Journal of Physics: Conference Series

Study experimental of blade NACA 4412 with pitch angle on horizontal wind turbine

Study experimental of blade NACA 4412 with pitch angle on horizontal wind turbine

Rusdi Febriyanto[1], Bayu Rudiyanto[2], Nugroho Agung Pambudi[1], Indah widiastuti[1], Kukuh Mukti Wibowo[1], Riyanto[1], Nova Dany Setyawan[1]
[1]Mechanical Engineering Education Department, Sebelas Maret University, Jl. Ir. Sutami 36A Kentingan Jebres Surakarta 57126, Indonesia
[2]Departement of Renewable Energy Engineering, Politeknik Negeri Jember, Jember, 68121, Indonesia

E-mail: agung.pambudi@staff.uns.ac.id

Abstract. This study aims to improve the performance of HAWT's wind turbines in low wind speeds condition. There are two possible approaches: developing low-speed rotor technology and improving the turbine's blades. In this research, we improve the turbine's blades by determining the type of airfoil, material and pitch angle. The airfoil used as its blade is NACA 4412 with teak wood material. Variations of pitch angles are at 0 °, 2 °, 4 °, 6 °, 8 °, 10 ° and 12 °. Testing is realized by making an artificial wind in the wind tunnel. The imitation speed are of 2 m/s, 2.5 m/s, 3 m/s, 3.5 m/s, 4 m/s, 4.5 m/s and 5 m/s. The result shows that at 4° is the best pitch angle that produces the maximum power output and rpm. The 4° pitch angle has a cut in of 2m/s wind speed and generates a power output of 9.71 Watt at an average Rpm of 505.6. The increasing pitch angle decreases the power output and RPM generator.

1. Introduction

The growth of the world's population and the development of human's civilization continues to increase. Thereby resulting in an impact on increased energy consumption. In the period of 2000-2030, EU are estimated to experience an increase in energy demand by 0.5% per year, while in Asian it increases to 3% per year [1]. This energy requirement is mostly derived from fossil fuels that include non-renewable energy sources [2]

The future usage of this fossil energy source needs to be reduced. Because of its diminishing presence and causing some global problems, such as global warming, caused by the production of carbon dioxide gas (CO2) resulting from the burning of fossil fuel [3]-[4]. Environmental awareness provides a boost for the provision of clean energy resources, such as wind power [5]. Wind energy has been the direction of clean energy development in the last 20 years. This development is a large scale or small scale wind turbine generator [6].

Small-scale wind turbines are wind turbines that can work at low wind speeds. The Horizontal Axis Wind Turbine (HAWT) which is a small-scale wind turbines type usually has a blade Diameter of 1-3 meters [7]. The number of blades is three pieces because it works efficiently at low and high wind speeds [8]. In an effort to improve the performance of HAWT wind turbines at low wind speeds. There are two possible approaches: developing low-speed rotor technology and plotting turbine blades. The blade plan involves determining the airfoil type, material and pitch angle.

The suitable type of airfoil used for the small-scale wind turbine (HAWT) is an airfoil type following the National Advisory Committee for Aeronautics (NACA) standard [9]. One of the most commonly

used is NACA 4412 because it has a high cl/cd ratio. The blade material uses teak because it has fabrication advantages, availability and cost effectiveness [10]. In addition, the selection of the use of blades of teak wood material is because of its light weight and has passed the tired test stage [11].
The pitch angle is a blade mounting angle designed to allow the horizontal wind turbine to have the lowest cut-in speed possible [12]. Cut-in speed is the minimum wind speed required for the generator to produce a useful power output [13]. This angle affects the angle of attack so that the aerodynamic force on the blade changes [14]. According to numerical simulations performed by Thumthae and Chitsomboon on the HAWT's wind turbine, variations in wind's speed and pitch angle forms different angle of attack [15]. The angle of attack causes the aerodynamic force of the curve cl / cd on each airfoil to have its own characteristics [16]. Varying the pitch angle can manipulate power coefficients so that it can generate power at low wind speeds [17]. Therefore, the determination of the pitch angle is very important in order to obtain the maximum power output point. [17].

2. Experimental Method

2.1 Experimental set-up

This experimental study was conducted to determine the effect of pitch angle variation on the power output generated by the HAWT's wind turbine and its performance. The blades used by NACA (National Advisory Committee for Aeronautics) 4412 specification shown in table 1.

Table 1. Blade specification

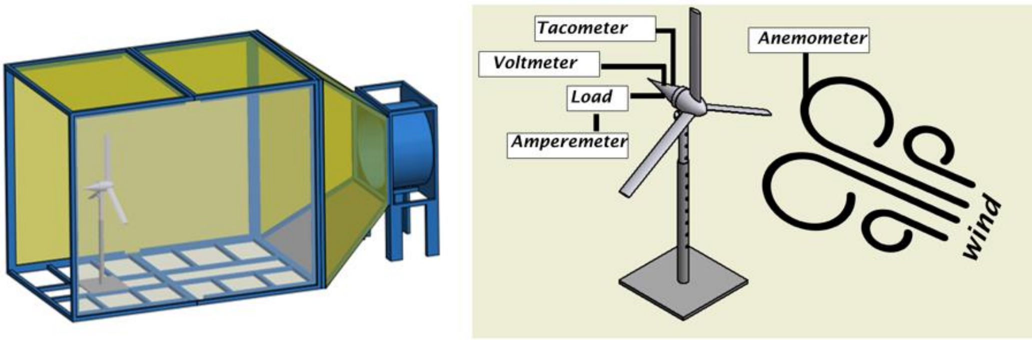
Variable	Specification
Airfoil Type	NACA 4412
Blades modeling type	Non twisted
Total Blades	3
Blades' length	600 mm
Blades' Base Width	100 mm
Blades' Tip Width	50 mm
Blade material	Teak wood
Generator (PMG type)	100 Watt

2.2 Experimental design

Wind turbine testing using Wind Tunnel with specifications as shown in the following table 2. The first procedure in this experimental research is placing the HAWT's wind turbine in the wind tunnel, creating an artificial wind speed. The variation of pitch angles is then set at 0 °, 2 °, 4 °, 6 °, 8 °, 10 ° and 12 °. Then, the power and RPM on each variation of pitch angle with an artificial speed of 2 m / s, 2.5 m / s, 3 m / s, 3.5 m / s, 4 m / s, 4.5m / s and 5 m / s is measured. Artificial winds will drive the HAWT's wind turbine so it spins.

Table 2. Specification Wind Tunnel

Variable	Specification
Wind Tunnel's Length	3000 mm
Wind Tunnel's width	2000 mm
Wind Tunnel's Height	2400



(a) (b)

Figure 1. (a)Wind Tunnel Design (b) Data Input Scheme

2.3. Angle of pitch and material

The tests in this study focused on a pitch angle with NACA 4412 type of blade using teak wood material. Variations of pitch angle at 0 °, 2 °, 4 °, 6 °, 8 °, 10 ° and 12 °. a combination of the pitch angle and the wooden material are a novel in this study for the development of small-scale HAWT's wind turbines.

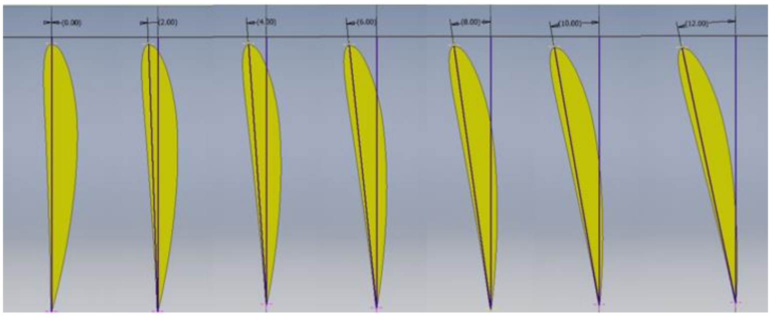
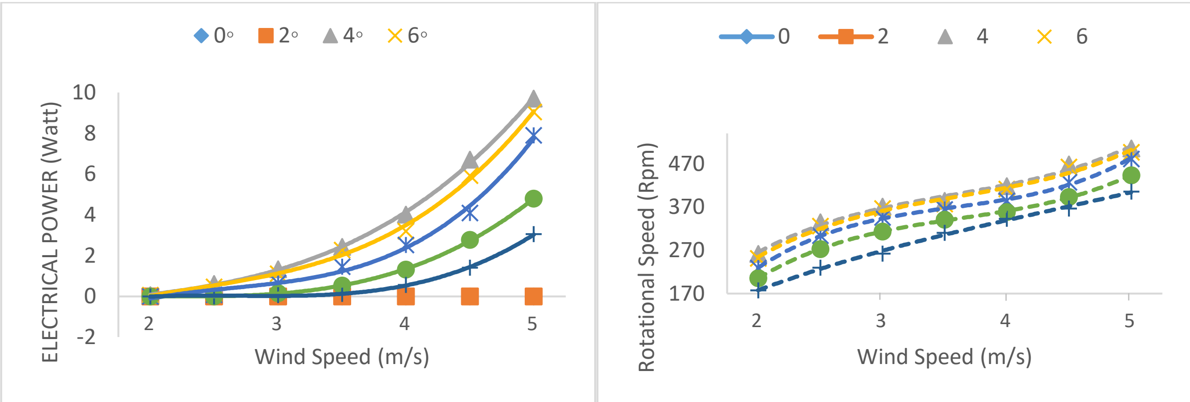


Figure 2. Variations of pitch angle

3. Results and discussion

3.1. Power output and RPM are produced by angle pitch variation

Testing the NACA 4412 wind turbines produces varying power output. The figure 3.(a) shown of the 7 variations of pitch angle, 5 of them produces power output. While the variation in pitch angle of 0^o and 2^o does not produce electrical power output. Electrical power starts to be generated by the turbine at a 4^o pitch angle. The additional wind speed is directly proportional to the output of electrical power.



(a) (b)

Figure 3. (a) Comparation of Wind Turbine's Electricity Result, (b) Comparation of Wind Turbine's Rotor Rotation Result

The figure 3 (a) and 3 (b) shown 4^{o} pitch angle produces maximum power, which at a wind speeds of 2 m/s and 5 m / s produces power of 0.064 Watt at 261 Rpm and 9.71 Watt at 505 Rpm. The pitch angle of 6^{o} produces maximum power, which at wind speed 2 m / s and 5 m / s produces power of 0.054 Watt at 251 Rpm and 9.05 Watt at 496 Rpm. The pitch angle of 12^{o} produces maximum power, which at wind speed 3 m / s and 5 m / s produces power of 0.055 Watt at 263 Rpm and 3,047 Watt at 405 Rpm.

Table 3. Wind Turbine's Electricity Result and Cut In Speed

		Wind speed						
		2 m/s	**2.5 m/s**	**3 m/s**	**3.5 m/s**	**4 m/s**	**4.5 m/s**	**5 m/s**
Pitch angle	0◦	0	0	0	0	0	0	0
	2◦	0	0	0	0	0	0	0
	4◦	0.064	0.608	1.329	2.428	4.01	6.71	9.71
	6◦	0.054	0.47	1.116	2.265	3.193	5.932	9.05
	8◦	0	0.075	0.648	1.458	2.522	4.084	7.901
	10◦	0	0	0.158	0.527	1.317	2.766	4.793
	12◦	0	0	0.055	0.114	0.563	1.41	3.047

The orange block on the table. 3. Shows the Cut in speed on every pitch angle variation. Cut in speed is the lowest wind speed in which the wind turbine's generator starts to produce useful electrical power output. A Cut in speed at 4^{o} and 6^{o} pitch angles occurs at a wind speed of 2 m / s and produce a power output of 0.064 Watt and 0.054 Watt. A Cut in speed at 8^{o} pitch angle occurs at a wind speed of 2.5 m / s and produces a power output of 0.075 Watt. Whereas the pitch angle of 10^{o} and 12^{o} has a cut in speed at wind speed of 3 m / s and produces 0.158 Watt and 0.055 Watt power output. The additional pitch angle leads to a decrease in electrical power and the cut in speed requires a greater wind.

3.2 Effect of variation angle pitch on power output

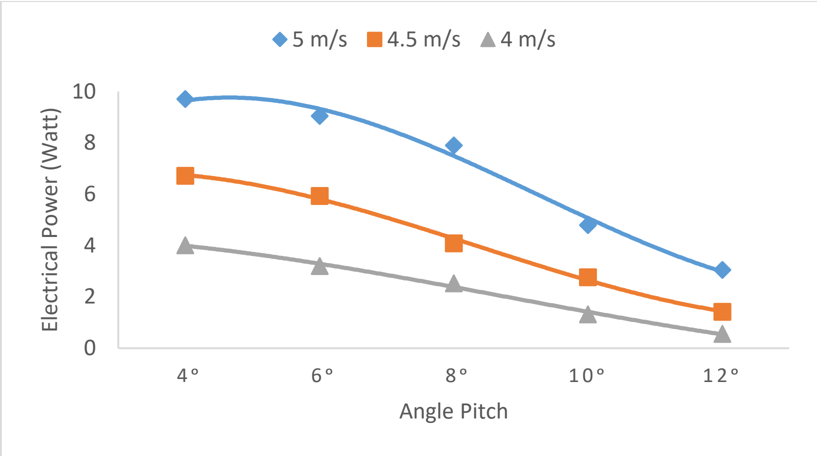


Figure 4. The Graph Angle Pitch with Electricity Power

The Figure 4. shows the graph power output based on wind speeds of 4 m / s, 4.5 m / s and 5 m / s with variations of pitch angles at 0 °, 2 °, 4 °, 6 °, 8 °, 10 ° and 12 °. The 4° pitch angle produces maximum power, at a wind speed of 5 m / s generating 9.71 Watt of power. The pitch angle of 6° at a wind speed of 5 m / s produces a power of 9.05 Watt and has a percentage decrease in power output of 6.7% compared to the pitch angle of 4°. The pitch angle of 12° at wind speed m / s produces power of 3,047 Watt and has a percentage decrease of power output equal to 68.6% compared to the 4°of pitch angle. The additional pitch angle causes the electrical power generated by the generator to experience a significant downward trendline.

3.3. Effect of variation angle pitch on Rpm

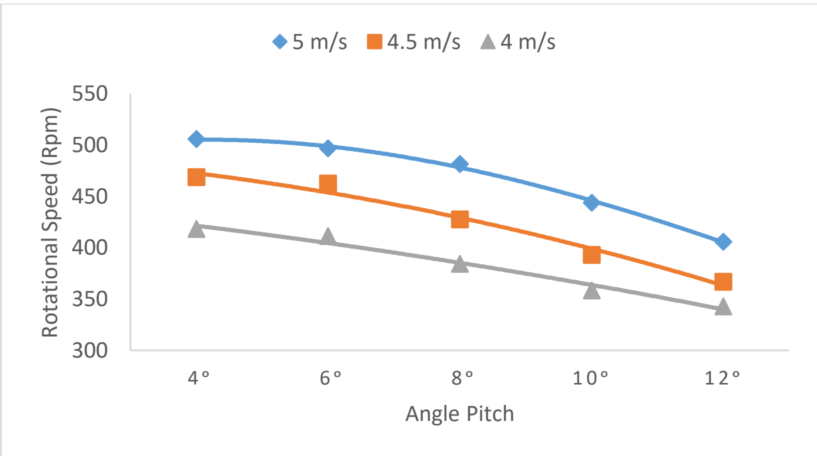


Figure 5. The Graph Angle Pitch with Rotor Rotational

The Figure 5. shows the graph Rpm Generator based on wind speeds of 4 m / s, 4.5 m / s and 5 m / s with a variation of pitch angles at 0 °, 2 °, 4 °, 6 °, 8 °, 10 ° and 12 °. The 4° pitch angle produces maximum Rpm, at a wind speed of 5 m / s resulting in an average Rpm of 505.6. The pitch angle of 6° at a wind speed of 5 m / s yields an average Rpm of 496.6 and a percentage decrease in power output by 1.7% compared to the pitch angle of 4°. The pitch angle of 12° at wind speed m / s produces an average Rpm of 405.8 and a percentage decrease in power output of 19.7% compared to the pitch angle of 4°. The additional pitch angle resulted in a decrease in the generator's rotation or Rpm although it's not very significant.

4. Conclusions

At the pitch angle of 0° and 2° the HAWT's wind turbine does not rotate and produces no electrical power output. The 4° pitch angle is the angle that produces the maximum power output and rpm. The additional pitch angle resulted in a cut in speed requires a larger wind. The additional pitch angle resulted in a significant decrease in electrical power output. The additional 12° pitch angle at wind speed m / s produces a power of 3,047 Watt and has a percentage decrease in power output of 68.6% compared to 4 p pitch angle. Additional pitch angle resulted in a decrease of the generator's rotation (Rpm). The pitch angle of 12° at wind speed m / s produces an average Rpm of 405.8 and a percentage decrease in power output of 19.7% compared to the pitch angle of 4°. The additional pitch angle resulted in a decreased in power output and Rpm generator. Otherwise it will cause cut in speed to require a larger wind.

5. Reference

[1] European Commission. (2003). *World energy, technology and climate policy outlook*. *Energy*. Retrieved from http://ec.europa.eu/research/energy/pdf/weto_final_report.pdf
[2] International Energy Agency. (2015). Key World Energy Statistics 2009. *Statistics*, 82. https://doi.org/10.1787/9789264039537-en
[3] Ahmad, N. N. N., & Hossain, D. M. (2015). Climate Change and Global Warming Discourses and Disclosures in the Corporate Annual Reports: A Study on the Malaysian Companies. *Procedia - Social and Behavioral Sciences*, *172*, 246–253. https://doi.org/10.1016/j.sbspro.2015.01.361
[4] Qazi, A., Fayaz, H., & Raj, R. G. (2014). Discourse on Data Mining Applications to Design Renewable Energy Systems, 29–31.
[5] Kumar, S. (2014). Analysis and Performance of Small Wind Turbine Blades. *International Journal of Advanced Research Trends in Engineering and Technology (IJARTET)*, *1*(1), 1–5.
[6] Stannard, N. J., & Bumby, J. R. (2006). Energy Yield and Cost Analysis of Small Scale Wind Turbines. *Proceedings of the 41st International Universities Power Engineering Conference*, 108–112. https://doi.org/10.1109/UPEC.2006.367725
[7] Adzic, E., Ivanovic, Z., Adzic, M., & Katic, V. (2009). Maximum power search in wind turbine based on fuzzy logic control. *Acta Polytechnica Hungarica*, *6*(1), 131–149. Retrieved from http://www.uni-obuda.hu/journal/Adzic_Ivanovic_Adzic_Katic_17.pdf
[8] Pambudi, N. A., Pristiandaru, D. L., Basori, Wijayanto, D. S., Sriwardani, N., Rahman, N., … Subagsono. (2017). Experimental Investigation of Wind Turbine Using Nozzle-lens at Low Wind Speed Condition. *Energy Procedia*, *105*, 1063–1069.
[9] Musyafa, A. (2014). Implementation of Fuzzy Logic Control (FLC) In Horizontal Axis Wind Turbine Prototype with Airfoil Profile NREL Stan .... *Australian Journal of Basic and Applied Sciences*, (April), 60–68.
[10] Sekhar Ȧ, C. K., Kumar Ȧ, N. G., & Reddy Ȧ Ȧ, B. G. (2014). Design of Blade for a Wooden Small scale wind turbine for domestic purpose. *International Journal of Current Engineering and Technology*, *44*(33), 1309–1313. Retrieved from http://inpressco.com/category/ijcet
[11] S.Maldhure, & Kharde, D. (2013). Fatigue Failure Analysis of Small Wooden Wind Turbine Blade. *International Journal Of Computational Engineering Research*, *3*(2), 2250–3005.
[12] Rocha, P. A. C., Araujo, J. W. C. De, Lima, R. J. P., Vieira, M. E., Albiero, D., Andrade, C. F. De, & Carneiro, F. O. M. (2018). The effects of blade pitch angle on the performance of small-scale wind turbine in urban environments. *Energy*, *148*, 169–178. https://doi.org/10.1016/j.energy.2018.01.096

[13] Manwell, J. F., & McGowan, J. G. (2011). Wind Energy. *IPCC Special Report on Renewable Energy Sources and Climate Change Mitigation*, 535–608. https://doi.org/10.5860/CHOICE.49-6309
[14] Sudhamshu, A. R., Pandey, M. C., Sunil, N., Satish, N. S., Mugundhan, V., & Velamati, R. K. (2016). Engineering Science and Technology , an International Journal Numerical study of effect of pitch angle on performance characteristics of a HAWT. *Engineering Science and Technology, an International Journal*, *19*(1), 632–641. https://doi.org/10.1016/j.jestch.2015.09.010
[15] Thumthae, C., & Chitsomboon, T. (2009). Optimal angle of attack for untwisted blade wind turbine. *Renewable Energy*, *34*(5), 1279–1284. https://doi.org/10.1016/j.renene.2008.09.017
[16] Sharifi, A., & Nobari, M. R. H. (2013). Prediction of optimum section pitch angle distribution along wind turbine blades. *Energy Conversion and Management*, *67*, 342–350. https://doi.org/10.1016/j.enconman.2012.12.010
[17] Djalal, M. R., Imran, A., & Setiadi, H. (2017). Desain Sistem Kontrol Pitch Angle Wind Turbine Horizontal Axis Menggunakan Firefly Algorithm. *Jurnal Teknik Elektro P-ISSN 1411 - 0059*, *9*(1), 2–7.
[18] Satrio, D., Nugroho, S., & Permatasari, P. D. (2015). Studi Eksperimen Pengaruh Sudut Pasang terhadap Kecepatan Putar Rotor Turbin Angin Sumbu Horizontal. *Pertemuan Ilmiah XXIX HFI Jateng & DIY ISSN : 0853-0823*, (April), 376–379.