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Renewable Energy Sources

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CHAPTER-4

Wind Energy

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Introduction

- Wind is flow of air carrying kinetic energy.
- Approx 2% of solar flux reaches earth the surface converted to wind energy.
- windmills are device harnessing wind energy.
- Earlier windmills are used to Grind grains, power boats and later on to pump water.
- In 19th century the generation of electricity using windmills was initiated.

Image source : https://www.piqsels.com/

Power in wind

- Wind Turbine converts kinetic energy of wind into Mechanical energy.

Air having mass m and moving with speed v, then kinetic energy in air is given by

Kinetic Energy = K.E = $1/2\ mv^2$ ……………………………………………(3.1)

Power = $1/2$ (Mass flow per second) v^2

Power = $1/2\ (\rho a v)\ v^2$ J/s ……………………………….(3.2)

Where , Mass flow rate = $\dot{m} = \rho a v$

Power in wind

Total Power = P_{total} = $1/2\rho av^3$ .....(3.3)

Where ,

P= Power in the moving air (watts),

$\dot{m}$ = Mass flow rate = ρav (kg/s),

ρ = air density (kg/m3),

a = Area swept by the rotor blades (m2), and

v = Velocity of the air (m/sec).

- The power available in wind is directly proportional cube of wind speed.

Wind Turbine Power Coefficient (Cp)

- Power coefficient is a measurement of how effectively the wind turbine converts the wind energy into electricity.
- It is the fraction of wind power that can be converted into electricity.

$$\text{Power coefficient} = \frac{\text{power developed by wind turbine}}{\text{total power available in wind}}$$

- Maximum theoretical value power coefficient = 0.593.
- For wind turbine it varies with operating conditions such as turbine blade angle, wind speed, turbine rotation speed, and other parameters.

Types of wind turbine

- **There are two types of turbines based on the direction of the rotating shaft.**

(a) Horizontal–axis wind Turbine (HAWT).

The axis of rotation is parallel to flow of air.

(b) Vertical-axis wind turbines (VAWT)

The axis of rotation is parallel to flow of air.

Image source : https://www.pikist.com/free-photo-ilmyi

Horizontal Axis Wind Turbine (HAWT)

- They are most successful type of turbines for commercial energy generation.
- HAWT have low cut in wind speed and have high power coefficient.
- More expensive and complex design due to requirement of generator and gear box to be placed at top of tower.

Image source : https://en.wikipedia.org

Horizontal Axis Wind Turbine (HAWT)

- **Main components**

- Turbine Blades

- Hub

- Nacelle

- Yaw Control Mechanism

- Tower

- Brake

- Generator

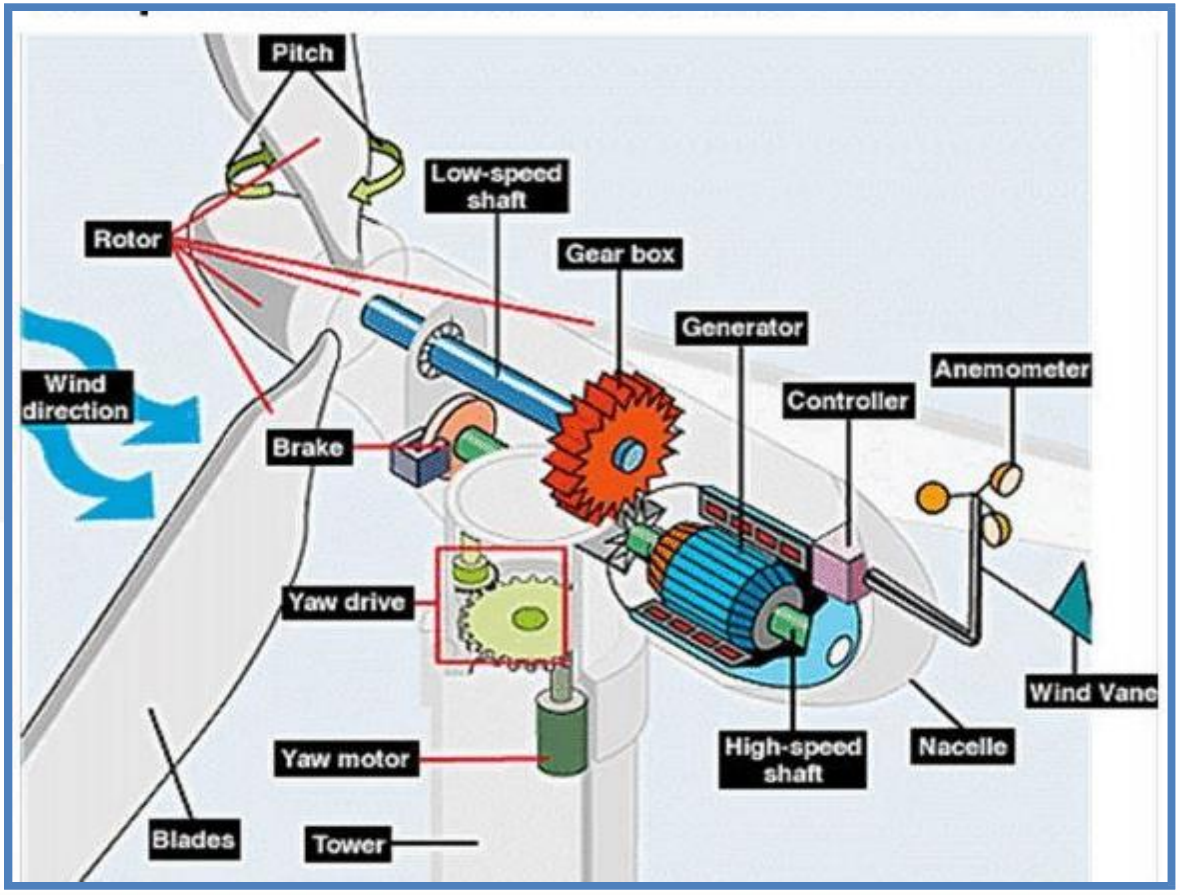

Image https://www.researchgate.net

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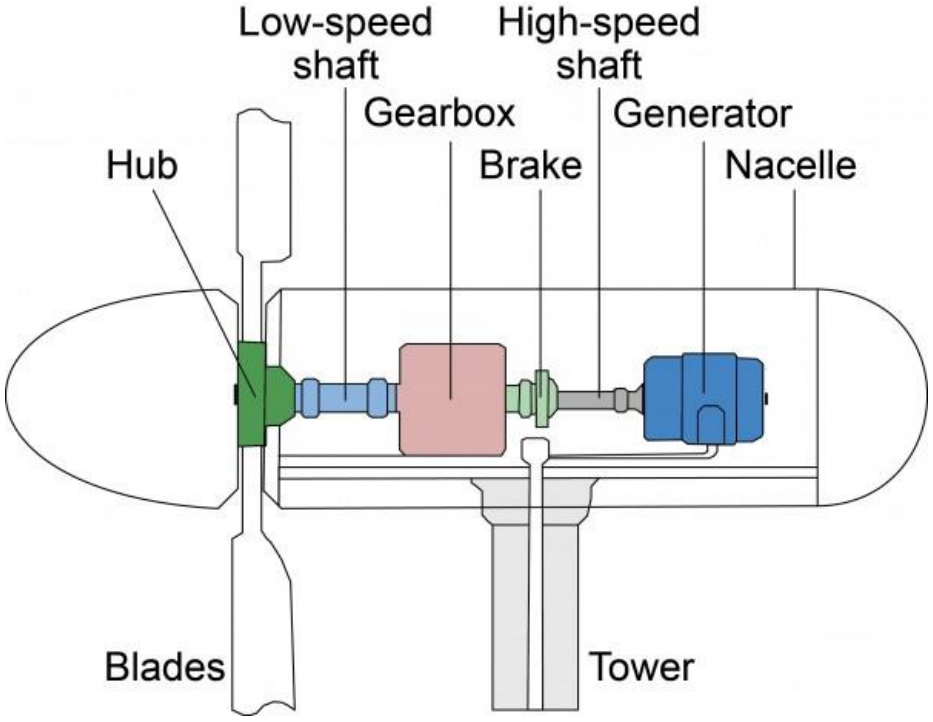

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Horizontal Axis Wind Turbine (HAWT)

Turbine Blades

Blades of turbine are of high-density wood, epoxy composites or glass fiber. They have airfoil type cross-section and are slightly twisted from the outer tip to the root to reduce the tendency to stall. Modern wind turbines have two or three blades and are also known as propeller type wind turbines. Three blades are more common in Europe and other developing countries while two blade rotors are practice more in America.

Hub

The rotor wheel central portion is called as hub .The blades are connected to the hub. The pitch angle control Mechanism is also provided in the hub.

Image https://www.researchgate.net

Horizontal Axis Wind Turbine (HAWT)

Nacelle

It contains rotor brakes, gearbox, generator and electrical switchgear and control. Brakes are used to stop the rotor when power generation is not desired. The shaft rpm is steps up by Gearbox to suit the generator. Protection and control functions are provided by switchgear and control block. Nacelle, mounted at the top of a tower linked to rotor.

Yaw Control Mechanism

It is provided at the base of nacelle to adjust the nacelle around vertical axis to keep it facing the wind

Image https://www.researchgate.net

Horizontal Axis Wind Turbine (HAWT)

Tower

Tower supports nacelle and rotor that are made up of both steel and concrete. The construction can be either tubular or lattice type. The tower vibrations and resulting fatigue cycles under wind speed fluctuations are avoided by careful design. This requires avoidance of all resonance frequency.

Brakes

Rotor is stopped by means of brakes when there is no Requirement of power generation

Generator

Generally grid connected large turbine are provided with induction generator. Medium size wind turbine are use synchronous generator provided to electrify rural places. The Small size wind turbine uses permanent magnet D.C generator for supplying power to microwave station and illuminating light house.

Image https://www.researchgate.net

Horizontal Axis Wind Turbine (HAWT)

- **Types of Rotor**

- Single blade

- two blade

- Three blade

- Sail wing Rotor

- Multiblade Rotor

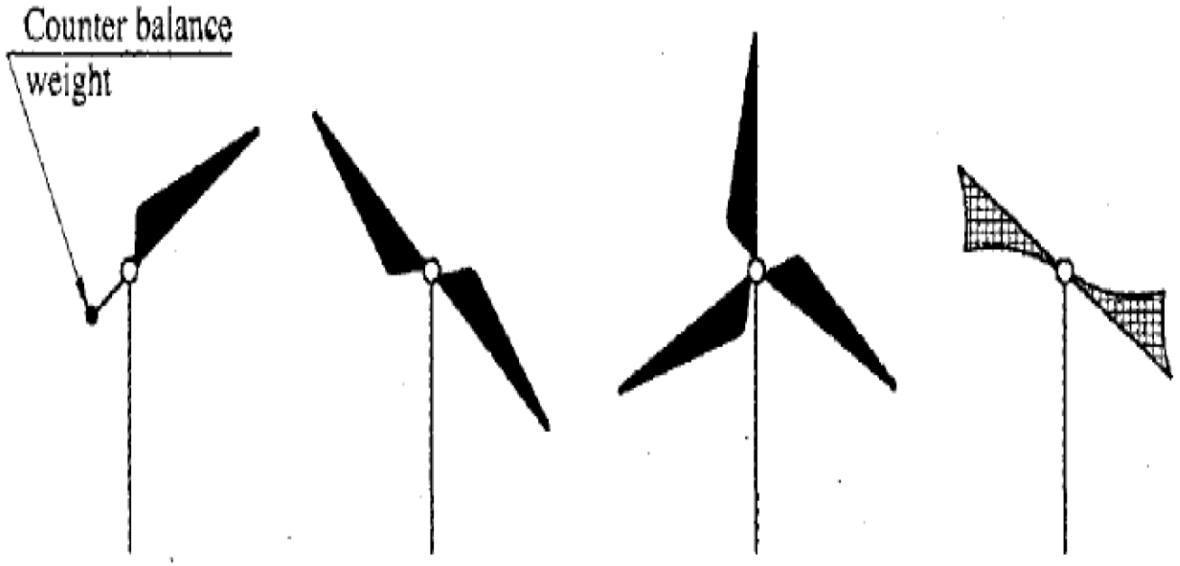


Image source : Non conventional energy sources by B.H Khan

Horizontal Axis Wind Turbine (HAWT)

- **Pitch Control System**

- Pitch of blade is controlled by rotating it from root.

- Pitch control mechanism is provided in the nacelle.

- It Continuously adjusts the pitch to obtain optimal performance.

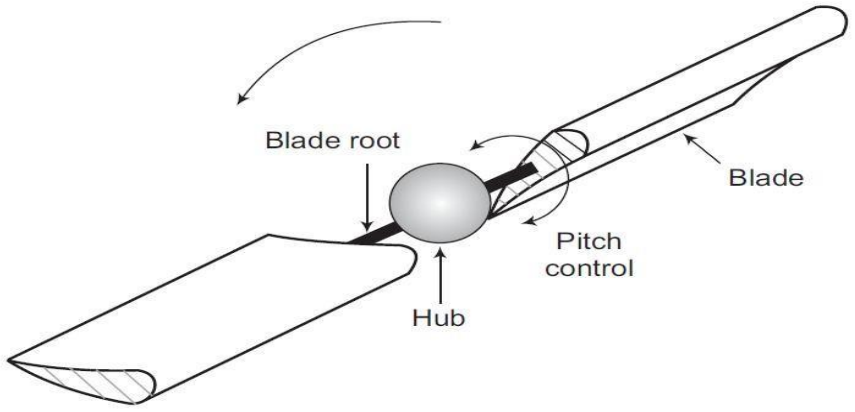


Image source : Non conventional energy sources by B.H Khan

Vertical Axis Wind Turbine (VAWT)

- It is simple in design
- The axis of rotation is vertical to the ground.
- It can receive wind from any direction
- Easier Inspection and maintenance as generator and gear box are provided at ground level.
- These turbines are not self starting .

Image source :http//www.researchgate.net

Vertical Axis Wind Turbine (VAWT)

- **Main component**

- Tower
- Blade
- support structure
- gear box
- Generator
- Brakes.

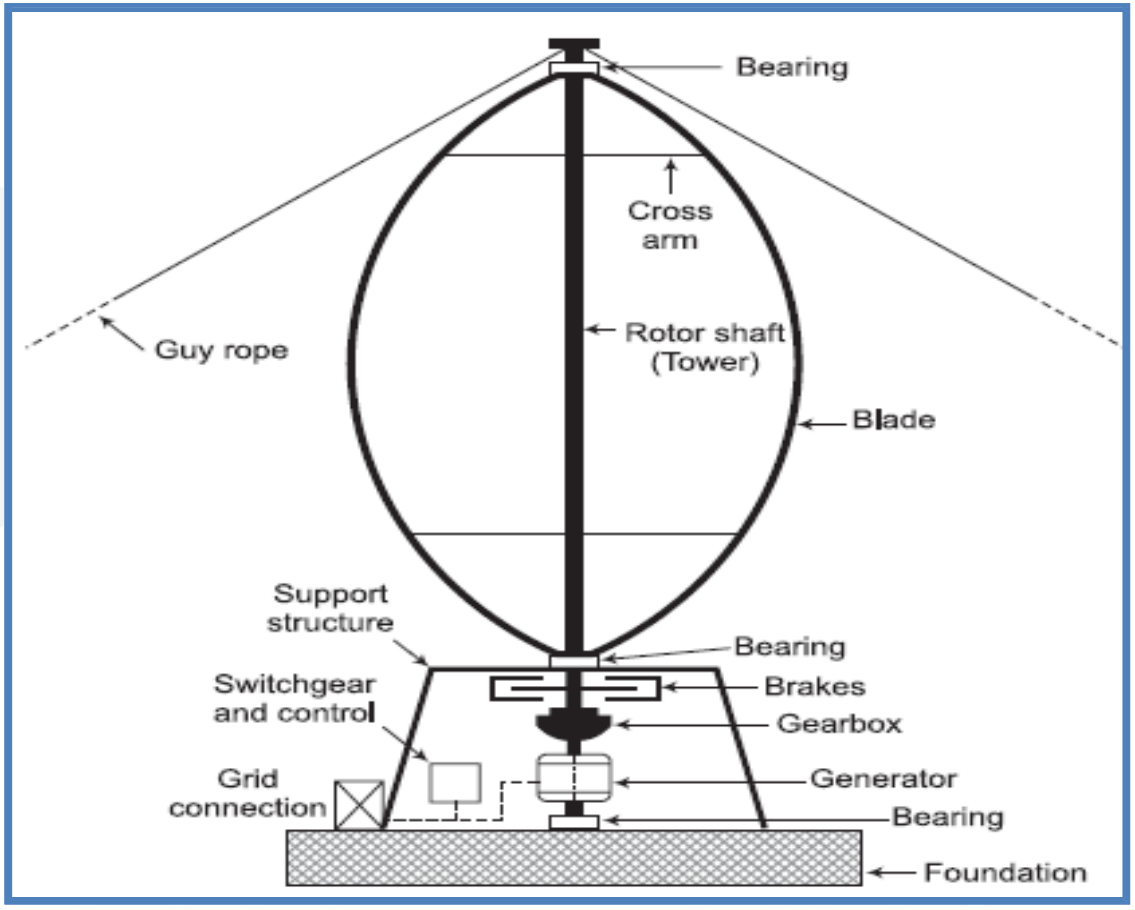
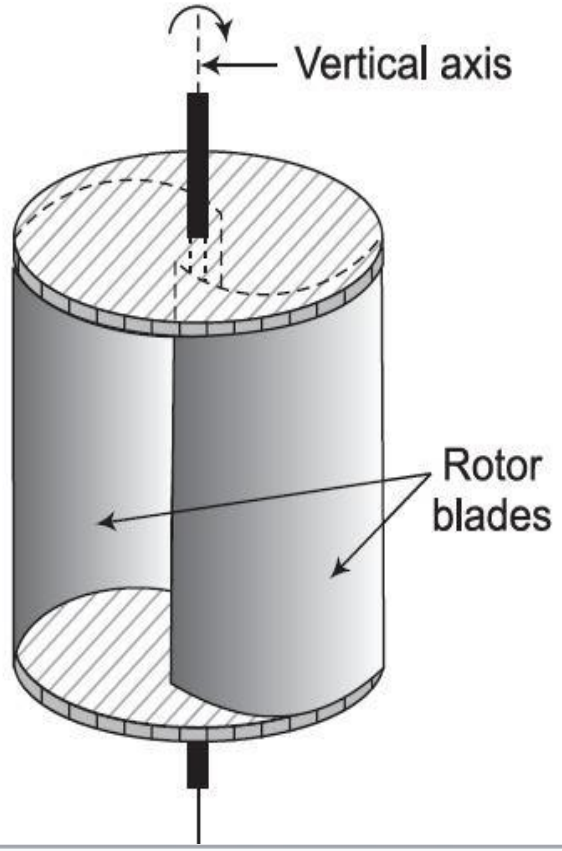


Image source :: Non conventional energy sources by B.H Khan

Rotor of Vertical Axis Wind Turbine (VAWT)

Savonius or S-rotor

- Developed by a Finnish engineer Sigurd J.
- Consist of two half cylinder attached to vertical axis.
- Drag type device consisting of two or three scoops.
- High starting torque, low speed and low efficiency.
- Extract lesser wind power than lift type turbine.
- It can be used for grinding grain and pumping water.
- Not suitable for large electricity generation.



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Rotor of Vertical Axis Wind Turbine (VAWT)

Darrieus Rotor

- The rotor blade has shape like egg beater.
- Consist of Curved blade mounted on rotating shaft.
- It can extract wind from any direction.
- Higher power coefficient than Savonius Rotor.
- Operate at high tip speed ratio.
- Rotor frequency increases with wind speed and output power.
- It is suitable for large scale power generation.

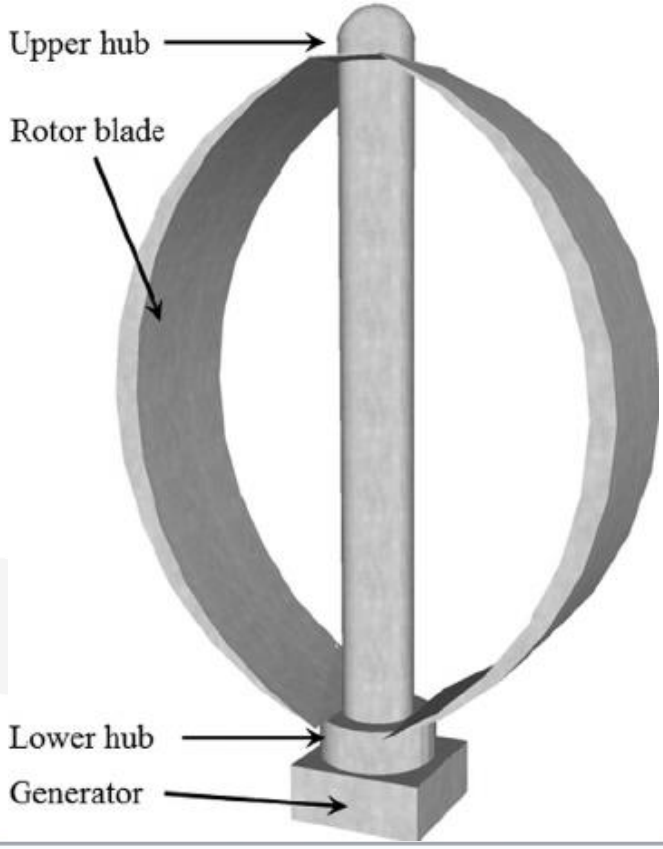


Image source :https://www.researchgate.net

Rotor of Vertical Axis Wind Turbine (VAWT)

Horizontal axis wind turbine	Vertical axis wind turbine
Axis of rotation is parallel to air stream	Axis of rotation is Perpendicular to air stream
Design is complex as gearing and generator are located at top of tower	Design is simple as gearing and generator are located at Ground level.
The power coefficient and tip speed ratio are high	The power coefficient and tip speed ratio are low.
It captures more power as the wind speed increases for same tower height.	It captures Less power as the wind speed increases for same tower height.
It is suitable for large scale power generation	It is suitable for small scale power generation
They are more costly	They are less costly
It create more noise	It create less noise

Image source :https://www.researchgate.net

Rotor of Vertical Axis Wind Turbine (VAWT)

Darrieus Rotor

- Major advantage of Darrieus wind mill is that the rotor blades can accept the wind from any point of the compass.
- The machine can be mounted on the ground eliminating the tower structures.
- One of the drawbacks of this rotor is that it is usually not self-starting and may be started using electrical generator as motor.
- The output power and the rotor frequency cannot be controlled as the pitch of the blade cannot be change.

Image source :https://www.researchgate.net

Performance of wind energy Conversion system

- The overall conversion efficiency of system is given by (η_o) of the system is given by

$$\eta_o = \frac{Useful\ power\ output}{wind\ power\ input} = \eta_A \cdot \eta_G . \eta_C . \eta_{Gen.}$$

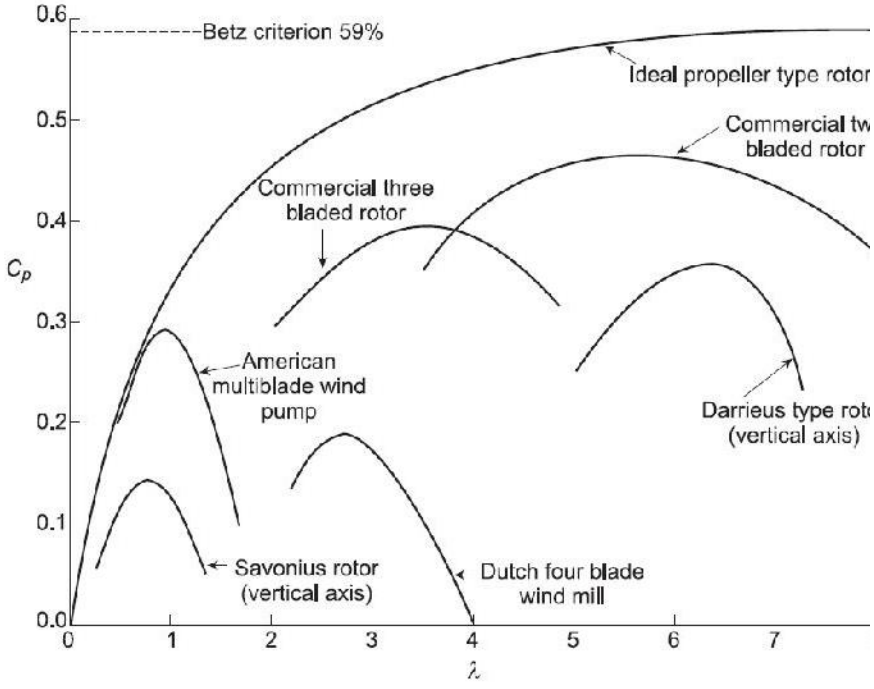
where

η_A = Efficiency of turbine
η_G = Efficiency of Gearing
η_C = Efficiency of mechanical Coupling
η_{Gen} = efficiency of generator.

- The system efficiency of wind turbine is lowest.
- Theoretically a turbine can extract a maximum of 59 per cent of the power in wind as per Betz criterion.

Performance of wind energy Conversion system

- There exist optimum turbine speeds to produce maximum output for particular wind speed.
- The variation of power coefficient with the tip speed ratio has been plotted for several horizontal and vertical axis rotors.



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Performance of wind energy Conversion system

- To obtain optimum efficiency the rotational frequency of the turbine should match with particular wind speed.
- The number of blade decreases with increase in tip speed ratio .
- The highest value of power coefficient can be obtained with propeller type blade.
- The American multi blade and Savonius rotor has low value of power coefficient and tip speed ratio than Darrieus rotor .
- The torque coefficient increases with the number of blade.
- The two blade rotor has potentially the best performance of system.

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Site selection for wind energy conversion system

- High average wind velocities in the range of 6 to 30 m/s should be available throughout the year
- It should be located away from cities and forest due to resistance of air flow.
- Installed in high wind intensity areas such as open areas, Desert, sea shore.
- The land should have good soil bearing capacity to reduce cost of foundation.
- The site should be close to power grid.
- The available wind turbines in the area, their production results are an excellent
- guide to local wind conditions for site selection .
- The minimum wind speeds at the site must be higher than 3.5 to 4.5 m/s. -

Advantages of wind energy system

- It is a renewable source of energy
- No Environmental pollution
- No cost associated with fuel and its transportation.
- Low Maintenance cost and in long run energy produced is almost free of cost.
- In most part of the world wind blows throughout the year and energy can be generated both during day and night time.
- Installation cost of wind energy system is competitive compare to other system.

Disadvantages of Wind energy system

- The available wind energy is fluctuating in nature
- It required storage of energy
- System create noise.
- Large areas are required for wind mill.
- Favourable wind is available in few geographical location.
- Economically payback period for wind energy system is high.

Applications of Wind Power

- As grid Connected electrical power source for supplying power to a utility grid.
- It can be used as off grid electric power source to operate various devices.
- For generating mechanical power used for irrigation and operating various other devices.
- It is used for heating purpose by direct dissipation of Mechanical power.
- wind turbines are used In sea transport to power propeller in ferries operating on shorter route.

Wind Energy Program in India

- Wind energy programme was Initiated in the year 1983–84.
- It is managed and implemented by Ministry of New and Renewable Energy Sources.
- The Ministry' wind power program covers survey and assessment of wind resources, implementation of private sector projects through various fiscal and promotional policies.
- In recent years Wind power generation capacity has significantly increased in India.

Wind Energy Program in India

- India's wind energy sector is led by indigenous wind power industry and has shown consistent progress.
- The expansion of the wind industry has resulted in a strong ecosystem, project operation capabilities and manufacturing base of about 10,000 MW per annum.
- The country currently has the fourth highest wind installed capacity in the world with total installed capacity of 39.25 GW (as on 31st March 2021) and has generated around 60.149 Billion Units during 2020-21.

Wind Energy Program in India

- Wind is an intermittent and site-specific resource of energy and therefore, an extensive Wind Resource Assessment is essential for the selection of potential sites.
- The Government, through National Institute of Wind Energy (NIWE), has installed over 800 wind-monitoring stations all over country and issued wind potential maps at 50m, 80m, 100m and 120m above ground level.

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Wind Energy Program in India

- The total installed wind power capacity was 37.669 GW as of 29 February 2020, the fourth largest wind power capacity in the world.
- The 10% of India's total installed generation capacity comes from wind power.
- The capacity utilization factor is nearly 19.33% in the fiscal year 2018-19.
- In five months duration from May to September there occurs 70% of annual wind generation is In India.
- The technology is continuously upgraded, keeping in view global developments in this area.

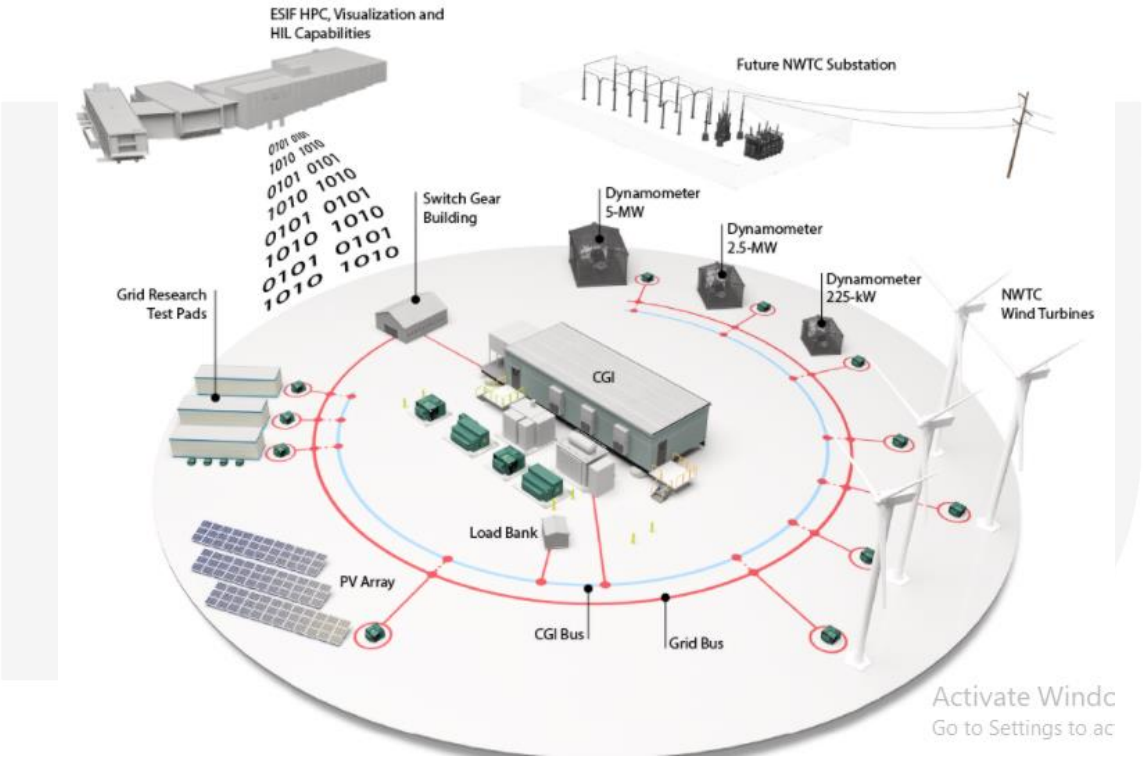
Wind Energy Program in India

- Researches activities are being undertaken through research institutions, for the development of cost effective technologies and systems to improve the quality of power generation from wind.

Example

- A WEG Generates 1500 watts at rated speed of 24 kmph at atmospheric pressure and temperature of 20 ^{O}C. Calculate the change in output if wind generator is operated an altitude of 1800m. Temperature 10 ^{O}C, Wind speed 30 kmph and air pressure 0.88 atmosphere

Controllable Grid Interface



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