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Optimizing Low-Speed Wind Turbines: The Impact of Blade Angle and Profile

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Abstract: This study investigates the optimization of horizontal axis wind turbines for low-speed wind conditions in Indonesia, focusing on blade configuration. Through experimental methods, the research evaluates how variations in the number of blades, blade profiles, and particularly the alpha angle of the NACA 0021 rotor blade affect turbine efficiency. Findings reveal that adjusting the blade angle significantly enhances the power coefficient, offering a potential pathway to increase the efficiency of wind turbines under low-speed conditions. This advancement could contribute to more sustainable and efficient use of wind energy globally.

Keywords: Wind Turbine Efficiency, Blade Angle Variation, Low-Speed Wind, NACA 0021 Profile, Renewable Energy

INTRODUCTION

The depletion of oil reserves and greenhouse gas pollution due to burning fossil fuels pose several severe threats to the lives of living beings on Earth. This urges the Indonesian government to pursue renewable energy sources.[1] The need for electricity is very high in urban and rural areas; in line with the increasing development of community welfare, various efforts have been made to provide electricity to remote corners of the village, and also the development of science and technology in the field of energy conversion from fossil fuels which causes pollution, exceptionally high air pollution (CO2) and the decreasing amount of supplies in nature, becomes renewable energy that is environmentally friendly and can be renewed,[2] The renewable energy solutions currently used commercially in Indonesia include water energy, geothermal, bioenergy, wind energy, solar energy, and many other renewable energies that are still in development.[3] One of the renewable energy sources that can be used on a small scale

[1] Ji-Hyung Park and others, 'Basin-Specific Pollution and Impoundment Effects on Greenhouse Gas Distributions in Three Rivers and Estuaries', *Water Research*, 236 (2023), 119982 <https://doi.org/10.1016/j.watres.2023.119982>.

[2] Long Ho and others, 'Impact of Salinity Gradient, Water Pollution and Land Use Types on Greenhouse Gas Emissions from an Urbanized Estuary', *Environmental Pollution*, 336 (2023), 122500 <https://doi.org/10.1016/j.envpol.2023.122500>.

[3] Aderiana Mutheu Mbandi and others, 'Assessment of the Impact of Road Transport Policies on Air Pollution and Greenhouse Gas Emissions in Kenya', *Energy Strategy Reviews*, 49 (2023), 101120 <https://doi.org/10.1016/j.esr.2023.101120>.

is wind energy. Wind turbines are one example of a prime mover from wind energy sources to generate electricity.[4] The turbines are divided into 2, namely horizontal-axis wind turbines or Horizontal Axis Wind Turbine (HAWT) and vertical-axis wind turbines or Vertical Axis Wind Turbines (VAWT); now, wind turbines are more widely used to accommodate the electricity needs of the community using the principle of energy conversion and using natural resources that can be renewed namely wind.[5] Although the development of wind turbines still cannot compete with conventional power plants (For example, Diesel Power Plant, Coal-fired Power Plant, etc.), scientists are still developing wind turbines because, shortly, humans will face the problem of a shortage of non-renewable natural resources, The main component of a wind power plant is a turbine.[6] The work of a wind turbine is based on the energy generated by wind speed to rotate the blades/fan. The rotation is converted into mechanical energy; then mechanical energy is converted into electrical energy by a generator, then mechanical energy is converted into electrical energy by a generator, generally wind turbines today use a horizontal axis with a propeller-type blade, Research on the Darrieus vertical-axis wind turbine type-H with NACA 0018 pitch angle 50° aims to determine the effect of the guide vane angle variation of 30°,40°,50°,60°,70°,80° and its impact on the power and torque produced by the wind turbine during loading.[7] Researching the Darrieus type-H wind turbine the purpose of this study is to find out the effect of the blade angle on the performance of the Darrieus type-H wind turbine; this experiment uses an experimental method by changing the tilt angle of the blade from 0°, 2.5°, 5°, 7.5°, and 10° and then evaluating the output power generated by the rotation of the turbine with the help of airflow from an electric blower.

Conducting experiments on the performance of horizontal-axis wind turbines, The performance of a kinetic turbine depends on the blade angle, blade width, and number of blades.[8] Changing the blade angle means that the speed varied in generating turbine power can be changed by adjusting the blade angle position to the direction of the wind flow. The research methodology uses experimental methods to achieve research results on the blade angle against the performance of this wind turbine;

[4] Yuanjun Dai and others, 'Study on the Vibration Characteristics of Wind Turbine by Fused Blade Tip Structure', *Ocean Engineering*, 305 (2024), 117869 <https://doi.org/10.1016/j.oceaneng.2024.117869>.
[5] Yiwen Cao and others, 'Improving Biomass and Dendrobine-Type Total Alkaloids (DTTAs) Production of Dendrobium Nobile through Combining Temporary Immersion Bioreactor System (TIBS) with Endophyte MD33 Elicitation', *Plant Cell, Tissue and Organ Culture (PCTOC)*, 156.1 (2024), 9 <https://doi.org/10.1007/s11240-023-02653-w>.
[6] Peter Deeney and others, 'End-of-Life Alternatives for Wind Turbine Blades: Sustainability Indices Based on the UN Sustainable Development Goals', *Resources, Conservation and Recycling*, 171 (2021), 105642 <https://doi.org/10.1016/j.resconrec.2021.105642>.
[7] Hong Chang and others, 'Effect of Discontinuous Biomimetic Leading-Edge Protuberances on the Performance of Vertical Axis Wind Turbines', *Applied Energy*, 364 (2024), 123117 <https://doi.org/10.1016/j.apenergy.2024.123117>.
[8] Mohammad Zareian, Amin Rasam, and Pooyan Hashemi Tari, 'A Detached-Eddy Simulation Study on Assessing the Impact of Extreme Wind Conditions on Load and Wake Characteristics of a Horizontal-Axis Wind Turbine', *Energy*, 2024, 131438 <https://doi.org/10.1016/j.energy.2024.131438>.

research was conducted on wind turbines designed to meet the expected data.[9] Conducting experiments on horizontal-axis wind turbines with NACA 0015 profile, this experiment aims to determine the effect of the blade angle on the power or watts generated by the performance of the horizontal-axis wind turbine with NACA 0015 profile. It is conducting tests on the vertical-axis Darrieus type-H wind turbine with NACA 0018 blade profile with wind speeds given three m/s and 3.67 m/s and pitch angles 15°, 20°, 25°, and 30° with loads of 200, 250 and 300 grams. From the test results above, several conclusions can be drawn about the effect of pitch angle changes on the performance of the Darrieus type-H vertical-axis wind turbine scale model in terms of power and performance coefficient with three blades, the higher the pitch angle; the performance of the vertical-axis wind turbine decreases with the best performance produced at a pitch angle of 15°. Designing rotor rotational speed calculates rotor diameter, calculates tip speed, and then uses the diameter-to-height wind ratio of 0.1 to calculate the ratio found in this study. Wind speed 0.8; 0.8 rotor area, diameter height, and RPM results make this wind turbine easy to make and can be used as the first layout of a fun wind turbine for beginners. The work of the wind turbine is based on the energy generated by the wind speed to rotate the blade. The rotation is converted into mechanical energy; then, a generator converts mechanical energy into electrical energy.

METHOD

This research was conducted from March to June 2020 at the Mechanical Engineering Laboratory, Faculty of Science and Technology, Universitas Muhammadiyah Sidoarjo. Materials were prepared, measured, cut, and assembled in the welding workshop at the village of Banjarsari, Buduran District, Sidoarjo Regency. Data collection and testing were conducted at the Mechanical Engineering Laboratory, Faculty of Science and Technology, Jl. Mojopahit no. 666 B Sidowayah celep Kec. Sidoarjo, Sidoarjo Regency, East Java, 61215, Universitas Muhammadiyah Sidoarjo.

The initial step in research is to collect literature to understand the correct methods and equations so that no mistakes occur during testing. Subsequently, research will be conducted according to the prepared research plan.[10] Assemble the testing installation circuit, such as a windmill with four blades, a pulley, fan belt, generator, and converter, and prepare the amperage and voltage meters. Testing of the wind turbine equipment using NACA blade 0021 at angles of 10, 15, 20, 0, -10, and -15 aims to determine the best equipment performance at certain angles. Observe and record the results shown on the amperage and voltage meter indicators. This research is conducted by performing tests. Thus, it is expected to obtain accurate data that will be analyzed and

[9] L. Pustina and others, 'Control of Power Generated by a Floating Offshore Wind Turbine Perturbed by Sea Waves', *Renewable and Sustainable Energy Reviews*, 132 (2020), 109984 <https://doi.org/10.1016/j.rser.2020.109984>.

[10] Zhuang Shen and others, 'Multi-Objective Optimization Study on the Performance of Double Darrieus Hybrid Vertical Axis Wind Turbine Based on DOE-RSM and MOPSO-MODM', *Energy*, 2024, 131406 <https://doi.org/10.1016/j.energy.2024.131406>.

then discussed in detail regarding the data obtained, after which a conclusion can be drawn to answer the research question being sought.[11]

Tools and Materials

1. Welding Machine
2. Tachometer
3. Anemometer
4. Voltmeter
5. Iron Pipe Od 20mm Id 18mm
6. Aluminum Pipe 14mm Id 12mm
7. Aluminum Plate 3mm
8. Pulley diameter 15mm
9. Bearing size 6302
10. Fanbelt
11. Airfoil Blade
12. Pliers
13. Ampere meter
14. Generator
15. Inverter

In this research, the parameters observed are the current (ampere) and voltage (Volt) generated from the wind turbine angle variations. The angle variations are 10°, 15°, 20°, 0°, -10°, -15°. The best angle to be tested will be determined using all the angle variations to be analyzed, which are current (ampere) and voltage (volt).

RESULT AND DISCUSSION

Table 1. Influence of Blade Angle (20°)

No	Angle	Wind Speed (m/s)	Ampere	Volt	Wind Power	Turbine Power	Efficiency
1	20°	6	1.1	10.2	82	11.22	0.136
2	20°	6	1.2	10.3	82	12.36	0.150
3	20°	6	1.2	10.3	82	12.36	0.150
	Average		1.1	10.2	82	11.98	0.146

[11] Wenxing Hao, Chun Li, and Fuzhong Wu, 'Adaptive Blade Pitch Control Method Based on an Aerodynamic Blade Oscillator Model for Vertical Axis Wind Turbines', *Renewable Energy*, 223 (2024), 120114 <https://doi.org/10.1016/j.renene.2024.120114>.

Table 2. Influence of Blade Angle (15°)

No	Angle	Wind Speed (m/s)	Ampere	Volt	Wind Power	Turbine Power	Efficiency
1	15°	6	1.3	11.2	82	14.56	0.177
2	15°	6	1.3	11.3	82	14.69	0.179
3	15°	6	1.4	11.5	82	16.10	0.196
	Average		1.3	11.3	82	15.11	0.184

Table 3. Influence of Blade Angle (10°)

No	Angle	Wind Speed (m/s)	Ampere	Volt	Wind Power	Turbine Power	Efficiency
1	10°	6	0.9	10	82	9	0.10
2	10°	6	1	10.3	82	10.3	0.12
3	10°	6	1	10.1	82	10.1	0.12
	Average		0.96	10.1	82	9.8	0.12

Table 4. Influence of Blade Angle (0°)

No	Angle	Wind Speed (m/s)	Ampere	Volt	Wind Power	Turbine Power	Efficiency
1	0°	6	0,6	9,6	82	5,76	0,070
2	0°	6	0,6	9,7	82	5,82	0,071
3	0°	6	0,7	9,8	82	6,86	0,083
	Average		0,6	9,7	82	6,14	0,074

Table 5. Influence of Blade Angle (-10°)

No	Angle	Wind Speed (m/s)	Ampere	Volt	Wind Power	Turbine Power	Efficiency
1	-10°	6	0,3	9,2	82	2,76	0,033
2	-10°	6	0,2	9,1	82	1,82	0,022
3	-10°	6	0,2	9,1	82	1,82	0,022
	Average		0,2	9,1	82	2,13	0,025

Table 6. Influence of Blade Angle (-15°)

No	Angle	Wind Speed (m/s)	Ampere	Volt	Wind Power	Turbine Power	Efficiency
1	-15°	6	0,1	8,2	82	0,82	0,01
2	-15°	6	0	8,1	82	0	0
3	-15°	6	0,1	8,3	82	0,83	0,010
	Average		0,06	8,2	82	0,55	0,006

Based on table 1-6, the average value of the blade angle (20°) effect on current (amps), voltage (volts), turbine power (watts), and efficiency has been shown in Table 4.1, and the average value of the 15° blade angle shown in Table 4.2, as well as the average value of the 10° blade angle shown in Table 4.3. Graph showing the average current (amps) values for angles 10°, 15°, and 20°, as shown in graph 4.1. Graph 4.2 shows the average voltage (volts), graph 4.3 shows the average turbine power (watts), and the last one, graph 4.4, shows the average efficiency values. With a value of 1.3 (amps) and a voltage of 11.3 (volts), the 15° angle is the highest. This is possible because the 15° angle achieves a more incredible tangential speed than the angles above and below it (20°, 10°). At the 15° angle, the wind hitting the blade passes more through one side than through both sides. This is also supported by previous research by Erwin Pratama (2010), which stated that wind turbines using a 10° blade angle perform better than those with angles below 10°. This also affects the turbine's power value or ability to generate much electricity. The best angle result for a wind turbine is at the 15° angle; subsequently, at the 15° blade angle (the best angle), further testing will be conducted to determine the performance impact of the wind turbine using NACA 0021 so that data on the effectiveness of the wind turbine at the 15° angle can be obtained.

CONCLUSION

The study conducted on the performance of wind turbines using NACA 0021 blades across varying blade angles (from -15° to 20°) provides valuable insights into the optimization of turbine efficiency and power output. It was found that the 15° blade angle yielded the highest performance in terms of current, voltage, power, and efficiency, suggesting an optimal balance between tangential blade speed and wind interaction compared to other tested angles. This indicates that slight alterations in blade angle can significantly affect a wind turbine's operational efficiency and energy generation capabilities. The findings suggest that wind turbines with a blade angle around 15° could be more efficient in harnessing wind energy, which is crucial for enhancing the viability of wind power as a sustainable and renewable energy source. Further research should focus on refining blade angle variations and exploring different airfoil designs to maximize turbine performance and efficiency. Additionally, employing materials that combine lightness and strength could improve the structural integrity and lifespan of the turbines, further enhancing their practical application in the field.

CONFLICT OF INTEREST STATEMENT

The author[s] declare that this article was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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