Check for updates

The Use of Coastal Wind for Electricity Generation Through Savonius Vertical Axis Wind Turbine at Remote Islands in East Java Offshore

Unung Lesmanah[1](✉), Artono Raharjo[1], Margianto[1], and Sugiono[2]

[1] Mechanical Engineering Department, Universitas Islam Malang, Jl. MT. Haryono 193, Malang, Indonesia
ununglesmanah@unisma.ac.id

[2] Electrical Engineering Department, Universitas Islam Malang, Jl. MT. Haryono 193, Malang, Indonesia

Abstract. Although Wind Turbine Generator has common use in several countries, in Indonesia, this thing is rarely used, even though Indonesia's geographic itself stored a lot of potential in developing such an energy source. Indonesia is an archipelagic nation with five main islands and thousands of small islands. Its condition makes coastal wind very important and a potential energy source that hasn't yet been developed. Here, we develop a limited-capacity electric generator to be used in remote small islands in East Java Offshore that are not yet connected to a national power grid. Because of the inconsistency of the direction of a coastal wind, we chose the Vertical Axis Wind Turbine to develop. This research studies the connection between wind blade curve angles and wind turbine efficiency. We used three different wind blade types and measured the rotation speed according to the respective wind velocity. Our experiment shows that the bigger the curve angle resulted in a higher rotational speed of the wind turbine. For example, with the wind velocity at 6 m/s, the results are as with 0° (flat blade) the average rotation speed is 175.5 rpm, 45° the average rotation speed is 212.55 rpm, and 90° the average rotation speed is 266.25 rpm.

Keywords: Wind turbine · vertical axis · power generation · blade shape

1 Introduction

Recently, the need for energy is already become overwhelming [1–3], while the growth tendency of energy consumption in the future is increasing rapidly [4]. On the other hand, fossil fuels, our main energy resource, are limited [5]. Another problem is the cheapest fossil fuel. Coal is also the major pollution distributor, so it is by far not environmentally friendly in the long term [6, 7]. The solution is to harness renewable energy resources, which in our case is wind [8–10]. Wind can be found all over the world for free. The main problem with wind energy is the inconsistent nature of the wind itself either in its speed or direction [11].

E. Susanti et al. (Eds.): ICGT 2022, AER 221, pp. 264–273, 2023.
https://doi.org/10.2991/978-94-6463-148-7_27

Indonesia is an archipelagic nation with five large islands and thousands of small islands [12–14], with hundreds of these islands inhabited. Geographically, Indonesia also lies between the continent of Asia and the continent of Australia, between the Atlantic Ocean and Pacific Ocean, and in the volcano's network known as the rings of fire. This created a big problem because many small islands haven't connected to the national power grid [15]. These remote islands use diesel power generators to provide electricity, which is expensive [16]. But the geographic position also brings many advantages.

Because of these geographic and topographic factors, strong wind is available throughout the year for many of these small remote islands. This study aims to provide these people with cheap, environment-friendly power generators that are easy to operate and maintain based on wind energy. And our choice was to develop a vertical-axis wind turbine to fulfill the needs. The choice is due to the independence of the vertical axis wind turbine to the wind direction, which always changes from time to time, and for the simplicity of its construction compared to the horizontal axis wind turbine [17, 18].

Wind potential in Indonesia generally has low wind speeds ranging from 3 m/s – 7 m/s, so this type of vertical wind turbine is considered very suitable for use in low wind speed conditions [19]. However, the Meteorology, Climatology, and Geophysics Agency Meteorological Station class I Juanda Surabaya reminded the public of the potential danger of changing seasons. One of them is the Gending wind that blows hard in Probolinggo.

The use of wind as an alternative energy source has been widely used in various parts of the world at this time. Still, in Indonesia, this has not been widely used, even though the geological contours in Indonesia, which are mountainous and hilly, will cause a lot of wind. With the Vertical Axis Wind Turbine, the Savonius type, the wind is converted into electrical energy [20, 21]. The workings of the Vertical Axis Wind Turbine convert wind energy into electrical energy when the wind blows. The wind turbine is installed in the direction of the wind flow so that the wind hits the turbine blades so that the wind turbine rotates, then the rotation of the wind turbine is forwarded to the generator to be converted into electrical energy [22, 23].

Savonius is a drag-based wind turbine, where the force of the wind will push the blade surface to rotate [24–27]. The blade will rotate because the drag force on the open surface or concave is greater than the closed surface or convex next to it.

In simple terms, Savonius can be formed from 2 pieces of half-drum blades connected by an axis in the middle with opposite positions. When operating, each side of the drum blade will catch the wind and rotate its axis, exposing its partner blade in the direction of the wind flow, and so on. Then the resulting shaft rotation will be used to drive an electric generator.

In this study, the Savonius Wind Turbine was developed with three blades. Therefore, in terms of efficiency, the vertical axis wind power plant is indeed lower than the horizontal axis. Still, this vertical axis wind power plant can capture wind speed from all directions and can be installed in a low position (close to the ground, making it easier to operate and treat).

This research aims to provide low capacities for wind turbine electric generators to be used in small remote islands in the northern part of East Java offshore in Indonesia.

2 Methods

The Fig. 1 explains the flowchart of the research. Based on Fig. 1, it can be seen that our first step was to measure the wind speed and wind direction in a coastal area of Probolinggo City, which lies in the northern part of east java. The wind speed measurement was done at the height of 2 m above sea level for seven months (march until September), twice a day, with 12 h intervals between the measurements.

The second step was to design the vertical-axis wind turbine suitable for our research purpose. In our first approach, we studied the effect of drag coefficient, which depended on blade shape on the turbine rotational speed as a function of the wind speed. In this study, the Savonius Wind Turbine was developed with three blades.

The first set was flat blade (0° blade angle) which has a drag coefficient of 1.9 (Fig. 2).

Second set was semicircular blade (45o blade angle) which have drag coefficient of 1.15 on the convex side and 2.15 on the concave side (Fig. 3).

The third set was a semicircular Blade (90° blade angle) which had a drag coefficient of 1,2 on the convex side and 2,3 on the concave side (Fig. 4).

With the three sets of the turbine blade, experiments with each of these blades to be set against 2 m/s, 4 m/s and 6 m/s wind speed, according to the wind speed data we collected earlier.

The kinetic energy in a wind turbine can be calculated using Eq. (1):

$$E_k = \frac{1}{2}mv^2 \tag{1}$$

m= air mass (kg),

v= wind velocity (m/s)

Then, the mass flow rate can use the following Equation:

$$m = \rho A v \tag{2}$$

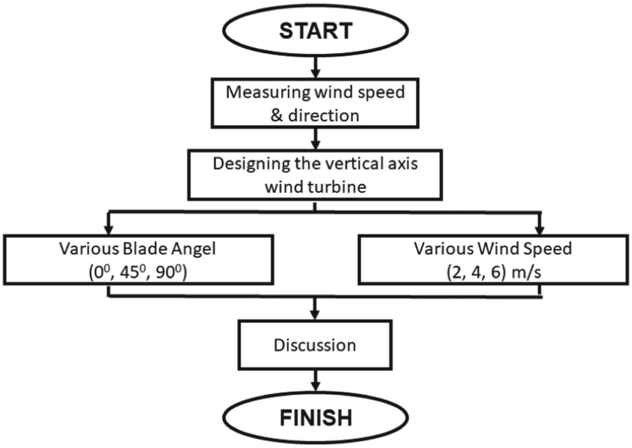


Fig. 1. Research flowchart

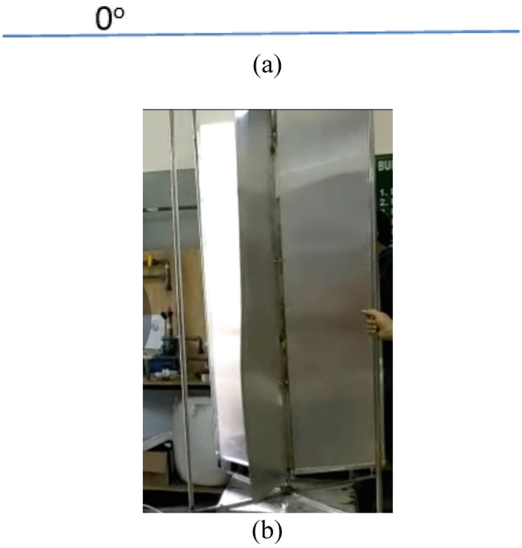


Fig. 2. a) Flat Blade (0^0 Blade Angle); b) Flat blade (0° Blade Angle).

Fig. 3. Semi Circular Blade (45^0 Blade Angle)

where:

ρ = wind density (kg/m^3)

A = turbine cross-sectional area ($A = \pi r^2$)

Equations (1) and (2) can be combined in Eq. (3):

$$P_w = \frac{1}{2}\rho A v^3 \tag{3}$$

where:

P_a = wind power (Watt)

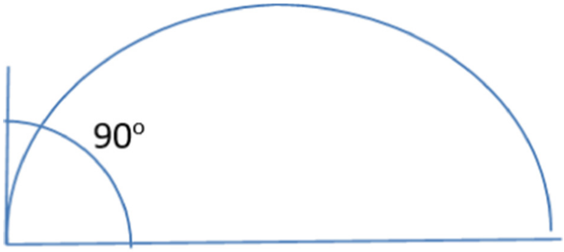
The maximum Power output from the Savonius rotor was

$$Pmax = 0,36kgm^{-3}.h.r.v^3 \tag{4}$$

where h and r are motor height and radius, while v is the wind speed, Eq. (4) represents turbine work efficiency. The angular frequency of the motor is

$$\omega = \frac{\lambda.v}{r} \tag{5}$$

where λ is the tip-speed ratio factor, which for the Savonius rotor the value is ≈1, for example, the Savonius rotor, where h = 1 m, r = 0.5 m and the wind speed v = 10 m/s, will yield maximum power equal to 180 W, and the angular speed is 20 rad/s (190 rpm).



(a)

(b)

Fig. 4. a) Semi Circular Blade (90^0 Blade Angle); b) Semi Circular Blade (90^0 Blade Angle).

The result will be analyzed using a statistical equation to determine the difference in rotor rotation of the Vertical Axis Wind Turbine:

$$s^2 = \sqrt{variance} = \frac{\sum_{i=1}^{n} (X_i - \overline{X}_1)^2}{n-1} \quad (6)$$

$$t_{hitung} = \frac{\overline{X}_1 - \overline{X}_2}{\sqrt{\left\{\frac{(n_1-1)s_1^2+(n_2-1)s_2^2}{n_1+n_2-2}\right\}\left\{\frac{1}{n_1}+\frac{1}{n_2}\right\}}} \quad (7)$$

3 Result and Discussion

Based on the data collection that has been carried out, the wind speed was obtained as follows (Table 1)

From experiment results for the kind of wind speed (2 m/s, 4 m/s and 6 m/s) can be seen in Table 2 and Fig. 5.

We suggested that because in vertical axes wind turbine like Savonius wind turbine, the concave part of the blade move in the direction of the wind and the convex part of the blade move against the direction of the wind, it means that the higher drag coefficient of the concave part will help the turbine to catch more energy from the wind. On the other hand, the lower drag coefficient of the convex part of the blade will make the Blade move easier in the direction against the wind, so fewer energy losses from this part.

Table 1. Wind speed in Coastal Area of Probolinggo

Months (2021)	**Wind Speed (m/s)**							
	1	2	3	4	5	6	7	8
March	2,2	2,1	2,2	2,4	2,0	1,9	2,0	2,1
April	3,2	3,5	3,2	3,4	3,3	3,3	3,2	3,4
May	4,3	3,5	3,2	3,3	3,5	3,0	4,4	4,4
June	4,7	4,7	4,8	4,5	4,7	4,4	4,5	4,7
July	4,7	4,7	4,7	4,5	4,7	4,7	4,6	4,7
August	5,8	5,6	5,7	5,8	5,9	5,7	5,8	5,9
September	5,9	6,2	5,9	6,1	5,9	5,9	6,0	6,2

Table 2. Rotor Rotation Test Results (Source: Lab, Faculty of Engineering, Universitas Islam Malang)

Blade Angel	**Wind Speed (m/s)**	**Rotor Rotation (Rpm)**		**Average (Rpm)**
		Max	Min	
0	2	207,6	32,3	119,95
	4	234,4	59,9	147,15
	6	281,3	69,7	175,5
45	2	331,9	62,3	197,1
	4	332,6	81,4	207
	6	363,5	61,6	212,55
90	2	413,4	67,1	240,25
	4	425,7	66,3	246
	6	458	74,5	266,25

Based on Table 2 and Fig. 5, the Savonius wind turbine, which has a rotor blade with a greater drag coefficient (90° blade angle) can produce higher rotational speed than the other model with the blade, which has a smaller drag coefficient. Based on Eqs. (3) and (4) representing turbine work efficiency, Table 2 shows that a turbine with a blade angle at 90^0 depicts the highest rotation speed leading to the highest turbine power. This output turbine power will have higher efficiency than blade angles 0^0 and 45^0. The blade angle at 0^0 shows the lowest wind turbine average speed compared with others.

Then a t-test was carried out to determine the difference in rotor rotation of the Vertical Axis Wind Turbine based on three blade shapes. The level of Significance used is 2,132. Therefore, H_0 accepted if $t_{count} \leq 2{,}132$ and H_0 rejected if $t_{count} > 2{,}132$.

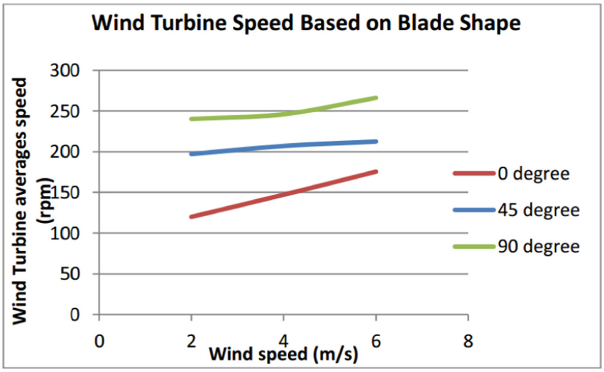


Fig. 5. Wind Turbine speed based on blade shape

In Table 3, The calculation result using Eqs. (6) and (7) is t_{count} 4,24519 > 2,132 then H_0 was rejected. Thus it is known that the Vertical Axis Wind Turbine with a Blade Angle of 45^0 has a higher rotation than the Blade Angle of 0^0.

Table 3. Rotor Rotation Comparison with Blade Angle (0^0 & 45^0)

No	Angle Blade		$(X_1 - \overline{X}_1)^2$	$(X_2 - \overline{X}_2)^2$
	45^0	**0^0**		
	X_1	X_2		
1	331,9	207,6	115,9211	1122,25
2	332,6	234,4	101,3378	44,89
3	363,5	281,3	434,0278	1616,04
Σ	1028	723,3	651,2867	2783,18
$\overline{X}$	342,6667	241,1		

Table 4. Rotor Rotation Comparison with Blade Angle (45^0 & 90^0)

No	Angle Blade		$(X_1 - \overline{X}_1)^2$	$(X_2 - \overline{X}_2)^2$
	90^0	**45^0**		
	X_1	X_2		
1	413,4	331,9	1061,247	115,9211
2	425,7	332,6	1061,247	101,3378
3	458	363,5	1061,247	434,0278
Σ	1297,1	1028	1061,247	651,2867
$\overline{X}$	432,367	342,67		

Moreover, Based on Table 4, statistical calculation shows the value of t_{count} 5,309438 > 2,132 then H_0 was rejected. Thus it is known that the Vertical Axis Wind Turbine with a Blade Angle of 90^0 has a higher rotation than the Blade Angle of 45^0.

4 Conclusion

This study showed that the drag coefficient, whose value depends on blade shape, significantly affects our Savonius Wind Turbine model. The experiment showed that while exposed to the same wind speeds (2 m/s, 4m/s and 6 m/s), the model with greater drag coefficient produced higher rotational speed (240 rpm, 246 rpm, and 266 rpm) than the other models (119 rpm, 147 rpm and 175 rpm for the flat blade and 197 rpm, 207 rpm and 212 rpm for the other semicircular blade). Thus, a turbine with a blade angle of 90^0 depicts the highest rotation speed leading to the highest turbine power and high efficiency.

Acknowledgments. The authors gratefully acknowledge to Ministry of Research, Technology and Higher Education of Indonesia in PDUPT 2021 No. 167/E4.1/AK.04.PT/2021.

References

1. Lucas, H., Fifita, S., Talab, I., Marschel, C., & Cabeza, L. F. (2017). Critical challenges and capacity building needs for renewable energy deployment in Pacific Small Island Developing States (Pacific SIDS). *Renewable energy*, *107*, 42-52.
2. Shaaban, M., & Petinrin, J. O. (2014). Renewable energy potentials in Nigeria: Meeting rural energy needs. *Renewable and sustainable energy reviews*, *29*, 72-84.
3. Timmons, D., Harris, J. M., & Roach, B. (2014). The economics of renewable energy. *Global Development And Environment Institute, Tufts University*, *52*, 1-52.
4. Cabeza, L. F., Urge-Vorsatz, D., McNeil, M. A., Barreneche, C., & Serrano, S. (2014). Investigating greenhouse challenge from growing trends of electricity consumption through home appliances in buildings. *Renewable and Sustainable Energy Reviews*, *36*, 188-193.
5. McGlade, C., & Ekins, P. (2015). The geographical distribution of fossil fuels unused when limiting global warming to 2 C. *Nature*, *517*(7533), 187-190.
6. Renn, O., & Marshall, J. P. (2016). Coal, nuclear and renewable energy policies in Germany: From the 1950s to the "Energiewende". *Energy Policy*, *99*, 224-232.
7. Rahman, Z. U., & Ahmad, M. (2019). Modeling the relationship between gross capital formation and CO 2 (a) symmetrically in the case of Pakistan: an empirical analysis through NARDL approach. *Environmental Science and Pollution Research*, *26*(8), 8111-8124.
8. Basit, M. A., Dilshad, S., Badar, R., & Sami ur Rehman, S. M. (2020). Limitations, challenges, and solution approaches in grid-connected renewable energy systems. *International Journal of Energy Research*, *44*(6), 4132-4162.
9. Haratian, M., Tabibi, P., Sadeghi, M., Vaseghi, B., & Poustdouz, A. (2018). A renewable energy solution for stand-alone power generation: A case study of KhshU Site-Iran. *Renewable Energy*, *125*, 926-935.
10. Solangi, Y. A., Tan, Q., Mirjat, N. H., Valasai, G. D., Khan, M. W. A., & Ikram, M. (2019). An integrated Delphi-AHP and fuzzy TOPSIS approach toward ranking and selection of renewable energy resources in Pakistan. *Processes*, *7*(2), 118.

11. Cassola, F., & Burlando, M. (2012). Wind speed and wind energy forecast through Kalman filtering of Numerical Weather Prediction model output. *Applied energy*, *99*, 154-166.
12. Farhan, A. R., & Lim, S. (2013). Improving vulnerability assessment towards Integrated Coastal Zone Management (ICZM): a case study of small islands in Indonesia. *Journal of Coastal Conservation*, *17*(3), 351-367.
13. Purwanto, H., & Mangku, D. G. (2016). Legal Instrument of the Republic of Indonesia on Border Management Using the Perspective of Archipelagic State. *International Journal of Business, Economics and Law*, *11*(4), 51-59.
14. Nugraha, D. C. A., & Aknuranda, I. (2017). An Overview of e-Health in Indonesia: Past and Present Applications. *International Journal of Electrical & Computer Engineering (2088–8708)*, *7*(5).
15. Nuru, J. T., Rhoades, J. L., & Gruber, J. S. (2021). The socio-technical barriers and strategies for overcoming the barriers to deploying solar mini-grids in rural islands: Evidence from Ghana. *Technology in Society*, *65*, 101586.
16. Chade, D., Miklis, T., & Dvorak, D. (2015). Feasibility study of wind-to-hydrogen system for Arctic remote locations–Grimsey island case study. *Renewable Energy*, *76*, 204-211.
17. Hand, B., & Cashman, A. (2020). A review on the historical development of the lift-type vertical axis wind turbine: From onshore to offshore floating application. *Sustainable Energy Technologies and Assessments*, *38*, 100646.
18. Monteiro, J. P., Silvestre, M. R., Piggott, H., & Andre, J. C. (2013). Wind tunnel testing of a horizontal axis wind turbine rotor and comparison with simulations from two Blade Element Momentum codes. *Journal of wind engineering and industrial aerodynamics*, *123*, 99-106.
19. Alit, I. B., Nurchayati, N., & Pamuji, S. H. (2016). Turbin angin poros vertikal tipe Savonius bertingkat dengan variasi posisi sudut. *Dinamika Teknik Mesin*, *6*(2).
20. Rus, T., Rus, L. F., Abrudan, A. C., Domnita, F. V., & Mare, R. (2016). Experimental tests in equipping vertical axis wind turbines with electric generator. *International Journal of Renewable Energy Research (IJRER)*, *6*(2), 465-471.
21. Siregar, A. M., & Siregar, C. A. (2019, November). Reliability test prototype wind turbine savonius type helical as an alternative electricity generator. In *IOP Conference Series: Materials Science and Engineering* (Vol. 674, No. 1, p. 012059). IOP Publishing.
22. Bhutta, M. M. A., Hayat, N., Farooq, A. U., Ali, Z., Jamil, S. R., & Hussain, Z. (2012). Vertical axis wind turbine–A review of various configurations and design techniques. *Renewable and Sustainable Energy Reviews*, *16*(4), 1926-1939.
23. Lesmanah, U., & Sugiono, S. (2020). Pemanfaatan Angin di Gedung UNISMA Sebagai Energi Alternatif Pengerak Wind Turbine Type Savonius pada Pengembangan Media Pembelajaran. *JURNAL TECNOSCIENZA*, *4*(2), 215-230.
24. Wenehenubun, F., Saputra, A., & Sutanto, H. (2015). An experimental study on the performance of Savonius wind turbines related with the number of blades. *Energy procedia*, *68*, 297-304.
25. Zhou, T., & Rempfer, D. (2013). Numerical study of detailed flow field and performance of Savonius wind turbines. *Renewable energy*, *51*, 373-381.
26. Alom, N., & Saha, U. K. (2019). Influence of blade profiles on Savonius rotor performance: Numerical simulation and experimental validation. *Energy conversion and management*, *186*, 267-277.
27. Alom, N., & Saha, U. K. (2018). Four decades of research into the augmentation techniques of Savonius wind turbine rotor. *Journal of Energy Resources Technology*, *140*(5).