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Design and Analysis of Roof Top Wind Turbine for Household Purpose

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Abstract

This project deals with the design and analysis of a small horizontal axis wind turbine which is designed to produce the electrical energy of 1.75kW for the household purpose. The fixed 1.75kw electrical energy is calculated based on the usage of ten household appliances where the average consumption per day is considered for the design of wind turbine. This type of wind turbines are used for roof top application. For the design of wind turbine blade, NACA-63415 series profile has been chosen by the appropriate calculations, this profile generates a maximum amount of lift around the wind turbine blades and gives a good aerodynamic performance. Finally, the total aerodynamic performances of the wind turbine are calculated based on operating conditions of various levels of rpms and the power curve is drawn for the corresponding wind turbine.

Keywords: *Horizontal Axis Wind Turbine, NACA, Aerodynamic Performance and Power Curve.*

1. Introduction

A wind turbine is a device that converts the winds kinetic energy into electrical energy. The wind turbine has added a provider of useful mechanical power for the last thousand years has been authoritatively established. The wind turbine is also describing as a wind energy conversation system (WECS) or, if used to produce electric power, as a wind turbine generator (WTG).

Types of wind turbine

a) Horizontal axis wind turbine
b) Vertical axis wind turbine

This project deals with small horizontal axis wind turbine.

We have designed small horizontal axis wind turbine to extract electrical energy from the kinetic energy of wind. By using best design methodology, we have fixed the co-efficient of lift (C_L) for the blade to generate good results.

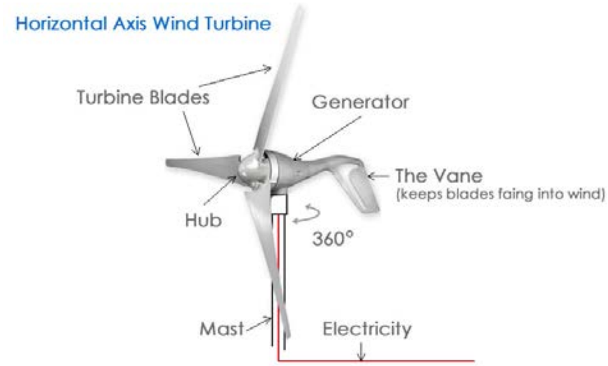

Figure 1 Small horizontal axis wind turbine

The kinetic energy formula used basically, to find out the electrical energy available in the wind.

Energy available in the wind = 0.5 * ρ * A * U^3

Where,

A – Span Area, **D** – Rotor Diameter, ρ – Air Density, **U** – wind Velocity, C_p – Coefficient of Performance

Finally, the wind turbine blade analysis performance results compared to the theoretical calculation values and results are represented graphically. The represented values based on the different velocities due to extracted electrical energy of the wind turbine.

2. Design of Small Horizontal Wind Turbine

Smaller scale turbines blades are usually 1.5 to 3.5 m in diameters and produce 1 to 10 kW of electricity at their optimal wind speed. Some units have been designed to be in very light weight in their construction. They are options for direct current output for battery charging and power invertors to convert the power back to AC but at constant frequency for grid connectivity.

Some small wind turbines can be designed to work at low wind speed but in general small wind turbines requires a minimum wind speed of 3m/s and the project designed wind turbine works to operate at wind speeds of 3m/s to 15m/s.

The Betz limit is the theoretical maximum efficiency for a wind turbine, conjectured by German physicist Albert Betz in 1919. Betz concluded that this value is 59.3%, meaning that at most only 59.3% of the kinetic energy from wind can be used to spin the turbine and generate electricity.

2.1 Blade Design Calculations

$$P_G = \frac{1}{2}\rho A u^3 Cp$$

Assumptions:

- Wind Velocity: 13 m/s
- Betz Limit (C_P): 0.4
- Fixed C_L Configuration.

Calculation:

5kW = 0.5 * 1.225 * A * (13^3) * 0.4

Length of the blade = 1.11m

Blade diameter = 2.22m

2.2 Power calculation

By considering 10 household appliances, the average power of 1.75kW is considered for design. so we have fixed 5kW for the theoretical power of this project.

Calculating per day,

Average Power = 42000 watts Per hr. = 42000 / 24
= 1750 watts

Average electrical energy calculated theoretically 1750watts per day for one house.

2.3 Tip Speed Ratio

The tip-speed ratio is the ratio of the product of rotational speed of the blade and the radius of the wind turbine blade to the wind speed.

$$J = \frac{\Omega * r}{V}$$

Where,

J = Tip Speed Ratio
Ω = Rotational Speed
r = Radius of The Wind Turbine Blade
V = Free Stream Velocity

The optimum tip speed ratio depends on the number of blades in the wind turbine rotor. From the references, the value of tip speed ration noted below for the different wind turbine blade configuration

- Two bladed rotor = 6
- Three bladed rotor = 5
- Four bladed rotor = 3

3. Design Concept

3.1 Airfoil selection

In the present state there is no unambiguous, rational procedure to determine the ideal for a given wind turbine rotor, or even for a given radial station on a blade. Chord and the twist possible in the blade design. A further factor relates to the different span wise aerodynamic requirements of the general rotor. For this reason, the current approach in airfoil section is to use a rotor performance computer code. NACA series airfoils have demonstrate the best overall performance characteristic of the NACA families, and they provide reasonable resistance to roughness losses. This result of both the very wide range of angles of attack over which a blade operates and the widely different geometrical combinations of airfoil selection.

3.2 NACA

The NACA (National Advisory Committee for Aeronautics) airfoils are airfoil shapes for aircraft wings developed by the NACA. The shapes of the NACA airfoils is described using a series of digits of following the word “NACA”. The parameters in the numerical code can be entered into equations to properties generate the cross section of the airfoils and calculate its properties.

3.2.1 NACA FIVE DIGIT SERIES

The NACA five-digit series describes more complex airfoil shapes. Its format is LPSTT, where:

- L: A single digit representing the theoretical optimum lift coefficient at ideal angle of attack (this is not the same at the lift coefficient,
- P: a single digit for the x-coordinates of the maximum chamber (max chamber at x=0.05p)
- S: a single digit indicating whether the chamber is simple (S=0) or reflex (S=1)

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- TT: the maximum thickness in percent of chord, as in a four digit NACA airfoil code

In this project, **NACA series 63415** is selected for wind turbine blade design.

3.2.2 NACA 63415

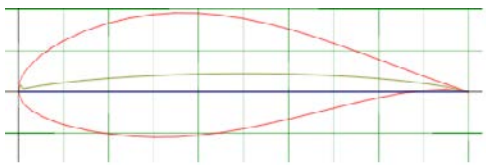

Figure 2. NACA 63415 Airfoil

NACA series airfoils are used the wind and they have a more lift performances with compared to the other airfoils. At the reason for choosing this blade profile to generate the more amount of the lift around the blade and giving the good performances of low wind speed regions with compare other wind turbine blade profiles. The power parameters are calculated and to design the wind turbine blade.

The designed parameters are, calculated on the optimum and linear conditions of the small horizontal axis wind turbine. They are followed to Betz Limit conditions and design the wind turbine blade. From the Betz limit wind turbine can extract maximum 59% efficiency from the wind.

The optimum conditions are calculated on the axial flow induction factors (a & a') and the limiting value of induction factor (a) is 0.25 to 0.3333at the reason is values to gives the performance after and below that range of this values to gives the poor amount of the lift generation. So, that the values are commonly used to designed the all kind of horizontal axis wind turbines.

The linear conditions are calculated and all the parameters of the blade design used which is defined by the Betz Limit concepts and compared with the referenced journals.

3.3 Power Curve

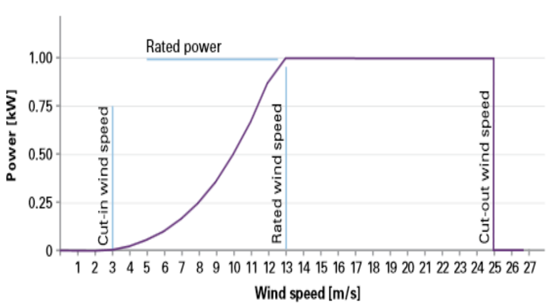

Figure 3. Power Curve

Cut in Speed

The cut-in speed is the wind speed required for a particular wind turbine to begin to generate electric power. The start-up speed is the wind speed at which the wind turbine blades will begin to rotate.

The cut-in speed is always greater than the start-up speed. If a manufacturer is promoting a low start-up speed for a wind turbine, then the buyer should be skeptical. A low start-up speed does very little to enhance the overall electric production of a wind turbine.

Cut out Speed

There is a risk of damage to the rotor. It's defined as the achieved the efficient power and apply the breaking system of the wind turbine generator. The speed not to be controlled and based on the incoming wind speed.

Rated Wind Speed

The power output reaches the limit that the electrical generator is capable of keep the power at constant level. It is the speed is definedasthe to reach the power output of the wind.

4. Blade Design Parameter

4.1 Angle of Attack

In aerodynamic, angle of attack specifies the angle between the chord line of the wing of affixed wing aircraft and the vector representing the relative motion between the aircraft and atmosphere.

4.2 Blade Number

The determination of the number of blades involves design considerations of aerodynamic efficiency, component costs, system reliability, and aesthetics. Aerodynamic efficiency increases with the number of blades but with diminishing return. Increasing the number of blades from one to two yields a 6% increase in efficiency, whereas increasing the blade count from two to three yields only an additional 3% in efficiency. In this project choosing on the three bladed wind turbine due to the high efficiency and the balancing the wind speed.

4.3 Blade Twist

Rotor blades for wind turbines are always twisted. Seen from the rotor blade, the wind will be coming from a much steeper angle (more from the general wind direction in the landscape), as you move towards the root of the blade, and the center of the rotor. A rotor blade will stop giving lift (stall), if the blade is hit at an angle of attack

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which is too steep. Therefore, the rotor blade has to be twisted, so as to achieve an optimal angle of attack throughout the length of the blade.

Table 1. Blade Locations, Scale and Stagger angle

Blade ratio (r / R)	Chord length (l)	Stager angle (β)
0.105	0.20	33.98011231
0.21	0.19	20.88605788
0.315	0.18	14.33774792
0.42	0.17	10.60964707
0.525	0.16	8.21078258
0.63	0.14	6.514930179
0.735	0.13	5.219209575
0.84	0.12	4.162521308
0.945	0.11	3.243920437
1.11	0.10	2.395338695

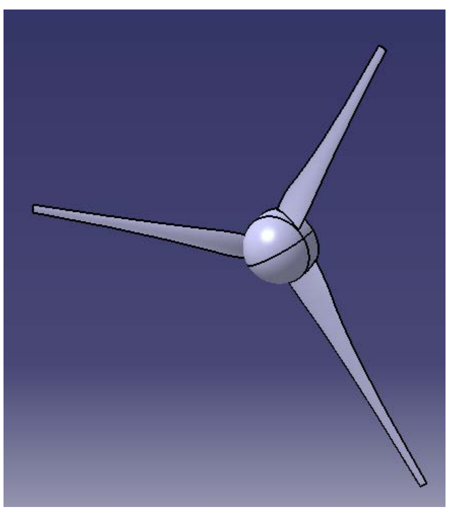


Figure 4. Blade Model

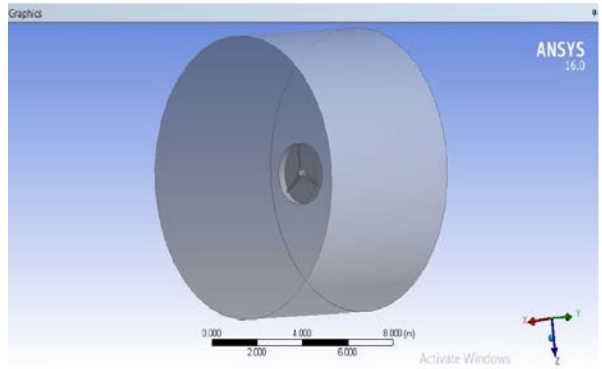


Figure 5. Blade with Outer domain

5. Analysis

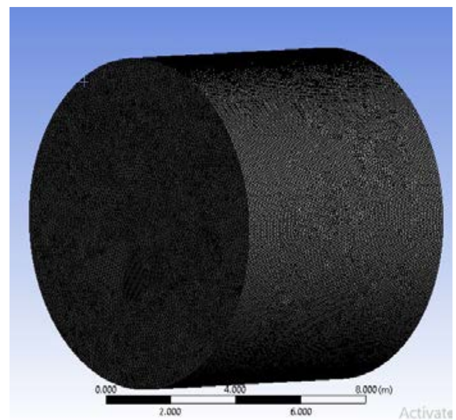


Figure 6. Meshed Model with Outer Domain, Blade and Rotating Frame

For the wind turbine analysis, Ansys- Fluent is used for finding the performance of Wind turbine.

Analysis Parameters:

- Turbulence model --- k-omega (SST)
- Rotating Reference Frame Model

In computational fluid dynamics, the **k–omega (*k*–ω) turbulence model** is two-equation turbulence model that is used as a closure for the Reynolds-averaged Navier–Stokes equations (RANS equations). The model attempts to predict turbulence by two partial differential equations for two variables, *k* and ω, with the first variable being the turbulence kinetic energy (*k*) while the second (ω) is the specific rate of dissipation (of the turbulence kinetic energy *k* into internal thermal energy)

6. Conclusion

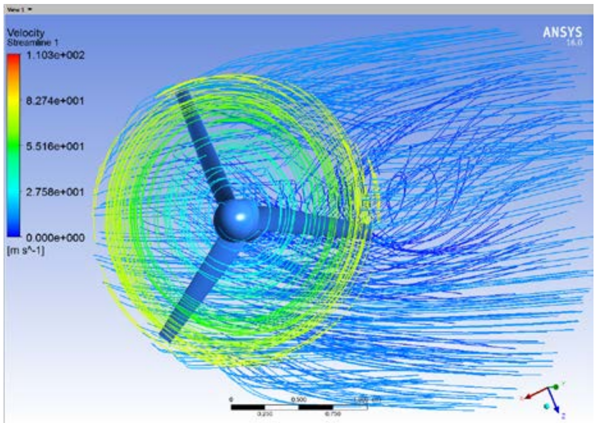
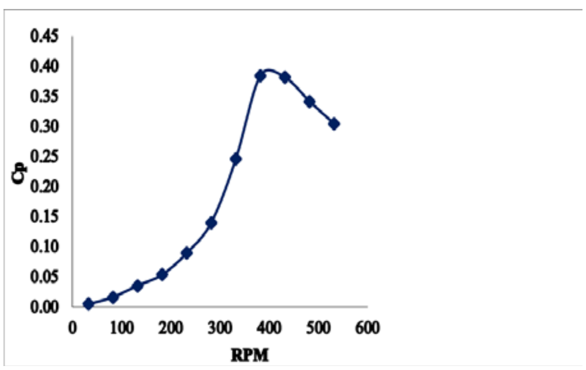


Figure 7. Velocity Flow Diagram

These results are extracted by the constant wind velocity of 13m/s with different rpm level. Finally, calculated performances of the wind turbine are drawn in a graph.



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