Design and Simulation of Horizontal Axis Wind Turbine (HAWT) Blade Variations Using Q-Blade Software Based on the Average Wind Speed in the Riau Islands

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Abstract. A wind turbine is a device that is able to convert wind energy into mechanical energy, then converted into electrical energy through a turbine generator. Wind turbines that rotate on a horizontal axis are called horizontal axis wind turbines (TASH) and those that rotate on a vertical axis are called vertical axis wind turbines (TASV). The efficiency of horizontal axis wind turbines can be increased to obtain maximum power coefficient. The aim of this research is to simulate a wind tunnel trainer kit that has been designed and made. Can find out the shape of a miniature wind turbine model and the maximum rotation produced during testing. This research method is to analyze the performance of wind turbines so that a Horizontal Axis Wind Turbine (TASH) simulation design is carried out with variations in the number of blades of 3, 5, 8, angle variations of 0°, 5° and variations in wind speed as well as analyzing the effective performance efficiency produced by the wind turbine. the. Measurement parameters are analyzed from Power, Torque and Thrust. Based on the results of the analysis and design that has been carried out, the wind turbine tested at the average wind speed in Riau Island, namely 6.13 m/s and a rotational speed of 325.27 rpm, found that the most efficient wind turbine is with 8 blades with a power of 325.27 rpm. watts, rotor torque 0.0170 Nm and thrust 0.74 N with a pitch angle of 5°. In calculating the greatest efficiency produced by wind speed, the best turbine efficiency was obtained at a speed of 1.972 m/s with a wind rotation speed of 104.67 rpm, turbine power of 0.27 watts and an efficiency of 56.6%. Based on the simulation results, the highest Reynolds number is found in 3 turbine blades.

Keywords: Horizontal Wind Turbine (TASH), Q-blade, Efficiency, Power Coefficient, Power, Rotor Torque, Thrust

1 Introduction

One of the causes of global warming is the increasing use of non-renewable energy. As the temperature of the Earth's atmosphere increases, more and more ice is melting at the North and South Poles [1]. If it is not treated immediately, it is feared that it will have a bad impact on

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human life. One of the efforts that has been made by many countries is to minimize the use of non-renewable energy and use all types of existing renewable energy sources. Indonesia has a lot of renewable energy. The potential for all types of renewable energy is also very large. But not all renewable energy is utilized optimally. Socialization of the use of renewable energy is also very necessary to make the Indonesian people aware of the abundance of renewable energy sources they have.

Renewable energy is an energy source produced from natural resources that can be renewed naturally and are continuously available, such as sunlight, wind, water and geothermal heat. Renewable energy can be used to produce electricity, heat and mechanical power, and is used in various sectors, including transportation, industry and households. Renewable energy is considered a more sustainable and environmentally friendly alternative compared to fossil energy sources, such as petroleum and natural gas, because it does not produce significant carbon emissions and can be continuously renewed. However, renewable energy also has its own challenges, such as relatively high costs for infrastructure installation and uncertainty in the availability of natural resources which are influenced by weather and climate conditions [2].

Population growth also causes an increase in energy needs, including electrical energy. Electricity is one of human energy needs, because almost all devices needed by humans today require electrical energy. Utilizing wind energy is one of the government's choices to meet Indonesia's electrical energy needs. Because Indonesia's position is close to the Indian Ocean, Indonesia has good potential in developing wind turbines. A wind turbine is a device used to generate electrical power using wind energy. This electricity will later be stored in the battery for use [3].

A wind turbine is a device that is capable of converting wind energy into mechanical energy and then converting it into electrical energy through a turbine generator. In principle, wind turbines are distinguished by their direction of rotation. Wind turbines that rotate on a horizontal axis are called horizontal axis wind turbines (TASH) or Horizontal Axis Wind Turbines (HAWT), while those that rotate on a vertical axis are called vertical axis wind turbines (TASV) or Vertical Axis Wind Turbines (VAWT). The efficiency of this horizontal axis wind turbine can be increased to obtain a maximum power coefficient [4].

2 Review Of Literature

A lot of research has been carried out in the development of horizontal axis wind turbines to produce a system that is able to work optimally. Where the efficiency of this turbine can be increased to get the maximum power coefficient [5]. One way is to use a large number of blades. This maximum power coefficient will increase the number of watts (power) produced so that to get a certain number of watts it is enough to use a smaller number of blades [6].

Muhammad Abdul Ghofur, Muhammad Irsan Pratama Putra, Rindu Alriavindra Funny, conducted research on designing a Horizontal Axis Wind Turbine Simulation (TASH) by varying the number of blades 3, 4, 5, 6, pitch angles 0°, 6°, 10° and varying wind speed and analyzed the performance produced by the wind turbine with the Power, Torque and Thrust parameters and obtained the greatest power value for the turbine with 3 blades, 6° angle, namely 2837 watts when the wind speed was 20 m/s and 1401.00 rpm [7].

Research carried out to determine the amount of energy that a turbine can produce at a certain location. This paper focuses on analyzing wind resources at a particular location using a mathematical model of wind turbines in MATLAB SIMULINK[8].

Research on the characteristics of wind turbines and the optimal leaf tip speed ratio method is analyzed, a wind turbine simulation model is built, a wind speed model combined with four wind speed characteristics is established to simulate the natural wind speed, and a semi-physical wind force The simulation system is built by combining software and devices hard. The correctness of the program is verified through simulation experiments of the operating state of the wind turbine at instantaneous wind speed and natural wind speed[9].

Arga Gideon Sarwando, Untung Budiarto, Ahmad Fauzan Zakki conducted research on the analysis of the effectiveness of horizontal axis wind turbines with variations in the number and type of airfoils as a source of additional electrical energy in fisheries inspections. It was found that the NACA 0018 airfoil type had the highest of the NACA 0015 and NACA 0025, with a torque of 351.72 Nm, a power of 11.05 KW, and a power coefficient of 0.488 [10].

In research on horizontal axis wind turbine (HAWT) blades with a power output of 10,000 Watts using blade element momentum (BEM) theory and a modified stall model, and blade aerodynamics were simulated to determine the flow structure and aerodynamic characteristics[11]. Paper about an improved numerical code based on BEM theory, applied to evaluate the performance of HAWTs (Horizontal Axis Wind Turbines)[12]

In a paper discussing the basic analysis of airfoil profiles in micro and small scale horizontal axis wind turbines (HAWT) for various angles of attack α and fixed Reynolds numbers. For turbine blade modeling, the data used comes from the National Advisory Committee of Aeronautics (NACA) in the form of a series of five-digit airfoils. The comprehensive relationship between the optimal angle of attack α and the Reynolds number has been analyzed. Low or high lift-to-drag ratios (L c /D c) can be identified at various angles of attack α. Computational analysis of the fluid dynamics of the NACA 63-415 airfoil was carried out at various angles of attack α at a wind speed of 5 m/s using ANSYS/Fluent software. Pressure, turbulence and velocity distribution plots have been observed [13]

Research that presents a simulation study on an airfoil based on a vertical axis wind turbine (VAWT) for the application of low wind speeds ranging from 2 to 8 meters per second. The main advantage of a VAWT over a horizontal axis wind turbine (HAWT) is its ability to capture wind from all directions. Therefore, the yaw system does not need to rotate the rotor in the direction of the wind[14].

In this research, to determine the performance of the wind turbine, a Horizontal Axis Wind Turbine (TASH) simulation design was carried out using variations in the number of blades of 3, 5, 8, angle variations of 0°, 5° and variations in wind speed as well as analyzing the effective performance efficiency produced by the wind turbine with Power, Torque and Thrust parameters.

3 Methodology

3.1 Research Design

In this research, the design of a Horizontal Axis Wind Turbine (TASH) was carried out using manual calculation analysis and Q-Blade Software simulation to determine the effectiveness and efficiency of the Horizontal Axis Wind Turbine (TASH) Performance and used Kinetic Turbine Calc software to determine the Re value. The performance results obtained are used as an analysis to determine the characteristics of effective and efficient wind turbines which can be used as a reference for making wind turbines. The design of a horizontal axis wind turbine consists of varying the number of blades and pitch angle. This research will also analyze the performance results in the form of power, thrust and rotor torque from the turbines produced. Meanwhile, in designing the horizontal axis wind turbine, a design will be created with the following characteristics: The number of blades used is 3, 5, 8, and the pitch angles used are 0° and 5°. In carrying out the horizontal axis wind turbine simulation design, the author used Q-Blade software for simulation. This software is used to create simulations to illustrate the movement of horizontal axis wind turbines.

In the research procedure, the first step in this process is planning the tools, this process is carried out so that the initial and final goals are achieved. After that, the author assembled the tool, in this process there were 2 stages, namely, system design and mechanical design. Then after assembling the tool, an object test is carried out, namely a miniature wind turbine and data is collected for analysis. Flowchart research design at Fig 3.1.

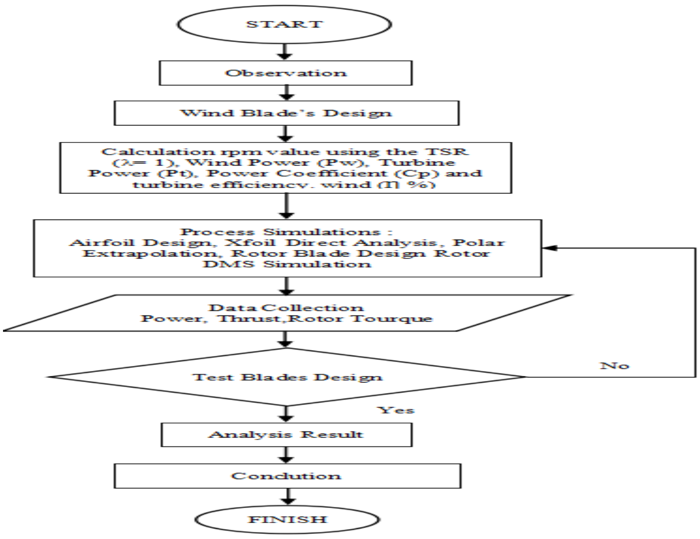

Fig 3.1 Flowchart Research Design

3.2 Wind Turbine Design

The Following is wind turbine design with 3, 5 dan 8 blades using Q-Blade Software.

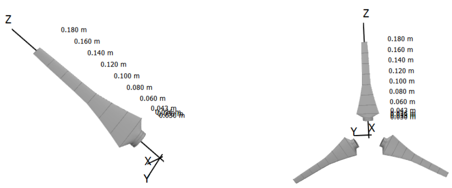

Fig 3.2 Wind Turbine Design with 3 Blades using Q-Blade Software.

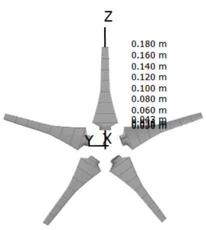

Fig 3.3 Wind Turbine Design with 5 Blades using Q-Blade Software.

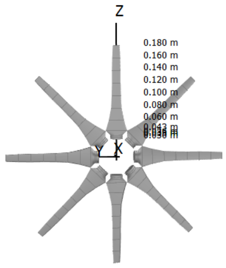

Fig 3.4 Wind Turbine Design with 8 Blades using Q-Blade Software.

3.3 Calculation Methode

The calculation method for this miniature wind turbine is as follows:

1. Determine the number of blades. In this study the author determined the number of blades used as material for analyzing miniature wind turbines, namely 3, 5 and 8 blades.
2. Determine the rotor diameter. The diameter used in this analysis is 360 mm.
3. Determine the radius of the rotor hub. The radius of the rotor hub used is 30 mm.
4. Determine minimum average the wind speed in Analysis.[15]

Table 3.1. Determine Minimum Average The Wind Speed Analysis

Variation	The wind speed
V1	1.97 m/s
V2	2.00 m/s
V3	2.12 m/s
V4	2.35 m/s
V5	2.55 m/s
V6	2.65 m/s
V7	2.78 m/s
V8	2.98 m/s
V9	3.15 m/s
V10	3.37 m/s

5. Determine Tip Speed Ratio (TSR). The value of TSR is (λ=1)
6. Determine Turbine Rotation Speed (RPM) value with equation

$$n\,(rpm) = \frac{60.\lambda.\,v}{2.\pi.\,R} \tag{1}$$

7. Determine the value of Blade Sweep Area with equation

$$A = \frac{1}{4}\,\pi\,D^2 \tag{2}$$

8. Determine the value of Wind Power with equation [16]

$$P_{angin}(Watt) = \frac{1}{2}\;x\,\rho\,x\,A\,x\;v^3 \tag{3}$$

9. Determine the value of Torque and Power of Wind Turbine with equation[17]

$$T\,(Nm) = F\,.\,r = m\,.\,g\,.\,r \tag{4}$$

$$P_{turbin\ angin} = \omega\,.\,T \tag{5}$$

10. Determine value of the chord length on a miniature wind turbine with equation[18]

$$C = \frac{16\,\pi.R.(\frac{R}{r})}{9\,.\lambda^2.\,B} \quad (6)$$

11. The Angle of attack (α) value used in this analysis is α = 5º
12. Determine value the Angle of twist (β) with equation [19]

$$\beta = arctan\,(\frac{2R}{3.r.\lambda}) - \alpha \quad (7)$$

13. Determine value the angle of apparent wind turbine (ϕ) with equation[20]

$$\varphi = arctan\,(\frac{R}{r.\,\lambda}) \quad (8)$$

14. Determine value of power coefficient (Cp) with equation

$$C_p = \frac{P_{mekanik}}{P_{turbin\ angin}} \quad (9)$$

15. Determine value of wind turbine efficiency with equation [21]

$$\eta = C_p \ \text{x}\ 100(\%) \quad (10)$$

16. Determine value of Reynold Number (Re) with equation [21]

$$Re = \frac{\rho V c}{\mu} \quad (11)$$

4 Data Analysis and Conclusion

4.1 Calculate the Efficiency value based on wind speed data

By determining the wind speed, can find the rpm value using the TSR (Tip Speed Ratio) value (λ = 1), so can find the value of Wind Power (Pw), Turbine Power (Pt), Power Coefficient (Cp) and turbine efficiency. wind (Ƞ %). Then the calculated values are obtained as follows :

Table 4. 1. The calculated values are obtained of value TSR Konstan (λ = 1).

v (m/s)	TSR (λ)	Rpm (n)	Pw (Watt)	Pt (Watt)	Cp	(α)	(η %)
1,972	1	104,67	0,477	0,27	0,566	5°	56,6
2		106,15	0,498	0,274	0,55		55
2,12		112,52	0,593	0,29	0,489		48,9
2,35		124,73	0,808	0,322	0,399		39,9
2,556		135,66	1,04	0,35	0,337		33,7
2,654		140,87	1,16	0,364	0,314		31,4
2,787		147,92	1,348	0,382	0,283		28,3
2,988		158,59	1,662	0,409	0,246		24,6
3,15		167,19	1,947	0,432	0,222		22,2
3,374		179,08	2,393	0,462	0,193		19,3

Based on data from calculations using constant TSR (λ = 1) and slowly increasing wind speed, it can be seen that the best turbine efficiency is obtained at a speed of 1.972 m/s with a wind rotation speed of 104.67 rpm, turbine power of 0.27 Watt and efficiency of 56.6%. And the smallest efficiency in the wind turbine was obtained at a speed of 3.374 m/s with a wind rotation speed of 179.08 rpm, turbine power of 0.46 watts and an efficiency of 19.3%. So it can be concluded that the greater the wind rotation speed, the greater the wind power and turbine power produced, but the value of the power coefficient (Cp), namely the ratio between values (turbine power divided by wind power), is smaller, so the efficiency of the wind turbine decreases.

4.2 Calculate the Reynolds value based on wind speed data

From the values of wind speed and wind turbine rotational speed as input parameters and the type of NACA4412 airfoil with 3 blades, the airfoil output parameters are obtained in the form of Reynolds (Re) values and wind power and turbine power. From tables 4.2 and 4.3 it can be seen that the greater the speed, the greater the value of Reynolds for blade (Re), but the greater the number of blades, the value of Reynolds for blade (Re) decreases.

Table 4. 2. Manual Reynolds (Re) value data using Excel

Number Of Blade	Fluida Speed (V)	Fluid Density (ρ)	Chord Lenght (c)	Dynamic viscosity fluids (μ)	Reynold (Re)
3	1.97 m/s	1.255 m^2	0.02907 m	0.0000186 kg/ms	3868.508
	2.00 m/s	1.255 m^2	0.02907 m	0.0000186 kg/ms	3923.43
	2.12 m/s	1.255 m^2	0.02907 m	0.0000186 kg/ms	4158.84
	2.35 m/s	1.255 m^2	0.02907 m	0.0000186 kg/ms	4610.038
	2.55 m/s	1.255 m^2	0.02907 m	0.0000186 kg/ms	5014.152
	2.65 m/s	1.255 m^2	0.02907 m	0.0000186 kg/ms	5206.4
	2.78 m/s	1.255 m^2	0.02907 m	0.0000186 kg/ms	5467.309
	2.98 m/s	1.255 m^2	0.02907 m	0.0000186 kg/ms	5861.614
	3.15 m/s	1.255 m^2	0.02907 m	0.0000186 kg/ms	6179.413
	3.37 m/s	1.255 m^2	0.02907 m	0.0000186 kg/ms	6618.837
5	1.97 m/s	1.255 m^2	0.01744 m	0.0000186 kg/ms	2321.105
	2.00 m/s	1.255 m^2	0.01744 m	0.0000186 kg/ms	2354.062
	2.12 m/s	1.255 m^2	0.01744 m	0.0000186 kg/ms	2495.305
	2.35 m/s	1.255 m^2	0.01744 m	0.0000186 kg/ms	2766.022
	2.55 m/s	1.255 m^2	0.01744 m	0.0000186 kg/ms	3008.491
	2.65 m/s	1.255 m^2	0.01744 m	0.0000186 kg/ms	3123.840
	2.78 m/s	1.255 m^2	0.01744 m	0.0000186 kg/ms	3280.3855
	2.98 m/s	1.255 m^2	0.01744 m	0.0000186 kg/ms	3516.9688
	3.15 m/s	1.255 m^2	0.01744 m	0.0000186 kg/ms	3707.647
	3.37 m/s	1.255 m^2	0.01744 m	0.0000186 kg/ms	3971.302
8	1.97 m/s	1.255 m^2	0.010903 m	0.0000186 kg/ms	1450.69
	2.00 m/s	1.255 m^2	0.010903 m	0.0000186 kg/ms	1471.288
	2.12 m/s	1.255 m^2	0.010903 m	0.0000186 kg/ms	1559.566
	2.35 m/s	1.255 m^2	0.010903 m	0.0000186 kg/ms	1728.764
	2.55 m/s	1.255 m^2	0.010903 m	0.0000186 kg/ms	1880.307
	2.65 m/s	1.255 m^2	0.010903 m	0.0000186 kg/ms	1952.4002
	2.78 m/s	1.255 m^2	0.010903 m	0.0000186 kg/ms	2050.24
	2.98 m/s	1.255 m^2	0.010903 m	0.0000186 kg/ms	2198.1055
	3.15 m/s	1.255 m^2	0.010903 m	0.0000186 kg/ms	2317.2799
	3.37 m/s	1.255 m^2	0.010903 m	0.0000186 kg/ms	2482.0642

4.3 Calculate the Efficiency and Reynolds value using the Q-Blade Software

Simulation Using Q-Blade Software

Characteristics of Horizontal Axis Wind Turbines (TASH) include:

Blade length = 0.18 m
Hub Radius = 0.03 m
Airfoil Type = NACA-0009 9.0% Smoothed

Tabel 4.3. Geometri Blade Characteristics

Elemen	r	TSR Parsial
0	0,03	0,8
1	0,033	0,82
2	0,036	0,84
3	0,043	0,86
4	0,06	0,88
5	0,08	0,9
6	0,1	0,92
7	0,12	0,94
8	0,14	0,96
9	0,16	0,98
10	0,18	1

The average wind speed in Riau Island (v = 6,13 m/s)
Calculation Turbine Rotation Speed (RPM)

$\lambda = \frac{2\pi . n . R}{60.v}$ $\quad\quad$ $n = \frac{60.\lambda . v}{2.\pi . R}$

$n = \frac{60.1.\ 6{,}13\ m/s}{2.\pi .\ 0{,}18\ m}$

$n = 325{,}27$ rpm

Table 4. 4. CalculationTurbine Rotation Speed (RPM) with average wind speed in Riau Island

v (m/s)	n (rpm)
6,13	325,27

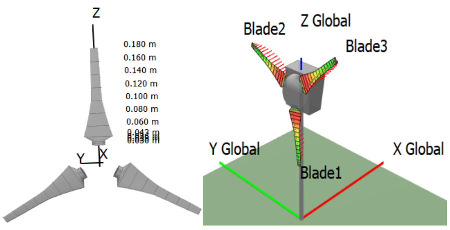

Fig 4. 1. TASH simulation uses Q-Blade with 3 Blade variations

The results of testing using the Q-Blade were obtained in the form of Power, Thrust, Rotational speed, Rotor Tourqe values with variations in the number of blades and pitch angles with wind speeds from 1.97 m/s to 6.13 m/s. The graphic results of a wind turbine with 3 blades with pitch angles of 0° and 5° have been obtained. The data obtained is that the greater the wind speed and rotational speed, the greater the performance produced.

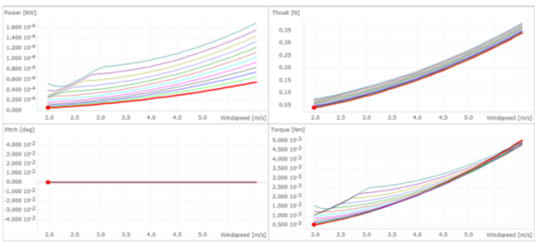

Fig 4. 2. Graphic of Performance Results for a 3 blade horizontal axis wind turbine at a pitch angle of 0°

From Fig 4.2, data is obtained that the power is greatest when the speed is 6.13 m/s with a rotational speed of 325.27 rpm, namely 0.1720 watts. Power tends to increase when the rotational speed is 112.52 rpm to 325.27 rpm. Meanwhile, rotational speeds of less than 112.52 rpm will decrease at wind speeds of 1.97 m/s to 2.12 m/s. The rotor torque produced is greatest when the wind speed is 6.13 m/s and the rotation speed is 325.27 rpm, namely 0.0049 Nm. The thrust value is greatest when the rotation speed is 325.27 rpm, namely 0.38 N. When the wind speed 3.37 m/s and a rotation speed of 179.08 rpm can produce 0.0256 watts of power.

Graphic results on a wind turbine with 3 blades with a pitch angle of 0°, there is a change in performance and thrust due to the changed pitch angle and tends to increase.

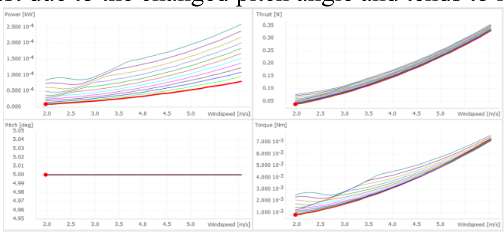

Fig 4. 3. Graphic of Performance Results for a 3 blade horizontal axis wind turbine at a pitch angle of 5°

From Fig 4.3, data is obtained that the power is greatest when the speed is 6.13 m/s with a rotational speed of 325.27 rpm, namely 0.2712 watts. Power tends to increase when the rotational speed is 135.66 rpm to 325.27 rpm. Meanwhile, rotational speeds of less than 135.66 rpm will decrease at wind speeds of 1.97 m/s to 2.35 m/s. The rotor torque produced is greatest when the wind speed is 6.13 m/s and the rotation speed is 325.27 rpm, namely 0.0076 Nm. The thrust value is greatest when the rotation speed is 325.27 rpm, namely 0.357 N. When the wind speed is 3, 37 m/s and a rotation speed of 179.08 rpm can produce 0.0413 watts of power.

Graphic results in a wind turbine with 3 blades with a pitch angle of 5° there are changes in power and thrust due to the changed pitch angle.

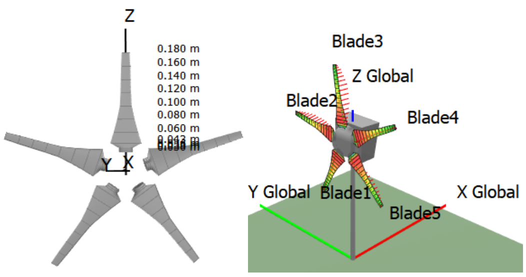

Fig 4. 4. TASH simulation uses Q-Blade with 5 Blade variations

The results of testing using the Q-Blade were obtained in the form of Power, Thrust, Rotational speed, Rotor Tourqe values with variations in the number of blades and pitch angles with wind speeds from 1.97 m/s to 6.13 m/s. The graphic results of a wind turbine with 5 blades with pitch angles of 0° and 5° have been obtained. The data obtained is that the greater the wind speed and rotational speed, the greater the performance produced.

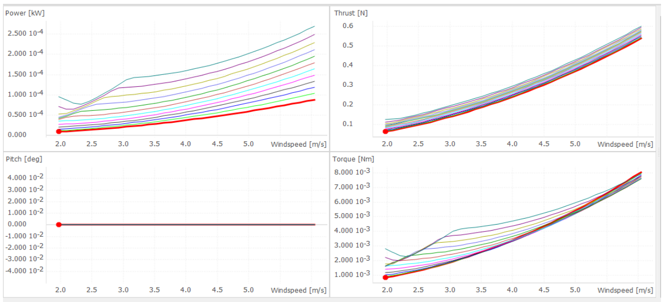

Fig 4. 5. Graphic of Performance Results for a 5 blade horizontal axis wind turbine at a pitch angle of 0°

From Fig 4.5, data is obtained that power is greatest when the speed is 6.13 m/s with a rotational speed of 325.27 rpm, namely 0.272 watts. Power tends to increase when the rotational speed is 158.59 rpm to 325.27 rpm, while for rotational speed of less than 158.59 rpm will decrease at wind speeds of 1.97 m/s to 2.98 m/s. The rotor torque produced is greatest when the wind speed is 6.13 m/s and the rotation speed is 325.27 rpm, namely 0.0077 Nm. The thrust value is greatest when the rotation speed is 325.27 rpm, namely 0.63 N. When the wind speed 3.37 m/s and a rotation speed of 179.08 rpm can produce 0.0425 watts of power.

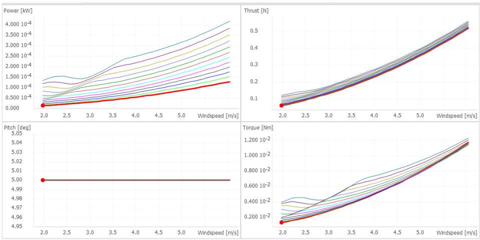

Fig 4. 6. Graphic of Performance Results for a 5 blade horizontal axis wind turbine at a pitch angle of 5°

From Fig 4.6, data is obtained that the power is greatest when the speed is 6.13 m/s with a rotational speed of 325.27 rpm, namely 0.4327 watts. Power tends to increase when the rotational speed is 167.19 rpm to 325.27 rpm. Meanwhile, rotational speeds of less than 167.19 rpm will decrease at wind speeds of 1.97 m/s to 3.15 m/s. The rotor torque produced is greatest when the wind speed is 6.13 m/s and the rotation speed is 325.27 rpm, namely 0.0123 Nm. The thrust value is greatest when the rotation speed is 325.27 rpm, namely 0.56 N. When the wind speed 3.37 m/s and a rotation speed of 179.08 rpm can produce 0.0680 watts of power.

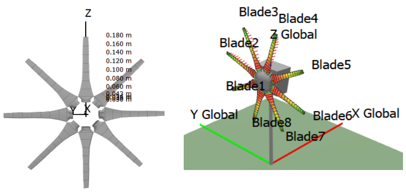

Fig 4. 7. TASH simulation uses Q-Blade with 8 Blade variations

The results of testing using the Q-Blade were obtained in the form of Power, Thrust, Rotational speed, Rotor Tourqe values with variations in the number of blades and pitch angles with wind speeds from 1.97 m/s to 6.13 m/s. The graphic results of a wind turbine with 8 blades with a pitch angle of 0° and 5° have been obtained. The data obtained is that the greater the wind speed and rotational speed, the greater the performance produced.

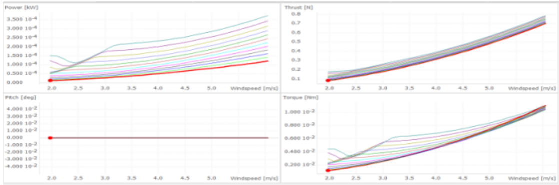

Fig 4. 8. Graphic of Performance Results for a 8 blade horizontal axis wind turbine at a pitch angle of 0°

From Fig 4.8, data is obtained that the power is greatest when the speed is 6.13 m/s with a rotational speed of 325.27 rpm, namely 0.3800 watts. Power tends to increase when the rotational speed is 158.59 rpm to 325.27 rpm. Meanwhile, rotational speeds of less than 158.59 rpm will decrease at wind speeds of 1.97 m/s to 2.98 m/s. The rotor torque produced is greatest when the wind speed is 6.13 m/s and the rotation speed is 325.27 rpm, namely 0.0110 Nm. The thrust value is greatest when the rotation speed is 325.27 rpm, namely 0.77 N. When the wind speed 3.37 m/s and a rotation speed of 179.08 rpm can produce 0.0670 watts of power.

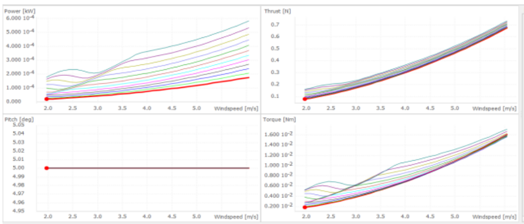

Fig 4. 9. Graphic of Performance Results for a 8 blade horizontal axis wind turbine at a pitch angle of 5°

From Fig 4.9, data is obtained that the power is greatest when the speed is 6.13 m/s with a rotational speed of 325.27 rpm, namely 0.5800 watts. Power tends to increase when the rotational speed is 179.08 rpm to 325.27 rpm. Meanwhile, rotational speeds of less than 179.08 rpm will decrease at wind speeds of 1.97 m/s to 3.37 m/s. The rotor torque produced is greatest when the wind speed is 6.13 m/s and the rotation speed is 325.27 rpm, namely 0.0170 Nm. The thrust value is greatest when the rotation speed is 325.27 rpm, namely 0.74 N. When the wind speed 3.37 m/s and a rotation speed of 179.08 rpm can produce 0.0900 watts of power.

Tabel 4.5. Data Performance Results for 3 blade Using Q-Blade Software

Performance Results for a 3 blade									
Pitch angel of 0°					**Pitch angel of 5°**				
No.	**V (m/s)**	**P (Watt)**	**T (Nm)**	**S (N)**	**No.**	**V (m/s)**	**P (Watt)**	**T (Nm)**	**S (N)**
1	1,97	0,0050	0,00048	0,040	1	1,97	0,0090	0,0008	0,037
2	2	0,00512	0,0005	0,045	2	2	0,0100	0,0009	0,04
3	2,12	0,00743	0,0006	0,049	3	2,12	0,0111	0,001	0,045
4	2,35	0,00902	0,0007	0,052	4	2,35	0,0150	0,0011	0,053
5	2,55	0,0130	0,00083	0,069	5	2,55	0,0170	0,0013	0,063
6	2,65	0,0146	0,0009	0,075	6	2,65	0,0212	0,0015	0,07
7	2,78	0,0149	0,00097	0,08	7	2,78	0,0236	0,0017	0,078
8	2,98	0,0168	0,0011	0,089	8	2,98	0,0298	0,0019	0,08

9	3,15	0,0200	0,0013	0,10	9	3,15	0,0351	0,002	0,09
10	3,37	0,0256	0,0015	0,12	10	3,37	0,0413	0,0023	0,11
11	6,13	0,1720	0,0049	0,38	11	6,13	0,2712	0,0076	0,357

Tabel 4.6. Data Performance Results for 5 blade Using Q-Blade Software

Performance Results for a 5 blade									
Pitch angel of 0°					**Pitch angel of 5°**				
No.	**V (m/s)**	**P (Watt)**	**T (Nm)**	**S (N)**	**No**	**V (m/s)**	**P (Watt)**	**T (Nm)**	**S (N)**
1	1,97	0,0093	0,0008	0,062	1	1,97	0,0146	0,0013	0,065
2	2	0,0100	0,0009	0,07	2	2	0,0150	0,0015	0,0067
3	2,12	0,0112	0,001	0,078	3	2,12	0,0167	0,0017	0,072
4	2,35	0,0150	0,0012	0,088	4	2,35	0,0238	0,0019	0,083
5	2,55	0,0175	0,0014	0,11	5	2,55	0,0273	0,0021	0,10
6	2,65	0,0220	0,0015	0,12	6	2,65	0,0357	0,0022	0,11
7	2,78	0,0250	0,0016	0,13	7	2,78	0,0416	0,0025	0,12
8	2,98	0,0311	0,0018	0,14	8	2,98	0,0498	0,0029	0,13
9	3,15	0,0361	0,0021	0,16	9	3,15	0,0564	0,0032	0,15
10	3,37	0,0425	0,0025	0,19	10	3,37	0,0680	0,0039	0,18
11	6,13	0,2720	0,0077	0,63	11	6,13	0,4327	0,0123	0,56

Tabel 4.7. Data Performance Results for 8 blade Using Q-Blade Software

Performance Results for a 8 blade									
Pitch angel of 0°					**Pitch angel of 5°**				
No.	**V (m/s)**	**P (Watt)**	**T (Nm)**	**S (N)**	**No.**	**V (m/s)**	**P (Watt)**	**T (Nm)**	**S (N)**
1	1,97	0,0120	0,0012	0,09	1	1,97	0,0200	0,002	0,079
2	2	0,0135	0,0013	0,10	2	2	0,0220	0,0022	0,086
3	2,12	0,0150	0,0014	0,11	3	2,12	0,0237	0,0024	0,095
4	2,35	0,0200	0,0015	0,12	4	2,35	0,0300	0,0027	0,11
5	2,55	0,0226	0,0019	0,14	5	2,55	0,0380	0,0030	0,13
6	2,65	0,0310	0,0020	0,15	6	2,65	0,0483	0,0032	0,14
7	2,78	0,0350	0,0023	0,17	7	2,78	0,0550	0,0035	0,15
8	2,98	0,0450	0,0026	0,18	8	2,98	0,0710	0,0040	0,17
9	3,15	0,0051	0,0029	0,21	9	3,15	0,0800	0,0043	0,20
10	3,37	0,0670	0,0035	0,25	10	3,37	0,0900	0,0052	0,23
11	6,13	0,3800	0,0110	0,77	11	6,13	0,5800	0,0170	0,74

From the data above, it can be concluded that the power is greatest when the pitch angle is 5° with a power of 0.5800 watts, and there is an increase in the thrust value where the greater the pitch angle, the greater the thrust value produced.

This research also analyzes the performance of 3 blade, 5 blade and 8 blade horizontal axis wind turbines. Then the table above specifically results from wind turbine performance testing for the average wind speed in Indonesia, namely 6.13 m/s and for a maximum rotation speed of 325.27 rpm for small scale wind turbines can be seen in the table.

4.4. Conclusion

1. Based on data from turbine performance simulation analysis using Q-Blade software, the greatest power value is in a turbine with 8 blades, with an angle of 5°, namely 0.0900 watts when the wind speed is 3.37 m/s and 179.08 rpm. For turbines with low speeds and blade lengths that are not too large, the power produced is not too large. The wind turbine tested at the average wind speed in Indonesia, namely 6.13 m/s and a rotational speed of 325.27 rpm, was found to be the most efficient wind turbine with 8 blades with a power of 325.27 watts, rotor torque of 0, 0170 Nm and thrust 0.74 N, for the most efficient pitch angle is a pitch angle of 5° for each variation in the number of blades tested. Meanwhile, calculation analysis using constant TSR (λ = 1) and slowly increasing wind speed, it can be seen that the best turbine efficiency is obtained at a speed of 1.972 m/s with a wind rotation speed of 104.67 rpm, turbine power of 0.27 Watt and efficiency amounting to 56.6%. And the smallest efficiency in the wind turbine was obtained at a speed of 3.374 m/s with a wind rotation speed of 179.08 rpm, turbine power of 0.46 Watt and efficiency of 19.3%. So it can be concluded that the greater the wind rotation speed, the greater the wind power and turbine power produced, but the value of the power coefficient (Cp), namely the ratio between the values (turbine power divided by wind power), is smaller, so the efficiency of the wind turbine decreases.
2. From the results of the calculation analysis, the difference in the number of Blades is influenced by the Reynolds (Re) value so it can be concluded that the smaller the number of Blades, the greater the Reynolds for Blade (Re) value, but the greater the number of Blades, the smaller the Reynolds for Blade (Re) value, and if the greater the wind speed for each number of blades, the greater the Reynolds number, so that after analysis the best Reynolds value is obtained using 3 blades with a speed of 3,374 m/s and a Reynold for Blade (Re) of 50,565.
3. Based on data from calculations of the effective efficiency of wind turbines for each model that have been carried out, using constant TSR, the Reynolds value (Re) is influenced by the number of blades (B). So, the greater the speed, the greater the value of Reynolds for blade (Re), but the greater the number of blades, the value of Reynolds for blade (Re) decreases. And the best Reynolds value is obtained by using 3 blades at a speed of 3.374 m/s and the Reynolds value for blade (Re) is 50565.

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