International Journal of Trend in Scientific Research and Development (IJTSRD)
Volume 3 Issue 5, August 2019 Available Online: www.ijtsrd.com e-ISSN: 2456 – 6470

Design Calculation of 1200W Horizontal Axis Wind Turbine Blade for Rural Applications

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How to cite this paper: Zin Mar Chan "Design Calculation of 1200W Horizontal Axis Wind Turbine Blade for Rural Applications" Published in International Journal of Trend in Scientific Research and Development (ijtsrd), ISSN: 2456-6470, Volume-3 | Issue-5, August 2019, pp.473-475, **https://doi.org/10.31142/ijtsrd25328**

IJTSRD25328

ABSTRACT

This paper provides to design 1200W horizontal axis wind turbine blade for rural application. The rotor blade is design to produce 1200W power output in order to install at Mandalay Hill of Mandalay City in Myanmar at rated wind velocity 7 m/s. The rotor diameter is 2.303m and tip speed ratio is 5. The design process includes the determination of the blade airfoil, pitch angle and chord length distribution along the blade span. By using blade element theory, blade is divided into 10 elements with equal length forming 11 sections throughout the blade. This paper is intended for commercial wind turbine in rural applications. The wind generator can produce 1200W at wind velocity 7 m/s. The use of wind energy for electricity is more economical than the conventional electricity generation. It is strongly recommended that the design prototype is economic and competitive for commercialization at any windy places in Myanmar.

KEYWORDS: *wind turbine blade, blade element theory and commercial wind turbine*

I. INTRODUCTION

The wind is essentially air in motion, carries with its kinetic energy. The amount of energy contained in the wind at any given instant is proportional to the wind speed at that instant. The temperature of the wind also influences the energy content of the wind but is not important in the content of wind based energy production system.

Winds are generated due to the atmospheric temperature differences caused by different areas getting different fluxes of sunlight. Air mass tends to move from hotter to the cooler regions, there by generating winds. In turn, wind movements cause atmospheric pressure differentials which lead to turbulence and more winds.

A wind turbine is a device that converts kinetic energy from the wind, also called wind energy, into mechanical energy in a process known as wind power [2]. Wind turbines are classified into two categories, according to the direction of their rotational axis: Horizontal Axis Wind Turbine (HAWT) and Vertical Axis Wind Turbine (VAWT). Horizontal Axis Wind Turbines capture kinetic wind energy with a propeller type rotor and their rotational axis is parallel to the direction of the wind. Vertical Axis Wind Turbines use straight or curved bladed rotors with rotating axes perpendicular to the wind stream. They can capture wind from any direction [5]. A wind turbine consists of several main parts: the rotor, generator, driven chain, control system and so on. The rotor is driven by the wind and rotates at predefined speed in terms of the wind speed, so that the generator can produce electric energy output under the regulation of the control system [3]. The wind turbine blade is a very important part of the rotor. Extraction of energy from wind depends on the design of blade [4]. In order to extract the maximum kinetic energy from wind, researchers put much efforts on the design of effective blade geometry [3].

Although the design procedure of the blade is different from each designing and manufacturing company, the common procedures are performing aerodynamic configuration design, dynamic and static load analyses, structural design, securing structural strength through static stress analysis, prediction of fatigue life from the random load spectrum and the modal analysis to prevent the resonance in order.

The following figure_1 shows main components of Small Horizontal Axis Wind Turbine [6].

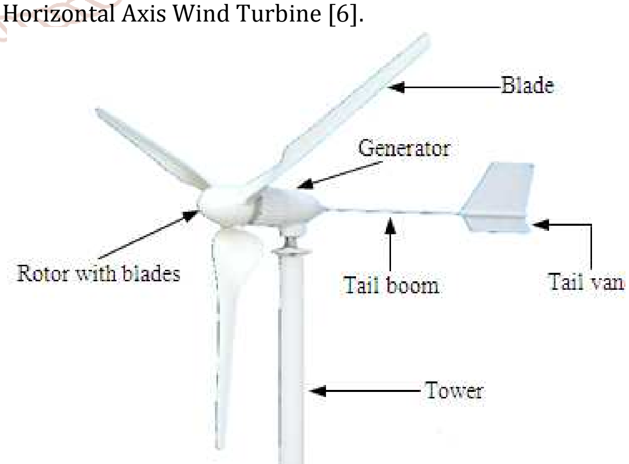

Figure1. Main Components of Small Horizontal Axis Wind Turbine

II. MATERIAL AND METHOD

In this research, turbine blade is made of glass reinforced plastic material. Number of blade mounted on rotor are 3 blades. So, choose the design tip-speed ratio to 5.One important factor that affects the power coefficients is the drag. Drag affects the expected power coefficient via the C_D/C_L ratio. For collection of maximum power coefficient, a range of design speed ratio $1 \le \lambda \le 10$ the theoretically attainable power coefficient lie between $0.35 \le C_{pmax} \le 0.5$, then get the value of C_p to 0.4861.

In this research, like blade material of glass reinforce plastic, high speed design of NACA 4412 airfoil was used, which can give very good results in angle of attack.

III. DESIGN CONSIDERATION OF WIND TURBINE BLADE

In design calculation of blade, consider the tower weight depending on the basics of the roughness of the terrain. The site location of turbine is Mandalay Hill of Mandalay Division in Myanmar at 240m from the sea level. So the total height for 5m tower height from sea level at Mandalay Hill is 245m.The most physical feature of Mandalay is 64m from the sea level. Specification data to design wind turbine blade are shown in Table 1.

Table1. Specification Data for Wind Turbine Blade

Description	Symbol	Value	Unit
average wind speed	V_{avg}	2.4	m/s
reference height from sea level for Mandalay	H_{avg}	64	m
total height from sea level	H	245	m
power output	P	1200	W
system efficiency	E	0.35	-
density of air	ρ	1.2	kg/m^3
assumed turbine efficiency	η_t	0.8	-
generator efficiency	η_g	0.9	-
no; of blade	B	3	-
lift coefficient	C_L	1.1725	-

Calculation of rotor diameter,

$$\overline{V} = V_{avg}\left[\frac{\overline{H}}{H_{avg}}\right]^{\delta} \quad (1)$$

$$V_{rated} = 2\,\overline{V} \quad (2)$$

$$A = \frac{2P_e}{\rho {v_r}^3 C_p \eta_g} \quad (3)$$

$$D = \sqrt{\frac{4 \times A}{\pi}} \quad (4)$$

Table2. Selection of Rotor Diameter

E	C_p	A	d
0.3	0.4166	19.44	4.97
0.31	0.4305	18.81	4.89
0.32	0.4444	18.22	4.81
0.33	0.4583	17.66	4.74
0.34	0.4722	17.15	4.67
0.35	0.4861	16.66	4.6

Calculation of tip speed ratio in each section,

$$\lambda_i = \lambda \times \frac{r_i}{R} \quad (5)$$

Where,
R = rotor radius
λ = design tip-speed ratio

Table3. Selection of Number of Blade

λ	1	2	3	4	5-8	8-15
B	6-20	4-12	3-6	2-4	2-3	1-2

Calculation of blade chord length,

$$c_i = \frac{r_i \times SP}{C_L \times B} \quad (6)$$

Where,
SP = shape parameters at each section
B = no. of blade
C_L = lift coefficient

Calculation of blade pitch angle of each section,

$$\Phi_i = \tan^{-1}\left[\frac{2}{3} \times \frac{1}{\lambda_i}\right] \quad (7)$$

$$\beta_i = \Phi_i - \alpha_d \quad (8)$$

Where, α_d = angle of attack
Φ_i = Incident Angle

Calculation of linearization blade chord length,

$$c_i = -0.0705 r_i + 0.1083 \quad (9)$$

Where, r_i = radius of blade element

Calculation of linearization blade pitch angle of each section,

$$\beta_i = -22.4142 r_i + 18.6874 \quad (10)$$

Table4. Results of Blade Chord, Incident Angle and Pitch Angle at each Section of NACA 4412

Cross Section No.	Radius of Blade Element, r_i	TSR, λ_i	Chord Length, c_i	Incident Angle, Φ_i	Pitch Angle, β_i
1	0.06	0.130	0.062	79	72.162
2	0.284	0.617	0.291	47	40.164
3	0.509	1.105	0.522	31.1	24.26
4	0.733	1.591	0.376	22.7	15.86
5	0.954	2.078	0.337	17.8	10.96
6	1.181	2.564	0.303	14.6	7.76
7	1.406	3.053	0.270	12.3	5.46
8	1.630	3.539	0.261	10.7	3.86
9	1.854	4.025	0.238	9.41	2.57
10	2.078	4.513	0.200	8.41	1.57
11	2.303	5.000	0.162	7.595	0.757

Table5. Results Data for Linearization of Blade Chords

Cross Section No.	r(m)	C(m)exact	C(mm) Linearization	Deviation (mm)
1	0,06	.062	431.4	-369
2	0.284	.291	406	-115
3	0.509	.522	380	142
4	0.733	.376	354	22
5	0.954	.337	329	8
6	1.181	.303	303	0
7	1.406	.270	277	-7
8	1.630	.261	251	10
9	1.854	.238	226	12
10	2.078	.2	200	0
11	2.303	.162	174	-12

Table6. Results Data for Linearization of Blade Angles

Cross Section No.	r(m)	(Deg) exact	(Deg) Linearization	Deviation (mm)
1	0.06	72.162	32.4286	39.733
2	0.284	40.162	28.354	11.808
3	0.509	24.26	24.261	0
4	0.733	15.86	20.186	-4.326
5	0.957	10.96	16.112	-5.152
6	1.181	7.762	12.037	-4.275
7	1.406	5.46	7.944	-2.484
8	1.630	3.86	3.870	0
9	1.854	2.57	-0.204	2.774
10	2.078	1.57	-4.278	5.843
11	2.303	0.757	-8.372	9.192

Figure2. Wind Turbine Blade design

IV. CONCLUSIONS

Turbine blades were designed based on Blade Element Momentum theory. The wind generator can produce 1200W at wind velocity 7m/s. To increase performance of the blade design, the blade with NACA4412 airfoil is more suitable than the others. NACA4412 is occurred at angle of attack 6°. Cut-in speed (2 m/s) at which the wind turbine is allowed to start revolving. Cut-out speed (20 m/s) at which the wind turbine is allowed to deliver power due to safety precaution at suitable wind speed.

V. ACKNOWLEDGEMENTS

The author is deeply grateful to Dr. Kyaw Aung, Professor and Head of Mechanical Engineering Department, Technological University (Mandalay) for his willingness to share his ideas helpful suggestions on this paper writing.

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