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Estimation of Power Rating of a Horizontal Axis Propeller Type Turbine

Gupta Saurabh

M. Tech (Mechanical Engineering, IInd Year), Rajshree Institute of Management & Technology, India

Abstract: ***Energy is a driving force for life on the earth. Much of the energy which is available on the Earth originates from the Sun. This also includes renewable sources of electricity generation such as solar, wind & wave energy, and hydropower (since weather patterns are driven, to a significant extent, by the energy input from the Sun). However one potential for electricity generation from is the wind energy as result of the uneven heating of the earth. About 1% to 3% of the solar energy falling on the earth surface gets converted into the wind energy. The solar energy to the energy conversion is about 50 to 100 times higher than the solar energy to biomass energy through photosynthesis. Presently in India there energy production through wind energy is estimated about 45000 MW. Currently we are exploring only 9000 MW (25%). All over the world, the annual wind market is growing with over 30% rate.***

1. Introduction

Wind energy is used in many ways from the ancient time (e.g. sailing the ships). With advancement of civilization wind energy was converted in various ways e.g. wind mills. Wind energy can be converted into the useful mechanical energy for grinding, water pumping or conversion into electrical energy by making use of generators.

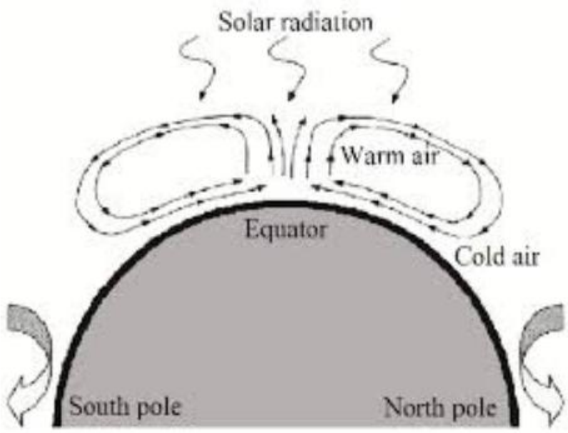
Due to more heating of air in the equatorial region, air becomes lighter and starts to rise. The rising at the equator moves southwards and northwards. These motions of air stop when air cools down 30°North and 30° South latitude. At these latitudes, air begins to sink down and flows towards the equator through the lowest layer of the atmosphere. In this way, the air completes one circle.

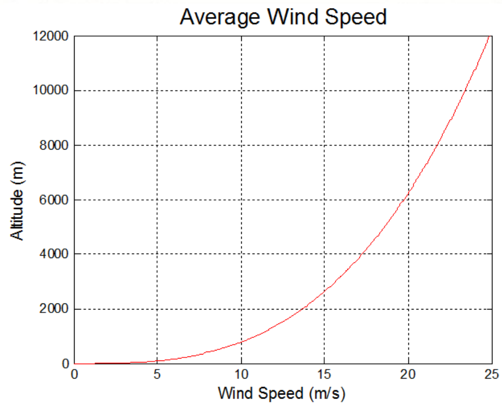
The motion of earth around its axis (west to east) has an effect on the direction of the wind flow. The rising air gets deflected towards east and return air gets deflected towards west.

This includes heating and cooling rate difference of earth and sea water, presence of local obstacles like trees, buildings, mountains, valleys etc.

At the surface the wind speed is zero due to the friction of air with the surface. As we go up, wind speed increases more rapidly at lower heights but less rapidly at greatest heights.

At about 2000 m from the ground the change is the wind speed becomes zero. A typical variation in the wind is shown in the graph (fig 2).





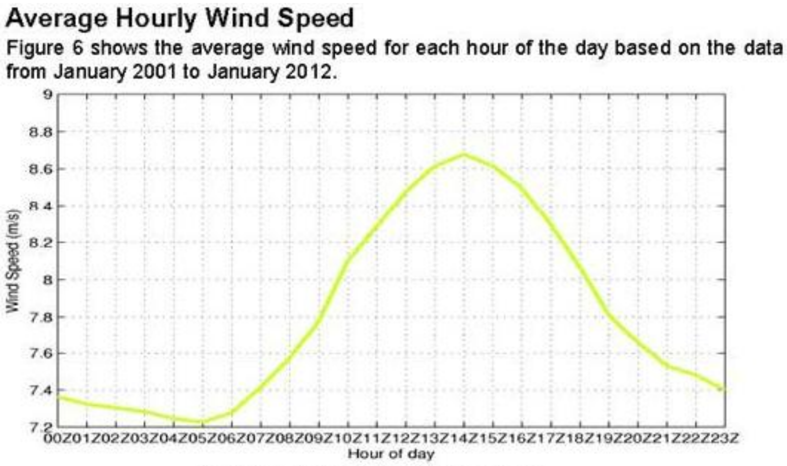
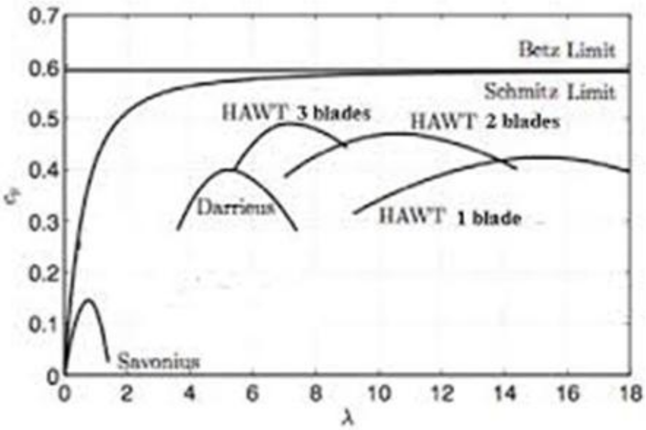


Figure 6 –Average hourly wind speed



2. Types of Wind Turbines

i) On the basis of force

A) Wind machine based on the drag:

Earlier type of wind turbines were mainly based on the drag force. The wind machines that use drag force provide high torque but rotate at the low rounds per minute (rpm) speed. Due to this characteristic, these machines are suitable for water pumping and grinding type of application. There machines are relatively inefficient, their coefficient of performance lies between 015 and 0.30, ie, the efficiencies are between 15 and 30%.

B) Wind machine based on lift force: The recent machines are based on the lift aerodynamic force for wind energy to electrical energy conversion. The characteristic of lift based machine is low to medium torque, high round per minute (rpm) speed. The coefficient of performance of these machines range between 0.30 and 0.40 (30 to 40%). These types of wind turbines are mainly used for electricity generation.

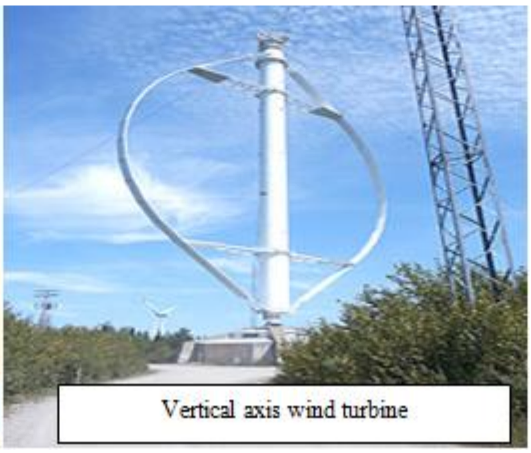
ii) On the basis of Axis

A) Turbine with horizontal axis

A horizontal axis turbine is one in which axis of rotation is parallel to the surface. These days over 90% of the wind turbines are horizontal axis machine, they are mostly two or three bladed propeller type of machines. Horizontal axis wind turbines requires special infrastructure to keep generator etc at the height of the hu. The horizontal axis wind turbines have advantage of higher hub height, i.e., the height from the ground increases the wind speed increases and higher power can be generated. These turbine works on the principle of lift force.

B) Turbine with vertical axis

A vertical axis turbine is one in which the rotor revolves over the axis that is perpendicular to the surface. Savonius machines and Darreius wind turbines are vertical axis machines. In these turbines generator, gear boxes etc can be kept on the ground.



The vertical variation in the wind speed depends on the roughness of the terrain and the wind speed near the ground. The terrain roughness factor is represented by a constant, α. This constant can have value between 0.01 and 0.3. For water area, like sea, α has a value of about 0.01, for farm lands with trees α has a value of 0.12, for the villages and town α is about 0.28.

If wind speed for a given location and at a given height is known, the wind speed (V) at any at the same location can be estimated using following formula

$$V\text{ (at unknown height)} = V\text{(at known height)}X\left(\frac{\text{New height}}{\text{Reference height}}\right)^{\alpha}.$$

At a given location, the wind speed varies over a day and over different seasons. Since the power can be extracted from the wind depends on the cube of the wind speed. It is important to know the variation in the wind speed at a given location. The hourly variation (even daily variation) of wind speed is not predictable, it can vary significantly. Therefore, wind speed data are measured over a long period (several years) and usually represented in the form of histogram.

A histogram presents the probability of wind speed to be in certain limits. It can be presented in the form of number of hours (out of the total hours in a year= 365X24=8760 hours) wind speed will be in a given range at a particular location.

The kinetic energy of the wind flowing across a wind flowing across a wind turbine is used to derive electrical energy from wind. The power (P) contained in a flowing wind is given by the formula below:

$$P = \frac{1}{2}\rho v^3 A \text{ in watts}$$

A= Swept area of wind turbines
ρ= Density of air
v=Velocity of air
Under standard condition (25°C, 760 mm Hg), air density is considered as 1.22 Kg per m^3 .
So power can be given
$P=0.6v^3A$ (watts)

This shows that wind turbines converts airflow into mechanical motion and gives us the electrical power. The power P represents the total power in the air stream. As in the case with all energy conversion processes, only a part of the air stream energy can be converted to useful energy. A wind derives the kinetic energy from the wind. The power available to a wind turbine is equal to change in the kinetic energy of the wind. Therefore, the higher the change in the kinetic energy of the wind across the turbine, the larger will be the power conversion.

Largest kinetic energy changes would occur when wind stops at the other side of the turbine (zero kinetic energy), implying that all its energy has been converted. This complete stopping of wind is not possible in rotating type wind machines. According to the Betz limit, which was formulated in 191, at most only 59% of the wind power can be converted into useful power. In practice, the real efficiency of wind turbine is less and it is normally referred to as coefficient of performance.

The coefficient of performance, C_p is defined as actual power output from a wind machine divided by the available wind power ($0.6v^3A$) or

$$C_p = \frac{P_{real}}{P_{ideal}}$$

$$C_p = \frac{P_{real}}{0.6v^3A}$$

The actual wind turbine convert wind energy at lower efficiency than given by the Betz limit, due to various losses (drag on the blade, swirl imparted to airflow by the rotor etc). The tip ratio (λ)is defined as the ratio of the speed of the rotor blade tip to the undisturbed wind speed. The undisturbed wind speed is the speed of wind away from the wind machine. If a rotor makes ω revolution per minute and the radius of the rotor is R, then the linear speed of the rotor tip would be ωXR, then the linear speed of the rotor tip speed will be given as

$$Tip\ speed\ ratio, \lambda = \omega X \frac{R}{V}$$

3. Design Calculations

The paper consists of design estimation of required wind turbine power rating for pump house which fulfils the water supply in the small village .
Following is input data
A) Annual energy requirement - 20000 kWh
B) Propeller type wind turbine is used
C) Coefficient of performance -0.40
D) Wind speed at 15 high is 5 m/s
E) Density of air = 1 kg per m^3
F) Capacity factor - 0.30
F) Number of hours in a year - 8760 hours

Calculations:

i) Power density of wind (power per unit area)
Turbine hub is 15 m height is considered.
Power density of air (ideal) - $\frac{1}{2}.1.(5X5X5)$
= 62.5 watt per m^2

ii) Overall loss factor
Coefficient of performance C_p = 0.40
Transmission losses (rotor to generator) =0.90
Generator losses = 0.90
Overall loss factor
= C_p X Transmission losses X Generator losses
= 0.40X0.90X0.90
=0.324

iii) Actual power density
= Power density of air (ideal) X Overall loss factor
=62.5X0.324
=20.25 watt per m^2

iv) Annual useful energy density
= Power density X number of hours per year
= 20.25X8760
=177.39 kWh per m^2

v) The real power energy density will be less as the wind of rated speed will not blow for 8760 hours. Thu, considering the capacity factor:

Real annual energy density =Annual energy density(useful) X capacity factor
= 177.39X0.30
= 53.2 kWh per m^2

vi) Rotor size and turbine power rating

$$The\ area\ of\ rotor = \frac{Total\ annual\ energy\ required}{Real\ annual\ energy\ density}$$
$$= \frac{20000\ kWh}{53.2\ kWhm^{-2}}$$
= 375.8 m^2

Radius of the rotor

$\pi R^2 = 375.8$
R =10.9 m

vii) Now we can estimate the actual power rating of the turbine. It is obtained by multiplying power density with area of the rotor:
Power rating of turbine
= Actual power density X area of rotor
=20.25 X 375.8
= 7.6 kW
= 8kW (approx)

4. Figures and Tables

Following design values are found for wind turbine

SN		Parameter	Value
1	Input Data	Annual energy requirement	20000 kWh
2		Type of Wind Turbine	Propeller type, Horizontal axis
3		Coefficient of performance	0.40
4		Wind speed at 15 high	5 m/s
5		Density of air	1 kg per m^3
6		Capacity factor	0.30
47		Number of hours in a year	8760 hours
8	Results	Power density of wind (power per unit area)	62.5 watt per m^2
9		Overall loss factor	0.324
10		Actual power density	20.25 watt per m^2
11		Annual useful energy density	177.39 kWh per m^2
12		Real annual energy density	53.2 kWh per m^2
13		Radius of rotor	10.9 m
14		Power rating of turbine	8 kW

5. Conclusions

Following conclusions are made
a) Power rating of turbine is 8 kW.
b) It saves fossil fuel.
c) It does not cause environmental pollution.
d) It will never get exhausted
e) E)Wind energy is available at free of cost

6. Limitations

1) Wind mill cannot be established everywhere. They can be established only at those place where wind blows for most part of the year.
2) They require large area of land
3) Gestation period is high.
4) They are costly
5) Wind required for generating electricity should be strong and steady to maintain desired level of generation.
6) The minimum wind necessary for satisfactory working of wind generator is about 15km per hour. This is not always so.

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