Characteristic of Taperless Blade Wind Turbine

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Abstract

Presently, source of energy in Indone sia is still predominated by fossil energy. Since fossil energy is limited and not environmentally friendly, alternative of energy should be considered to be implemented. As consequences, research in renewable energy field has developed due to a bove reason. One of renewable energy source is wind energy. The potential of wind energy in Indone sia is estimate d 9.290 MWe, and presently, the installed capacity of wind energy conversion system (WECS) approxima tely is 1.1 MWe. Nevertheless, there is problem in development of utilize of WECS in Indonesia , due to most of the WECS, which available in market, are not designed for Indonesia wind condition. Based on this fact, it is reasonable if the WECS whic h operated in Indone sia not working properly (in performance point of view). Blades in a WECS are the main components, which have major influenced on the performance of WECS. In this research, design of blades will be carried out based on predetermined power capacity, using wind velocity condition in Indonesia. As an outcome this research, concept of blade based on aerodynamic design have been proposed and ready to be implemented.

Keywords: Renewable energy, wind velocity, wind energy conversion system (WECS), aerodynamic design, WECS performance.,

1. Introduction

The concept on renewable enery is known since 1970's, as efforts to balance the use of nuclear and fossil fuels. The common definition of that is that energy resources that can be naturally renewed, and the process is sustainable. By this definition, fossil and nuclear are not categorized as renewable energy resources. Hence, research and development of water, geothermal, biomass, solar, and wind need to be done.

Indonesia is a country with wind potential that can be used to produce electricity. Indonesia wind energy potential is predicted arount 9,290 MWe if it is converted to electricity, and the utilization of it untill the date is about 11 MWe (BPPT, 2014:17).

Most of Wind Energy Convertion System (WECS) that available in markets are producted not from Indonesia which the design is adjusted with the wind condition of where this WECS is produced or designed. It is reasonable to design the blades of Wind Energy Convertion System (WECS) the meet the condition of Indonesia wind.

2. Research Methodology

Overall, method that I have used to design the blades of wind turbine is studying literature, choosing airfoil, optimizing dimension, simulating and documenting the concept of wind turbine blades that ready to be produced.

3. Rotor / Blade

Base on the shape of the blades from the hub to tip, Blades of WECS are divided into 3 type which are taper, taperless, and inverse-taper, as can be seen in Figure 1. In this research, writer choosed taper blade with assumption it will suit for low wind velocity.

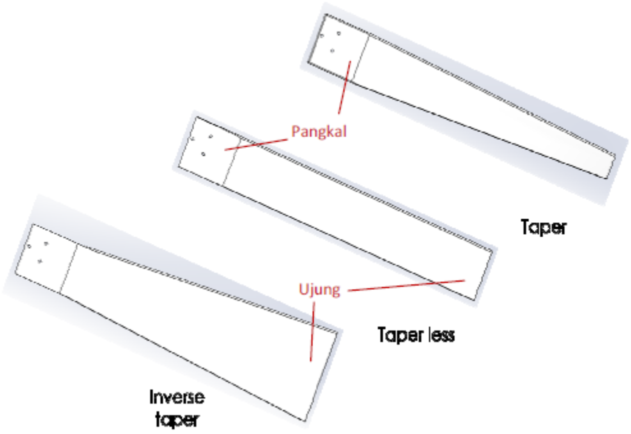

Fig. 1: Types of Blade Based on Its shape (Lentera Angin Nusantara, 2014)

4. Coefficient of Performance

Overall, method that I have used to design the blades of wind turbine is studying literature, choosing airfoil, optimizing dimension, simulating and documenting the concept of wind turbine blades that ready to be produced.

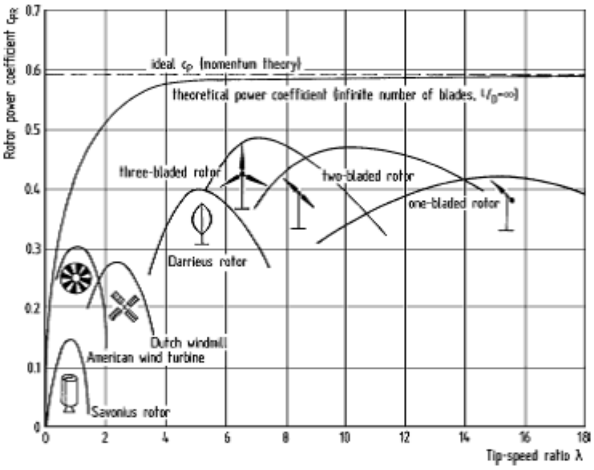

Fig. 2: Characteristic of different types of wind turbines (Wind Turbine Technology, 2014)

5. Dimension Optimization

Dimension optimization of blades of WECS in this research is using predetermined of maximum power at 500 Watt.

5.1. Rotor radius calculation

In order to determine the chord of the blades, these equations that Cancelli used in his thesis, Aerodynamic Optimization of A Small-Scale Wind Turbine Blade for Low Windspeed Conditions, are used.

$$W_{wind} = \frac{W_{design}}{\eta_{sys}} \tag{1}$$

$$A = \frac{2 \times W_{wind}}{v_{max}{}^3} \tag{2}$$

$$R = \sqrt{\frac{A}{\pi}} \tag{3}$$

Table 1: Calculations results of rotor radius

Power Capacity (Watt)	Efficiency (%)				Wind Power (W_{angin})	V_{max} (m/s)
	Blades	Generator	*Controller*	System		
500	0.3	0.8	0.8	0.192	2604.166667	12
	0.4			0.256	1953.125	

Cross-Sectional Area (A)	Radius	Average Radius	Used Radius
2.460474931	0.8849822	0.825699634	0.80
1.845356198	0.76641707		

After getting the "used radius" for the rotor/blades, dividing the blades into 10 section is done in order to get the accuracy in this design. In this design, dimension of the hub section is already determined by 0.14 m, which is suited to the supporting component for testing process. The calculation is using equation 4 and the result is shown in Table 2.

$$r = 0.14 + \left[\frac{R-0.14}{n}\right] \times (element) \tag{4}$$

Table 2: Calculation result of radius section

Segmen	r (m)
0	0.14
1	0.21
2	0.27
3	0.34
4	0.40
5	0.47
6	0.54
7	0.60
8	0.67
9	0.73
10	0.80

5.1. Airfoil selection

Airfoil is chosen based on Cl max in Cl vs α graph, and Cl/Cd max in Cl/Cd vs α graph. Also, I choose the airfoil that the gap is not steep. Hence, the change of α will not have big impact to Cl. Below, is the list of airfoils that is categorized as "common use" for wind turbine in low wind velocity.

1. SD7034
2. SD7032-099-88
3. S4180-098-84
4. Rhode St. Genese 30
5. NACA 4412, NACA 4415, NACA 2410, NACA 4418, NACA 6412, NACA 25112
6. Goe 225, Goe 426, Goe 621, Goe 795
7. MH 102, MH 110.

From the graph Cl vs α and Cl/Cd vs α, also from the shape of the graph that declivous, It can be decide to used SD7032-099-88, as the shape can be seen in Figure 3.

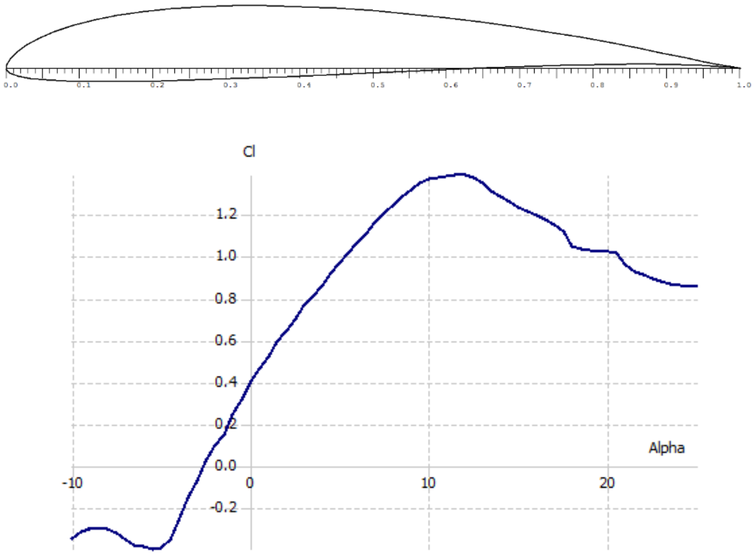

Fig. 3: Airfoil Profile, Graph Cl vs α, and Graph Cl/Cd vs α of SD7032-099-88

3.1. Chord calculation

In order to determine the chord of the blades, these equations that Cancelli used in his thesis, Aerodynamic Optimization of A Small-Scale Wind Turbine Blade for Low Windspeed Conditions, are used. And safety factor for the blades for an uncertain condition are predetermined, 1.25.

$$Dynamic\ Pressure\ (qs) = \frac{1}{2}\rho v^2 \quad (6)$$

$$Axial\ Load\ (P) = qs.\ ct.\ c \quad (7)$$

$$Momen: \frac{P}{2}(R^2 - r^2) \quad (8)$$

$$Tegangan\ (\sigma) = \frac{Md}{Iyy} \quad (9)$$

$$Dynamic\ Pressure\ (qs) = \frac{1}{2}\rho v^2 \quad (10)$$

$$Tegangan\ izin\ (\sigma) = 36000\ Pa\ \text{(Properties of Wood)} \quad (11)$$

$$Sf = 1.25 = \frac{Allowable\ Stress\ (\sigma)}{Actual\ Stress\ (\sigma)} \quad (12)$$

An approach in Airfoil profile is needed to get Iyy and d, as can be seen in Figure 4 and its result in Table 3.

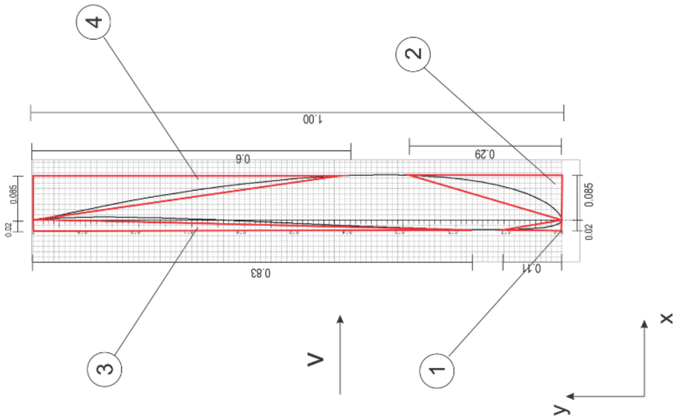

Fig. 4: An approach to airfoil profile (SD7032-099-88)

Table 3: Calculation Result of Iyy dan d

Geometry	Plane	Xbar (m)	Ybar (m)	Iyy (c^4) (m^4)	d (c) (m)	c (m)
Triangle	1	0.044135	0.430369	0.000171	0.044135	0.126172
Triangle	2			0.00143		
Triangle	3			0.00103		
Triangle	4			0.003994		
Rectangular	All			0.009259		
Iyy Airfoil				0.002634		

3.1. Twist at the blades

Other needed dimension for simulation is twis. Initialy, TSR partial is calculated then followed by Cl, α (angle of attack) and ϕ (flow angle).

$$\lambda_r = \frac{r}{R} \times \lambda_R \tag{10}$$

$$C_l = \frac{16\pi \times R \times \frac{R}{r}}{9\lambda_R \times B \times C_r} \tag{11}$$

$$\phi = \frac{2}{3} tan^{-1} \frac{1}{\lambda_r} \tag{12}$$

$$\beta = \phi - \alpha \tag{13}$$

From the twist, a graph are made and a linearisation from section 7 to 8 are done. This is to simplify the design and to make it easy to be produced without reduce its performance. This linearisation can be seen in Figure 5. Dotted line (blue line) show the twist of each section after linearisation.

Table 4: Calculation Result of Twist

Section	r (m)	TSR Parsial	Cl	α (°)	ϕ (°)	β (°)
0	0.14	1.225	1.34	9.5	26.15	16.65
1	0.21	1.8025	0.91	4.5	19.35	14.85
2	0.27	2.38	0.69	2.4	15.19	12.79
3	0.34	2.9575	0.55	1.2	12.45	11.25
4	0.40	3.535	0.46	0.5	10.53	10.03
5	0.47	4.1125	0.40	-0.05	9.11	9.16
6	0.54	4.69	0.35	-0.3	8.02	8.32
7	0.60	5.2675	0.31	-0.55	7.17	7.72
8	0.67	5.845	0.28	-0.75	6.47	7.22
9	0.73	6.4225	0.25	-1	5.90	6.90
10	0.80	7	0.23	-1.1	5.42	6.52

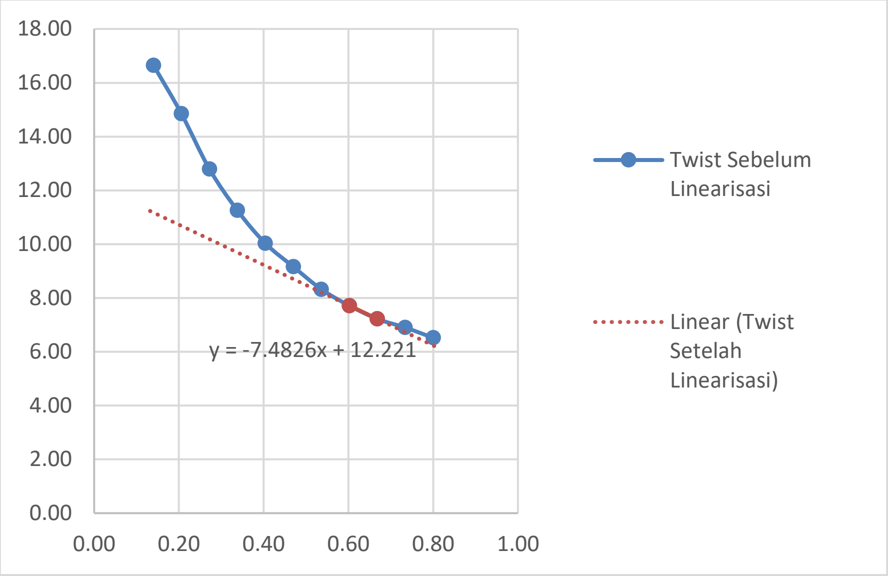

Fig. 5: Graph of twist angle vs r (section radius) dan linearization of the twist

Table 4: Twist that already linear (β')

β (°)	β' (°)
11.17	11.00
10.68	Linear
10.19	
9.69	
9.20	
8.70	
8.21	
7.72	
7.22	
6.73	
6.23	6.00

6. Simulation

Simulation are done using software, Qblade, by putting data as an input such as airfoil types, chord, and twist of the blades.

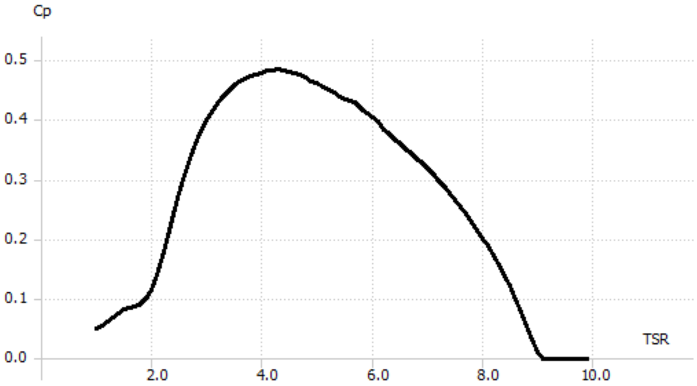

Fig. 6: Result of simulation, Cp vs TSR

7. Conclusion

An important conclusion from designing this blades of horizontal axis wind turbine, 500 Watt as maximum power, is that the dimension of the blade are obtained. In addition, from the result, the 3D visualization of the blades are made and ready to be produced.

8. Nomenclature

A	Wind cross-sectional area of the blade	m2
R	Rotor radius	m
R	Radius, to n element	m
W	Power	Watt
I	Inertia moment in y axis	m4
d	the outer distance from the center of mass from the load come	m
M	Momen	Nm
ct	Coefficient trust	
cl	Coefficient lift	
c	Chord	m

Greek letters

α	angle of attack	^{o}
ϕ	flow angle	^{o}
β	twist angle	^{o}
ρ	residence time	kg/m^3

Subscripts

yy	in Y axis
sys	system

9. References

Cancelli, Nicolette Arnalda. 2006. Aerodynamic Optimisation of a Small-Scale Wind Turbine Blade for Low Windspeed Conditions.

Piggott, Hugh. 2000. Windpower Workshop Building Your Own Wind Turbine. UK: British Wind Energy Association

Sugiyono, Agus, Anindhita, M. Sidik Boedoyo, Adiarso. Outlook Energi Indonesia 2014. Jakarta: BPPT.

Tim LAN. 2014. Pengenalan Teknologi Pemanfaatan Energi Angin. Tasikmalaya: 2014

Wind Energy How It Work. tersedia di: http://www.renewableuk.com/en/renewable-energy/wind-energy/how-it-works.cfm, diakses tanggal 15 September 2015.

Wind Turbine Technology. Tersedia di: https://energypedia.info/wiki/Wind_Turbine_ Technology, diakses pada 12 Januari 2016.

Shaun. Mechen. Tersedia di: http://www.shaunmechen.com/Props/Props.html, diakses pada 12 Januari 2016.