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Study and Analysis of Wind Turbines

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ABSTRACT

With the development of the modern technology and industrialization the standard of living of human has increased. The standard of living is directly proportional to the total energy utilized by the particular person. In highly developed countries per capita consumption of energy is Greater as compared to developing and low developed countries. Thus the demand of energy is continuously increasing. Till now we are merely depending on the thermal resources like Coal Petroleum gas for generation of the power. But in Modern era Emphasis is done on renewable energy. Wind energy is a source of renewable energy from high speed wind by using of wind turbines. In this paper a study is being done on the wind and later analysis of wind turbines is done to search the opportunities of power generating in low wind speed areas. This is a review and study paper which is related to conversion of wind Energy in to Mechanical Energy.

1. INTRODUCTION

Wind– Atmospheric air in motion may be defined as wind.

Energy source: Solar energy is absorbed by different part of the Earth surface by different amount. Normally surface gets more heated than the sea surface so the temperature above the ground become high with respective to the temperature above sea. This temperature difference cause pressure difference and due to this pressure difference atmospheric air flow from one region to another region .this is main cause of wind flow**.** Wind posse's energy by virtue of its motion. For installation of a wind turbine the average speed of wind in that area should me minimum 10 m/s. but in north India average speed of wind is about 3.5 m/s.the main objective of our study is to find possibilities in power generation in low wind areas. It is found that wind speed is high in costal regions and as we move deep towards ground areas wind speed decreases. but population density of most countries like India is more in ground areas. In India more than 500 million people lives in grounded areas which are far from costal region. Delhi, Haryana, Punjab Utter Pradesh, Bihar are the more populated states in India and situated at a far distance from sea. And hence these states have low wind energy as compared to other states.

Here is a map of annual average wind speed of India. And that matches inversely to population distribution.

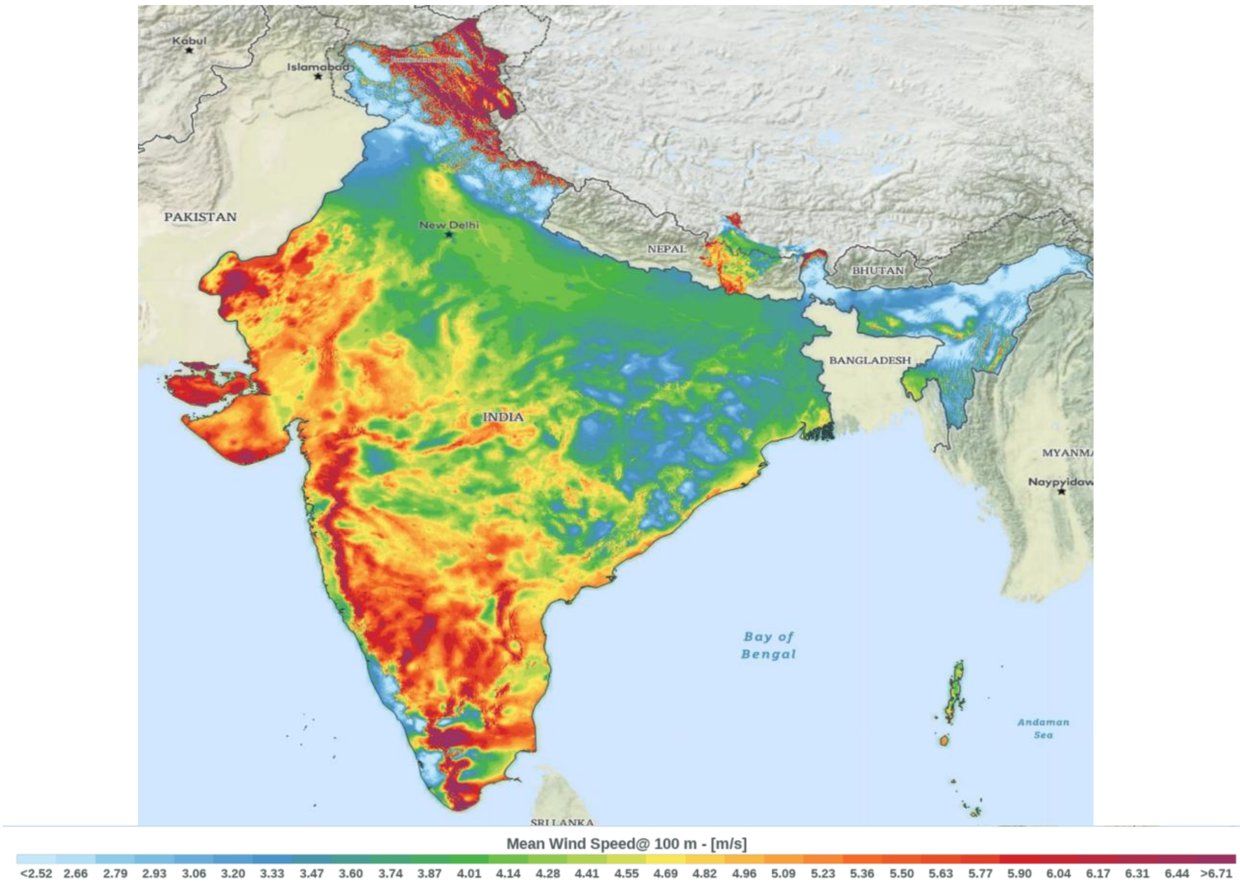
Wind Speed in Rewari, Haryana, India

The primary aim is develop wind power in low wind speed areas as in north India. So air speed of Rewari, Haryana is studied and average wind speed of this area is tabulates as below.

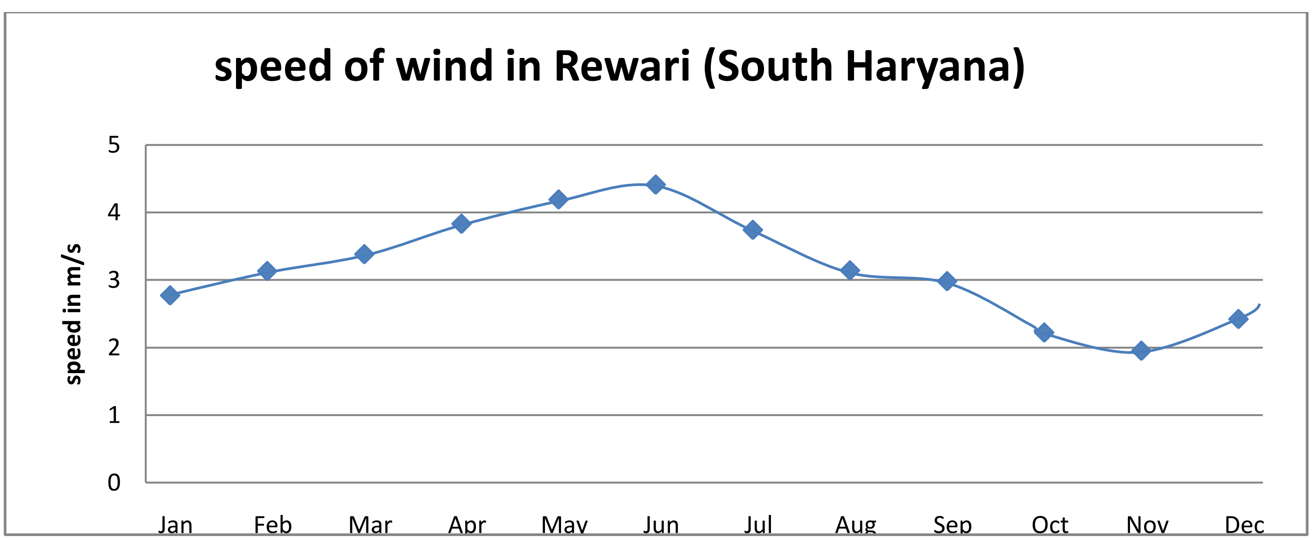
Table 1: Wind Speed in Rewari, Haryana

Months	Jan	Feb	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec
Average speed (m/s)	**2.77**	3.13	3.38	3.83	4.19	4.41	3.74	3.14	2.98	2.22	1.95	2.42

So the average wind speed annually is: **3.18 m/s**
Annual Average = 3.18 m/s
Same is shown in the below graph



That the wind speed of Rewari area is studied and results are formulated below:-



The speed is much lower to install wind power plant that should be approximately 9 m/s minimum.

2. HARNESSING OF WIND ENERGY

From ancient time wind mills are used to convert kinetic energy to mechanical energy. Later wind turbines were designed which reaches an efficiency up to 50%. There are two types of turbines used in power generation

On the basis of axis of turbine the wind turbine can be classified in two types

Horizontal Axis Wind Turbine (HAWT)

Vertical Axis Wind Turbine(VAWT)

2.1 Horizontal Axis Wind Turbine (HAWT):- as indicated by the name the axis of wind turbine is horizontal, this type of arrangement is most successful arrangement and almost all modern turbine are of this type. Our main study is also focused on these types of turbine. History of wind turbine is very old. Some famous old HAWT are:- In 1888 Charles Brush builds first large-size wind electricity generation turbine having a diameter of 17 m coupled with 12 kW generator. This was popular turbine of that time. After that in 1890s New York Electric Company Lewis sells generators which are retro-fit onto existing wind mills. This is the popularisation of wind turbine at that time. In 1920 to 1950 a lots of turbine were developed in American agriculture rural areas which were very popular and that time, this was the main starting of the wind turbine power generation system. After 1950 there is a decrease of wind power and wind turbines due to popularization and development of engines base on fossil fuel, but now due to more emphasis on renewable energy wind power generation system and development of new wind turbines gain popularisation in Europien and American states.

2.2 Vertical Axis Wind Turbine(VAWT) :- This kind of turbine have very limited use and most imported in where direction of wind continuously changes. In ancient time, proof of uses of VAWT. Vertical Axis wind turbine is used where the wind speed is comparatively high and turbulence is also high. In VAWT the rotor shaft is vertically fixed and it is fitted perpendicular to the direction of the wind. The main advantage of vertical Axis wind turbine is that it can harness energy from air flowing from all the direction. so it is also called a omnidirection wind turbine.
main disadvantage regarding the vertical Axis wind turbine is that there is a significantly difference in torque by every revolution that is also called ripple, although in the modern design the ripple effect is minimized by the latest development. Hence VAWT are popular turbines in modern era. Below is the main mechanism behind power generation of wind turbines.

2.3 Propulsion in wind turbine:- There are two type of mechanism used in the wind turbine first is the drag mechanism and second one is the lift mechanism. Normally lift mechanism is used in HAWT while the drag mechanism is used in vertical Axis wind turbines. The lift mechanism is very popular and horizontal Axis wind turbine are work on that because of its high efficiency, but there is a limit of utilizing the total energy and that is called the **belt limit** which will be discussed later in the chapter. There is a drag factor that is also kept in mind while selection of turbine. Lift and drag mechanism used in propulsion of different types of wind turbines.

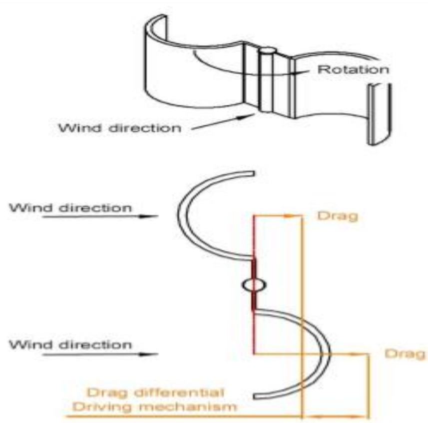
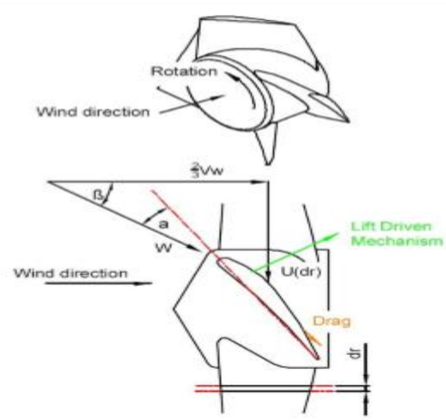
Propulsion	*Drag*	*Lift*
Diagram		
Relative Wind Velocity	$= Wind\ velocity - Blade\ velocity$	$= \sqrt{\frac{2}{3} Wind\ velocity^2 + Blade\ velocity(dr)}$?
Maximum Theoretical Efficiency	16% [4]	50% [6]

Figure. 4 Lift & Drag forces mechanism

The VAWT mostly uses drag principle, while in HAWT use lift principle. There also occur drag forces in lift based HAWT which one designer have to minimise. Lift forces gives motion to the HWAT while drag force pushes the turbine blade backward direction. To understand the lift and drag forces following figure may be very helpful:

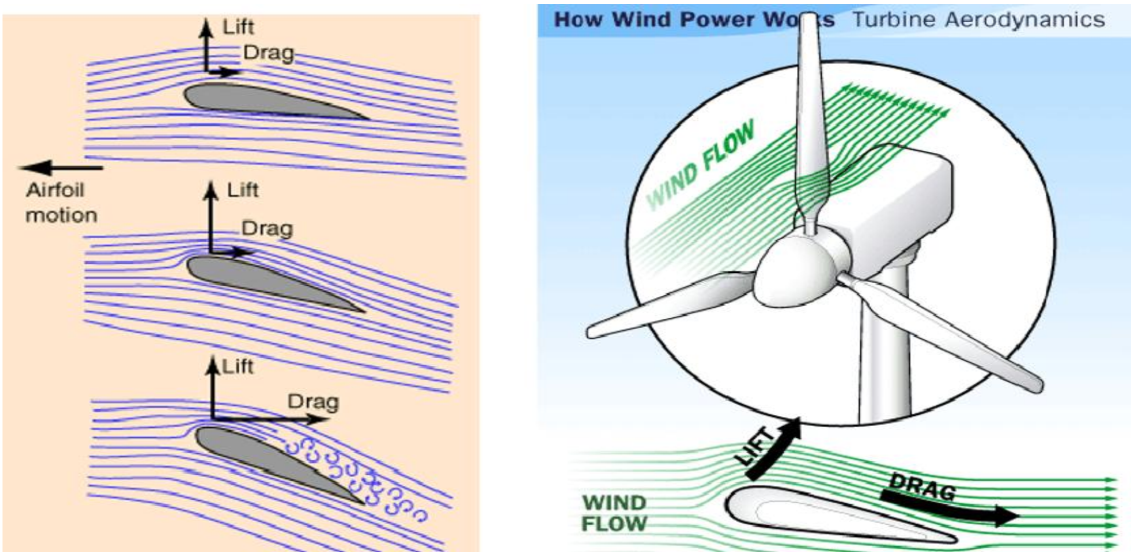


Fig. 5: Lift and drag force

Lift forces pushes the blade in upward direction, while drag forces acted in horizontal direction. So HAWT works on lift forces where VAWT works on Drag forces.

<u>2.4 Power production by Wind turbine</u> :- Let's take a look on theoretical aspects of power production of wind turbines

Wind Power produced by a turbine mainly depends on:

- (volume) amount of air
- (velocity)wind speed
- (density) mass of air flowing through the area of interest (flux)

–Kinetic Energy definition: the energy possessed by air due to its velocity

$$K.E. = ½\ m\ V^2$$

–Power may be defined as K.E. per unit time

$$Power = ½\ m\ v^2$$

mass flow rate i.e. (dm/dt) is given in Fluid mechanics as below

Mass flow rate = (Density * volume flux)

$dm/dt = \rho * A * v$

here ρ is density & ($A * v$) Area multiply by Volume gives volume flux.

3 WIND ENERGY STUDY AND ANALYSIS:

Conventional and modern way of producing wind energy is by using wind turbine. A wind turbine is a wheel that converts the kinetic energy of the wind in mechanical power and then in to the electrical power by means of a small generator usually attached behind the turbine. When air passes through the Blades of a wind turbine it exerts torque on the turbine blades that cause rotor to rotate the amount of torque or you can say the power given to the rotor depend upon the the velocity of the air and amount of air passing through it and the size of the blade. The wind turbines size varies between small commercial turbine to large power plant turbines. Where the small wind turbines have small rotor diameter and they give direct output. These are coupled with the small dynamometer where big turbines are used for the power generation. In these high power turbines special gear trains arranged in the Rotor that increase the velocity ratio for current generation.

Fig 6: **A simple 3 blades wind turbine**

These wind turbines are usually mounted on the high heights by means of tower to obtain high wind speed. The schematic diagram of a simple horizontal axis, 3 blade wind turbine is shown in figure below.

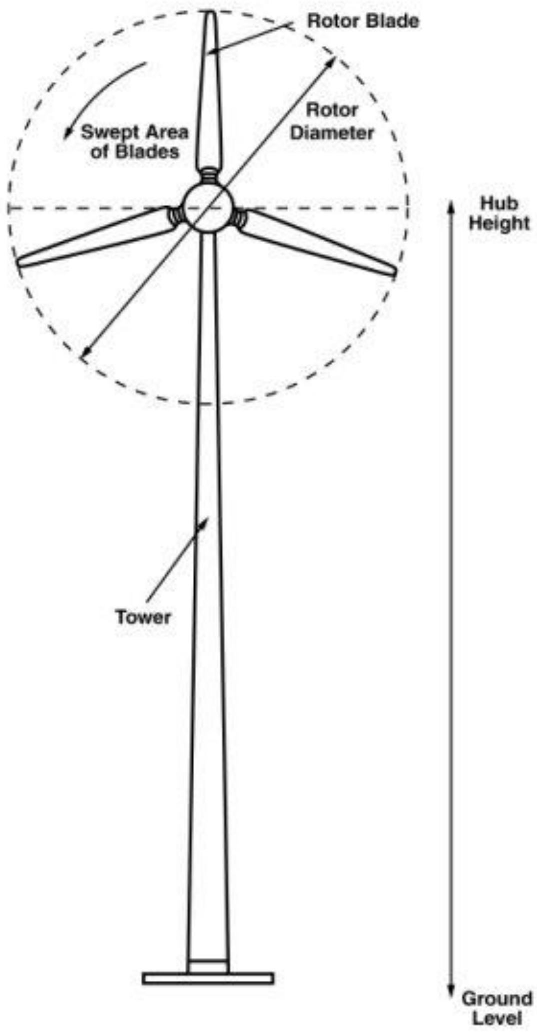


Fig 7 - Wind turbine details

The power produce by wind turbine is generally proportional to the square of the diameter of the rotor & cube of the wind speed. As in this project we are decreasing the diameter of turbine up to 40 cm or 50 cm so to obtain a considerable amount of energy we need to increase the wind speed.

To characterize the performance of a wind turbine following three main parameters are often used. These parameters are:-

a. Power coefficient, (Cp)
b. Torque coefficient
c. Overall efficiency.

First thing Power coefficient is defined as the ratio of amount of mechanical power produced by the wind turbine to the total available wind power(Kinetic energy per unit time). Mathematically, it is defined by using following expression:

$$Cp = \frac{Mechanical\ Power}{\left(\frac{1}{2}\right)\rho\pi r\mu^3}$$

$\left(\frac{1}{2}\right)\rho\pi r\mu^3$ denotes the total available wind power passing across the swept area of the wind turbine rotor.

Second parameter, torque coefficient is used to balance the theoretical torque produced and actual torque produced.

Overall efficiency may be defined by total electrical power produced by wind turbine to total wind power available. Here losses in generator is also counted i.e. mechanical efficiency is also taken in to account.

Let's take a look of annual energy produced by wind turbine of different rotor diameter under different velocities of air. Below here is a table given that gives the annual energy in kilowatt hour at different diameters of the Wind Turbine. Power produced also depends upon the wind speed so there are different columns for different wind speeds that is a total power production in kilowatt hour in a year. For example is 7 meter diameter wind turbine produce almost 12000 power of energy(KWh) in the year when the wind speed is 5 meter per second, as wind speed reduces the total annual energy is also reduces and the diameter of the shaft is reduces then the total annual energy is also reduces. The wind speed is highly dependent upon the tower height, higher is the tower higher is the wind speed but the density of the air is also decrease at high altitude but that altitude is in range of the thousand meter.

3.2 Wind Speed And Rotor Diameter effect on annual Energy production:-

Below table shows that how much of energy in KWh (kilowatt hours) produced by different sizes of wind turbines at different wind speed in a year.

Table -2 annual Energy produced by different turbines

Turbine Diameter (m)	**Annual Energy in KiloWatt hours(kWh)**							
7m	4391	6554	9332	12801	17038	21121	28124	35127
6.5m	3786	5651	8047	11038	14691	19073	24250	30288
6m	3226	4815	6856	9405	12518	16252	20663	25807
5.5m	2711	4046	5761	7903	10519	13656	17362	21685
5m	2240	3344	4861	6531	8693	11286	14349	17922
4.5m	1815	2709	3857	5290	7041	9142	11623	14517
4m	1434	2140	3047	4180	5564	7223	9183	11470
3.5m	1098	1639	2333	3200	4260	5530	7031	8782
3m	806	1204	1714	2351	3130	4063	5166	6452
2.5m	560	836	1190	1633	2173	2822	3587	4480
2m	358	535	762	1045	1391	1806	2296	2867
1.5m	202	301	429	588	782	1016	1291	1613
1m	90	134	190	261	348	451	574	717
Wind Speed (m/s)	**3.5m/s**	**4m/s**	**4.5m/s**	**5m/s**	**5.5m/s**	**6m/s**	**6.5m/s**	**7m/s**

The annual energy production by a wind turbine can be approximated by the equation:

E= $2.09 * d^2 * v^3$

Where E=Energy [kWh]

d= Diameter [m]

v = Wind speed [m/s]

If we calculate our annual power produced by our system that will be equal to

E= $2.09 * 0.02^2 * 49^3$ = 98.35 KWh

As we see from the above equation that the energy produced is directly proportional to the cube root of the wind speed. For example by increasing the wind speed two time we may get output energy 8 times. This is achieved by designing the tunnel.

4. WIND TERMINOLOGY

- ***Start-up Speed*** - When rotor and blade start to rotate that speed is known as starter speed.
- ***Cut-in Speed*** - The minimum wind speed required by wind turbine to generate usable power is known as cut in speed. Cutting speed for most of the turbines is generally 7 to 10 mph.
- ***Rated Speed*** - To generate the designated rated power a minimum wind speed is required by turbine that speed is known as rated speed. E.g.wind turbine with designated power of 10 kilowatt will only be able to generate its power when the wind speed crosses 25 mph. Rated speed for most of the machines lie between 25 mph to 35 mph. The graph provided by most of the manufactures known as power graph gives us the information regarding how the output of turbine varies with the speed of wind. Above the rated Speed the output of most of the machines level offs. When the speed of wind is between rated speed and cut in speed the output of turbine increases with the increase in wind speed.
- ***Cut-out Speed*** - The speed at which most wind turbines cease power generation and shut down is known is cut out speed or furling speed..it is generally generally between 45 to 80 mph. This is a safety feature which protects went wind turbine from damage. Shutdown can occur in many ways like Wind speed sensor can put automatic brake in provided machines. for spelling of wind twisting and pitching of blades are provided in some turbines. At hugh rotor RPM spoiler and drag flaps (on blade/hub) are activated. They can also be activated mechanically by spring loaded devices which turn the machine away from (sideways?) windstream. When the wind drops back to the safe level normal speed wind turbine operation usually resumes
- ***Tip speed ratio*** The relationship between rotor blade velocity and relative wind velocity is known as tip speed ratio below equation. Tip speed ratio is the most important parameter used in design of a wind turbine. Normally it is defined by **λ.**

$$\lambda \text{ (Tip Speed Ratio)} = \mathbf{\Omega R / V_w} \qquad \text{equation 3}$$

Where λ = tip Speed Ratio

R = radius of rotor (half of rotor diameter)

V_w =Wind speed

Normally high tip speed ratio gives you high effieciency but on the cost of high centrifugal stresses, high noise, high maintenance and other things also. Yet it is always desired to achieve high tip speed ratio. Below is the table that describe the application of tip speed ratio.

Application of tip speed ratio high vs low tip speed ratio.

Table 3: Application of tip speed ratio high vs low tip speed ratio

Tip Speed Ratio	Low	High
Value	1 and 2 tip speed ratio is considered low	10 Tip Speeds higher than 10 are considered high
Application	Old wind turbines used in rotation water pumps	Single/double or VAWT which operates on high wind speed
Torque	High torque	Low torque
Centrifugal Stress	Less Centrifugal Stress	Less Centrifugal Stress
Aerodynamics Stress	lower	Higher (proportion with rotational velocity
Area of Solidity	multiple 20+ blades required Decreases significantly	Area of Solidity Increases
Blade Profile Large Significantly Narrow	Blade Profile Large Significantly Narrow	Blade Profile Large Significantly Narrow
Aerodynamics	Simple Aerodynamics	Critical and complex Aerodynamics
Noise	Increases with increase in tip speed(6th power approximately)	

Increases proportionally with rotational velocity [4] Area of Solidity Increases, multiple 20+ blades required Decreases significantly Blade Profile Large Significantly Narrow Aerodynamics Simple Critical Noise Increases to the 6th power approximately [4]

A higher tip speed demands reduced chord widths leading to narrow blade profiles. This can lead to reduced material usage and lower production costs. Although an increase in centrifugal and aerodynamic forces is associated with higher tip speeds. The increased forces signify that difficulties exist with maintaining structural integrity and preventing blade failure. As the tip speed increases the aerodynamics of the blade design become increasingly critical. A blade which is designed for high relative wind speeds develops minimal torque at lower speeds. This results in a higher cut in speed [10] and difficulty self-starting. A noise increase is also associated with increasing tip speeds as noise increases approximately proportionately to the sixth power [4,11]. Modern HAWT generally.

Nine to ten tip speed ratio is used for two bladed rotors and six to nine for three blades. This has been found to produce efficient conversion of the winds kinetic energy into electrical power.

- **Wake** : wake is the path of air behind the wind turbine. It also effect the performance of wind turbine
- ***Theoretical Maximum Efficiency:*** Energy (E) carried by moving air is expressed as total kinetic energy possessed by the air. And kinetic energy is $1/2mv^2$ which in terms of density and area of interest can be written as below:

$$E = \rho A v^3 \qquad (5)$$

Where, E = Energy

ρ = Air Density

A = Swept Area

v = Air Velocity

The limit for that we can convert the total wind energy into the mechanical energy however optimise the design is 59 %of total available energy.

Energy from the wind is harnessed when the speed of the air is reduced with the help of wind turbine 100%. energy conversion means at the end we have zero wind speed which is practically not possible. So there is a limit for which we can convert the wind energy into the mechanical energy and it is universally accepted that this limit is 59 %.

And hence the power Coefficient can be maximized up to 0.59, higher the power Coefficient higher the energy efficiency of the turbine. This 59% maximum limit is first produced by an engineer name Belt and has it is known as Belts limit while calculating the limit he assume the linear velocity of the the air which is also not truth. there are some rotational forces some turbulence, some wake behind the turbines and any other drag forces that are acting on the turbine and that is also reducing its total conversion Efficiency losses are generally reduced by:

- limiting lo w tip speed ratios which increase the wake rotation behind the turbine
- Selecting aerofoils which have a high lift to drag ratio. This is in case of HAWT
- Load on turbine can be increased to maximise the efficiency.

5. WIND SPEED FACTS:

One of the key things to know about wind speed is that the amount of energy which wind can generate is not a one to one function. Rather energy increases by the cube of the wind speed. If you double the wind speed, you get eight times the energy. That is one reason that looking at wind maps is so useful. Even a small difference in wind speed within a given area can have a big impact on the amount of energy a wind turbine can generate. It is also one of the reasons why a taller wind tower can make so much of a difference. If the wind speed increases even a few miles an hour by going with a taller tower the energy generation potential goes way up (see sidebar chart).

One way to get a sense of the amount of energy a wind turbine will produce at different speeds is look at a power curve graph. Most wind turbine manufacturers will show the power curve for their particular turbines. This type of chart shows the power output (usually in watts) on one axis and the wind speed on the other. The chart below shows power curve for an Air-X wind turbine. It should be noted that the sudden drop off at above 30 mph is caused by a safety cut off. Tip Speed Ratio

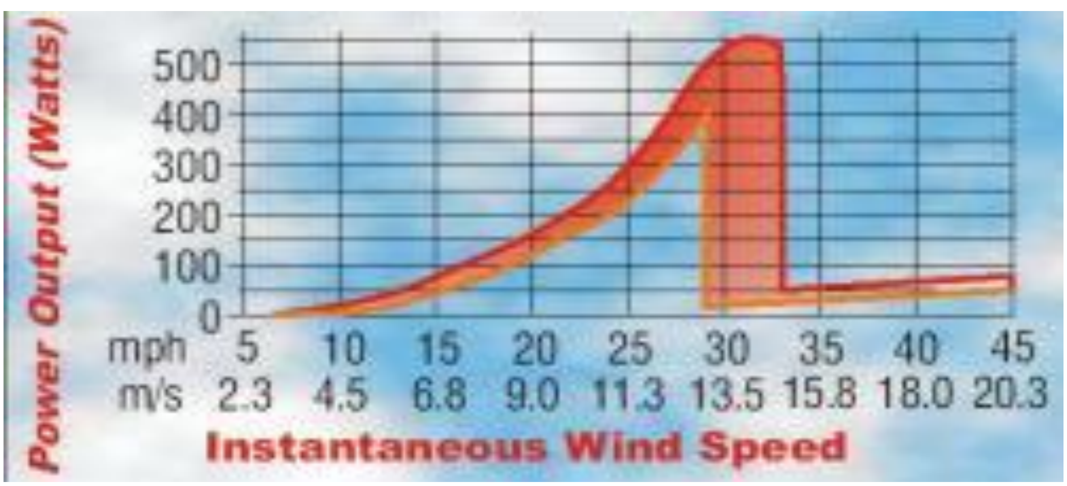


Fig. 8 ***Power output at different wind speed***

5.1 Capacity Factor(CF): •The time in a year at which turbine power generator is operating at rated (peak)power rated.

Simply it is given as by

Capacity Factor = Average Output / Peak Output ≈ 30%(commonly areas)

CF is based on both the characteristics of the turbine and the site characteristics (typically 0.3 or above for a good site) it depends upon the area where the wind turbine is installed. Wins speed at a particular area vary wrt time and session. Also it is a function of tower height Below are the graph representing wind speed at different hub height.

5.2 Betz Limit

It is the flow of air over the blades and through the rotor area that makes a wind turbine function. The wind turbine extracts energy by slowing the wind down. The theoretical maximum amount of energy in the wind that can be collected by a wind turbine's rotor is approximately 59%. This value is known as the Betz limit. If the blades were 100% efficient, a wind turbine would not work because the air, having given up all its energy, would entirely stop. In practice, the collection efficiency of a rotor is not as high as 59.3%. A more typical efficiency is 35% to 45%. A complete wind energy system, including rotor, transmission, generator, storage and other devices, which all have less than perfect efficiencies, will (depending on the model) deliver between 10% and 30% of the original energy available in the wind.

CONCLUSION

Wind study is done in the geographical area of India and it is found at the wind speed is comparatively low in the ground area that are far from the coastal regions. And most of the population of India lives in this ground area. So to provide wind energy to these some different methodology of wind generation system should be adopted by increasing the wind speed by any means.

Later different characteristics of wind turbines are studied. And it is observed that the most of the wind turbines are designed for the mediator range that lies between 10 meter per second to 20 meter per second and for lower wind speed and for higher wind speed there is a sump of designed turbine. So to harness wind Energy from these large geography area we have to work on the design & Development of turbines which operates on low wind speed. Also some different kind of wind turbines can be developed like VAWT or Ventury Turbines.

REFERENCES

[1]. Bechkaoui, A. Ameur, S. Bouras, and A. Hadjadj, “Open-circuit and inter-turn short-circuit detection in PMSG for wind turbine applications using fuzzy logic,” Energy Procedia, vol. 74, pp. 1323–1336, 2015.
[2]. E. T. Karagöl and İ. Kavaz, Dünyada ve Türkiye’de Yenilenebilir Enerji, vol. 197, Turkuvaz Haberleşme ve Yayıncılık A.Ş, Istanbul, Turkey, 2017.
[3]. E. Kovac-Andriģ, T. Radanoviģ, I. Topaloviģ, B. Markoviģ, and N. Sakaģ, “Temporal variations in concentrations of ozone, nitrogen dioxide, and carbon monoxide at Osijek, Croatia,” Advances in Meteorology, vol. 2013, Article ID 469786, 7 pages, 2013.
[4]. J. L. Pearce, J. Beringer, N. Nicholls, R. J. Hyndman, and N. J. Tapper, “Quantifying the influence of local meteorology on air quality using generalized additive models,” Atmospheric Environment, vol. 45, no. 6, pp. 1328–1336, 2011.
[5]. S. Mathew, Wind Energy Fundamentals, Resource Analysis and Economics, Springer, Berlin, Germany, 2006.
[6]. Ş. Menteş, Rüzgar Enerjisi ve Sistemleri Ders Notları, İ.T.Ü. Uçak Uzay Fakültesi, İstanbul, Turkey, 2008.
[7]. P. Gipe, Wind Power, Chelsea Greer Publishing Company, White River Junction, VT, USA, 2003.
[8]. H. Badihi and Y. Zhang, “Passive fault-tolerant cooperative control in an offshore wind farm,” Energy Procedia, vol. 105, pp. 2959–2964, 2017.
[9]. Indian Wind Turbine Manufacturers Association, http://www.indianwindpower.com.
[10]. R Abrutat, “Unleashing business opportunities for wind energy”, Renewable Energy 22 (2001) 403-410.
[11]. M.F Trivedi, “Environmental factors affecting wind energy generation in western coastal region of India”, Renewable Energy 16 (1999) 894-898.
[12]. S Kumar, “Wind Energy – India Overview”, Renewable Energy 16 (1999) 961-964.