JOURNAL OF ENGINEERING AND MANAGEMENT IN INDUSTRIAL SYSTEM VOL. 10 NO. 2 YEAR 2022
e-ISSN 2477-6025
DOI: 10.217776/ub.jemis.2022.010.02.5

DESIGN AND PERFORMANCE ANALYSIS OF HORIZONTAL AXIS WIND TURBINE TAPERLESS NACA 6510 USING QBLADE SOFTWARE

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Abstract *The crisis of non-renewable energy resources has pushed the global community to overcome the dominance of fossil fuel power plants. The utilization of new renewable energy sources is a solution because it is considered to have energy sources that will continue to be renewed, including wind energy. Since ancient times, wind energy can be harvested and converted into electrical energy using wind turbines. This research was conducted to analyze the feasibility of the design performance of the horizontal axis wind turbine blade NACA airfoil 6510. The feasibility analysis of the performance can be known from the simulation results by referring to the resulting efficiency value. The analysis was carried out by studying literature to determine the characteristics of the NACA airfoil 6510 and performance simulation using Qblade software. The design is carried out using data on the average maximum wind speed in Indonesia of 12 m/s. Therefore, the results of the feasibility of wind turbine blade design performance with NACA airfoil 6510 have an efficiency of 44%.*

Keywords*: Horizontal Axis Wind Turbine, NACA 6510, Performance Coefficient, QBlade*

1. Introduction

Indonesia's electrical energy needs are projected to increase by 4.7% per year by 2050. This encourages the large amount of energy generated by power plants. As many as 66-80% of power plants in Indonesia are dominated by fossil fuel power plants [1]. Fossil fuel energy sources will run out according to their availability in nature. This fact shows that the availability of fossil fuel plants is inversely proportional to the increasing energy demand. So, the use of new and renewable energy as a source of generating energy can be a middle ground [2].

Wind energy is one of the new renewable energy sources that can be used to generate electricity [3]. Wind turbine is considered to apply for the energy source because the sizes of current wind turbine can be applied for utilities ranging from homes to larger uses [4] and in Indonesia wind turbine is being developed. Many potential points have been installed with wind turbines and used as research areas and power plants. With the fact that Indonesia has a characteristic average wind speed of 4-12 m/s, micro-scale wind turbines are suitable for application [5].

Wind energy can be converted into electrical energy with the help of wind turbines. The blades of a wind turbine rotate when blown by the wind. The rotating blades will produce rotation of the generator which results in friction which produces DC electrical energy. Wind-blown blade rotation performance is affected by blade type design and NACA airfoil design. The blade type design and the NACA airfoil design can be adapted to the wind conditions in an area.

Parameters of the design performance analysis of wind turbine blades can be viewed from the resulting efficiency. The calculation of the efficiency of a blade is a sequence of analysis of geometric parameters, radius, airfoil, TSR, cord, setting angel, angel of attack, flow angel, number of blades on a wind turbine and selection of blade types. In a previous study, Kuntara [6] obtained different performance results on the horizontal axis wind turbine blade design (Horizontal Axis Wind Turbine) with NACA airfoil 4412.

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Published online at http://Jemis.ub.ac.id

Site this Article as Said, A., Dwiyani, F. (2022) DESIGN AND PERFORMANCE ANALYSIS OF HORIZONTAL AXIS WIND TURBINE TAPERLESS NACA 6510 USING QBLADE SOFTWARE. *Journal of Engineering and Management in Industrial System, 10 (2), p 24-28*
Paper Accepted : 5th December 2022
Paper Published : 29th December 2022

e-ISSN 2477-6025
DOI: 10.217776/ub.jemis.2022.010.02.5

The design is carried out on inverse, taper and taperless blades. Besides, Oktaviani [7] obtained different coefficients in the comparison analysis of NACA 6412 and 6415 airfoils.

Thus, this study aimed to analyze the performance of the wind turbine blade design model using the NACA airfoil digit 4 with a chamber value of 6%, cord length 5% of tenths of cord. The analysis was carried out using data on the average wind speed in Indonesia. This is intended as a feasibility analysis of the feasibility of wind turbine blade design as an effort to increase the feasibility of wind turbines in Indonesia as a power plant.

2. Methodology

The methodology used in this study is a simulation model using Microsoft Excel and QBlade software. The collected data of wind speed in Indonesia were inputted to the software to determine the coefficient of performance (Cp) of the wind turbine. The initial parameters were determined before the analysis using QBlade software.

The following are the test steps used in determining the initial parameters of the data in the analysis using QBlade software:

a. Calculating Efficiency Value

$$K = \eta_b \times \eta_g \times \eta_t \times \eta_c \quad (1)$$

where η_b = blade efficiency, η_g = transmission efficiency, η_t = generator efficiency, and η_c = controller efficiency.

b. Calculating Wind Power Value

$$P_{wind} = \frac{P_{el}}{K} \quad (2)$$

where P_{wind} = wind power, P_{el} = generator power capacity, K= system efficiency

c. Calculating the Sweep Area of the Blade

$$A = \frac{2 . P_{wind}}{\rho v_{max}{}^3} \quad (3)$$

where A = blade sweep area, P_{wind} = wind power, ρ = air density, v_{max^3} = maximum wind speed

d. Counting Blade Radius

$$R = \sqrt{\frac{A}{\pi}} \quad (4)$$

where R = blade radius, A = width of sweep,

e. Calculating the Value of Tip Speed Ratio

Tip Speed Ratio (TSR) is the ratio of the linear speed of the blade tip to the wind speed.

$$\lambda = \frac{V_{tip}}{V_{wind}} = \frac{\omega . r}{V_{wind}} \quad (5)$$

where λ = tip speed ratio, ω = the angular velocity, r = blade radius, V_{wind} = air speed

f. Preparing Blade Geometry Parameter Data

The bar is divided into 11 elements (1 base element and 10 equal length elements).

g. Calculating the Value of Partial Radius

$$r = 0{,}17 + [\left(\frac{R-0{,}17}{n}\right) \times (elemen)] \quad (6)$$

where r = partial radius, R= blade radius, N = number of elements,

h. Calculating Partial Tip Speed Ratio (TSR)

$$\lambda_r = \frac{r}{R} . \lambda \quad (7)$$

where λ_r = tip speed ratio partial, R= blade radius, r = partial radius, λ = tip speed ratio

i. Calculating the Value of the Lift Coefficient (Cl) for Each Element

$$C_l = \frac{16\pi . R . (\frac{R}{r})}{9\lambda^2 . B . C_r} \quad (8)$$

where C_l = elevator coefficient, B = number of blades, R = blade radius, C_r = blade chord length, λ = tip speed ratio, r = partial radius

j. Calculating Chord Value or Bar Width

$$C_r = \frac{16\pi . R . (\frac{R}{r})}{9\lambda^2 . B . C_l} \quad (9)$$

where C_l = elevator coefficient, B = number of blades, R = blade radius, λ = tip speed ratio,

r = partial radius

k. Calculating the Flow Angle Value/ Inflow Angel

$$\theta = \frac{2}{3} \frac{1}{\lambda_r} \quad (10)$$

where θ = flow angle, λ_r= *tip speed ratio* partial

l. Calculating Twist Angle Value

$$\beta = \theta - \alpha \quad (11)$$

where β = twisting angle, θ = flow angle, α = angle of attack

e-ISSN 2477-6025
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3. Analysis

The initial planning for the design of this horizontal axis wind turbine is collecting data of wind speed. The average wind speed for several regions in Indonesia has been presented in Table 1.

Table 1. Average Wind Speed Data [8]

Location	Wind speed (m/s)
Selayar,Sulawesi Selatan	4
Sidrap, Sulawesi Selatan	7.04
Jeneponto, Sulawesi Selatan	8.11
Garut, Jawa Barat	6,6
Purworejo, Jawa Tengah	5.32
Sukabumi, Jawa Barat	6.6
Bantul, DIY	4.1
Oelbubuk, NTT	6.7
Nusa Penida, Bali	4.9
Lebak, Banten	5.5
Baron, DIY	5.8

By using equations (1), (2), (3) and (4), the total efficiency value, wind power, blade area and blade radius are obtained. While the other parameter values are determined based on the use of the rotor type on the generator. This study used a simulation using the capacity and efficiency of the generator, transmission, and controller from the specifications of a micro-scale wind turbine with an output of 500 Watt.

Table 2. Blade Initial Parameters

Specification								
Generator Power Capacity	Efficiency				Wind Power	Maximum Wind Speed	Blade Sweep Area	Blade Fingers
	Blade	Generator	Controller	Transmission				
We	η_b	η_g	η_c	η_t	Wa	V_{max}	A	R
Watt	%	%	%	%	Watt	m/s	m^2	Meter
500	0.3 0.4	0.9	0.9	1	2,058 1,543	12	1.94 1.46	0.8

In order to rotate, the wind turbine blades must have a lift (Cl) greater than the resistance (Cd).

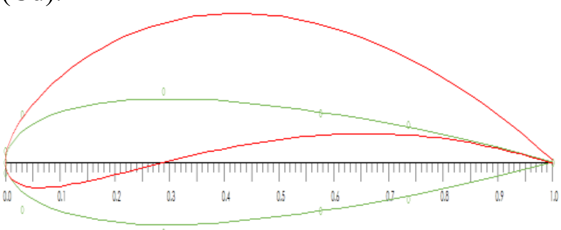

Fig 1. NACA *Airfoil* 6510

Based on the simulation results, the value of Cl/Cd for NACA airfoil 6510 is as follows:

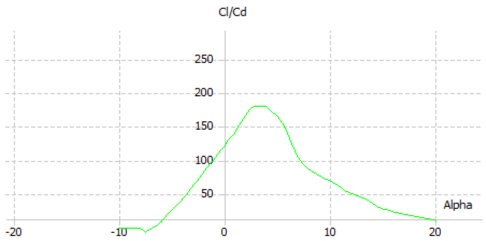

Fig 2. NACA Airfoil 6510. Cl/Cd Graph

e-ISSN 2477-6025
DOI: 10.217776/ub.jemis.2022.010.02.5

Table 3. Value of Cl/ Cd against Alpha NACA Airfoil 6510

Cl/ Cd	Alpha
164	5
141	6
140	6
105	7
104	7
86	8

The blade initial parameter is used as a performance analysis parameter for 3 taperless blades. The number of blades affects a wind turbine affects the TSR value. The TSR value in the study is assumed to be worth 7 from a range of values 6-8 [5]. Microsoft Excel software is used to determine the value of the wind turbine blade design parameters. Parameter calculations are calculated from elements 0 to 10. Data of partial fingers, TSR parsial, flow angel, twist are presented in table 4 (blade geometry design parameters)

Table 4. Blade Geometry Design Parameters

Elemen	Partial Fingers	TSR Parsial	*Flow Angle*	Cl	Alpha	Twist	Twist Linear 75%	Twist Optimum
0	0.17	1.49	22,61	1.19	4.80	17.81		11.91
1	0.23	2.04	17,42	0.87	2.48	14.94		11.45
2	0.30	2.59	14,07	0.68	1.18	12.89		10.98
3	0.36	3.14	11,77	0.56	0.24	11.54		10.51
4	0.42	3.69	10,10	0.48	-0.41	10.51		10.04
5	0.49	4.24	8,84	0.42	-0.86	9.70		9.58
6	0.55	4.80	7,85	0.37	-1.22	9.07		9.11
7	0.61	5.35	7,06	0.33	-1.58	8.64	8.64	8.64
8	0.67	5.90	6,42	0.30	-1.76	8.18	8.18	8.18
9	0.74	6.45	5,88	0.27	-2.04	7.92		
10	0.80	7.00	5.42	0.25	-2.22	7.64		7.71
								7.24

Parameters simulated using QBlade software with rotor simulation using the Blade Element Momentum method for 100 iterations and air density of 1,225 Kb/m^3 [9]. Based on the simulation results, the value of Cp for NACA airfoil 6510 is as follows:

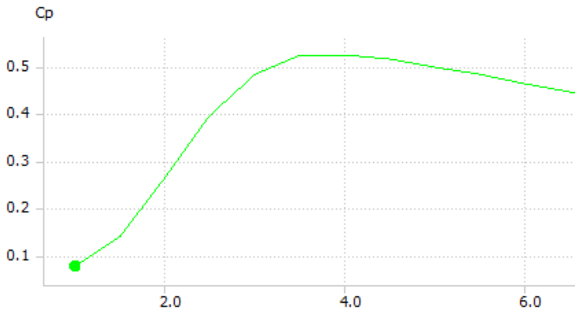

Fig 3. NACA airfoil 6510 Coefficient Power Graph

Table 5. Data Cp/TSR NACA *Airfoil* 6510

TSR	**Cp**
3	0.52
3.5	0.52
4	0.51
4.5	0.50
5	0.48
6	0.46
7	0.43

Based on the simulation results, the coefficient of power produced by wind turbine blades with NACA airfoil 6510 is 0.43 at TSR 7 with no losses. The simulation also shows the design of a micro-scale wind turbine with three blades at relatively low wind speeds with a NACA airfoil 6510 having an efficiency value of 44%.

e-ISSN 2477-6025
DOI: 10.217776/ub.jemis.2022.010.02.5

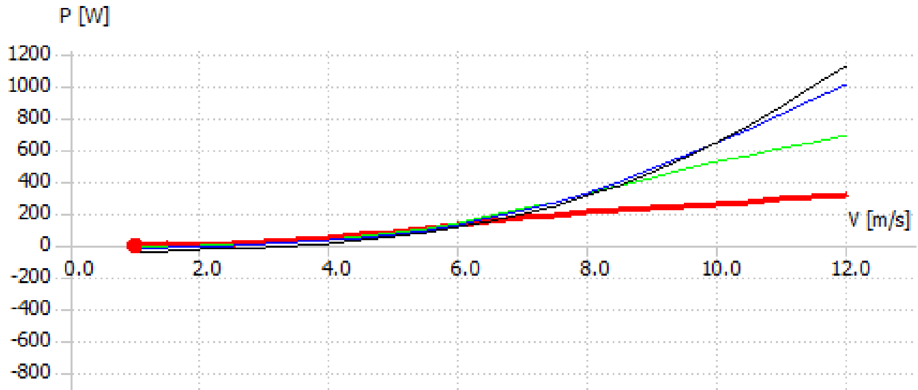

Fig 4. Graph of P against W on NACA airfoil 6510

It takes a minimum wind speed of 3 m/s to be able to rotate the blades of a wind turbine with NACA 6510. In addition, the type of taperless blade affects the effectiveness of the rotating blade when blown by relatively low and moderate winds. With this efficiency value, the blade can produce a maximum power of 1,100 Watt at a wind speed of 12 m/s at an angular speed of 700 rpm and 210 Watt at an angular speed of 200 rpm.

4. Conclusion

The simulation results of the NACA airfoil design of wind turbine blades using QBlade software show that the lift coefficient to the TSR value has an efficiency value of 49% without any losses. This exceeds the previously found upper limit of 32%.

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