1.5 WIND POWER PLANT

A wind power plant, also known as a wind farm, is a facility that uses wind turbines to generate electricity.

Wind energy is a form of solar energy. Wind is caused by the uneven heating of the atmosphere by the sun, variations in the earth's surface, and rotation of the earth. Wind power is the conversion of wind energy into electricity or mechanical energy using wind turbines. Wind turbines convert the kinetic energy in the wind into mechanical power. A generator can convert mechanical power into electricity.

The mechanism used to convert air motion into electricity is referred to as a turbine. The power in the wind is extracted by allowing it to blow past moving blades that exert torque on a rotor. The rotor turns the drive shaft, which turns an electric generator. The amount of power transferred is dependent on the rotor size and the wind speed.

Windmills: People have been using windmills for centuries to grind grain, pump water, and do other work. Windmills generate mechanical energy, but they do not generate electricity.

Wind Turbines: In contrast to windmills, modern wind turbines are highly evolved machines with more than 8,000 parts that harness wind's kinetic energy and convert it into electricity.

Wind farm: Oftentimes a large number of wind turbines are built close together, which is referred to as a wind project or wind farm. A wind farm functions as a single power plant and sends electricity to the grid.

WIND ENERGY CHARACTERISTICS:

Three key factors affect the amount of energy a turbine can harness from the wind: wind speed, air density, and swept area

<u>WIND POWER:</u>

Kinetic energy exists whenever an object of a given mass is in motion with a translational or rotational speed. When air is in motion, the kinetic energy in moving air can be determined as

$$E_k = \frac{1}{2}mv^2$$

where, m – air mass, v – mean wind speed

$$P_w = \frac{dE_k}{dt} = \frac{1}{2}mv^2$$

BLADE SWEPT AREA:

Blade swept area can be calculated as

$$A = \pi[(l + r)^2 - r^2] = \pi l(1 + 2r)$$

where, l is the length of wind blades and r is the radius of the hub.

AIR DENSITY:

Air density is given by,

$$\rho = \frac{P}{RT}$$

where, P – local air pressure, R – gas constant (287 J/kg-K), T – local air temperature

POWER COEFFICIENT

The power coefficient C_p deals with the converting efficiency in the first stage, defined as the ratio of the actually captured mechanical power by blades to the available power in wind.

$$C_p = \frac{P_{out}}{P_W} = \frac{P_{out}}{\frac{1}{2}\rho A v^3}$$

The total power conversion efficiency from wind to electricity η_t is the production of these parameters,

$$\eta_t = C_p \eta_{gear} \eta_{gen} \eta_{elec}$$

The effective power output from a wind turbine to feed into a grid becomes

$$P_{eff} = P_w C_p \eta_{gear} \eta_{gen} \eta_{elec}$$

WIND SPEED – POWER CURVE

Higher wind speeds generate more power because stronger winds allow the blades to rotate faster. Faster rotation translates to more mechanical power and more electrical power from the generator. The relationship between wind speed and power for a typical wind turbine is shown in Fig 2.

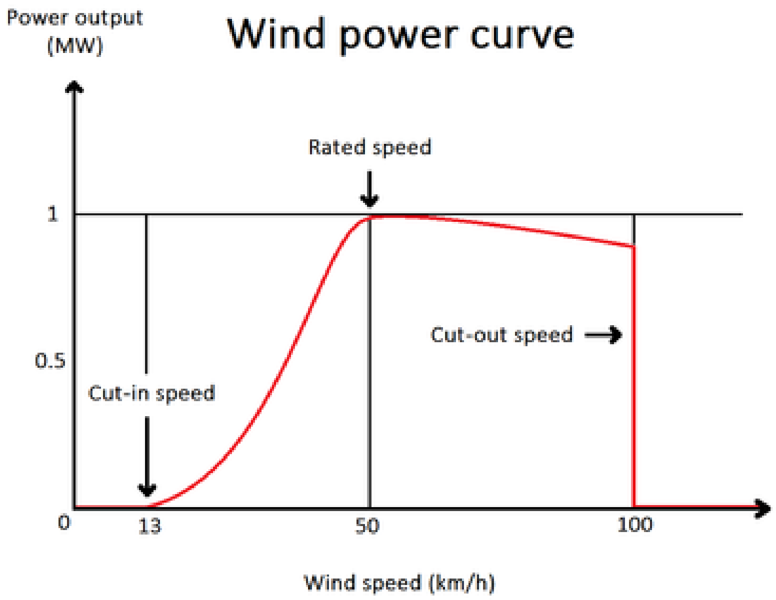

Fig.1.14 Wind-Power curve

[https://energyeducation.ca/encyclopedia/Wind_power]

TYPES OF WIND POWER PLANTS (based on capacity):

- **Utility-scale wind:** Wind turbines that range in size from 100 kilowatts to several megawatts, where the electricity is delivered to the power grid and distributed to the end user by electric utilities or power system operators.
- **Distributed or "small" wind:** Single small wind turbines below 100 kilowatts that are used to directly power a home, farm or small business and are not connected to the grid.
- **Offshore wind:** Wind turbines that are erected in large bodies of water, usually on the continental shelf. Offshore wind turbines are larger than land-based turbines and can generate more power.

TYPES OF WIND POWER PLANTS (based on construction, size & usage):

- Remote Wind Power Plants
- Hybrid Wind Power Plants
- Grid Connected Wind Power Plants

TYPES OF WIND TURBINES:

1. Horizontal Axis Wind Turbines (HAWT)

Horizontal axis wind turbines have the main rotor shaft and electrical generator at the top of a tower, and they must be pointed into the wind. Small turbine is 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. 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.

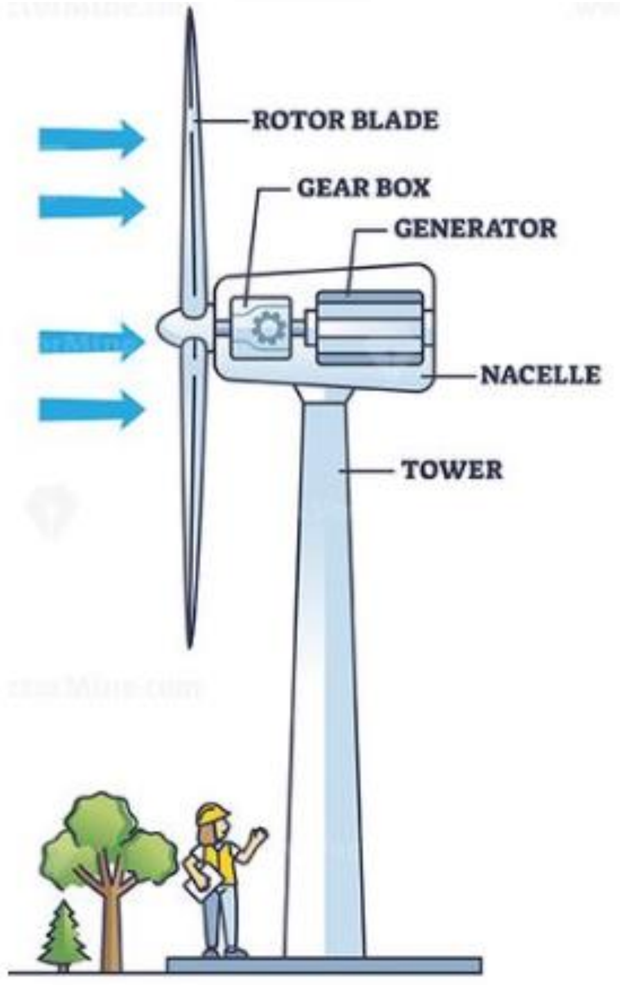

Fig.1.15 HAWT

[https://vectormine.com/item/horizontal-vs-vertical-axis-wind-turbine-principle-structure-outline-diagram/]

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.

2. Vertical Axis Wind Turbines (VAWT)

Vertical wind turbines (VAWTs), have the main rotor shaft arranged vertically. The main advantage of this arrangement is that the wind turbine does not need to be pointed into the wind. This makes them suitable in places 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 is that, it generally creates drag when rotating into the wind.

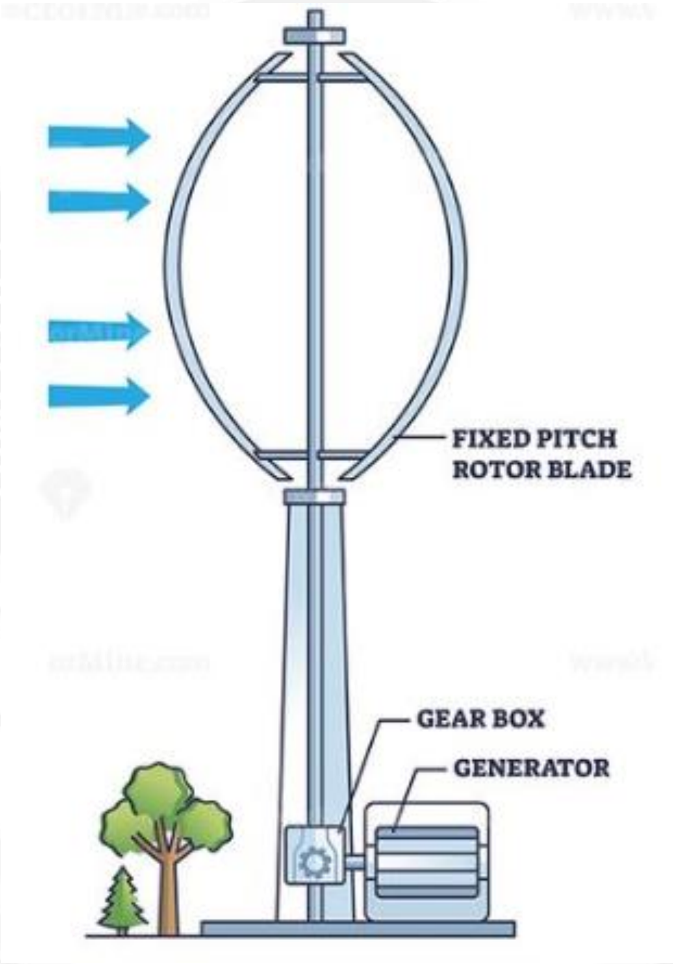

Fig.1.16 VAWT

[https://vectormine.com/item/horizontal-vs-vertical-axis-wind-turbine-principle-structure-outline-diagram/]

Components of Wind Power Plant:

There are three categories of components: mechanical, electrical, and control.

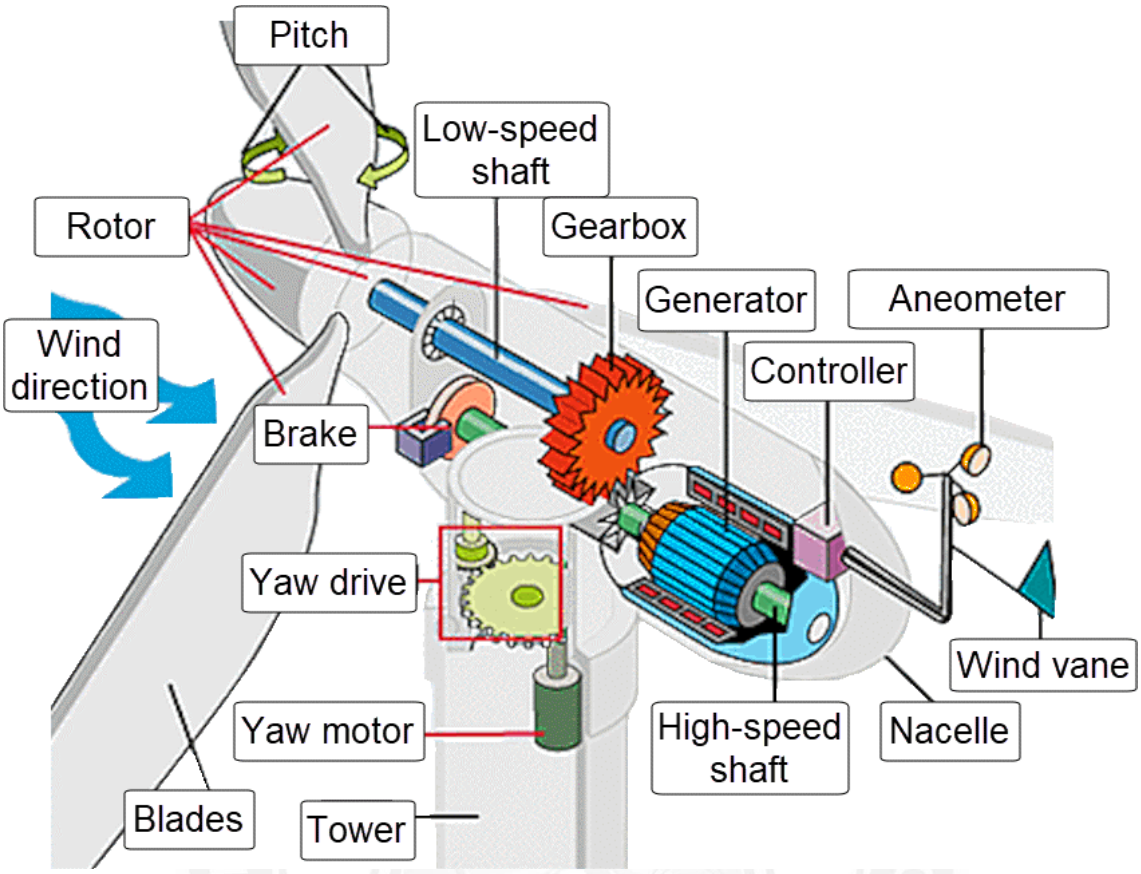

Fig.1.17 Components of Wind Turbine

[https://www.researchgate.net/figure/Wind-turbine-parts-Source-Wind-turbine-parts-Wikimedia-Available_fig9_348338145]

- The tower is the physical structure that holds the wind turbine. It supports the rotor, nacelle, blades, and other wind turbine equipment. Typical commercial wind towers are usually 50–120 m long and they are constructed from concrete or reinforced steel.
- Blades are physical structures, which are aerodynamically optimized to help capture the maximum power from the wind in normal operation with a wind speed in the range of about 3–15 m/s. Each blade is usually 20m or more in length, depending on the power level.
- The nacelle is the enclosure of the wind turbine generator, gearbox and internal equipment. It protects the turbine's internal components from the surrounding environment.
- The rotor is the rotating part of the wind turbine. It transfers the energy in the wind to the shaft. The rotor hub holds the wind turbine blades while connected to the gearbox via the low-speed shaft.

- Pitch is the mechanism of adjusting the angle of attack of the rotor blades. Blades are turned in their longitudinal axis to change the angle of attack according to the wind directions.
- The shaft is divided into two types: low and high speed. The low-speed shaft transfers mechanical energy from the rotor to the gearbox, while the high-speed shaft transfers mechanical energy from gearbox to generator.
- Yaw is the horizontal moving part of the turbine. It turns clockwise or anticlockwise to face the wind. The yaw has two main parts: the yaw motor and the yaw drive. The yaw drive keeps the rotor facing the wind when the wind direction varies. The yaw motor is used to move the yaw.
- The brake is a mechanical part connected to the high-speed shaft in order to reduce the rotational speed or stop the wind turbine over speeding or during emergency conditions.
- Gearbox is a mechanical component that is used to increase or decrease the rotational speed. In wind turbines, the gearbox is used to control the rotational speed of the generator.
- The generator is the component that converts the mechanical energy from the rotor to electrical energy. The most common electrical generators used in wind turbines are induction generators (IGs), doubly fed induction generators (DFIGs), and permanent magnet synchronous generators (PMSGs).
- The controller is the brain of the wind turbine. It monitors constantly the condition of the wind turbine and controls the pitch and yaw systems to extract optimum power from the wind.
- Anemometer is a type of sensor that is used to measure the wind speed. The wind speed information may be necessary for maximum power tracking and protection in emergency cases.
- The wind vane is a type of sensor that is used to measure the wind direction. The wind direction information is important for the yaw control system to operate.

Working of Wind Power Plant:

1. Wind blows toward the turbine's rotor blades.

2. The rotors spin around, capturing some of the kinetic energy from the wind, and turning the central drive shaft that supports them. Although the outer edges of the rotor blades move very fast, the central axle (drive shaft) turns quite slowly.
3. In most large modern turbines, the rotor blades can swivel on the hub at the front so they meet the wind at the best angle (or "pitch") for harvesting energy. This is called the pitch control mechanism. On big turbines, small electric motors or hydraulic rams swivel the blades back and forth under precise electronic control. On smaller turbines, the pitch control is often completely mechanical.
4. Inside the nacelle (the main body of the turbine sitting on top of the tower and behind the blades), the gearbox converts the low-speed rotation of the drive shaft (perhaps, 16 revolutions per minute, rpm) into high-speed (perhaps, 1600 rpm) rotation fast enough to drive the generator efficiently.
5. The generator, immediately behind the gearbox, takes kinetic energy from the spinning drive shaft and turns it into electrical energy. Running at maximum capacity, a typical 2MW turbine generator will produce 2 million watts of power at about 700 volts.
6. Anemometers (automatic speed measuring devices) and wind vanes on the back of the nacelle provide measurements of the wind speed and direction.
7. Using these measurements, the entire top part of the turbine (the rotors and nacelle) can be rotated by a yaw motor, mounted between the nacelle and the tower, so it faces directly into the oncoming wind and captures the maximum amount of energy. If it is too windy or turbulent, brakes are applied to stop the rotors from turning (for safety reasons). The brakes are also applied during routine maintenance.
8. The electric current produced by the generator flows through a cable running down through the inside of the turbine tower.
9. A step-up transformer converts the electricity to about 50 times higher voltage so it can be transmitted efficiently to the power grid (or to nearby buildings or communities). If the electricity is flowing to the grid, it is converted to an even higher voltage by a substation nearby.

10. The consumer enjoys clean, green energy: the turbine has produced no greenhouse gas emissions or pollution as it operates.
11. Wind carries on blowing past the turbine, but with less speed and energy and more turbulence (since the turbine has disrupted its flow).

Site Selection of Wind power plant:

- Wind Resource Assessment:
    - Wind Speed and Consistency: High and consistent wind speeds are essential for efficient energy production. Wind speed increases with height, so taller turbines are placed on towers range from 500 to 900 feet.
    - Anemometer Data
    - Seasonal Variability
- Topography and Geography:
    - Terrain: Favorable sites include smooth, rounded hills, open plains, and mountain gaps that funnel wind.
    - Altitude: Higher altitudes generally experience stronger winds.
    - Land Conditions: Ground stability and slope are important for construction and maintenance.
    - Proximity to Water Bodies: Areas near large bodies of water can have increased wind speeds.
- Proximity to Infrastructure:
    - Power Lines: Connecting to the existing power grid is crucial for transmitting the generated electricity.
    - Roads: Accessibility for construction, maintenance, and transportation of materials is necessary.
- Environmental Considerations:
    - Wildlife: Potential impact on bird and bat migration routes needs to be assessed.
    - Land Use: Minimizing impact on agricultural land and protected areas is important.
    - Community Impact: Noise, visual impact, and potential disturbance to local residents need to be considered.

- Economic Viability:
  - Cost Analysis: Construction, operation, maintenance costs need to be evaluated.
  - Return on Investment: The potential revenue generated by the plant needs to justify the investment.
- Other Factors:
  - Geological Conditions: Soil type, stability, and potential for landslides or earthquakes need to be assessed.
  - Meteorological Conditions: Wind direction, temperature, and humidity can affect turbine performance.
  - Local Regulations and Permits: Adhering to local ordinances and securing necessary permits is essential

Advantages:

- Renewable and Sustainable
- Clean Energy Source
- Cost-Effective
- Job Creation
- Suitable for Remote Locations
- Small Land Footprint

Disadvantages:

- Intermittency of Wind
- Visual and Noise Pollution
- High Initial Costs
- Location Limitations
- Potential for Radio Interference
- Maintenance and Upkeep