Performance Analysis of Preliminary Taperless Small HAWT Design

Abdul Goffar Al Mubarok

Abstract— Wind energy potential in Indonesia is relatively small, because it lies in the equator. More studies are necessary to be conducted for advance development of wind turbine technology in Indonesia. This study aims to propose a preliminary design of a small three blade taperless horizontal axis wind turbine (HAWT) which is feasible with wind energy potential from the previous study. In the current study, NACA 4418 airfoil was used to design the 3D model of the blade with 0.9 m radius of the blade. QBlade v0.963 was used to test the characteristic properties of the airfoil. QBlade was also used to test the performance of the blade with the Turbine BEM Simulation. The performance analysis simulation was done based on the data from the previous study about wind energy potential at the Faculty of Engineering, Universitas Negeri Jakarta, Indonesia. In conclusion, the design and simulation showed that three blade HAWT with NACA 4418 airfoil could be considered to be developed in the future.

Index Terms— Airfoil, BEM analysis, HAWT, Small wind turbine.

◆

1 INTRODUCTION

Wind energy has become one of the fastest growing renewable energy resources in the worldwide[1]. The depletion of fossil fuels, global warming, and the increase of carbon emission acceletare its development because people are currently looking for alternative energy which uses renewable resources[2, 3].

Wind energy is not considered to be developed well in Indonesia because of the lack information of its potential. In addition, the present wind turbines were not managed properly and built without concerning to the technical feasibility. These conditions grew doubts about the potential of wind energy in Indonesia[4]. Actually, the wind energy potential in Indonesia is small because of its location in the equator [5]. However, the potential is quite good in the range of 3 – 6 m/s with the available resources of 970 MW [4].

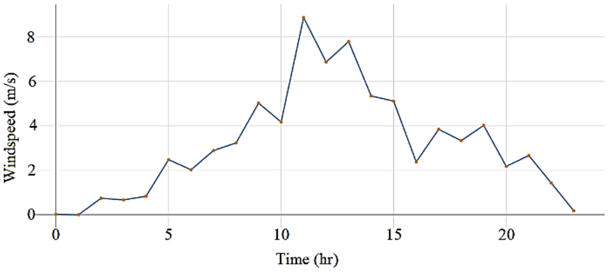

Fig. 1. Wind speed graph from the previous research. The data taken at the rooftop of L Building, Faculty of Engineering, Universitas Negeri Jakarta on Januari 16th, 2018

The previous study proved that the wind energy potential in Indonesia is quite good in the range of 3 – 9 m/s[6] as shown by Figure 1. Based on the previous study, this research is aimed to propose a preliminary design of a small three blade taperless horizontal axis wind turbine (HAWT) which is feasible with wind energy potential in Indonesia. The small HAWT was designed to convert maximum 600 Watt power. This study is limited to computer design and simulation only.

2 BLADE DESIGN

2.1 Airfoil Selection

Airfoil is a streamlined body bounded by two flattened curves and whose length and width are very large in comparison with the thickness[7]. The amount of lift and drag coefficients are esentially required for the selection of airfoil. The coordinates of airfoil for typical application can be checked from NACA and NREL sites[8]. NACA 4418 airfoil (Figure 2) was selected to be used in this study.

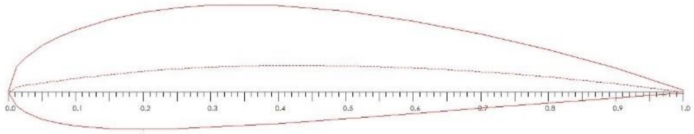

Fig. 2. NACA 4418 airfoil.

2.2 Blade Length Calculation

The small HAWT was designed to convert maximum 600 Watt power with the assumption that the efficiency (C_P) value of the blade is 0.4. There is no wind turbine can convert more than 16/27 percent power from the wind[8]. The turbine was design to operate in critical condtions of 12 m/s wind speed and 1.225 kg/m^3 of air density (ρ).

$$P_{wind} = \frac{1}{2}(\rho \cdot v_{wind}^3 \cdot A) \quad (1)$$

$$P_{wind} \cdot C_P = P_{mechanics} \quad (2)$$

$$R = \sqrt{A/\pi} \quad (3)$$

- *Abdul Goffar Al Mubarok was finished his bachelor degree program in electonic engineering vocational education in Faculty of Engineering, Universitas Negeri Jakarta, Indonesia, Mobile: +6285224703621. E-mail: a.goffar.almubarok@gmail.com*

IJSER

IJSER

From (1) and (2), (3) the chord length (R) would be 0.9 m.

2.3 Gliding Ratio

Gliding ratio is related to lift force, simply higher gliding rasio higher the lift force of an airfoil. Gliding ratio is a ratio between lift coefficient (C_l) to drag coefficient (C_d) [8]. QBlade was used to find both C_l and C_d. The coordinate data of the selected airfoil is necessary to find these coefficients. The coordinate data of the NACA 4418 airfoil were obtained from NACA data site as .dat file. It was imported into the software then XFOIL analysis was conducted.

2.4 Blade Segments Calculation

Segments of the blade consist of some parameters to be calculated such as chord length per segment, tip speed ratio (TSR) per segment, C_l per segment, flow angle (Φ), twist angle (β). Besides the value of alpha (α) and twist angle (β) obtained by analyzing the simulation result.

$$r = 0.12 \times [(R - 0.12/N)]n \tag{4}$$

$$\lambda_r = (r/R)\lambda_R \tag{5}$$

$$C_l = [16\pi \times R \times (R/r)]/(9\lambda_R^2 \times B \times C_r) \tag{6}$$

From (4), the chord length per segment (r) were obtained. In this study, total segment of the blade (N) is 10. Where n is the number of segment. From (5), TSR per segment (λ_r) were obtained using multiplication of assumed TSR (λ_R), 7, by chord length per segment and blade's chord length ratio.

From (6), the lift coefficient per segment were obtained. In (6), B means total blade of the turbine and C_r means chord width. Assumed total blade of the turbine is three blades and the chord width is 0.2 m. C_l per segment is required to know the value of α from the XFOIL simulation.

$$\phi = (2/3)tan^{-1}(1/\lambda_r) \tag{7}$$

$$\beta = \phi - \alpha \tag{8}$$

From (7), the flow angle were obtained. Then from (8), the twist angles of the blade were obtained. Twist angle are required for modelling the blade.

3 RESULT

3.1 XFOIL Simulation

XFOIL analysis was done on the imported NACA 4418 airfoil. Figure 3 shows the characteristic of the NACA 4418 airfoil which is represented by graph of gliding ratio with the variation of alpha.

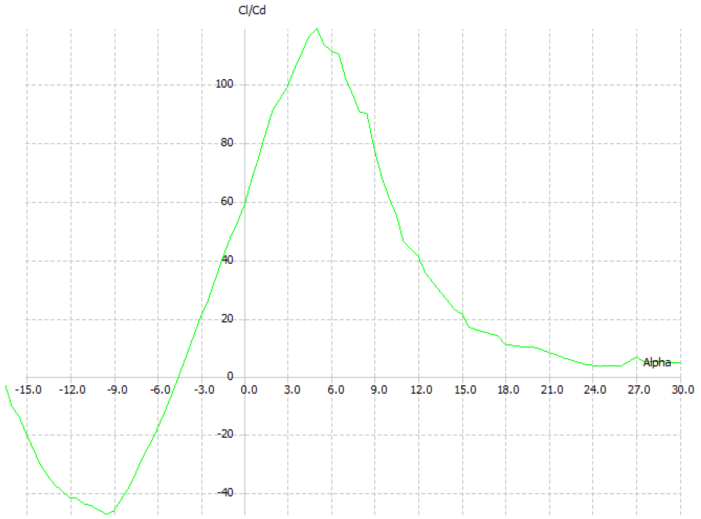

Fig. 3. Gliding ratio of NACA 4418 airfoil with the variation of angle of attack (alpha).

3.2 HAWT Rotorblade Design

Rotorblade design is highly related to blade segments calculation. From the calculation, values of desired parameters were obtained as shown in Table 1.

TABLE 1
PROPERTIES OF BLADE SEGMENTS

Seg. No.	r (m)	λ_r	C_l	β (deg)
0	0.12	0.93	1.28	-8.90
1	0.20	1.54	0.78	-1.95
2	0.28	2.15	0.56	0.65
3	0.35	2.75	0.43	2.18
4	0.43	3.36	0.36	3.28
5	0.51	3.97	0.30	4.39
6	0.59	4.57	0.26	5.23
7	0.67	5.18	0.23	5.81
8	0.74	5.79	0.21	6.39
9	0.82	6.39	0.19	7.15
10	0.90	7.00	0.17	7.63

Definition of symbols in the table (with unit):
r = chord length per segment (m); λ_r = tip speed ratio per segment; C_l = lift coefficiency; and β = twisted angle (deg)

Twisted angle in Table 1 was too extreme to be implemented. It was in the range of -8.90 degree to 7.63 degree. Linearization is required by taking segment number 8 and 9 as the sample. Figure 4 show the linearization of twist angle. (9) was used to proceed the linearization of twist angle.

$$\beta = 0.5789r + 1.1795 \tag{9}$$

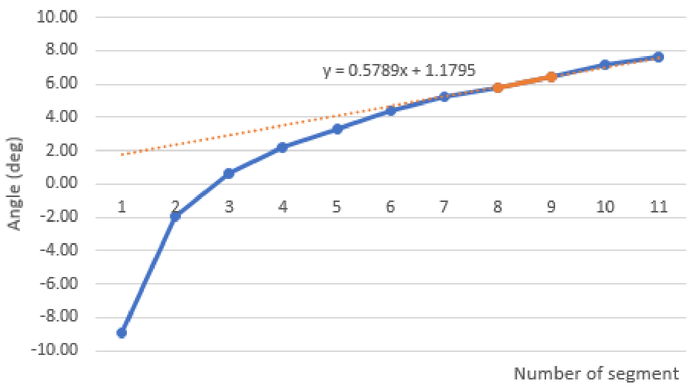

Fig. 4. Linearization of extreme twist angle.

The new twist angle was shown by Table 2.

TABLE 2
TWIST ANGLE LINEARIZATION RESULT

Seg. No.	Old β (deg)	Linear β (deg)
0	-8.90	1.25
1	-1.95	1.29
2	0.65	1.34
3	2.18	1.38
4	3.28	1.43
5	4.39	1.47
6	5.23	1.52
7	5.81	1.56
8	6.39	1.61
9	7.15	1.65
10	7.63	1.70

The type of the designed blade is taperless blade, so the chord width (C_r) remains the same. Then the calculated parameters were given into the QBlade form for rotorblade design. Figure 5 shows the rotorblade design using existed parameters.

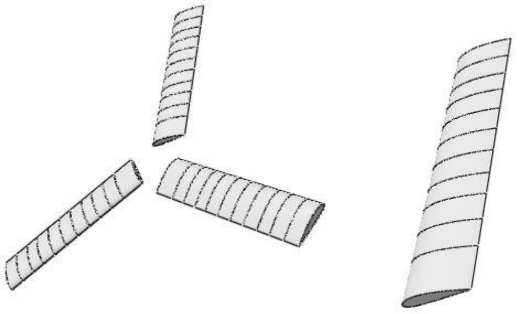

Fig. 5. 3D model of HAWT blade and rotor blade with NACA 4418 airfoil

3.3 Rotor BEM & Multiparameter BEM Simulation

The 3D model of rotor blade with NACA 4418 was simulated in QBlade. C_p and Power (P) were obtained as the result of the simulation. Figure 6 shows C_p vs TSR and Figure 7 shows P vs TSR.

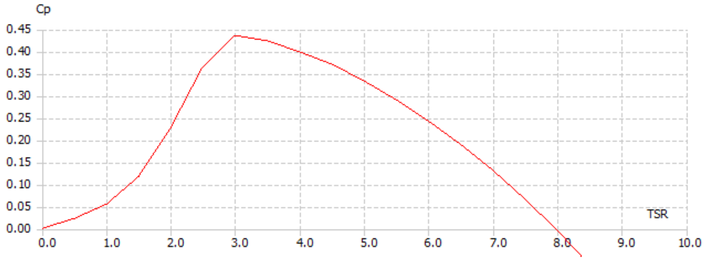

Fig. 6. Power coefficient (C_p) vs tip speed ratio (λ).

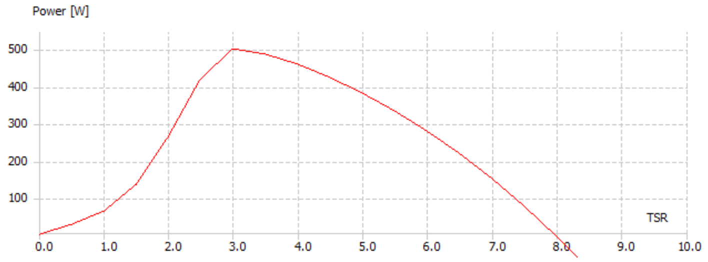

Fig. 7. Power (P) vs tip speed ratio (λ).

Besides, multiparameter BEM simulation was also conducted to obtain the cut in windspeed, cut out windspeed, and optimum rotational speed (ω) value to optimize wind turbine performance. Based on the simulation, obtained that the optimum ω value is 192.73 rpm with 0 degrees pitch. Power vs Windspeed plot is shown by Figure 8.

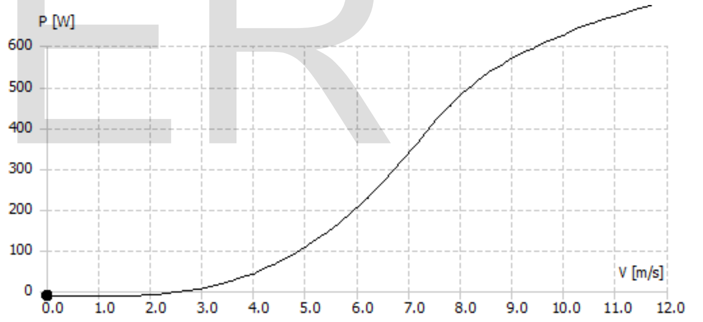

Fig. 8. Power (P) vs wind speed (v) obtained by the multiparameter BEM simulation. Obtained that the cut in wind speed is 3 m/s and cut off wind speed is 9.5 m/s with 192.73 rpm as the optimum value of ω.

3.4 Turbine Performance Analysis

All the plotted graphs of turbine performance analysis were obtained by turbine BEM simulation in QBlade. Simulation started after defining the simulation conditions and filling in the value of cut in wind speed, cut out wind speed, and rotational speed. Figure 9 and Figure 10 were obtained as the performance analysis result.

IJSER

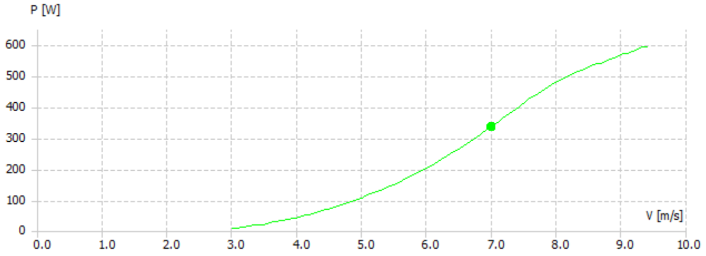

Fig. 9. Power (P) vs wind speed (v) obtained by the multiparameter BEM simulation. Obtained that the cut in wind speed is 3 m/s and cut off wind speed is 9.5 m/s with 192.73 rpm as the optimum value of ω.

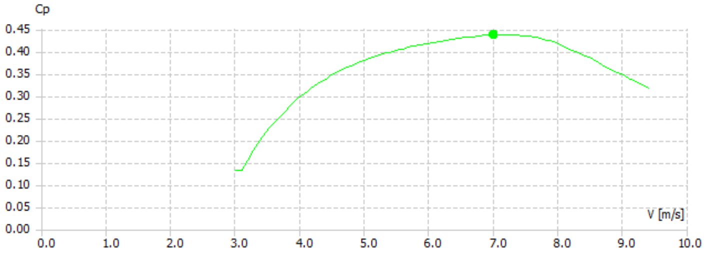

Fig. 10. Power (P) vs wind speed (v) obtained by the multiparameter BEM simulation. Obtained that the cut in wind speed is 3 m/s and cut off wind speed is 9.5 m/s with 192.73 rpm as the optimum value of ω.

4 DISCUSSION

NACA 4418 airfoil was selected to model a small HAWT turbine blade with power capacity of 600 Watts. The first analysis was airfoil characteristic analysis using XFOIL simulation. XFOIL simulation was done using QBlade software. Figure 3 shows that the maximum gliding ratio of NACA 4418 is 119 between 3 degrees to 6 degrees alpha.

Then blade segments calculation was done to obtain some necessary paramters such as chord length per segment, tip speed ratio per segment, lift coefficiency, twist angle. Twist angle is essentially needed to model the geometry of the blade. The calculation of twist angle was resulted an extreme or nonlinear curve, so an action was done to make the twist angle more linear. After linearization, 3D model of blade and rotor was obtained.

The last analysis of this study was performance analysis using Turbine BEM Simulation in QBlade. Rotor BEM Simulation and Multiparameter BEM Simulation were conducted before. Rotor BEM Simulation was resulted plot of power coefficient vs TSR and plot of power vs TSR. Multiparameter BEM Simulation was resulted the cut in wind speed, cut out wind speed, and rotational speed of wind turbine. These parameters were needed to perform Turbine BEM Simulation. Turbine BEM Simulation was done and obtained the plot output power of wind turbine vs wind speed and power coefficient vs wind speed.

5 CONCLUSIONS

Theoritical and simulated model were tested in this study. Performance analysis showed that the designed wind turbine blade could obtain 0.45 power coefficient which is relatively high. This result was promising to be tested in manufacturing stage in the future. More aspects are also needed to be considered such as CFD analysis and stress analysis of the material.

REFERENCES

1. Wang, J., Zhou, Q., Jiang, H., Hou, R.: Short-Term Wind Speed Forecasting Using Support Vector Regression Optimized by Cuckoo Optimization Algorithm. Math. Probl. Eng. 2015, 619178 (2014). doi:10.1155/2015/619178
2. Samrat, N.H., Ahmad, N., Choudhury, I.A., Taha, Z.: Technical Study of a Standalone Photovoltaic – Wind Energy Based Hybrid Power Supply Systems for Island Electrification in Malaysia. 1–35 (2015). doi:10.1371/journal.pone.0130678
3. Cho, K., Jeong, S., Sari, D.P.: Harvesting wind energy from aerodynamic design for building integrated wind turbines. Int. J. Technol. 2, 189–198 (2011). doi:10.14716/ijtech.v2i3.65
4. Wargadalam, V.J.: Potensi Energi Angin dan Kelayakan Harga Listrik yang Dihasilkan, (2014)
5. KESDM: Rencana Strategis Ditjen EBTKE. J. Energi Media Komun. Kementeri. Energi dan Sumber Daya Miner. 2, (2016)
6. Al Mubarok, A.G., Djatmiko, W., Yusro, M.: Design of Arduino-based small wind power generation system. Int. Trop. Renew. Energy Conf. 3, (2018) "unpublished"
7. Patankar, S.P., Deshmukh, S.J., Kolhekar, R.R.: Theoretical Analysis of Horizontal Axis Wind Turbine for Low Wind Velocity. 2, 93–98 (2015)
8. Manivannan, A., Thanapaul, A.: Small Hawt Blade Design Made of Sustainable Natural Fiber, (2016)

IJSER