from power plants. However, power plants will continue to damage the earth as the greenhouse gases produced while generating energy contribute to global warming. Using renewable sources to generate clean energy is one of the sustainable methods to deal with such challenges. Wind energy is one such renewable source that can be accessed anywhere in the world, creating green energy. Wind turbines are mainly categorized into Horizontal Axis Wind Turbines (HAWT) and Vertical Axis Wind Turbines (VAWT) [1], [2].

Renewable energy resources, especially wind energy, have seen significant growth in energy markets around the world as a clean energy source. This has drawn attention to areas with low and moderate wind speeds. Small-scale Darrieus vertical axis wind turbines (VAWTs) with omnidirectional capabilities capture the potential energy in these areas on a cost-effective scale. Much research has been done to optimize their design, thereby improving the performance of these turbines. Turbine solidity, representing the ratio of the overall area of the blades over the sweep area of the turbine, is one of the influential geometric factors that significantly affect wind turbine performance. Previous studies on solidity focused on the number of blades and blade length variations, while studies on the turbine diameter were limited. Therefore, the study was intended to numerically investigate the solidity effects corresponding to turbines of different diameters. Power performance and flow characteristics were carefully investigated according to different solidities, and tip speed ratios, using a high-fidelity computational fluid dynamic (CFD) method, which solves the instability of the Reynolds-Averaged Navier-Stokes (RANS) equations. The solidity study conducted mainly focuses on changing the blade chord length and the number of blades. Changing the chord length naturally modifies the blade Reynolds number; therefore, the findings in previous studies may be affected by Reynolds number effects, such as dynamic stall and flow curvature effects, which will significantly affect the turbine performance. [3].

The purpose of this research is to analyze the impact of solidity on the performance of the horizontal axis wind turbine (TASH) type 6 spiral blades to determine the character of the turbine's Coefficient Power (C_p), Coefficient Torque (C_t) and Tip Speed Ratio (λ) both theoretically and experimentally.

1.1 Wind energy

Wind energy is one of the renewable energies available around which is formed due to air flow caused by the rotation of the earth and the difference in air pressure around. Wind flow flows from high to low pressure places. The heated wind will cause expansion, the expanding wind will then become lighter so that it rises, when this happens, the wind pressure will drop because the air becomes less. Wind energy can be utilized to convert wind energy into electrical energy using wind turbines. Wind turbines require development because the wind speed is dynamic, therefore research on wind turbines is still being developed. [4].

1.2 Wind Turbines

From the research "Design and Implementation of Wind Turbine Test Bench to Know the Characteristics of Wind Turbines", wind turbines are windmills used to generate electricity. This wind turbine was originally made to accommodate the needs of farmers in milling rice, irrigation purposes. Early wind turbines were built in Denmark, the Netherlands, and other European countries and were better known as Windmills. Now wind turbines are more widely used to accommodate the electricity needs of the community, using the principle of energy conversion and using renewable natural resources, namely wind. Although until now the development of wind turbines has not been able to compete with conventional power plants (Example: PLTD, PLTU), wind turbines are still being developed by scientists because in the near future humans will be faced with the problem of lack of non-renewable natural resources (Example: coal, petroleum) as a basic material for generating electricity. [5].

VAWT (Vertical Axis Wind Turbine), Vertical Axis Wind Turbine is a wind turbine with a propeller position that is vertical to the ground. This turbine has a turbine rotor with low rotation (below 100 rpm), but has a strong moment of force. Vertical Axis has several models, including: Lift Type (Darrieus) In this model each blade has a maximum lift moment only twice each rotation and its output power so that it can be used to grind grain, water pumps, but is not suitable for generating electricity with 1000 rpm. As shown in Figure 1 [6]

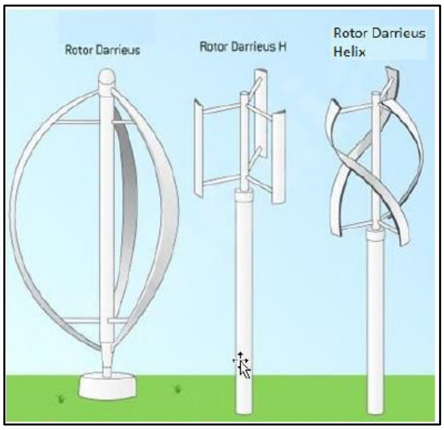

Figure 1. Darrieus Wind Turbine [6]

Thrust type (Savonius) In this model, the thrust force will occur when TSR < 1. In this model, the maximum speed generated by the blade is equivalent to the wind speed. Savonius turbines have low power efficiency but produce more power and power output and have high efficiency. As shown in Figure 2.

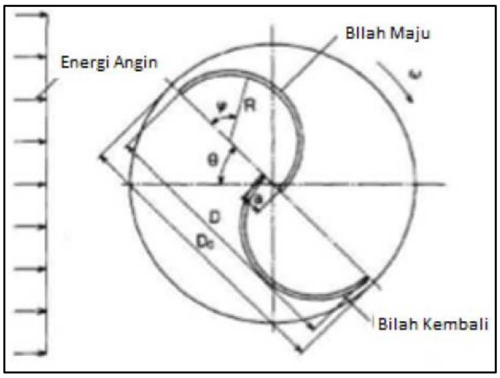

Figure 2. Savonius Wind Turbine [6]

HAWT (Horizontal Axis Wind Turbine), Horizontal Axis Wind Turbine is a wind turbine with horizontal blades parallel to the ground. This turbine consists of two types, namely upwind machines and downwind machines. As shown in Figure 3 [4].

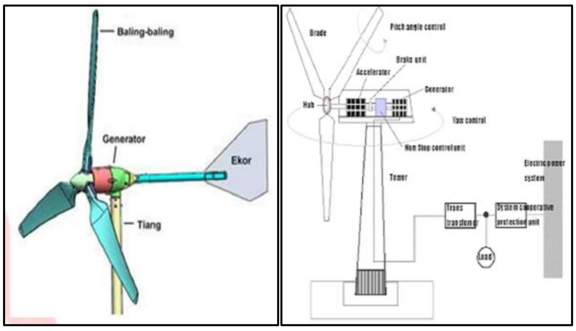

Figure 3. Upwind and downwind engine wind turbines [4]

2. METHOD

2.1 Research Methods

This research was conducted using experimental research methods, namely making observations to find data in a process through experiments so as to determine the performance of the six-blade spiral horizontal axis wind turbine related to the effect of solidity number.

2.2 Flow Chart

Flowchart of the Horizontal Axis Wind Turbine field test process as shown in Figure 4:

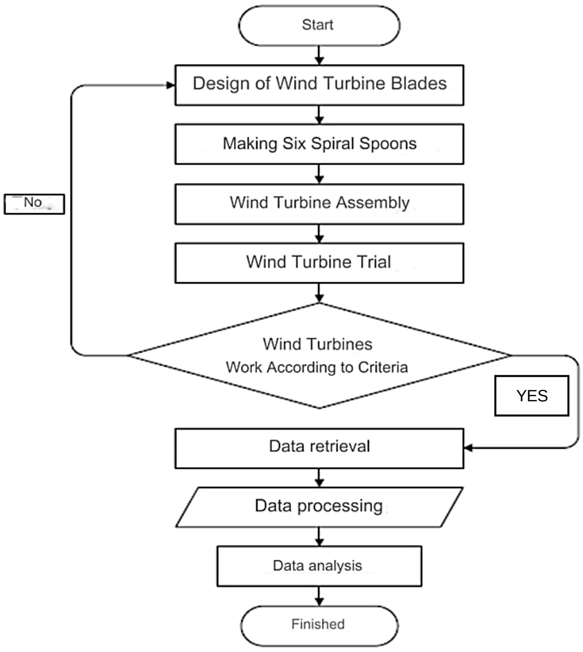

Figure 4. Flowchart of the field test process

2.3 Research Parameters

For field testing of the six-blade horizontal axis wind turbine there are several parameters that will be measured including: Coefficient Torque (C_T), Experimental Actual Power (Pw_{exp}), Power Coefficient (C), Tip Speed Ratio (TSR), Solidity Number ($\boldsymbol{\sigma}$).

The following are the equations used to calculate these parameters:Calculation of theoretical torque value (T_{th}), obtained from [7], i.e.:

$$T_{th} = \frac{1}{2}\rho.A.R.HV_w^2 \quad (1)$$

Where:
T_{th} = Theoretical Torque Value
ρ = density of air (1 Kg/m^3)
A = Sweep area (m^2)
R = Turbine radius (m)
HV_W = Wind velocity (m/s)

And the value of the torque coefficient [8], determined from:

$$C_T = \frac{T_{exp}}{T_{th}} \quad (2)$$

Where:
C_T = Torque Coefficient
T_{exp} = Experimental torque value (Nm)
T_{th} = Theoretical torque value (Nm)

$$Pw\ exp = V\ x\ I \quad (3)$$

Where:
Pw exp = Experimental Actual Power ($Watt$)
V = Voltage ($Volt$)
I = Strong Current ($Ampere$)

Power Coefficient Value [9], determined from:

$$C_p = \frac{Pw\ exp}{Pw\ ideal} \quad (4)$$

Where:
C_p = Power Coefficient
PW exp = Experimental actual power ($Watt$)
Pw ideal = Theoretical power ($Watt$)

theoretical power is derived from [2], i.e.:

$$Pw, ideal = \frac{1}{2}.\frac{16}{27}(\rho AV^3) \quad (5)$$

Where:
Pw ideal = Theoretical power ($Watt$)
ρ = Density of air (Kg/m^3)
A = Luas area sapuan (m^2)
V = Wind flow speed (m/s)
16/27 = Betz limit

Rasio kecepatan turbin terhadap kecepatan angin (Tip Speed Ratio), TSR [2], i.e:

$$\lambda = \frac{Cp}{Ct} \quad (6)$$

Where:
λ = Tip speed ratio

Cp = Power coefficient
Ct = Wind speed (m/s)

Solidity Number is defined from [2], i.e:

$$\sigma = \frac{n.c}{d} \quad (7)$$

Where:
n = number of blades
c = blade chord length (m)
d = turbine diameter (m)

2.4 Measurement tools

The measuring instrument used is as shown in Figure 5 below:

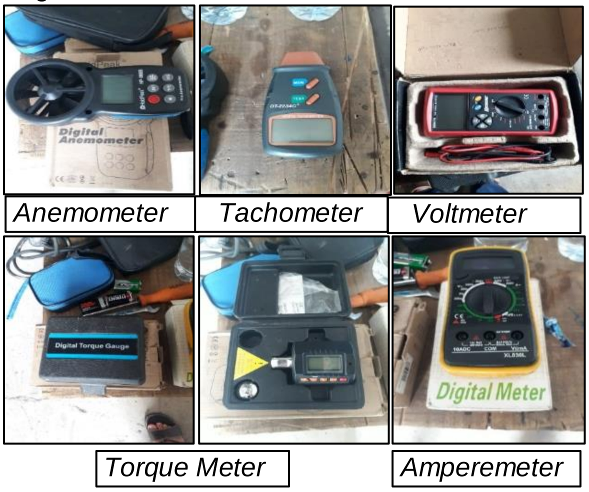

Figure 5. Measuring instruments used

Anemometer to measure wind speed.Tachometer to measure the number of shaft revolutions (RPM). Voltmeter to measure voltage. Torque Meter to measure the amount of torque.Amperemeter to measure current strength.

Figure 6. Research location

2.5 Research location

The research location is in the seaside area of Tanjung Pasir, Mauk District, Tangerang Regency, Banten, as shown in Figure 6.

2.6 Bahan Prototipe TASH

The TASH prototype material is made of 2.5 millimeter thick fiber.

Table 1. Design parameters of spiral type TASH

Turbin	L_r [mm]	D_i [mm]	D_o [mm]	c [mm]	σ_r
5 blade	768	800	1536	500	1.627
6 blade	768	800	1536	500	1.953
8 blade	768	800	1536	500	2.604

Where:
L_r : Rotor length
D_i : Inside diameter
D_o : Diameter luar
c : Outside diameter
σ_r : Solidity number

3. RESULTS AND DISCUSSION

3.1 Results

From the data obtained in the TASH trial, the average value is taken so that the actual values of wind speed, RPM, voltage, current and torque are obtained. Table 2 displays the data obtained from the results of data collection during field testing.

Table 2. TASH Testing Result Data

NO	Wind Speed (m/s)	TASH Round (RPM)	Voltage (V)	Current (A)	Torque (N.m)
1	3.0	58.6	4.25	0.05	7.8
2	3.3	62.8	4.73	0.13	8.3
3	3.5	66.3	5.32	0.22	8.7
4	3.7	69.2	5.53	0.25	9.1
5	4.0	70.4	5.64	0.36	9.2
6	4.1	74.5	6.12	0.39	9.6
7	4.2	84.6	6.37	0.42	9.8
8	4.3	88.5	6.65	0.47	10.2
9	4.4	96.2	7.21	0.58	10.5
10	4.5	98.7	7.34	0.75	10.7

Table 3. Analysis and calculation data

Wind Speed (m/s)	Actual Power (Pexp) (Watt)	Theoretical Power (Pw, ideal)) (Watt)	Torque Coefficient (Ct)	Power Coefficient (Cp)	Tip Speed Rasio (TSR)
3.0	0.21	25.01	1.2180	0.0083	0.0068
3.3	0.61	33.29	1.0711	0.0183	0.0170
3.5	1.17	39.72	0.9981	0.0294	0.0294
3.7	1.38	46.93	0.9341	0.0294	0.0313
4.0	2.03	59.29	0.8080	0.0342	0.0423
4.1	2.38	63.85	0.8026	0.0372	0.0463
4.2	2.67	68.64	0.7807	0.0388	0.0496
4.3	3.12	73.66	0.7752	0.0423	0.0545
4.4	4.18	78.92	0.7622	0.0529	0.0694
4.5	5.50	84.42	0.7425	0.0651	0.0876

3.2 Discussion

1. The relationship between wind speed and voltage is shown in Figure 7 below.

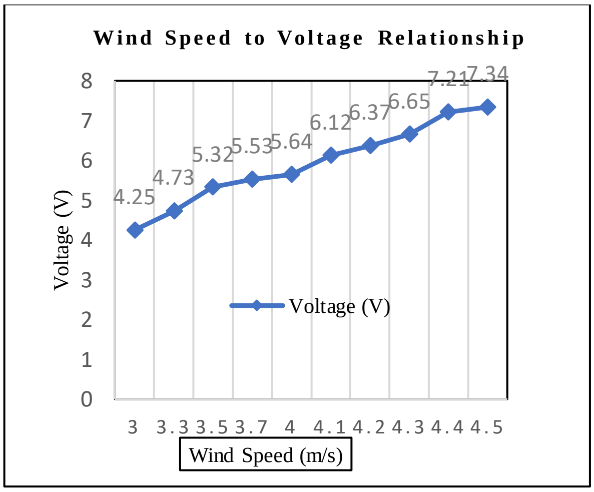

Figure 7. Graph of the relationship between wind speed and voltage

The highest voltage was achieved with a wind speed of 4.5 m/s with a voltage value of 7.34 V and the lowest voltage with a value of 4.25 V at a wind speed of 3 m/s.

2. The relationship between wind speed and current is shown in Figure 8 below.

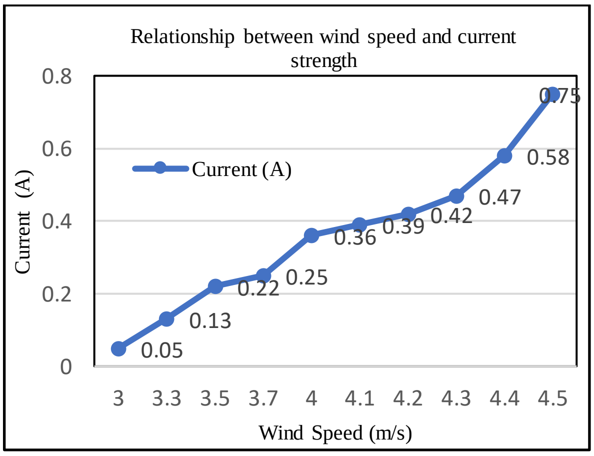

Figure 8. Graph of the relationship between wind speed and current strength

The highest current strength was achieved with a wind speed of 4.5 m/s with a current strength value of 0.75 A and the lowest current strength with a value of 0.05 A at a wind speed of 3.0 m/s.

3. The relationship between wind speed and Experimental Actual Power is shown in Figure 9 below.

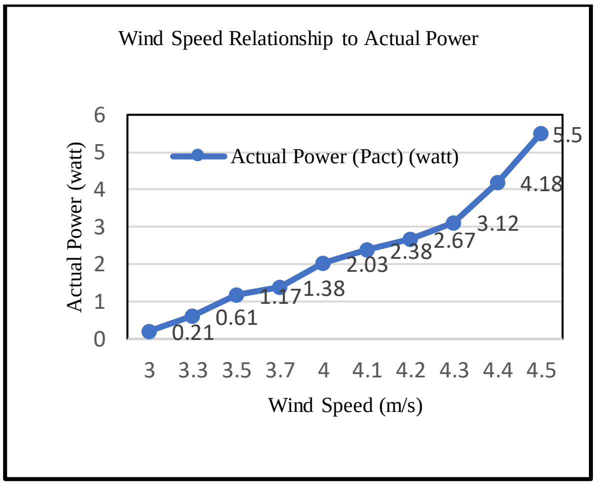

Figure 9. Graph of the relationship between Wind Speed and Actual Power

The highest actual power is achieved with a wind speed of 4.5 m/s with an actual power value of 5.50 watts and the lowest actual power with a value of 0.21 watts at a wind speed of 3.0 m/s.

4. The relationship of wind speed to the Theoretical Power generated is shown in Figure 10 below.

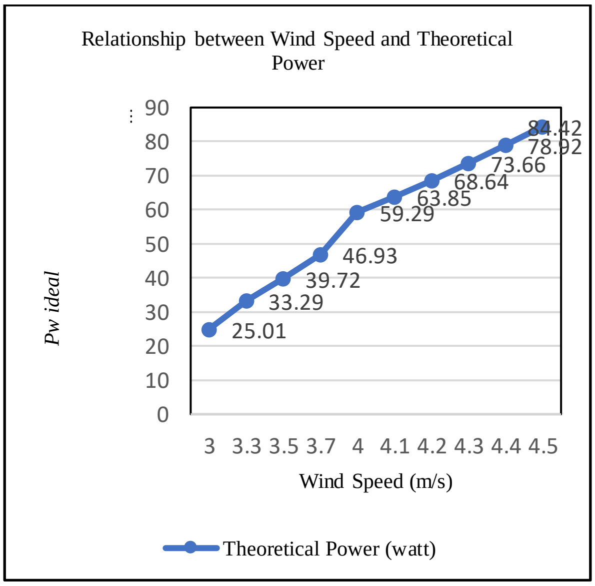

Figure 10. Graph of the relationship between wind speed and theoretical power

The highest wind power was achieved with a wind speed of 4.5 m/s with a wind power value of 84.42 watts and the lowest wind power with a value of 25.01 watts at a wind speed of 3.0 m/s.

The relationship between wind speed and torque coefficient is shown in Figure 11 below.

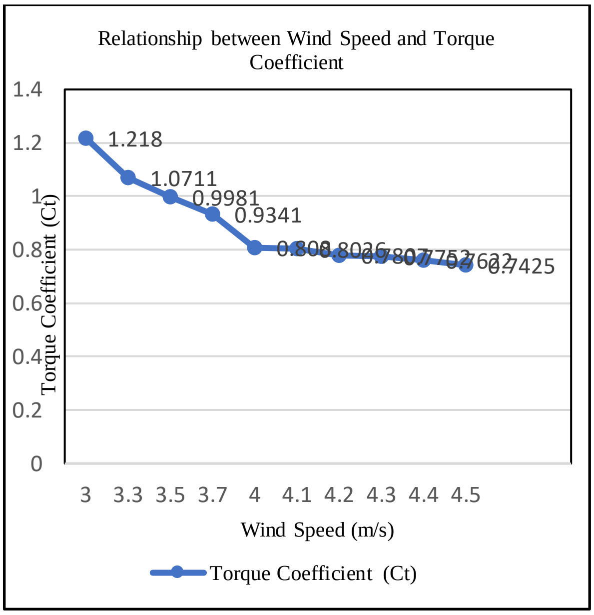

Figure 11. Graph of the relationship between wind speed and torque coefficient

The higher the wind speed, the lower the torque coefficient. At 6 blades, the highest torque coefficient value is at 3.0 m/s wind speed with a value of 1.2180 and the lowest value is 0.7425 at 4.5 m/s wind speed.

The relationship between wind speed and power coefficient is shown in Figure 12 below.

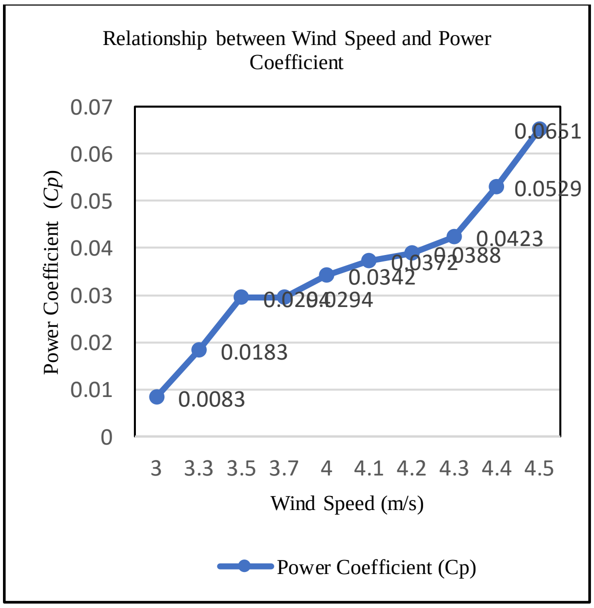

Figure 12. Graph of the relationship between wind speed and power coefficient

At 6 blades, the highest power coefficient value is achieved in a wind speed of 4.5 m/s at 0.0651 and the lowest power coefficient value is when the wind speed is 3.0 m/s at 0.0083.

The relationship of wind speed to tip speed ratio value is shown in Figure 13 below.

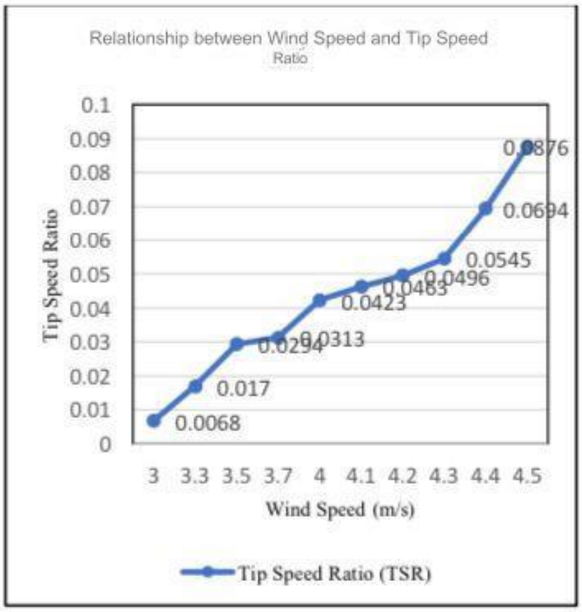

Figure 13. Graph of the relationship between wind speed and tip speed ratio

From the graph above, it can be seen that the highest tip speed ratio value occurs at a wind speed of 4.5 m/s with a value of 0.0876 and the lowest tip speed ratio value at a wind speed of 3.0 m/s of 0.0068.

4.3 Effect of Solidity Number

The obtained solidity value based on the calculation results is 1.627 for the 5 blade wind turbine. while for the 6 blade and 8 blade wind turbines. the solidity value is 1.953 and 2.604. Based on the power coefficient graph above, it can be seen that with the increase in turbine solidity value, the power coefficient will also increase. this is inversely proportional to what is shown by the torque coefficient graph. that the increasing value of turbine solidity, the torque coefficient will decrease.

5. CONCLUSIONS

From the discussion and analysis carried out based on the potential wind speed during testing. it can be concluded as follows:

1. Based on the results of the analysis. the lowest voltage and current strength that can be generated is 4.25 V and 0.05 A at a turbine rotation speed of 58.6 rpm with a wind speed of 3.0 m/s. and the highest voltage that can be generated is 7.34 V and 0.75 A at a turbine

rotation speed of 98.7 rpm with a wind speed of 4.5 m/s. The higher the wind speed. the higher the turbine rotation generated. The higher the wind speed. the higher the turbine rotation produced.
2. At a wind speed of 4.5 m/s the maximum value for actual power (Pexp) is 5.50 watts and the maximum value for theoretical power (Pwideal) is 84.42 watts while the lowest value is 0.21 watts and 25.01 watts at a wind speed of 3.0 m/s. For the maximum torque coefficient (Ct) value of 1.2180 with a wind speed of 3.0 m/s. The maximum power coefficient (Cp) is 0.0651 with a wind speed of 4.5 m/s. and the maximum value for the tip speed ratio (TSR) is 0.0876 at a wind speed of 4.5 m/s.
3. Based on the data obtained. for wind speeds with values less than 5.0 m/s are more suitable for conversion into mechanical energy or small-scale wind power production.

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