ISSN Print : 2621-3745
ISSN Online : 2621-3753
DOI : 10.31328/jsae.v6i2.4820
(Page.30-39)

AERODYNAMIC STUDY OF CHORD LENGTH EFFECT IN LOW SPEED WIND TURBINE USING 6 DOF CFD METHOD

S. A. Susanto[1], H. Wicaksono[2,*], H. I. Firmansyah[3], M. Fakhruddin[4]

[1,2,3]Department of Mechanical Engineering, Politeknik Negeri Malang, Malang, Indonesia
**Email:wicaksonohangga@polinema.ac.id*

Submitted : 17 July 2023; *Revision :* 27 August 2023; *Accepted :* 5 October 2023

ABSTRACT

The dependencies on fossil energy as a basic energy source has many negative impacts, therefore alternative energy is needed to overcome the problem, one of which is the alternative green energy wind turbines. However, wind turbines in Indonesia are difficult to implement because the wind speed in Indonesia is low, which is around 4-8 m/s, therefore it is necessary to do research to improve the ability of wind turbines applied in Indonesia. The analysis method using the 6 DoF CFD method and the experimental carried out using the wind tunnel. The blade used in this study is a custom combination airfoil with the chord lengths of 0.1 m, 0.15 m and 0.2 m. The results shows that, at wind speed of 8 m/s the blade with a chord length of 0.2 m has the greatest pressure of 47 Pa and rotational speed per minute of 76.1 rpm, this variation can be applied to low rpm generators. Whereas blades with a chord length of 0.1 m and a twist angle of 15o have a pressure of 47 Pa, and rotational speed of 97.24 rpm per minute, this variation can be applied to high rpm generators.

Keywords HAWT; CFD 6DoF; Chord Length; Alternative Energy;
Paper type Research paper

INTRODUCTION

The energy usage in Indonesia has a highly dependencies on fossil fuel. The energy used comes from fossil fuels such as oil, natural gas and coal. Because the need for the use of fossil energy sources will increase, the availability of fossil energy sources will decrease. The government estimates that per capita electricity consumption in the country will increase in 2023, the amount is projected to grow5.3%. The government has set a target for the energy mix for power plants by the end of 2025 for Coal at 54.4%, Renewable Energy 23.0%, Gas 22.2% and Fuel Oil 0.4%. [1].

Utilization of wind energy is by using wind turbines. There are two types of wind turbines, namely vertical wind turbines and horizontal wind turbines. A Vertical Axis Wind Turbine (or VAWTf producing 50% lower efficiency than a horizontal wind turbine because of the additional drag it has when the wheel rotates [2]. Horizontal Axis Wind Turbines (or HAWT) have a higher efficiency than vertical wind turbines, because the blades always move perpendicular to the wind direction. Therefore the linear speed of the blades can be greater than the wind speed, but this turbine is more suitable for use in medium and high wind types [3] [4]. Due to Indonesia's low average wind speed, high technology installation costs, and the lack of manufacturing institutions or manufacturers that produce wind turbines, horizontal wind turbines are difficult to implement in Indonesia.

One of the main components of a wind turbine is the blades. In a wind turbine the blades are in direct contact with the wind. The blade used must fulfill physical aspects which include strength, elasticity, and resistance [5]. The blade itself is divided into three types based on its shape, namely taperless, taper and inverse taper [6]. The blade will be affected by the presence of drag (compressive force) which is parallel to the direction of fluid flow and lift (lift) which is perpendicular to the direction of fluid flow. So that the blade can rotate due to the lift and drag forces but it is also influenced by the shape of the blade, wind speed and surface area of the plane [7].

In turbine blades, the front is called the leading edge and the rear is called the trailing edge. The distance from the leading edge to the trailing edge of an airfoil is called the chord length.

ISSN Print : 2621-3745
ISSN Online : 2621-3753
(Page.30-39)

Vol. 6, No. 2, October 2023
DOI : 10.31328/jsae.v6i2.4820

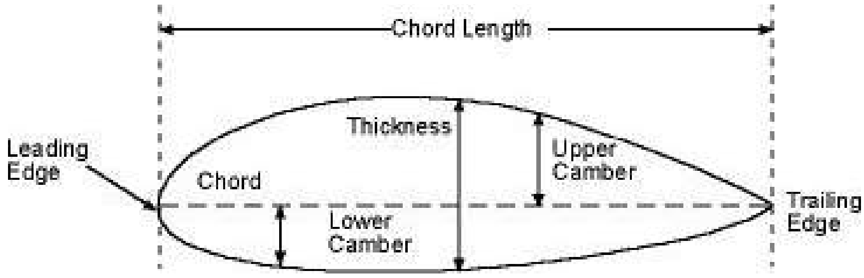


Figure 1. Chord length definition [8]

According to Refference [9] the determinination of the chord as a function of the distance from the center of rotation can be found using the Betz approach with the equation:

$$C = \frac{16\pi R(R/r)}{9\lambda^2 B} \tag{1}$$

Whereas: C = chord (m)
R = blade radius (m)
r = distance from the center of rotation (m)
λ = tip speed ratio
B = number of blades

The angle of twist is defined as the difference in angle between the airfoil at the base of the blade and the tip of the blade.

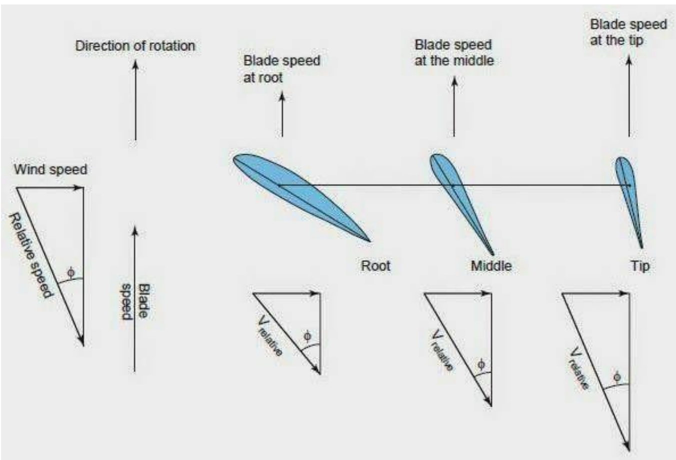


Figure 2. Twist angle [10]

The equation (2) can be used to determine the twist angle

$$\beta = \arctan\left(\frac{2R}{3r\lambda}\right) - a \tag{2}$$

Whereas: β = twist angle
R = radius of the rotor (m)
r = distance from the center of rotation (m)
λ = tip speed ratio
α = sudut serang (angle of attack)

Further investigation is needed so that horizontal axis wind turbines can be applied to low wind speeds in Indonesia. To get optimal performance from a horizontal wind turbine, it is important to test the blades on the wind turbine. The blades are the part of the turbine that is in direct contact with the wind. This research was conducted to determine the effect of Twist Angle and Chord Length on the aerodynamic characteristics of conventional wind turbines with low wind speeds.

ISSN Print : 2621-3745
ISSN Online : 2621-3753
DOI : 10.31328/jsae.v6i2.4820
(Page.30-39)

METHOD

Blade Design and CFD Methods

The creation process of the blade design are conducted by using Q-Blade software. The blade design using the NACA 4412 airfoil:

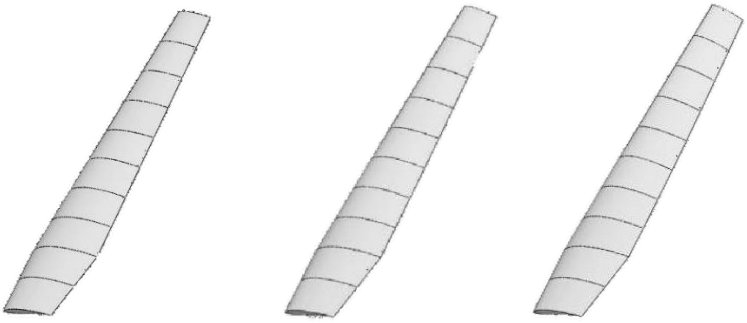


Figure 3. Blade with chord length of 0.1 m and twist angle of 5º, 15º, 25º

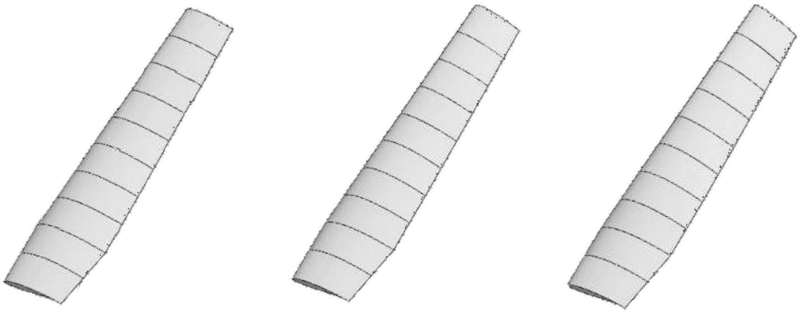


Figure 4. Blade with chord length of 0.15 m and twist angle of 5º, 15º, 25º

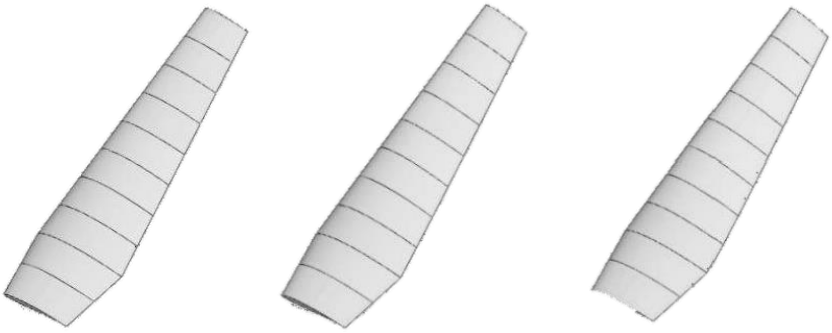


Figure 5. Blade with chord length of 0.2 m and twist angle of 5º, 15º, 25º

The CFD simulation study conducted using the 6 DOF method to determine the initial rotation [11]. Transient study using 0.5 s of timestep resulting on some data collected. The accumulated pressure data on the blade is collected in the last timestep to indicate the zone of the torque generated.

ISSN Print : 2621-3745
ISSN Online : 2621-3753
(Page.30-39)

DOI : 10.31328/jsae.v6i2.4820

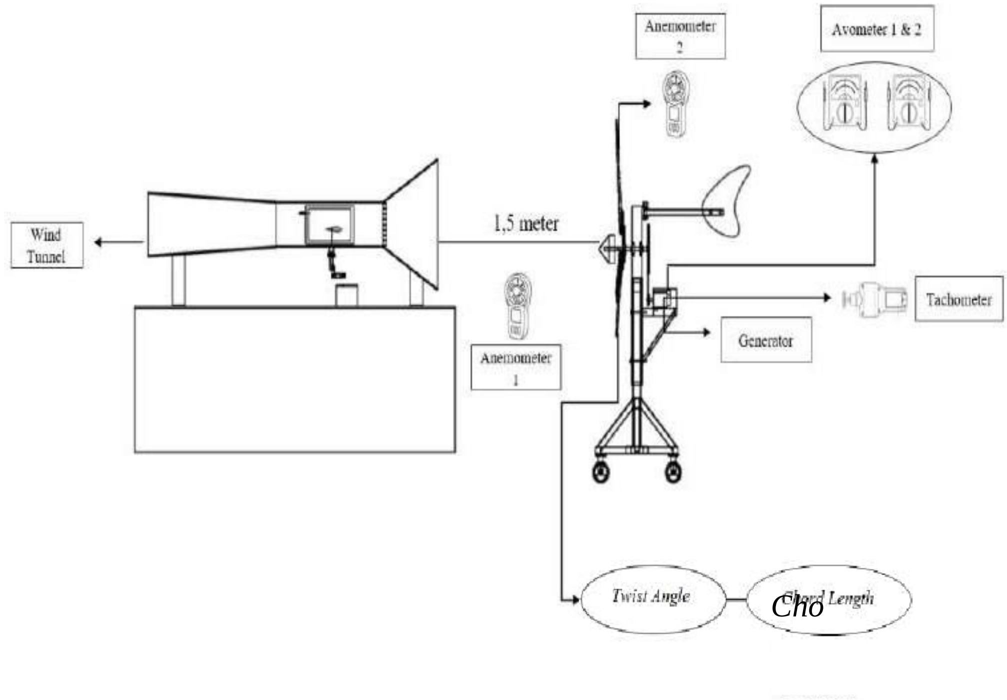


Figure 6. Experimental setup

The experimental method is carried out using the optimal data from the simulation results. Preparation of tools and materials by using the wooden carving. Some of the steps is as follows : Punch holes in the airfoil made of teak wood by 5 mm and 8 mm according to the design of each part. Reduce the diameter of the dowel so that it can enter the airfoil hole. Assemble the airfoil and dowel wood with glue so that the blade frame becomes sturdy. Coating the slats with wire mesh. The wire mesh is attached using G-glue and tissue. Fill the inside of the blade with PU foam by spraying it at every point evenly, then let it harden. Clean dry PU foam that extends over the airfoil frame and shapes it to follow the blade geometry. Coating the blade frame with fiber and resin. The ratio of resin and hardener is 10:1. The first layer of fiber is attached to the blade, then rubbed with resin. After all the first layer has been smeared with resin, proceed with the second layer in the same way, and wait for it to dry completely. The finished blade is then mounted on the turbine hub. Set the angle of attafck by 5°. Perform data collection consisting of the shaft rpm in each of the chord length and the twist angle of the wind turbine.

Figure 7. Experimental blade manufacture process

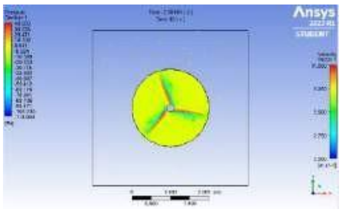
of Science and Applied Engineering (JSAE)
Vol. 6, No. 2, October 2023
DOI : 10.31328/jsae.v6i2.4820
ISSN Print : 2621-3745
ISSN Online : 2621-3753
(Page.30-39)

Figure 8. Assembled blade for experimental study

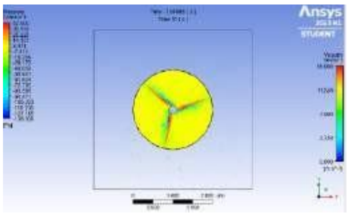
DISCUSSION

Pressure Contour Data

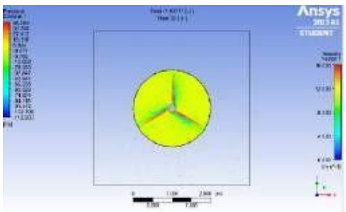
In the pressure test in the simulation, the results are obtained in the form of numbers and images in the CFD Software based on 6DoF method. In this simulation, a wind turbine blade is blown by the wind with the constant speed of 8 m/s, then the turbine will start rotating at low speed until it reaches its maximum.



(a)



(b)



(c)

Figure 9. Pressure contour at *Chord Length* 0.1 m
(a) *Twist Angle* 5° (b) *Twist Angle* 15° (c) *Twist Angle* 25°

The maximum pressure value in the turbine simulation with a Chord Length of 0.1 m is summarized in tabular form as follows:

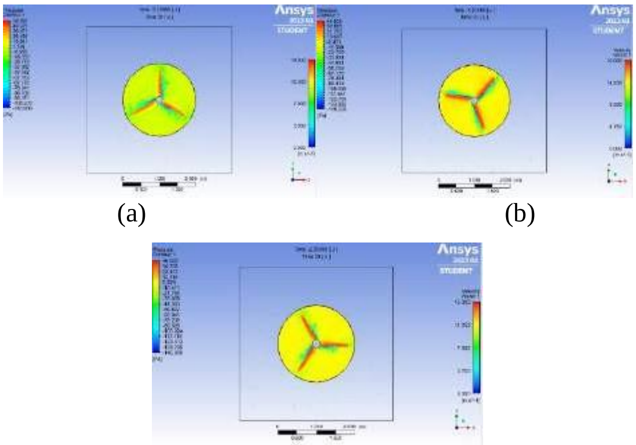
TABLE I. PRESSURE VALUE AT CHORD LENGTH 0.1 M

No.	Wind Speed (m/s)	Twist Angle	Pressure (Pa)
1	8 m/s	5^{0}	48
2	8 m/s	15^{0}	47
3	8 m/s	25^{0}	46

ISSN Print : 2621-3745
ISSN Online : 2621-3753
(Page.30-39)

Vol. 6, No. 2, October 2023
DOI : 10.31328/jsae.v6i2.4820

The highest pressure value on the surface of the blade is obtained at Twist Angle 5°, namely, 48 Pa. In this chord length variation the pressure tends to decrease along with the highere twist angle. The minimum pressure generated was 46 Pa at the twist angle of 25°.



(a) (b)

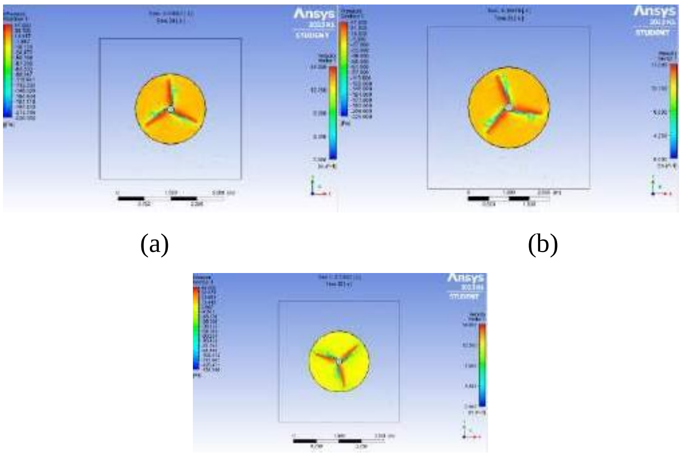
(c)

Figure 10. Pressure contour at Chord Length 0.15 m
(a) *Twist Angle* 5° (b) *Twist Angle* 15° (c) *Twist Angle* 25°

TABLE II. PRESSURE VALUE AT CHORD LENGTH 0.15 M

No.	Wind Speed (m/s)	Twist Angle	Pressure (Pa)
1	8 m/s	5^0	44
2	8 m/s	15^0	50
3	8 m/s	25^0	46

The highest pressure value on the surface of the blade is obtained at a Twist Angle of 15°, that is, 50 Pa. In this chord length variation the lowest pressure value gain at the twist angle of 50. The average pressure value of this chord length variation was 46.67 Pa.



(a) (b)

(c)

Figure 11. Pressure contour at Chord Length 0.2 m
(a) *Twist Angle* 5° (b) *Twist Angle* 15° (c) *Twist Angle* 25°

The maximum pressure value in the turbine simulation with a Chord Length of 0.2 m is summarized in tabular form as follows:

ISSN Print : 2621-3745
ISSN Online : 2621-3753
DOI : 10.31328/jsae.v6i2.4820
(Page.30-39)

TABLE III. PRESSURE VALUE AT CHORD LENGTH 0.2 M

No.	Wind Speed (m/s)	Twist Angle	Pressure (Pa)
1	8 m/s	5^0	44
2	8 m/s	15^0	50
3	8 m/s	25^0	46

The highest pressure value on the surface of the blade is obtained at the Twist Angle of 5° and 15°, that is, 47 Pa.

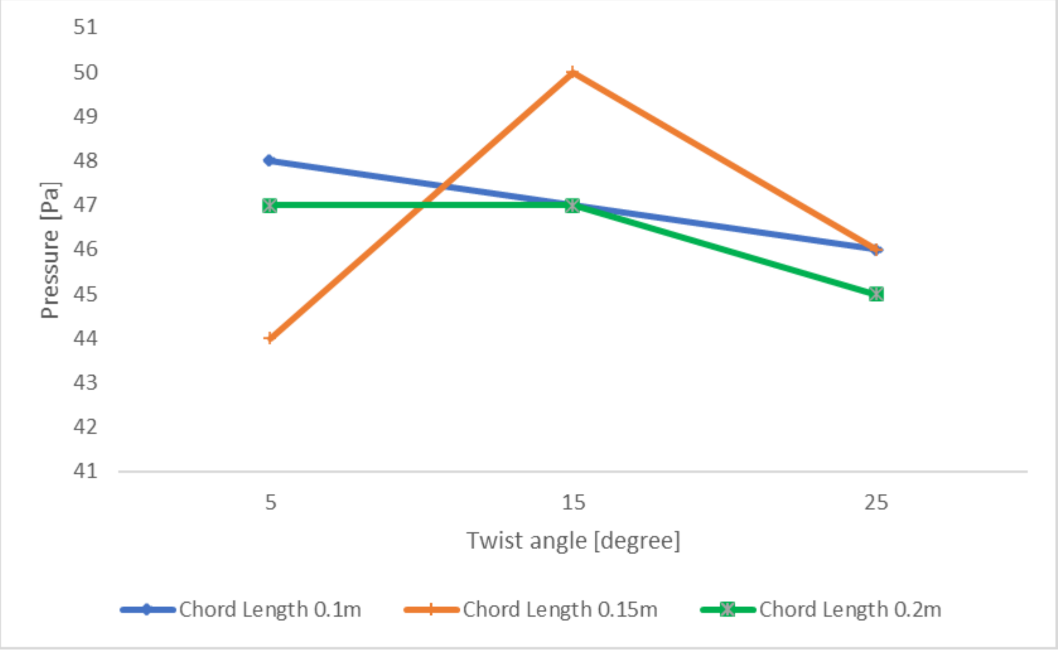


Figure 12. The effect of Chord Length and twist angle towards maximum pressure

From the results of the simulation test using 6 DoF method above, the chord length and twist angle variations produce different maximum pressures. When the wind passes through the blade, the wind will exert a force on the blade, namely drag and lift. The lift force is caused by the fluid velocity on the upper surface of the airfoil flowing faster than on the lower surface, so the pressure on the upper surface area of the blade is lower than the lower surface, it is this pressure difference that causes the blade to lift. The length of the chord length and the tilt angle of the twist can affect the lifting force of the blade. Too sharp a twist slope can affect the pressure distribution around the airfoil, significantly reducing lift and increasing drag.

Revolution per Minute (RPM)

RPM is a measure of the number of times a wind turbine blade rotates in one minute. The optimal RPM for a wind turbine at low speed can vary depending on the design and size of the wind turbine. In general, low speed wind turbines are designed to operate at lower RPM than high speed wind turbines. The goal of using lower RPM on a low speed wind turbine is to optimize efficiency and power generation. Low wind speed means the blades must rotate more slowly to generate maximum power. By keeping the RPM at the optimal range, wind turbines can achieve better efficiency in converting wind kinetic energy into electrical energy. The RPM values in the turbine with a Chord Length of 0.1 m are summarized in tabular form as follows:

TABLE IV. RPM VALUES AT CHORD LENGTH 0.1 M

No.	Wind Speed (m/s)	Twist Angle	Pressure (Pa)
1	8 m/s	5^0	57,5945
2	8 m/s	15^0	97,2409
3	8 m/s	25^0	73.2846

ISSN Print : 2621-3745
ISSN Online : 2621-3753
(Page.30-39)

Vol. 6, No. 2, October 2023
DOI : 10.31328/jsae.v6i2.4820

The highest RPM value at the 30s time step is obtained at a 15° Twist Angle, namely 97.2409 rpm. The table above is summarized in the Figure 13 below:

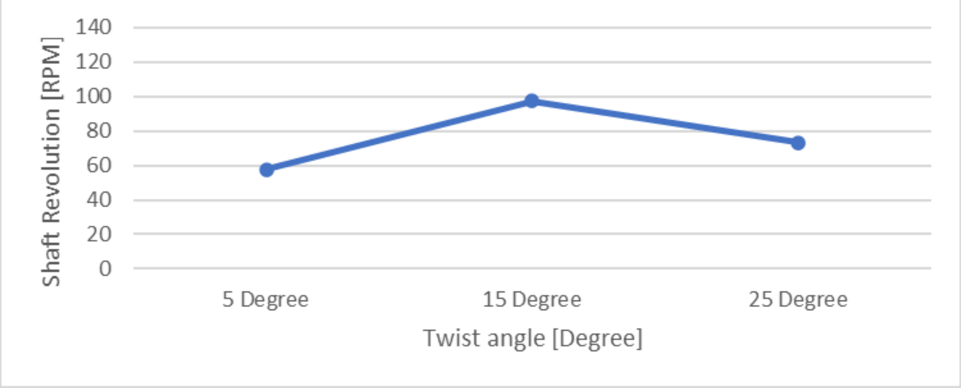


Figure 13. Graph of the twist angle effect towards the shaft revolution in 0.1 m chord length

The RPM values in the turbine with a Chord Length of 0.15 m are summarized in tabular form as follows:

TABLE V. RPM VALUES AT CHORD LENGTH 0.15 M

No.	Wind Speed (m/s)	Twist Angle	Pressure (Pa)
1	8 m/s	5^{0}	55,2314
2	8 m/s	15^{0}	74,2049
3	8 m/s	25^{0}	61,4946

The highest RPM value at the 30s time step is obtained at a 15° Twist Angle, namely 74.2049 rpm. The table above is summarized in the Figure 14 below:

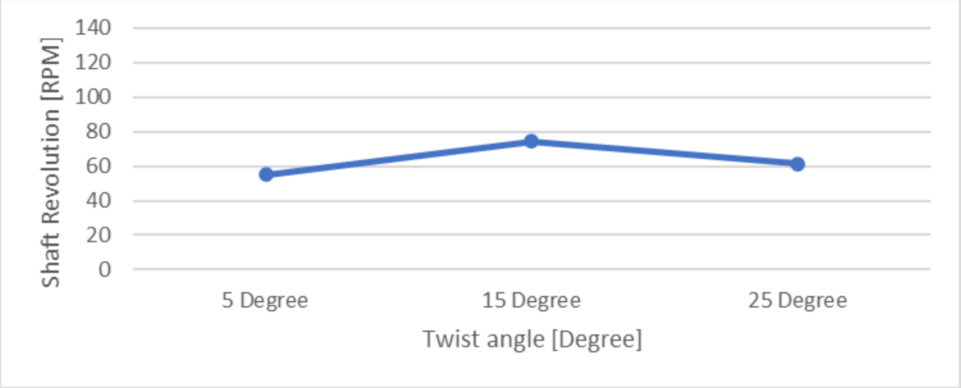


Figure 14. Graph of the twist angle effect towards the shaft revolution in 0.15 m chord length

The RPM values in the turbine with a Chord Length of 0.2 m are summarized in tabular form as follows:

TABLE VI. RPM VALUES AT CHORD LENGTH 0.2 M

No.	Wind Speed (m/s)	Twist Angle	Pressure (Pa)
1	8 m/s	5^{0}	76,0668
2	8 m/s	15^{0}	78,5472
3	8 m/s	25^{0}	58,7201

The highest RPM value at the 30s time step is obtained at a 15° Twist Angle, namely 78.5472 rpm.

ISSN Print : 2621-3745
ISSN Online : 2621-3753
DOI : 10.31328/jsae.v6i2.4820
(Page.30-39)

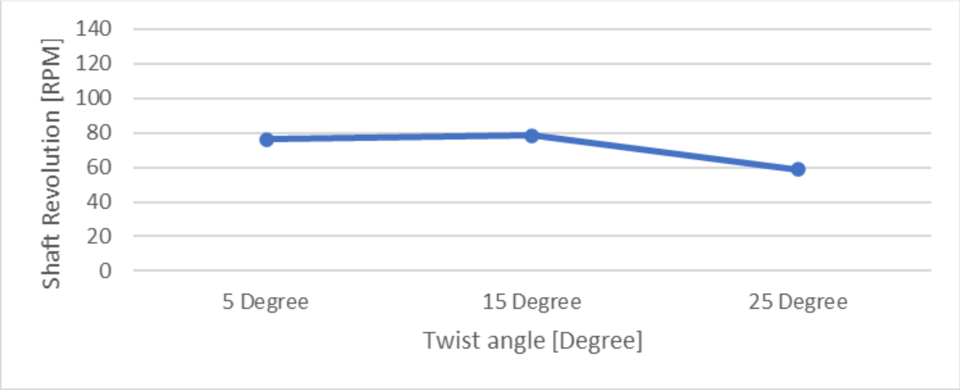


Figure 15. Graph of the twist angle effect towards the shaft revolution in 0.2 m chord length

Based on the data above, longer chord lengths tend to produce lower rpm in wind turbines. This is due to the increased surface area on the turbine blades with longer chord lengths, which results in an increased torque required to rotate the blades at a certain speed. Twist angle can affect wind turbine rpm, especially in low speed wind turbines. A larger twist angle tends to result in higher rpm at lower wind speeds.

CONCLUSION

The chord length and twist angle highly affected the wind turbine characteristic. By investigating the aerodynamics phenomenon it can be concluded that larger chord length tends to have a higher pressure area but leads to a lower RPM value. The twist angle affected the wind direction thus the speed of the blade rotation tends to faster in the smaller twist angle

At a wind speed of 8 m/s, blades with a chord length of 0.2 m and a twist angle of 5o have the pressure of 47 Pa, and rotational speed of 76 per minute .0668 rpm, this variation can be applied to lower rpm generators. Whereas blades with a chord length of 0.1 m and a twist angle of 15o have a pressure of 47 Pa, and a rotational speed of 97.2409 rpm per minute, this variation can be applied to higher rpm generators.

REFERENCES

[1] Website Ministry of Energy and Mineral Resources of Indonesia https://ebtke.esdm.go.id/post/2023/01/20/3405/ : accessed on: May 2023
[2] Akbari, V., Naghashzadegan, M., Kouhikamali, R., Afsharpanah, F., & Wahiba Yaïci. (2022). Multi-Objective Optimization of a Small Horizontal-Axis Wind Turbine Blade for Generating the Maximum Startup Torque at Low Wind Speeds. Machines, 10(9), 785. https://doi.org/10.3390/machines10090785
[3] Aryanto, F., Mara, I. M., & Nuarsa, M. (2013). Pengaruh Kecepatan Angin Dan Variasi Jumlah Sudu Terhadap Unjuk Kerja Turbin Angin Sumbum Horizontal. Dinamika Teknik Mesin, Volume 3 ISSN: 2088-088X, 50-59.
[4] Chaudhary, M.K. and Roy, A. (2015), "Design & optimization of a small wind turbine blade for operation at low wind speed", World Journal of Engineering, Vol. 12 No. 1, pp. 83-94. https://doi.org/10.1260/1708-5284.12.1.83
[5] Manwell, J. F., McGowan, J. G., & Rogers, A. L. (2009). Wind Energy Explained. UK: A John Wiley and Sons, Ltd.
[6] Sifa, A., Casiman, S., & Habib, R. H. (2014). Pengujian Kincir Angin Horizontal Type Di Kawasan Tambak Sebagai Energi Listrik Alternatif Untuk Penerangan. IRWNS, 166-171.
[7] Sayoga, I. M., Wiratama, I. K., Mara, I. M., & Catur, A. D. (2014). Pengaruh Variasi Jumlah Blade Terhadap Aerodinamik Performan Pada Rancangan Kincir Angin 300 Watt. Dinamika Teknik Mesin, Vol. 2 ISSN- 2088-088X, 103109.
[8] Dheeraj M, Lakshmi Swathi S, Naresh D C. (2020). "Airfoil Design and Optimization for tailless aircrafts". Journal of Engineering Research and Application Vol. 10, Issue 4
[9] Ismail, & Arrahman, T. (Juli 2017). Perancangan Turbin Angin Sumbu Horizontal Tiga Sudu Dengan Kapasitas 3 MW. Presisi, Vol.18, 10-19.
[10] Purusothaman, M., Valarmathi, T. N., & S, P. R. (2016). Selection of Twist and Chord Distribution of Horizontal Axis Wind Turbine in Low Wind Conditions. IOP Conference

Journal of Science and Applied Engineering (JSAE)
Vol. 6, No. 2, October 2023
DOI : 10.31328/jsae.v6i2.4820

Series.Materials Science and Engineering, 149(1)https://doi.org/10.1088/1757-899X/149/1/012203

[11] H Wicaksono, SH Susilo, B Pranoto, M Fakhruddin. (2020). "Initial Rotation Characteristic Investigation of a Hybrid Savonius-Darrieus Wind Turbine using 6 DOF Computational Fluid Dynamics". Mekanika: Majalah Ilmiah Mekanika 20 (1), 9-17