Characteristic Analysis of Horizontal Axis Wind Turbine Using Airfoil NACA 4712

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ABSTRACT

Wind energy has been developed and used as a source of electrical energy by converting wind energy into electrical energy using a generator. There are some wind turbine parameters that important for wind turbines design and model, includes the size of the rotor radius, airfoil selection, chord length, and pitch angle. The study aims to characterize the performance of a horizontal axis wind turbine using computational methods. The methods used a design and simulation of NACA 4412 and NACA 4712 airfoil using QBlade software using wind conditions in the region of Pancer, Jember. Results show that the maximum Cl value of NACA 4712 is higher than in NACA 4412. NACA 4712 has a maximum Cl value = 1.696 at $\alpha = 14^o$ while NACA 4412 airfoil has a maximum value of Cl = 1.628 at $\alpha = 15^o$. NACA 4712 has the maximum value of Cl/Cd = 153 at $\alpha = 2^o$, while the NACA 4412 has a maximum value of Cl/Cd = 133.5 at $\alpha = 5.5^o$. The maximum value of Cl/Cd 4712 is higher than the NACA 4412. At 7.66 m/s of wind speed with 10% turbulence conditions, wind turbines with NACA 4712 airfoil have Cp turbine performance parameters of 0.49929 and obtain a power of 1.15 kW, while wind turbines with NACA 4412 have Cp turbine performance parameters of 0.395365 and obtained power of 0.889 kW at the same wind speed.

Keywords: *Airfoil NACA, angle of attack, Qblade, tip speed ratio, wind turbine*

I. Introduction

Energy resources can be grouped into two types, renewable energy, and non-renewable energy. Non-renewable energy can be produce from fossil energy, such as petroleum, coal, and natural gas. Total sectoral energy requirements in Indonesia in 2015 is 876,594,000 Barrel oil Equivalent (BOE). Total production of primary energy, such as coal, natural gas, petroleum, and renewable energy of Indonesia, in 2015, is 2,848,025,000 with BOE around 1,887,366,000 BOE exported to another country consists of coal, petroleum and natural gas. Indonesia also imports as much energy 348,267,000 BOE in the same year, consist of petroleum, fuel, and LPG. The transportation sector is the largest energy consumer, followed by industry and non-energy, household, commercial and other sectors [1].

Indonesia has the potential to be able to use renewable energy resources to electrify in rural areas. Thousands of islands from the archipelago make it difficult to build an electricity distribution connected to each other [2]. Wind energy is a renewable energy resource that has abundant availability, excellent energy density, and energy transfer. The development of wind energy in Indonesia is possible to do because of the wind speed potential, which is

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a coastal region so that it will be good enough for use as an energy resource for wind power generation [1].

Wind characteristics on the south coast of Java Island in 2010 showed wind speed varies from 1.72 m/s up to 10.15 m/s [3]. On the wind energy conversion system, various factors affect the performance of the wind turbine. One of them to consider is the design of the turbine rotor, including the rotor radius, airfoil, chord length, and turbine tread angle [4]. Higher wind speed produces a faster rotation of the turbine. It will generate higher mechanical power or even electrical power [5].

Blades design is one of the efforts to increase the reliability of wind turbines through developing airfoil structures as well to reduce the noise produced by wind turbines during rotation. Wind turbine blades have an important role because the blades are the part that interacts directly in system energy absorption. The wind turbine must be well designed to make it possible to absorb energy with the highest efficiency. Numerical modeling can be done using full three-dimensional computational fluid dynamics (CFD) with turbulence model k-ω STT. It is known that CFD predictions produce the most accurate power coefficient modeling. A good relationship about Coefficient of performance (Cp) that measured and calculated from the model is greatly impressive because it is possible to use the CFD method for accurate predictions of horizontal axis wind turbine (HAWT) performance at full scale [7]. The study aims to characterize the performance of a horizontal axis wind turbine with NACA 4412 and NACA 4712 using CFD methods.

II. Material and Methods

This research was conducted in the Pancer Beach, Puger, Jember, East Java. The computational method uses the Qblade v.0.6 open-source software was chosen to approach the real conditions in the field. Environment parameters for a wind turbine system were collected and further processed, expected to be able to produce data that can illustrate the wind energy potential into electrical energy that can be obtained from a horizontal axis wind turbine in the Puger coastal region. This research was conducted at the IT Laboratory of Engineering Faculty, Jember University.

The equipment used in this research was the computer, anemometers, and datalogger. There were three kinds of software used, such as Inventor to create the 3D design, Qblade, and Microsoft Excel, for calculating the wind turbine parameters. The independent variables were the angle of attack (α), tip speed ratio (TSR), and pitch angle (β). The dependent variables are Cp and output power generated by the wind turbine (P). The control variables were wind turbine type (horizontal axis wind turbine), blade type (taperless), airfoil types (NACA 4412 and NACA 4712), chord length (c) (0.15 m), and assumed efficiency value of the generator, controller, and transmission were 90%, 90%, and 80%, respectively.

The stages carried out in this research are literature studies, field studies, analysis of wind energy potential, determination of turbine type and airfoil, calculation, airfoil modeling and configuration, and makes the 3D CAD model of blades geometry.

III. Results and Discussions

A. *Wind speed and available wind power.*

The results of wind speed measurements on Pancer beach obtained wind speed distribution data shown in Figure 1. The maximum wind speed is 7.9 m/s and minimum wind speed 1.03 m/s. The average wind speed that occurs is 5.5 m/s. This average value is used as a reference in wind turbine blades design.

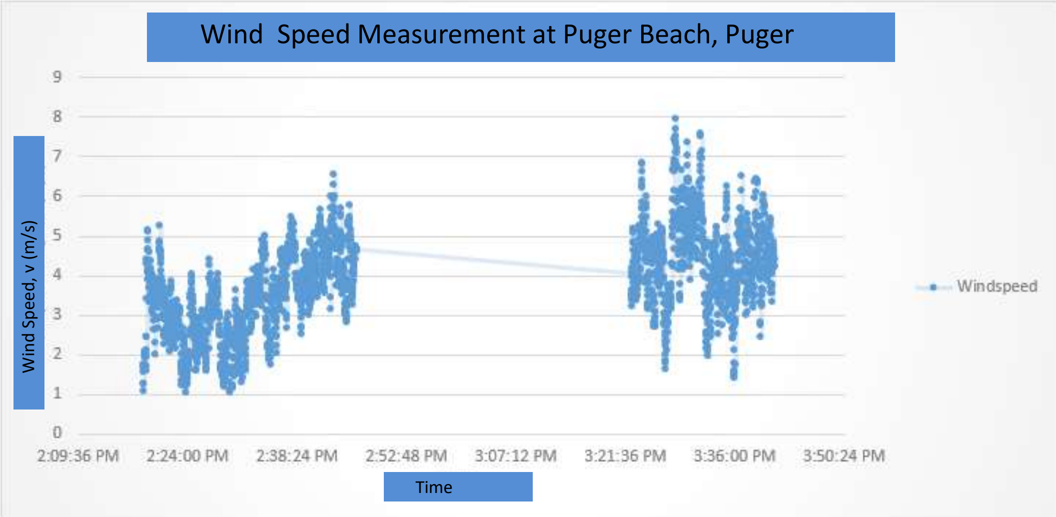

Fig. 1. Wind speed measurement at Pancer beach, Puger

The amount of wind power available at maximum wind speed = 7.9 m/s was calculated using Eq. 1:

$$Pw = \frac{1}{2}\,\rho A\, v^3 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

$$\frac{Pw}{A} = \frac{1}{2}\,\rho\, v^3$$

$$\frac{Pw}{A} = \frac{1}{2}\, 1.225\ kg/m^3 \,.\, (5.5\ m/s)^3$$

$$\frac{Pw}{A} = 301.9\ W/m^2$$

From the equation above can be known that there is wind power as much as $301.9\ W/m^2$ sweep area. Wind turbines can capture not all of that wind power, but only a part of it can be converted to mechanical energy, according to Betz theory, the maximum wind energy that can be captured by modern wind is 59%.

B. *Calculations*

In this research, the expected electric power (Pe) is 500 Watts. Several factors that affect the efficiency of the system is also determined, i.e., the blade efficiency, transmission efficiency generator efficiency, and efficiency controller. Each value of the efficiency of the components is shown in Table 1.

Table 1. Estimated efficiency of wind turbine components

No.	Component	Efficiency
1.	Blades	0.3 and 0.4
2.	Transmission	0.8
3.	Controller	0.9
4.	Generator	0.9

Cp is determined though multiplied the efficiency by using (Eq. 2) [8].

$$Cp = \eta Blades \; x \; \eta Transmission \; x \; \eta Controller \; x \; \eta Generator \quad \text{.......... (2)}$$

with: η = efficiency (%)

$$Pw = \frac{Pe}{Cp} \quad \text{..........(3)}$$

with: Pw = windpower (Watt)
Pe = electric power (Watt)
Cp = coefficient of performance

Table 2. Needs of wind power

Power capacity (W)	Efficiency					Wind power
500	Blades	Transmission	Controller	Generator	System	
	0.3	0.8	0.9	0.9	0.19	2572.02
	0.4				0.26	1929.01

After knowing the wind power needed, the radius of the rotor was calculated by using Eq. 4 :

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

with: A = sweep area of the rotor (m^2)
R = rotor radius (m)

Table 3. Rotor radius calculation

Wind power (W))	V_{max} (m/s)	Sweep area (m^2)	R (m)	Real R (m)
2572.02	7.9	8.52	1.65	1.54
1929.01		6.39	1.43	

Value of Speed Ratio Tip (TSR) and a number of blades is selected based on the work function of the wind turbine. In this research, the wind turbine function as a wind power generation.

Table 4. Correlation TSR and the number of blades [4]

TSR	Number of blades	Function
1	6-20	Slow pump
2	4-12	Faster pump
3	3-6	Dutch 4 blades
4	2-4	Slow generator
5-8	2-3	Generator

In this research, two types of airfoil are used with characteristics, as shown in Figure 2. NACA 4712 airfoil has the highest Cl/Cd ratio of 153 at alpha 2 degrees. This condition is shown in Figure 3, and the NACA 4412 airfoil has the highest Cl/Cd ratio of 133.5 at alpha 6 degrees, this condition shown in Figure 4. The turbine, which is made has a type of taperless blades, so the chord value is set constant at 0.15 meters.

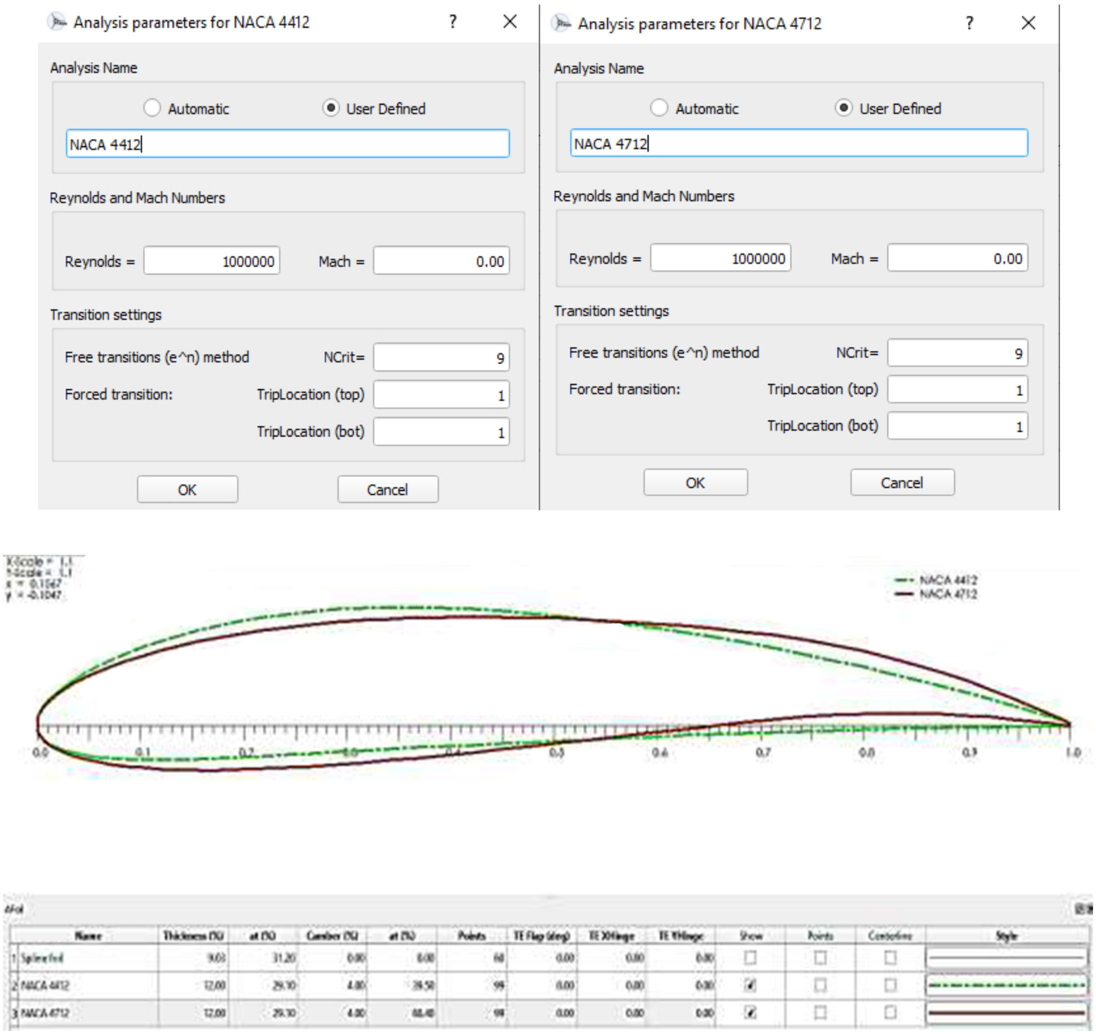

Fig. 2. XFOIL direct analysis input parameter

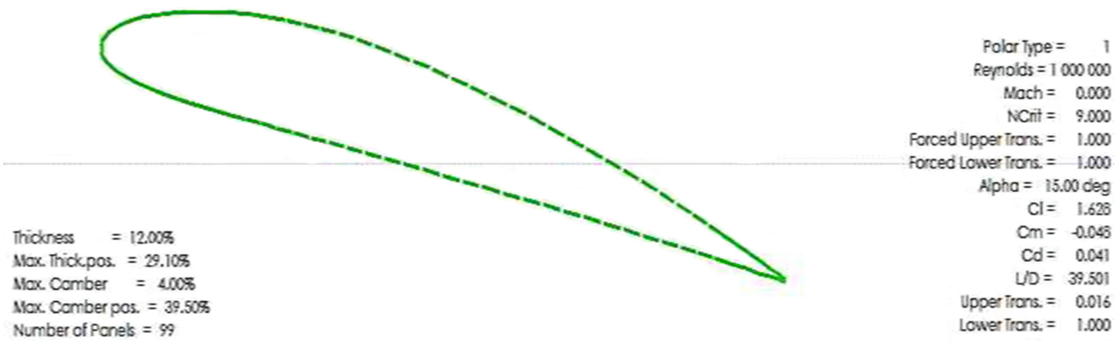

Fig. 3. The angle of attack position (α) airfoil NACA 4412 at the maximum coefficient of lift (Cl)

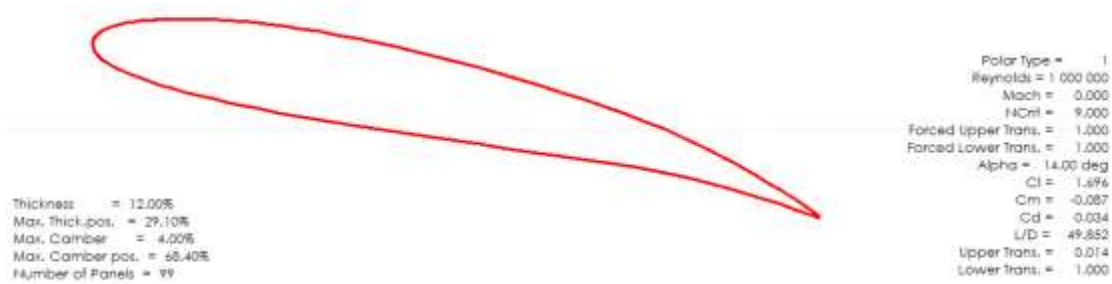

Fig. 4. The angle of attack position (α) airfoil NACA 4712 at the maximum coefficient of lift (Cl)

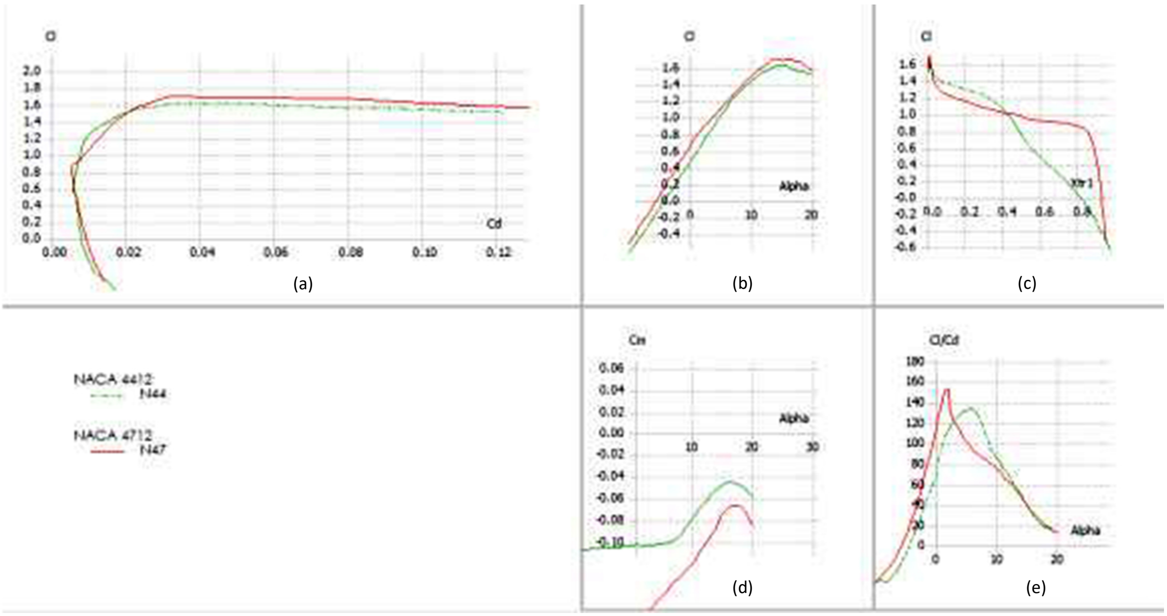

Fig. 5. XFOIL direct analysis result. (a) Correlation coefficient of drag (Cd) and coefficient of lift (Cl); (b) Correlation angle of attack (α) and coefficient of lift (Cl); (c) Corelation Xtr1 and coefficient of lift (Cl); (d) Correlation angle of attack (α) and coefficient of the moment (Cm); (e) Correlation angle of attack (α) and Cl/Cd

Turbine blades will be divided into 20 elements, the 0th element (innermost station) is at 0.20 m from the center of the hub. The number of division of blades elements is based on Eq. 5 :

$$r = 0.2\ x\ \left[\left(\frac{R-0.2}{n}\right)\right] x\ (element) \quad \text{.......................................}(5)$$

with: r=partial radius (m)
R=rotor radius (m)
n= number of element
element= element position

The coefficient of lift at every blade element is different. Chord and number of blades affect this coefficient at each of the blades elements. Eq. 6 is used to calculate the coefficient of lift at every element and the calculation result is shown in Figure 6.

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$$Cl = \frac{16\,\pi\;x\;R\;x\;\frac{r}{R}}{9\lambda^2\;x\;B\;x\;C} \qquad (6)$$

with: c= chord = 0.15
B= number of blade = 3

Elemen	r (m)	TSR Parsial(λr)	Cl	α
0	0.20	0.91	2.99	15.00
1	0.27	1.22	2.24	15.00
2	0.33	1.52	1.79	15.00
3	0.40	1.82	1.49	11.00
4	0.47	2.13	1.28	7.68
5	0.53	2.43	1.12	5.94
6	0.60	2.74	1.00	4.80
7	0.67	3.04	0.90	3.86
8	0.73	3.35	0.81	3.40
9	0.80	3.65	0.75	2.48
10	0.87	3.96	0.69	1.92
11	0.94	4.26	0.64	1.46
12	1.00	4.56	0.60	1.18
13	1.07	4.87	0.56	0.84
14	1.14	5.17	0.53	0.52
15	1.20	5.48	0.50	0.24
16	1.27	5.78	0.47	0.05
17	1.34	6.09	0.45	-0.21
18	1.40	6.39	0.43	-0.41
19	1.47	6.70	0.41	-0.59
20	1.54	7.00	0.39	-0.78

(a)

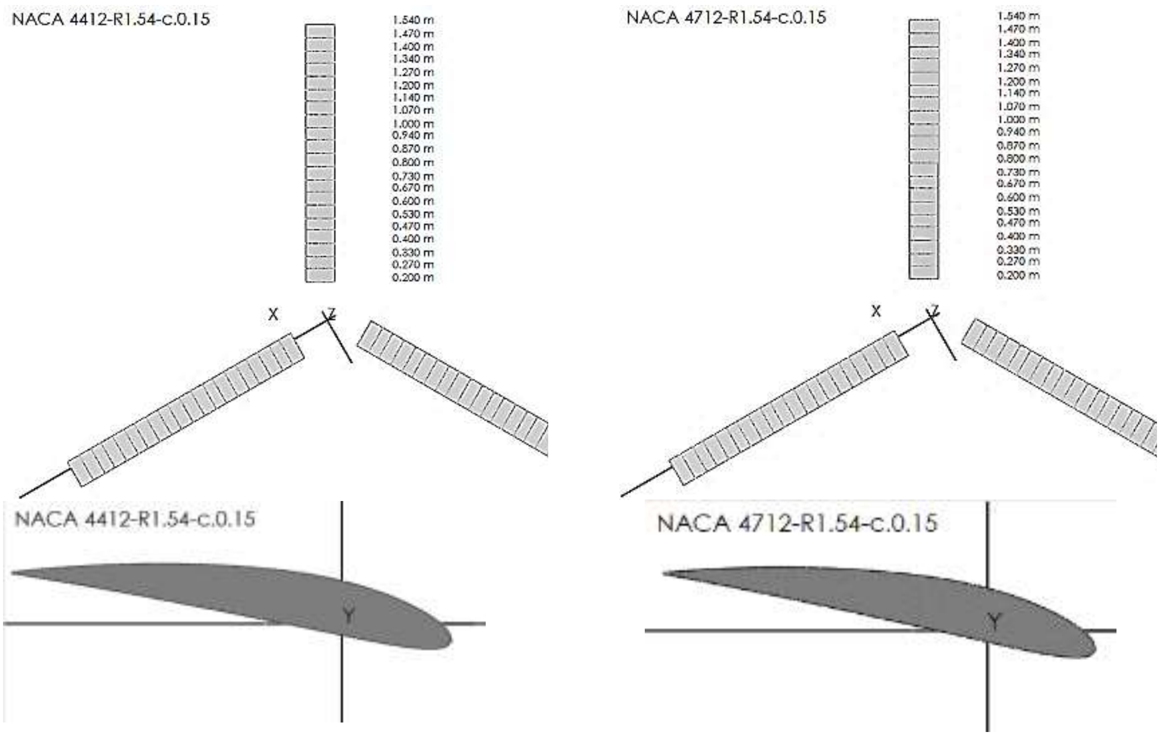
Elemen	r (m)	TSR Parsial(λr)	Cl	α
0	0.20	0.91	2.99	14.00
1	0.27	1.22	2.24	14.00
2	0.33	1.52	1.79	14.00
3	0.40	1.82	1.49	10.00
4	0.47	2.13	1.28	7.25
5	0.53	2.43	1.12	5.20
6	0.60	2.74	1.00	3.70
7	0.67	3.04	0.90	2.30
8	0.73	3.35	0.81	1.25
9	0.80	3.65	0.75	0.70
10	0.87	3.96	0.69	0.18
11	0.94	4.26	0.64	-0.25
12	1.00	4.56	0.60	-0.63
13	1.07	4.87	0.56	-0.93
14	1.14	5.17	0.53	-1.20
15	1.20	5.48	0.50	-1.47
16	1.27	5.78	0.47	-1.72
17	1.34	6.09	0.45	-1.89
18	1.40	6.39	0.43	-2.06
19	1.47	6.70	0.41	-2.18
20	1.54	7.00	0.39	-2.35

(b)

Fig 6. Correlation of lift coefficient (Cl) with an angle of attack (α) on an airfoil (a)NACA 4712 and (b) NACA 4412

There are two different types of rotors using different airfoil, NACA 4412 and NACA 4712, as shown in Figure 7.

Multi-parameter BEM simulation results show that there is an influence of pitch angle on both wind turbine rotor performance. An increase in pitch value causes a decrease in turbine output power. Figure 8 and Figure 9 show the characteristics of wind turbine parameters with NACA 4412 airfoil.



(a) (b)

Fig 7. Turbine rotor using (a)airfoil NACA 4412 and (b) airfoil NACA 4712

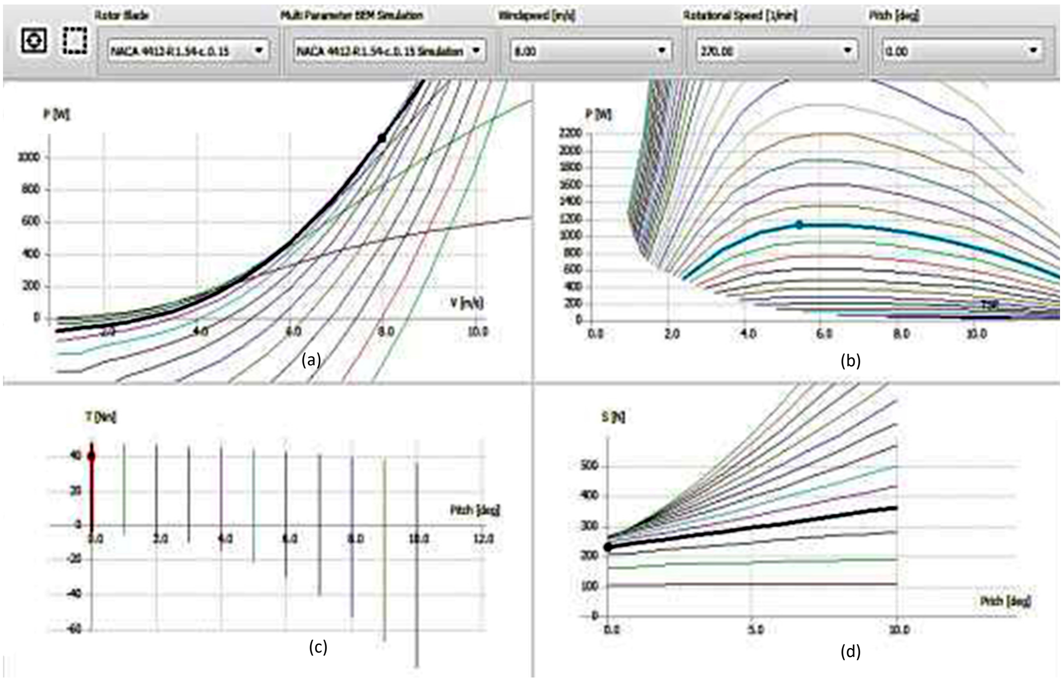


Fig. 8. Characteristics of wind turbine parameters with NACA 4412 airfoil at a wind speed of 8 m/s and a pitch angle of 0°. (a) Correlation wind speed and wind turbine power; (b) Correlation TSR and wind turbine power; (c) Correlation pitch angle and torque; (d) Correlation pitch angle and thrust

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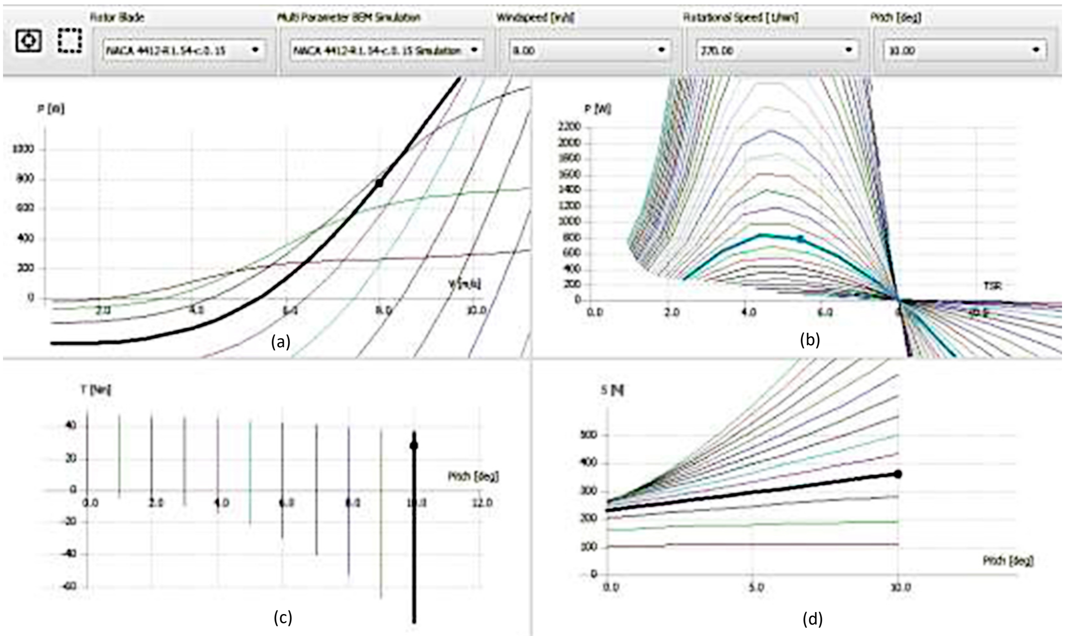

Fig. 9. Characteristics of wind turbine parameters with NACA 4412 airfoil at a wind speed of 8 m/s and a pitch angle of 10°. (a) Correlation wind speed and wind turbine power; (b) Correlation TSR and wind turbine power; (c) Correlation pitch angle and torque; (d) Correlation pitch angle and thrust

Figure 10 and Figure 11 show the characteristics of wind turbine parameters with NACA 4712 airfoil.

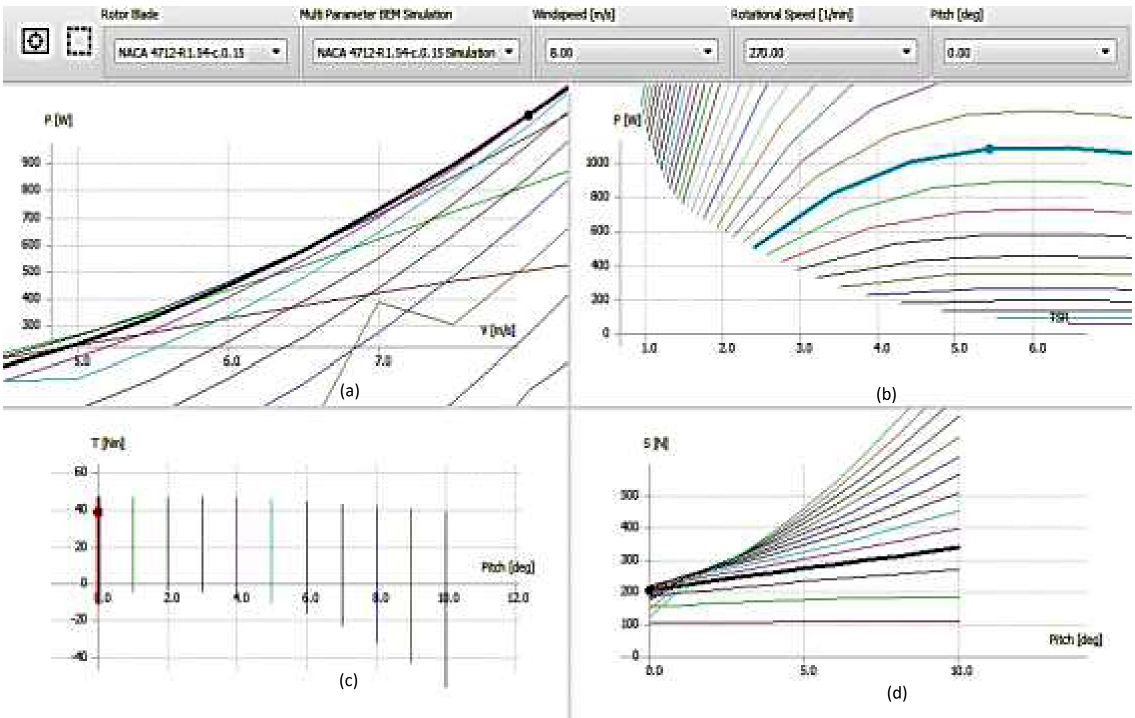

Fig. 10. Characteristics of wind turbine parameters with NACA 4712 airfoil at a wind speed of 8 m/s and a pitch angle of 0°. (a) Correlation wind speed and wind turbine power; (b) Correlation TSR and wind turbine power; (c) Correlation pitch angle and torque; (d) Correlation pitch angle and thrust

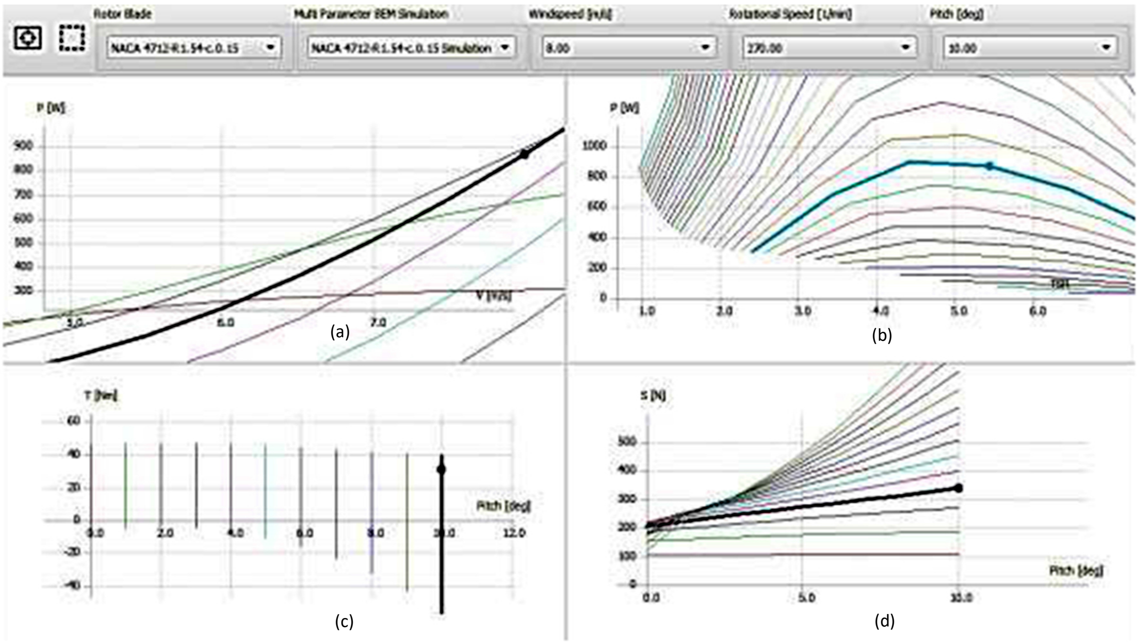

Fig 11. Characteristics of wind turbine parameters with NACA 4712 airfoil at a wind speed of 8 m/s and a pitch angle of 10°. (a) Correlation wind speed and wind turbine power; (b) Correlation TSR and wind turbine power; (c) Correlation pitch angle and torque; (d) Correlation pitch angle and thrust

BEM Turbine Simulation aims a comparison of the results of the acquisition of power between turbines with the NACA 4412 airfoil and the NACA 4712 airfoil. Turbines with NACA 4412 airfoil get 500 Watt power at wind speeds 6.11 m / s. While the turbine with NACA airfoil 4712 obtains 500 Watt power at a wind speed of 6.2 m/s. Both types of turbines operating in the rotating speed range of 120 rpm to 1000 rpm (Figure 12). This condition is adjusted accordingly specifications of the generator used.

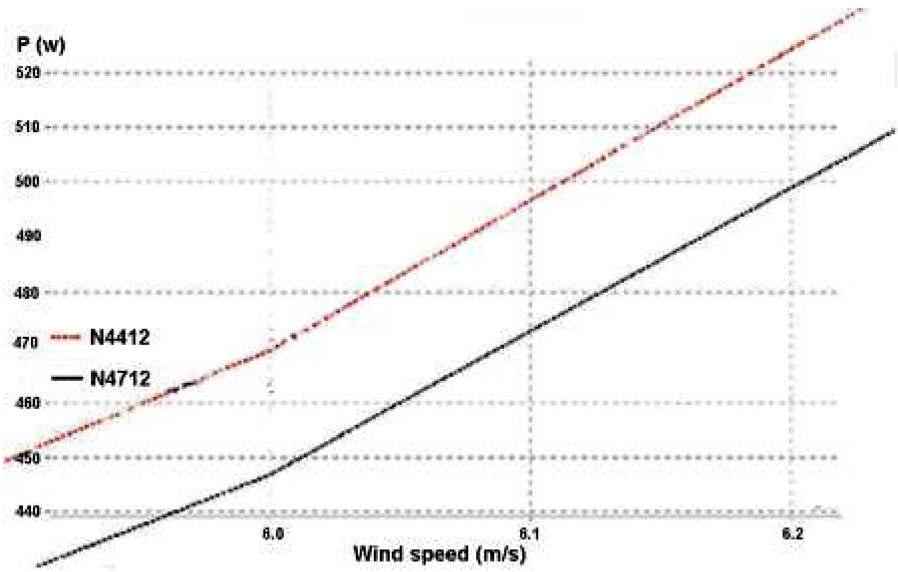

Fig. 12. Correlation between output power and wind speed

Based on the result of nonlinear lifting line simulation, a wind turbine using the NACA 4712 airfoil produces Cp 0.49929 at a wind speed of 7.66 m/s and gets 1.15 kW of power, as shown in Figure 13. Cp value is not constant for the period specified in the simulation process. While wind turbines using the NACA 4412 airfoil, it produces Cp 0.395365 at a wind speed of 7.66 m/s and gets 0.889 kW of power, as shown in Figure 14.

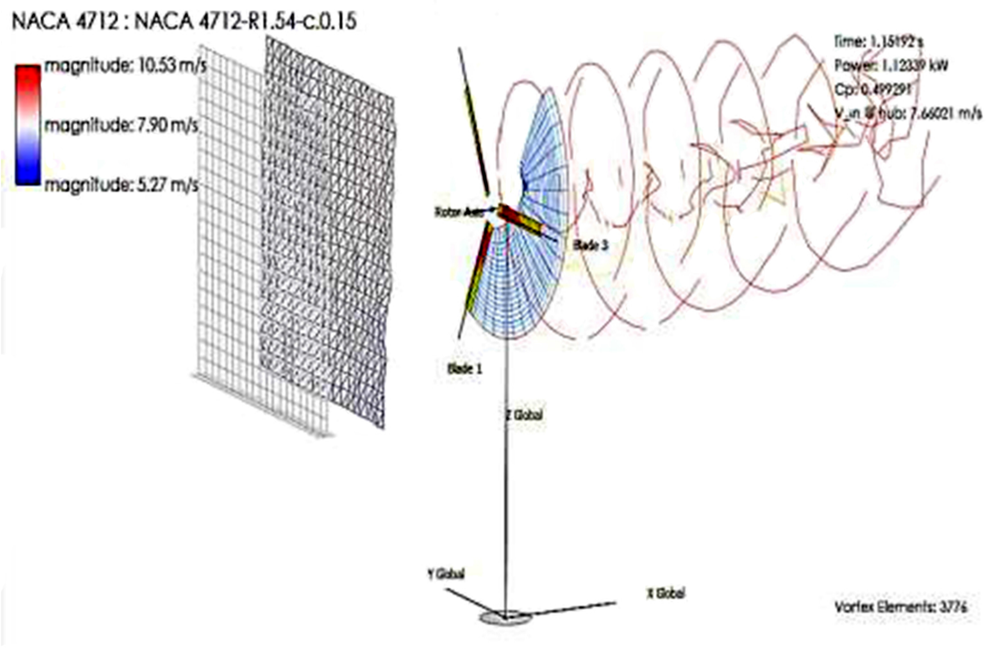

Fig. 13. Nonlinear lifting line simulation of wind turbine using NACA 4712 airfoil

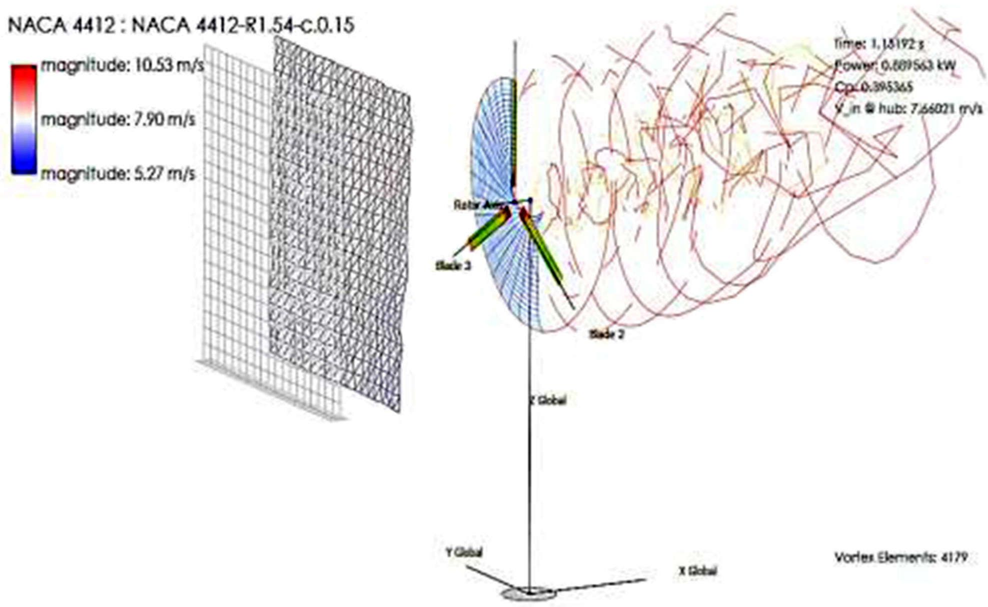

Fig. 14. Nonlinear lifting line simulation of wind turbine using NACA 4712 airfoil

From the calculation results of the blade geometry, 3-dimensional modeling was performed to interpret the shape of the turbine blades. Figure 12 shows the 3D model of the blade using NACA 4712 airfoil.

Fig. 15. 3D model of the blade using NACA 4712 airfoil

IV. Conclusions

The characteristic of wind turbines with Airfoil NACA 4712 are maximum Cl = 1.696 at position $\alpha = 14^o$. At the same time, the NACA 4412 airfoil has a maximum Cl = 1.628 at position $\alpha = 15^{o,}$ which is mean that the maximum Cl of NACA 4712 airfoil is higher than NACA 4412 airfoil. A 0-degree pitch angle produces the best output power for wind turbines with both types of NACA 4712 and 4412 airfoil. At a wind speed of 7.66 m/s with 10% turbulence conditions, wind turbines with NACA 4712 airfoil have Cp = 0.49929 and get 1.15 kW of power, while the turbine wind with airfoil NACA 4412 has Cp = 0.395365 and get the power of 0.889 kW at speed same wind. It means that the turbine using NACA 4712 has better performance at the same wind speed.

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