Module-3a: Wind Energy

Syllabus

1. Properties of wind
2. Availability of wind energy in India,
3. Wind velocity and power from wind;
4. Major problems associated with wind power,
5. Basic components of wind energy conversion system (WECS);
6. Classification of WECS- Horizontal axis- single, double and muliblade system. Vertical axis- Savonius and darrieus types.

Introduction to wind

- Sun is the main source of wind, and hence, wind is a form of solar energy.
- Winds are caused by:

✓ uneven heating of the atmosphere by the sun
✓ the irregularity of the earth's surface
✓ rotation of the earth.

1. Properties of wind

1. Direction: Wind is described by the direction from which it is blowing.
2. Speed: Wind speed refers to the rate at which the air is moving. miles per hour (mph) or kilometers per hour (km/h).
3. Pressure Gradient: The difference in air pressure between two points is the driving force behind wind.
4. Turbulence: Wind can exhibit turbulence, which refers to irregular and chaotic airflow. Turbulence can cause fluctuations in wind speed and direction, resulting in gusts and eddies.
5. Vertical Profile: Wind can vary with height above the Earth's surface. As you move higher in the atmosphere, away from surface influences, wind speed tends to increase and become more consistent in direction.
6. Seasonal and Local Variations: Wind patterns can vary based on seasonal and local factors.
7. Wind Energy: Wind turbines capture the kinetic energy of the wind and convert it into electricity.

2. Availability of wind energy in India

- India has the third largest operational wind power plants in the world
- The states with the highest wind energy potential are Tamil Nadu, Gujarat, Maharashtra, Rajasthan, and Karnataka.

- Apart from these states, several other regions in India have significant wind energy potential, including Andhra Pradesh, Madhya Pradesh, Kerala, and Odisha.
- Installed capacity of Wind Energy 42633 MW (March 2023)
- Wind Energy's contribution to Renewable Energy: 34.06%

Highest Wind Energy Producing State in India 2022

State	Capacity
Tamil Nadu	9000 MW
Gujarat	7855 MW
Maharashtra	4789 MW
Karnataka	4779 MW
Rajasthan	4292 MW

2.1 Basic Principles of Wind Energy Conversion

- The circulation of air in the atmosphere is caused by the nonuniform heating of the earth's surface by the sun.
- The air immediately above a warm area expands, it is forced upwards by cool, denser air which flows in from surrounding areas causing a wind.
- The nature of the terrain, the degree of cloud cover and the angle of the sun in the sky are all factors which influence this process.
- In general, during the day, the air above the land mass tends to heat up more rapidly than the air over water.
- At night, the process is reversed because the air cools down more rapidly over the land and the breeze therefore blows off shore.
- Despite the wind's intermittent nature, wind patterns at any particular site remain remarkably constant year by year.
- Average wind speeds are greater in hilly and coastal areas than they are well inland.
- The winds also tend to blow more consistently and with greater strength over the surface of the water where there is a less surface drag.
- Wind speeds increase with height. They have traditionally been measured at a standard height of ten metres where they are found to be 20-25% greater than close to the surface.
- At a height of 60 m they may be 30-60% higher because of the reduction in the drag effect of the earth's surface.

3. The Power in the Wind

- Wind possesses energy by virtue of its motion. Any device capable of slowing down the mass of moving air, like a sail or propeller, can extract part of the energy and convert is into useful work.
- Three factors determine the output from a wind energy converter:
  - ✓ The wind speed
  - ✓ The cross-section of wind swept by rotor and
  - ✓ The overall conversion efficiency of the rotor, transmission system and generator or pump
- The power in the wind can be computed by using the concept of kinetics.
- The wind mill works on the principle of converting kinetic energy of the wind to mechanical energy.
- We know that power is equal to energy per unit time.
  The energy available is the kinetic energy of the wind.
- The kinetic energy of any particle = $\frac{1}{2}mV^2$, *where m- mass, V-Velocity*
- The amount of air passing in unit time, through an area A, with velocity V such that its mass m is given by
  M=ρAV…………(1) *Where, ρ - density of air.*
- Substituting this value of the mass in the expression for the kinetic energy, we obtain, **kinetic energy =** $\frac{1}{2}\rho AV.V^2$ **watts**

$$= \frac{1}{2}\rho A.V^3 \text{ watts} \quad ....(2)$$

- Equation (2) Indicates the following :
  - ✓ A small increase in wind speed can have a marked effect on the power in the wind.
  - ✓ The power available is proportional to air density (1.225 kg/m3 at sea level). It may vary 10-15 % during the year because of pressure and temperature change.
  - ✓ Wind power is proportional to the intercept area.
- Thus an aeroturbine with a large swept area has higher power than a smaller area machine; but there are added implications.
- In horizontal axis aeroturbines , the area is normally circular of diameter D, then

$$A = \frac{\pi}{4}D^2 \quad \text{sq.mt}$$

$$\text{Available wind power } P_a = \frac{1}{2}\rho\frac{\pi}{4}D^2V^3 \text{ watts}$$

$$= \frac{1}{8}\rho\pi D^2V^3 \quad ....(3)$$

- The equation (3) indicates that
  - ✓ *Maximum power available from the wind varies according to the square of the diameter of the intercept area (or square of the rotor diameter).*
  - ✓ *Thus doubling the diameter of the rotor will result in a four-fold increase in the available wind power.*
- The combined effects of wind speed and rotor diameter variations are shown in. Fig.
- Wind machines intended for generating substantial amounts of power should have large rotors and be located in areas of high wind speeds.

- The physical conditions in a wind turbine are such that only a fraction, of the available wind power can be converted into useful power.

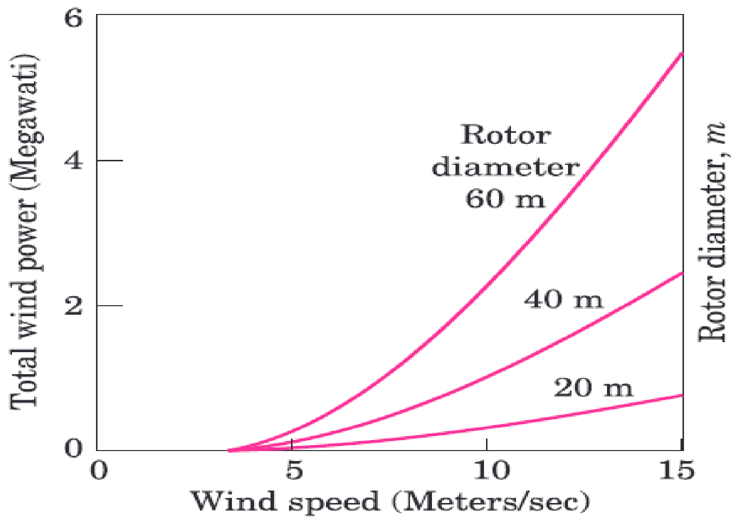


Fig: Dependence of wind-rotor power on wind speed and rotor diameter.

4. Major problems associated with wind power

1. Intermittency and variability: Wind's fluctuating nature requires backup power or energy storage.

2. Land and space requirements: Large-scale wind farms need significant land area and can face land use conflicts.

3. Visual and noise impact: Some find wind turbines visually unappealing, and noise can be a concern.

4. Wildlife and environmental impact: Collisions with turbines and disruption to ecosystems affect wildlife.

5. Grid integration and transmission: Extensive infrastructure is needed to connect remote wind farms to the grid.

6. Capital investment and costs: Initial investment for wind farms can be high.

7. Public acceptance and community opposition: Concerns about visual impact and noise can lead to opposition.

8. Despite these challenges, ongoing research and technology advancements aim to address these issues and improve wind power's efficiency, reliability, and environmental compatibility

4.1 Site Selection Considerations

1. High annual average wind speed
2. Availability of anemometry data
3. Availability of wind V_t curve at the proposed site

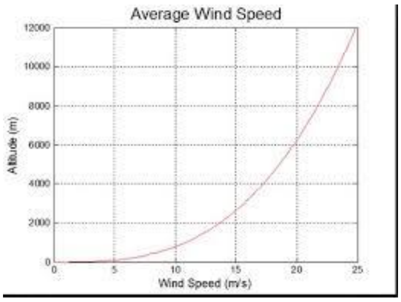
4. Wind structure at the proposed site
5. Altitude of the proposed site
6. Terrain and its aerodynamics
7. Local ecology
8. Distance to road and railways
9. Nearness of site to local Centre/users
10. Nature of ground
11. Favourable Land Cost
12. Other Conditions like icing problem, salt spray or blowing dust

1. High annual average wind speed.

- A fundamental requirements to the successful use of WECS, is an adequate supply of wind. The wind velocity is the critical parameter. The power in the wind P, through a given cross-sectional area for a uniform wind velocity V is $\mathbf{P_w=KV^3}$……(1), where K is constant.
- Small increases in V markedly affect the power in the wind, e.g., doubling V, increases P, by a factor of 8.
- It is obviously desirable to select a site for WECS with high wind velocity.
- Thus a high average wind velocity is the principal fundamental parameter of concern in initially appraising a WECS site.

Strategy for siting is generally recognized to consists of:

(i) Survey of historical wind data.
(ii) Contour maps of terrain and wind are consulted.
(iii) Potential sites are visited.
(iv) Best sites are instrumented for approximately one year.
(v) Choose optimal site.



2. Availability of anemometry data.

- It is another important siting factor. The principal object is to measure the wind speed which basically determines the WECS output power.
- The anemometry data should be available over some time period at the precise spot where any proposed WECS is to be built and that this should be accomplished before a siting decision is made.

3. Wind structure at the proposed site.

- The ideal case for the WECS would be a site such that the V curve was flat, i.e., a smooth steady wind that blows all the time; but a typical site is always less than ideal.
- Wind specially near the ground is turbulent and gusty, and changes rapidly in direction and in velocity.
- This departure from homogeneous flow is collectively referred to as "the structure of the wind.

4.Altitude of the proposed site.

- It affects the air density and thus the power in the wind and hence the useful WECS electric power output.

- Also, as is well known, the winds tend to have higher velocities at higher altitudes.

5. Terrain and its aerodynamic.

- One should know about terrain of the site to be chosen.
- If the WECS is to be placed near the top but not on the top of a not too blunt hill facing the prevailing wind, then it may be possible to obtain a 'speed up' of the wind velocity over what it would otherwise be.

6. Local Ecology.

- If the surface is bare rock it may mean lower hub heights hence lower structure cost.
- If trees or grass or vegetation are present, all of which tend to destructure the wind, then higher hub heights will be needed resulting in larger system costs than the bare ground case.

7. Distance to Roads or Railways.

- This is another factor the system engineer must consider for heavy machinery, structures, materials, blades and other apparatus will have to be moved into any chosen WECS site.

8. Nearness of site to local centre / users.

- This obvious criterion minimizes transmission line length and hence losses and costs.

9. Nature of ground.

- Ground condition should be such that the foundations for a WECS are secured.
- Ground surface should be stable. Erosion problem should not be there, as it could possibly later wash out the foundations of a WECS, destroying the whole system.

10. Favourable land cost.

- Land cost should be favourable as this along with other siting costs, enters into the total WECS system cost.

The characteristics of a good wind power site may be summarized as follows:

- A site should have a high annual wind speed.
- There should be no tall obstructions for a radius of 3 km.
- An open plain or an open shore line may be a good location.
- The top of a smooth, well rounded hill with gentle slopes lying on a flat plain or located on an island in a lake or sea is a good site.
- A mountain gap which produces to wind funneling is good.

5. Basic Components of Wind Energy Conversion System (WECS)

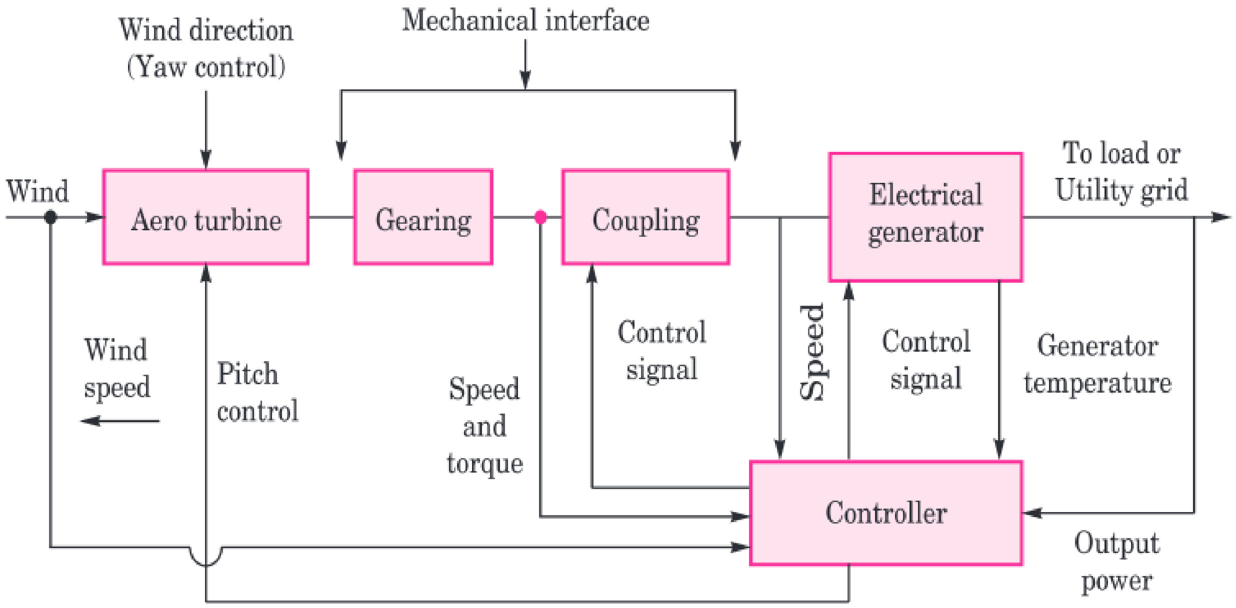


Fig. 6.12. Basic components of a wind electric system.

Mechanical Components	Electrical Components
1. Rotor	1. Generator
2. Main Shaft	2. Power Converter
3. Gearbox	3. Step-up Transformer
4. Mechanical Break	4. Wind Farm Collection Points or Point of Common Coupling
5. Nacelle	
6. Pitch and Yaw Drives	
7. Wind Measuring Equipment	

5.1 Mechanical Components

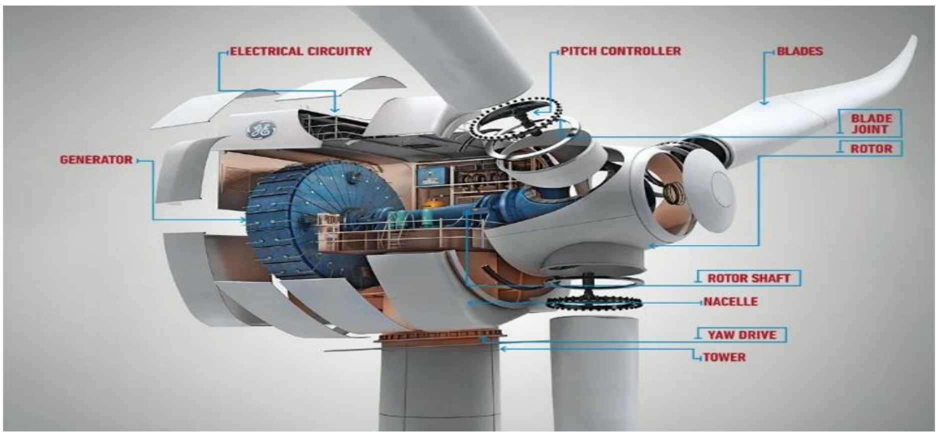


Fig: Mechanical components of WECS (Only for information)

The mechanical components of a WECS include the rotor, the main shaft, gearbox, mechanical breaks, nacelle, pitch and yaw drives, and wind measuring equipment,

1. Rotor: It is the most important component of a WECS. It is a large wheel that has blades attached to it. The rotor is what captures the wind and turns it into mechanical energy.
2. Main Shaft: The main shaft is the shaft attached to the rotor. It is made of steel or aluminum and connected to the gearbox.
3. Gearbox: The gearbox is a device that increases the rotational speed of the rotor. It is made of gears, and it is located in the nacelle.
4. Mechanical Breaks: Mechanical breaks are used to stop the rotor from spinning. They are located in the nacelle and activated when the wind speed is too high.
5. Nacelle: The nacelle is the housing that contains all of the electrical and mechanical components of the WECS. It is located at the top of the turbine, and it is made of steel or aluminum.
6. Pitch and Yaw Drives: Pitch and yaw drives are used to adjust the angle of the blades. They are located in the nacelle, and a computer operates them.
7. Wind Measuring Equipment: Wind measuring equipment is used to measure wind speed and direction. It is located in the nacelle and consists of anemometers and wind vanes.

5.2 Electrical Components

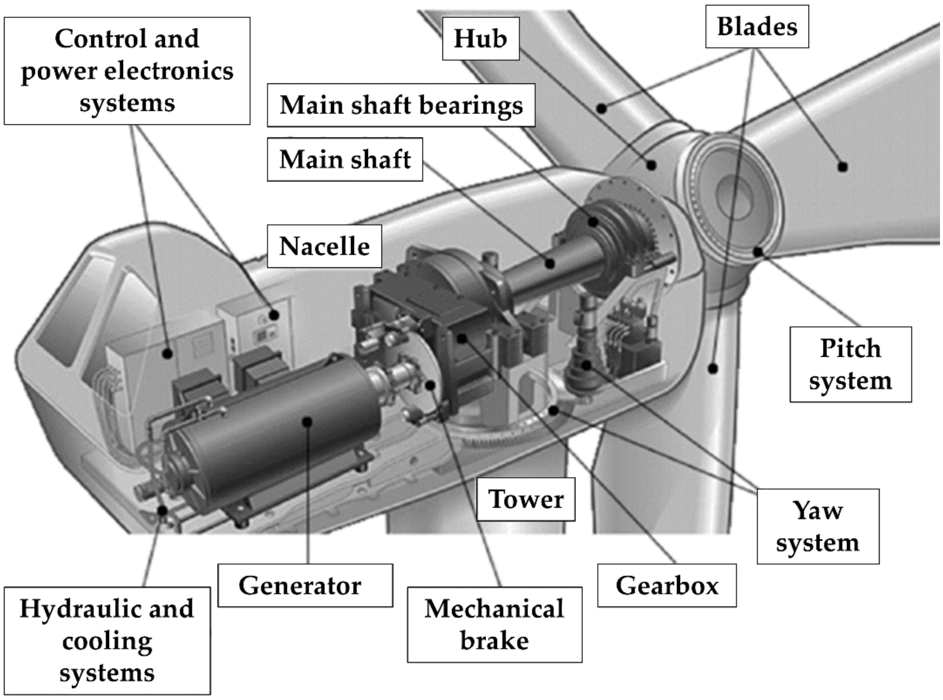


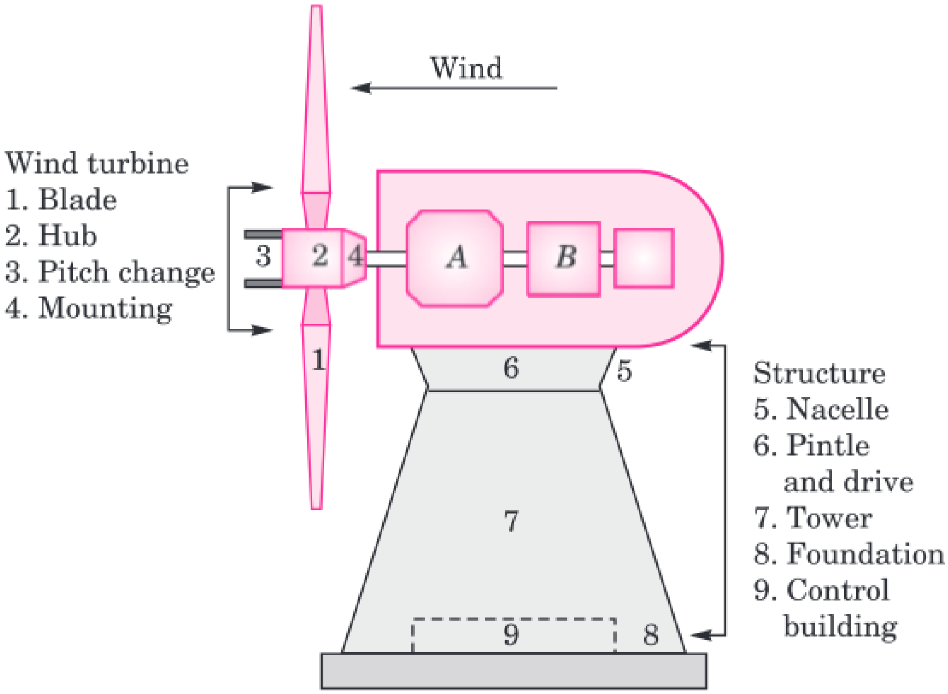
Fig: Electrical components of WECS (Only for information)

The electrical components of a WESC include the generator, power converter, step-up transformer, and wind farm collection points or points of common coupling.

1. Generator: A device that converts mechanical energy into electrical energy. It is located in the nacelle and is connected to the main shaft.

2. Power Converter: The power converter is a device that converts DC into AC. It is located in the nacelle, connected to the generator.
3. Step-up Transformer: The step-up transformer is a device that increases the voltage of the electricity. It is located in the nacelle, connected to the power converter.
4. Wind Farm Collection Points or Point of Common Coupling: Are used to collect the electricity from the turbines. They are located at the turbine's base, and they are connected to the power converter.

5.3 The physical embodiment for such an areo-generator is shown in a generalized form in Fig. below.



A—Transmissin B—Electrical

The sub components of the windmill are:

1) Rotors are mainly of two types:

- ✓ Horizontal axis rotor
- ✓ Vertical axis rotor

• One advantage of vertical axis machines is that they operate in all wind directions

• The portion of the wind turbine that collects energy from the wind is called the rotor.

2) Windmill head

• Supports the rotor, housing the rotor bearings

• Also incorporated like changing the pitch of the blades for safety devices and tail vane to orient the rotor to face the wind

3) Transmissions:

• The number of revolutions per minute (rpm) of a wind turbine rotor can range between 40 rpm and 400 rpm, depending on the model and the wind speed.

• Generators typically require rpm's of 1,200 to 1,800.

• As a result, most wind turbines require a gear-box transmission to increase the rotation of the generator to the speeds necessary for efficient electricity production.

• Some DC-type wind turbines do not use transmissions.

• Instead, they have a direct link between the rotor and generator.

• These are known as direct drive systems.

• Without a transmission, wind turbine complexity and maintenance requirements are reduced.

• But a much larger generator is required to deliver the same power output as the AC-type wind turbines.

4) Control:

• The modern large wind turbine generator requires a versatile and reliable control system to perform the following functions:

• Orientation of the wind in the rotor

• Generator output monitoring — status, data computation and storage

5) Towers:

Four types of supporting towers deserve consideration, these are:

(l) the reinforced concrete tower,

(2) the pole tower,

(3) the built up shell-tube tower, and

(4) the truss tower.

Advantages and Disadvantages of WECS

Advantages:

1. It is a renewable source of
2. non-polluting, so it has no adverse influence on the environment.
3. Wind energy systems avoid fuel provision and transport.
4. On a small scale upto a few kilowatt system is less costly. On a large-scale costs can be with conventional electricity and lower costs could be achieved by mass production.

Disadvantages

1. Wind available in dilute and fluctuating in nature.
2. Unlike water wind energy needs storage capacity because of its irregularity.
3. Wind energy systems are noisy in operation.
4. Wind power systems have a relatively high overall weight. For large systems a weight of 110 kg/kW (rated) has been estimated.
5. Large areas are needed, typically, propellers 1 to 3 m in diameter, deliver in the 30 to 300 W range.
6. Present systems are neither maintenance free not-practically reliable.

6. Classification of WECS

1. Two broad classifications:

i. **Horizontal Axis Machines:** The axis of rotation is horizontal and the aeroturbine plane is vertical facing the wind.

ii. **Vertical Axis Machines:** The axis of rotation is vertical. The sails or blades may also be vertical.

2. Based on size:

i. **Small Size** –upto 2kW

ii. **Meduim Size-** 2 to 100kW

iii. **Large Size** -100kW and above:

2 Sub types: a. Single Generator b. Multiple Generators

3. Based on Output Power:

i. DC output

a.DC generator

b. Alternator rectifier

ii AC output

a. Variable frequency, variable or constant voltage AC.

b. Constant frequency, variable or constant voltage AC.

4. Based on rotational speed of the aeroturbines

i. **Constant Speed with variable pitch blades:** This made implies use of synchronous generator with its constant frequency output.

ii. **Nearly Constant Speed with fixed pitch blades**: This mode implies an induction generator.

iii. **Variable Speed with fixed pitch blades:** This mode could imply, for constant frequency output

(a) Field modulated system

(b) AC-DC-AC link

(c) Double output induction generator

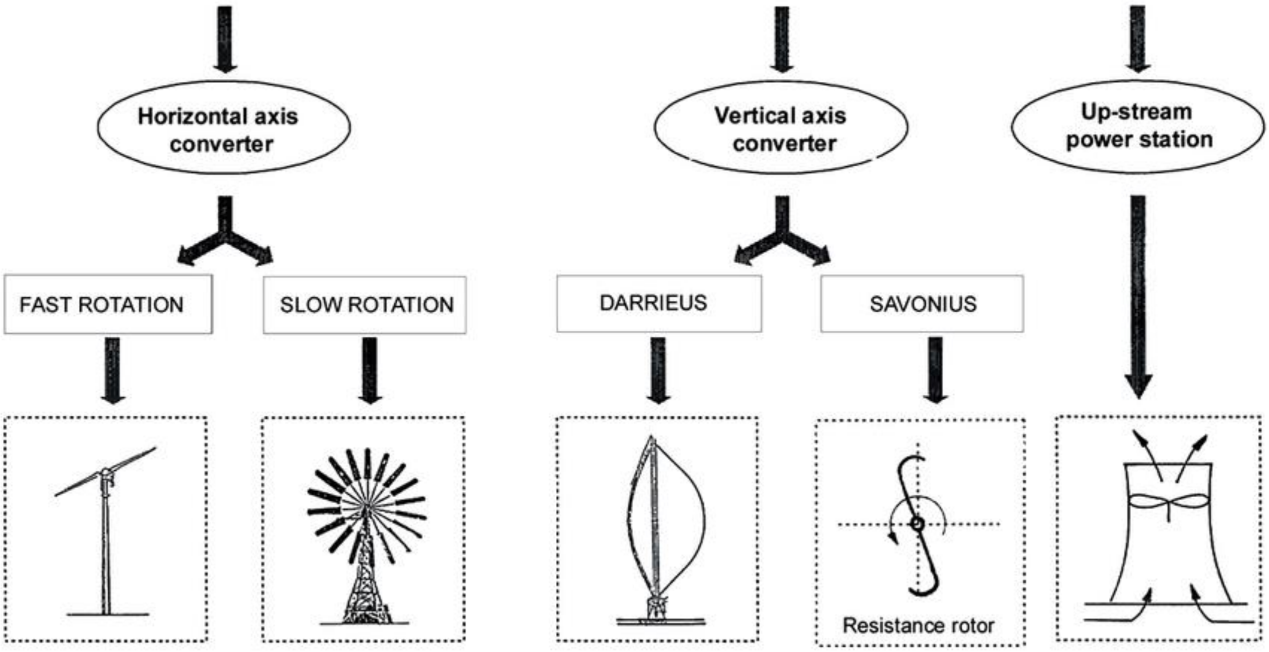
(d) AC commutator generators

(e) Other variable speed constant frequency generating systems.

5. Based on utilization of output :

i. Battery storage.
ii. Direct connection to an electromagnetic energy converter.
iii. Other forms (thermal potential etc.) of storage.
iv. Interconnection with conventional electric utility grids.

6.1 Wind Collectors



6.2 Rotational Axis

There are two types of rotational axis: horizontal and vertical.

1. A horizontal axis wind turbine (HAWT): is the most commonly used type. The rotor blades are mounted on a horizontal shaft perpendicular to the ground.

2. A vertical axis wind turbine (VAWT): has its rotor blades mounted on a vertical shaft parallel to the ground. VAWT is less common than HAWT because it is more expensive and complicated to build and is not as efficient in converting wind energy into electricity.

7. Horizontal Axis Wind Turbines (HAWT)

- A HAWT has a similar design to a windmill, it has blades that look like a propeller that spins on the horizontal axis as shown in the figure
- Horizontal axis wind turbines have the main rotor shaft and electrical generator at the top of a tower, and oriented perpendicular to the wind.
- Small turbine are pointed by a simple wind vane placed square with the rotor (blades), while large turbines generally use a wind sensor coupled with a servo motor to turn the turbine into the wind.

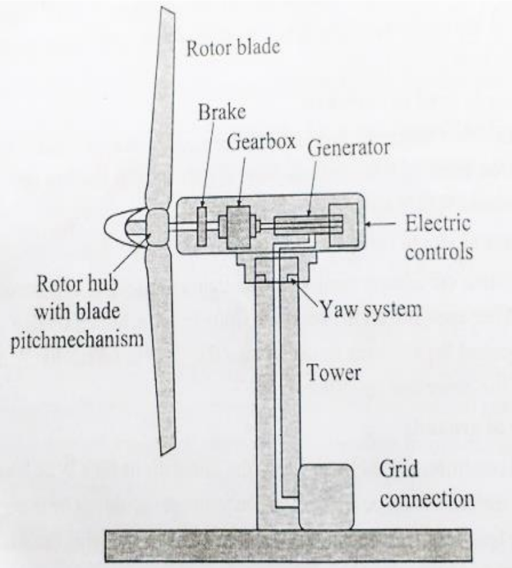


Fig. 5.8 Schematic Structure ofHorizontal Axis Wind Turbines

- Most large wind turbines have a gearbox, which turns the slow rotation of the rotor into a faster rotation that is more suitable to drive an electrical generator.
- Since a tower produces turbulence behind it, the turbine is usually pointed upwind of the tower.
- Wind turbine blades are made stiff to prevent the blades from being pushed into the tower by high winds.
- Additionally, the blades are placed a considerable distance in front of the tower and are sometimes tilted up a small amount

HAWT Advantages

1. It includes high output power as compared to the vertical wind turbine.
2. A tall tower gets stronger winds once the wind shear alters.
3. High efficiency.
4. It is not expensive as compared to a vertical-type turbine.
5. It has high reliability.
6. It has a high rate of capacity.
7. Its rotational speed is high.
8. It is more consistent.
9. The blade can also tilt the rotor during a storm to reduce damage.

HAWT Disadvantages

1. These are available in large size
2. Weight is high
3. We cannot move easily
4. Installation is difficult
5. High noise
6. To design this wind turbine, large machinery is needed
7. Its maintenance is difficult as compared to other wind turbines.

HAWT Applications

The applications of horizontal-axis wind turbines include the following.

1. These are the most frequently used wind turbines for commercial and industrial purposes due to their large power output and high efficiency.
2. These are mostly used in wind farms
3. Horizontal axis wind turbines achieve better power output & higher energy efficiency, so used in large-scale wind power plants & also for electricity generation.
4. In industrial plants, large-scale wind farms, or national projects, these wind turbines are most frequently seen. So they are the perfect solution for the production of mass electricity.

7.1 Classification of HAWT: Classified based on no of blades

1. Single-Blade Turbines

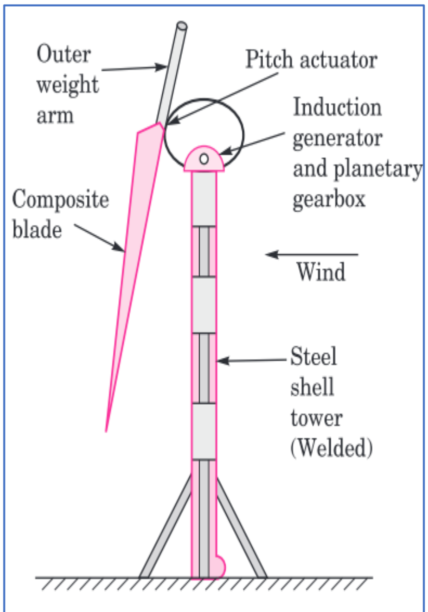
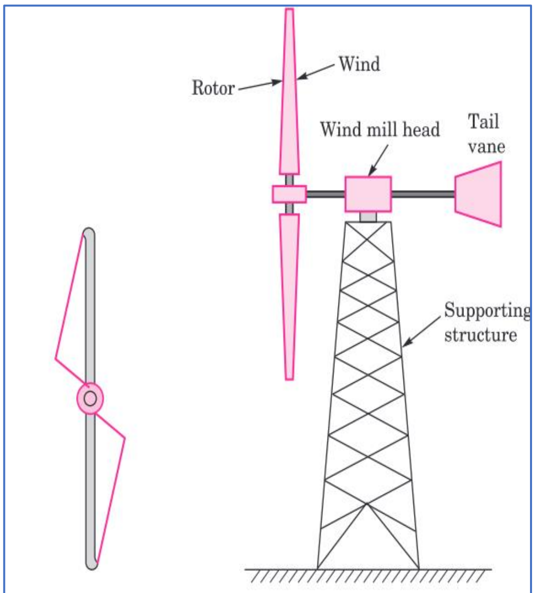


Fig. 6.15. Horizontal axis single blade wind mill.

- Single-blade wind turbines are used in a few limited applications, but they are the least used of all the Horizontal-Axis Wind Turbines.
- To rotate smoothly, single-blade turbines must have one or two counterbalances. The figure shows a single-blade wind turbine with two counterbalances.
- The advantage of this type of wind turbine is the lower cost because of the use of only one turbine blade (and the small weight savings).
- single-blade turbines must run at much higher speeds to convert the same amount of energy from the wind as two-blade or three-blade turbines with the same size blades.

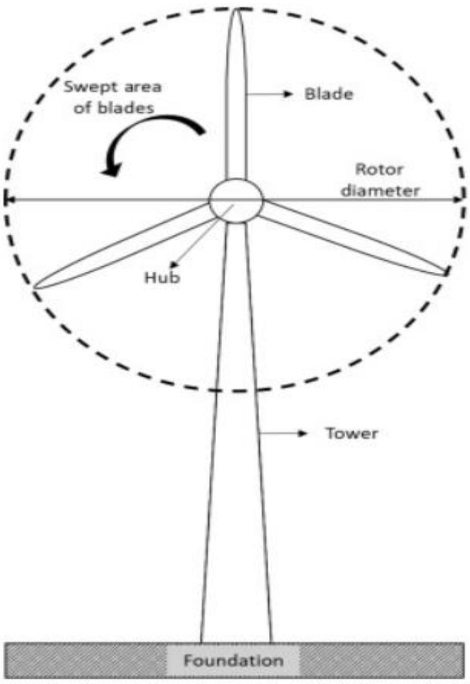
2. Two-Blade Wind Turbines



(a) Two blade prufile (b) Schematic of a horizontal axis type wind mills

- Compared to three-blade turbines, two-blade wind turbines have the advantage of saving on the cost and the weight of the third rotor blade, but they have the disadvantage of requiring higher rotational speed to yield the same energy output.
- This is a disadvantage in terms of both noise and wear of critical bearings, shafts, and gearboxes.

3. Three- blade Wind Turbine



The majority of large horizontal-axis wind turbines use three blades, with the rotor position maintained upwind by the yaw control.

The three blades provide the most energy conversion while limiting noise and vibration. The three blades provide more blade surface for converting wind energy into electrical energy than a two-blade or single-blade wind turbine.

The blades for the larger horizontal-axis wind turbines are so large they must be transported individually by a truck and trailer. This also means that one or more very large cranes are needed to set the tower and turbine in place.

The tower to hold the larger three-blade turbine must also be larger and reinforced to support the weight and to withstand the increased wind power that is harvested to produce its maximum output.

4. Horizontal axis multibladed type:

Here the multiblades are made from sheet metal or aluminium. The rotors have high strength to weight ratios and have been known to service hours of freewheeling operation in 60 km/hr winds. They have good power coefficient, high starting torque and added advantage of simplicity and low cost.

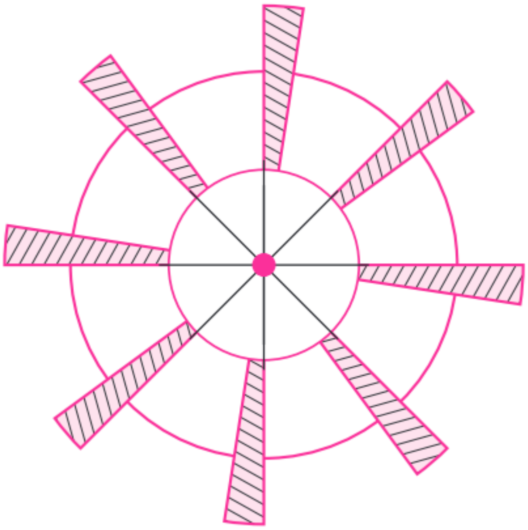


Fig. 6.16. Multiblade propeller.

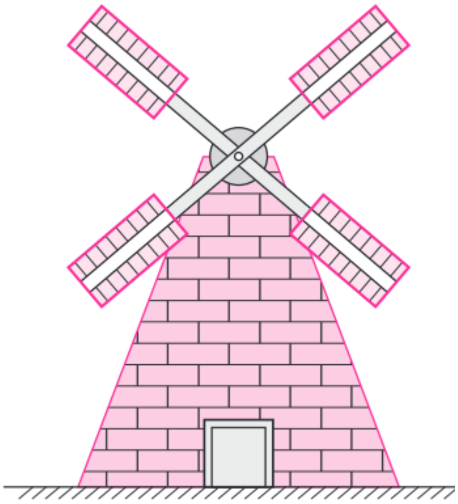


Fig. 6.17. Horizontal axis, Dutch type wind mill.

5. Sail type: The blade surfaces is made from cloth, nylon or plastics arranged as mast and pole or sail wings. There is also variation in the number of sails used. The horizontal axis types generally have better performance. They have been used for various applications, but the two major areas of interest are electric power generation, and pumping water. The latter introduces some complexity into the design as the mechanical energy has to be transmitted over a distance. Also in some cases the rotor motion has to be converted to reciprocating motion.

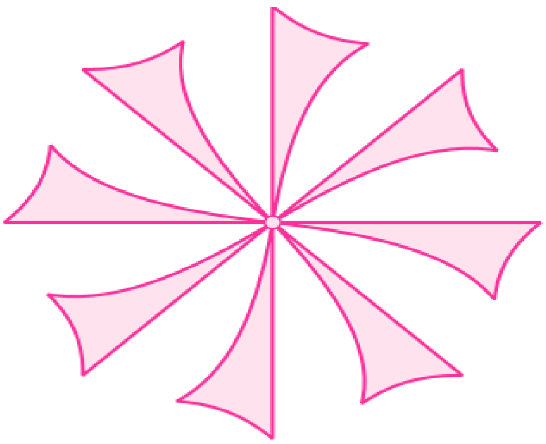


Fig. 6.18. Blades of sail type wind mill.

8. Vertical Axis Wind Turbines(VAWT)

- Vertical wind turbines(VAWTs), have the main rotor shaft arranged vertically as shown in Fig .
- The main advantage of this arrangement is that the wind turbine does not need to be pointed into the wind. This is an advantage on-site where the wind direction is highly variable or has turbulent winds
- With a vertical axis, the generator and other primary components can be placed near the ground, so the tower does not need to support it, also makes maintenance easier. The main drawback of a VAWT generally creates drag when rotating into the wind.
- VAWTs are a type of wind turbine where the main rotor shaft is set transverse to the wind (but not necessarily vertically) while the main components are located at the base of the turbine
- Vertical axis turbines are powered by wind coming from all 360 degrees, and even some turbines are powered when the wind blows from top to bottom.

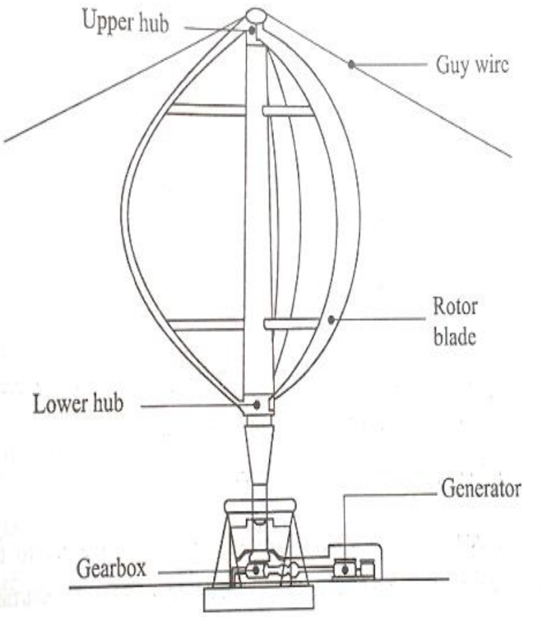


Fig. 5.9 Schematic Structure of Vertical Axis Wind Turbines (Darrieus wind turbine)

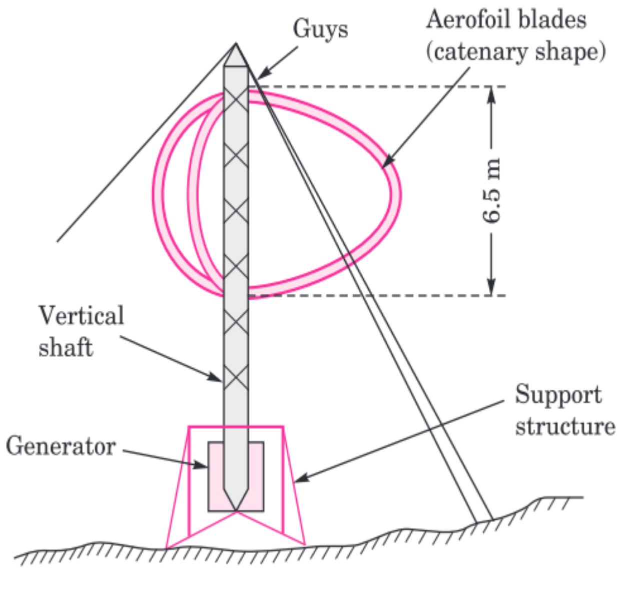
VAWT Advantages

1. No yaw mechanisms is needed
2. A VAWT can be located nearer the ground, making it easier to maintain the moving parts.
3. VAWTs have lower wind startup speeds than the typical the HAWTs.
4. VAWTs may be built at locations where taller structures are prohibited.
5. VAWTs situated close to the ground can take advantage of locations where rooftops, means hilltops, ridgelines, and passes funnel the wind and increase wind velocity.

VAWT Disadvantage

1. Most VAWTs have an average decreased efficiency from a common HAWT, mainly because o the additional drag that they have as their blades rotate into the wind. Versions that reduce drag produce more energy, especially those that funnel wind into the collector area.
2. Having rotors located close to the ground where wind speeds are lower and do not take advantage of higher wind speeds above.
3. Because VAWTs are not commonly deployed due mainly to the serious disadvantage mentioned above, they appear novel to those not familiar with the wind industry. This has often made them the subject of wild claims and investment scams over the last 50 years.

8.1 Darrieus Wind Turbine



- Darrieus turbine has long, thin blades in the shape of loops connected to the top and bottom of the axle; it is often called an "eggbeater windmill."
- The Darrieus turbine is characterized by its C-shaped rotor blades which give it its eggbeater appearance.
- It is normally built with two or three blades.
- They have good efficiency but produce large torque ripple and cyclic stress on the tower, which contributes to poor reliability

Advantages

(1) The rotor shaft is vertical. Therefore it is possible to place the load, like a generator or a centrifugal pump at ground level. As the generator housing is not rotating, the cable to the load is not twisted and no brushes are requires for large twisting angles.

(2) The rotor can take wind from every direction.

(3) The visual acceptation for placing of the windmill on a building might be larger than for an horizontal axis windmill.

(4) Easily integrates into buildings.

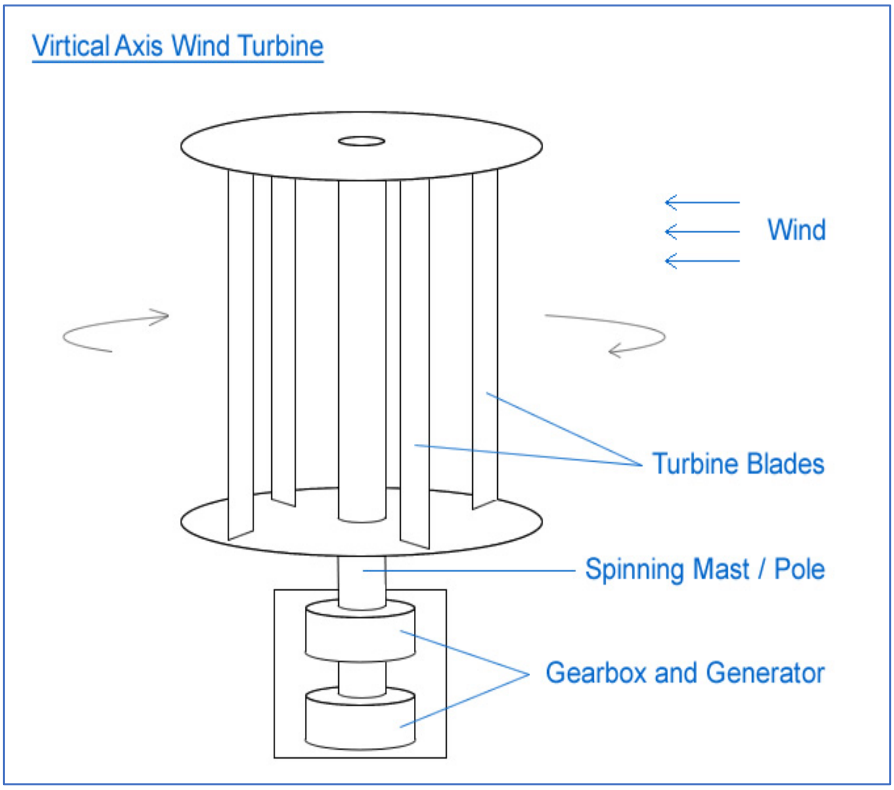
Disadvantages

(1) Difficult start unlike the Savonius wind turbine.

(2) Low efficiency.

8.2 Savonius wind turbine

1. The Savonius wind turbine is a type of vertical-axis wind turbine
2. It consists of two to three “scoops” that employ a drag action to convert wind energy into torque to drive a turbine.
3. A Savonius is a drag type turbine, they are commonly used in cases of high reliability in many things such as ventilation and anemometers.
4. They are a drag type turbine they are less efficiency than the common HAWT.
5. Savonius are excellent in areas of turbulent wind and self starting.



Advantages

(1) Having a vertical axis, the Savonius turbine continues to work effectively even if the wind changes direction.

(2) Because the Savonius design works well even at low wind speeds, there’s no need for a tower or other expensive structure to hold it in place, greatly reducing the initial setup cost.

(3) The device is quiet, easy to build, and relatively small.

(4) Because the turbine is close to the ground, maintenance is easy.

Disadvantages

The scoop system used to capture the wind’s energy is half as efficient as a conventional turbine, resulting in less power generation.