Module-4
Tidal Energy

- Tide is a periodic rise and fall of the water level of sea. The large scale up and down movement of sea water represents unlimited source of energy. Tidal energy is a renewable source of energy used by converting energy from tides into useful forms of power, mainly electricity using various methods.
- The highest level of tidal water is known as flood tide or high tide.
- The lowest level is known as low tide or ebb.
- The level difference between the high and low tide is known as tidal range.
- The tidal range varies greatly with location. Only sites with large tidal ranges (about 5 m or more) are considered suitable for power generation.

❖ Tides as Energy Suppliers

- Tidal energy is primarily driven by the gravitational interactions between the Earth, Moon, and Sun. The mechanics of tides involve the rise and fall of ocean water levels, which occur at regular intervals throughout the day.

▪ Mechanics (To study about Force and Motion) of Tidal Energy:

1. **Gravitational Forces:**

- The Moon's gravitational pull causes water to bulge out on the side of the Earth facing the Moon, creating a high tide. A second high tide occurs on the opposite side of the Earth due to centrifugal forces created by the Earth-Moon system's rotation.

2. Solar Influence:

- The Sun also has a gravitational effect on Earth's oceans, but it is weaker than the Moon's.

3. Tidal Range:

- The difference in water height between high and low tides is called the tidal range. Locations with large tidal ranges are most suitable for tidal energy generation.

❖ Fundamental Characteristics (Basic Principles) of Tidal Power

1. **Predictable and Reliable**

- **Tidal movements** are highly predictable, governed by the gravitational pull of the moon and sun. Unlike wind or solar power, tidal energy does not depend on weather conditions or time of day, making it a **reliable** source of renewable energy.

2. **Renewable Energy Source**

- Tidal power is **renewable**, as it depends on natural processes that are inexhaustible and continuously occurring due to the Earth's rotation and the gravitational forces of the moon and sun.

3. **High Energy Density**

- Tidal energy is **energy-dense**, meaning it can generate a significant amount of power from relatively small water areas compared to other renewable sources like wind or solar. Water's density and movement allow tidal turbines to capture a large amount of energy.

4. **Types of Tidal Power**

- **Tidal Range Power**: Utilizes the difference in water levels between high and low tides to drive turbines.
- **Tidal Stream Power**: Harnesses the kinetic energy of moving water (similar to underwater wind turbines).
- **Dynamic Tidal Power**: A more experimental method involving the construction of dams or barriers in the ocean to harness both tidal and non-tidal currents.

5. **Environmental Impact**

- Generally considered environmentally friendly, tidal energy is **low in carbon emissions** and does not produce air or water pollution. However, it can affect local marine ecosystems, especially in areas where tidal barrages or turbines are placed.

6. **Energy Storage and Intermittency**

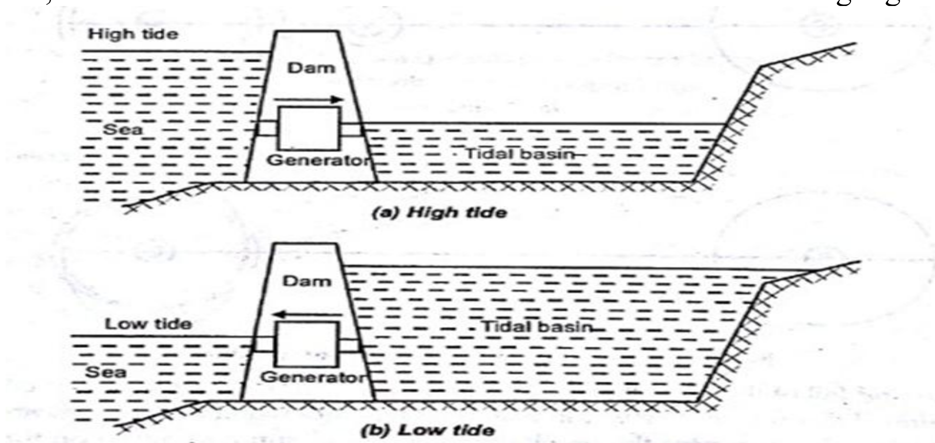
- Like other renewable energy sources, tidal power has periods of **low energy generation** (e.g., at slack tide), so it may need **energy storage systems** to ensure consistent energy availability.

❖ Harnessing of Tidal Energy

- Harnessing of tidal energy refers to the process of capturing and converting the kinetic and potential energy of ocean tides into usable electrical energy using various technologies such as tidal barrages, tidal stream generators, and tidal lagoons (A shallow body of water separated from large body of water from ocean).
- **Tidal Energy Source**: Tidal energy is generated from the natural rise and fall of ocean tides caused by the gravitational pull of the moon and the sun.
- **Tidal Barrage System**: A dam-like structure (barrage) is built across a tidal basin to trap water at high tide, which is then released through turbines to generate electricity during low tide.
- **Tidal Stream Generators**: These function like underwater wind turbines, capturing kinetic energy from fast-moving tidal currents to drive turbines.
- **Tidal Lagoons**: A tidal lagoon is a coastal structure built to capture and store seawater during high tide and release it through turbines during low tide to generate electricity. Man-made lagoons trap water during high tide and release it through turbines as the tide falls, generating power in both directions.

❖ Construction and Working Principle of Tidal Power Plant

- The main components of
- a tidal plant is:
- The power house
- The barrage (dam) to form the basin
- Sluice-ways
- Turbine-generator
- The construction and working of a tidal power plant is shown in Fig. The barrage (or small dam) is the basic component of a tidal plant. It is essential to form a barrier between the sea and the basin, so that water can be collected in the basin from the sea during high tides.



- The sluice-ways are required either to fill the basin during the high tide or empty the basin during the low tide. These are in the form of gates and used as and when operational requirements arise. Power house is situated adjacent to the sluice-ways. It has the turbine-generator kept inside.

❖ Classification of Tidal Plants

- The different techniques for tidal energy harnessing available are:
- Single basin - one way system
- Double basin system

❖ Single Basin-One Way Cycle

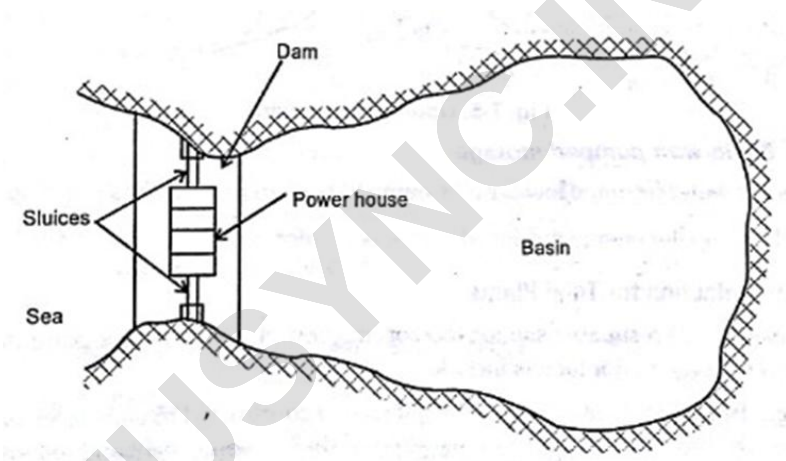


Fig: Single basin plant

- In this a basin is allowed to fill in flood tide. There is a dam with sluice gates and power house at the neck of the basin as shown in Fig. During ebb-tide the basin starts emptying through tubes, which are connected to turbines, thus running them. These turbines in turn run a generator to produce power.

❖ Double Basin Type

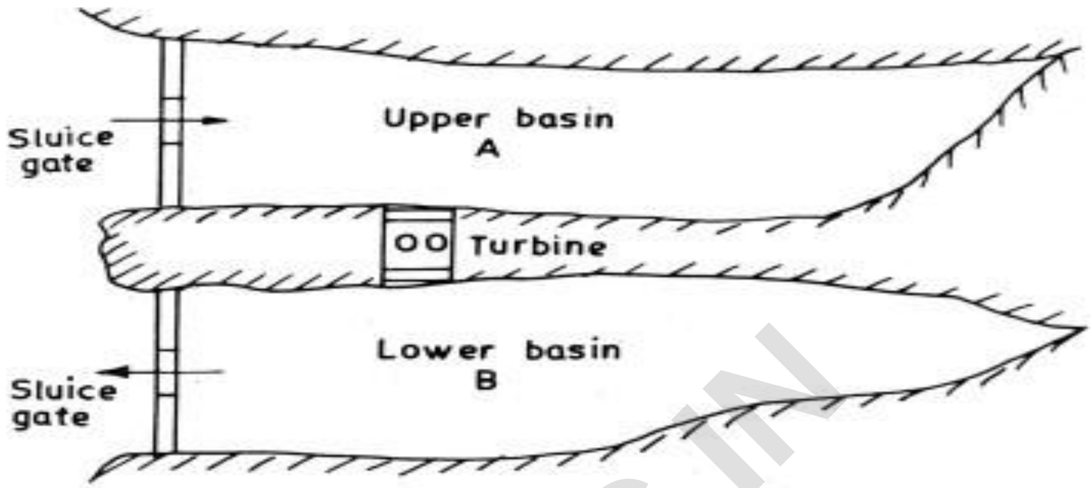


Fig. 9.3.4.4. Tidal power plant Double Basin Operation.

- It requires two separate but adjacent basins. In one basin called "upper basin" (or high pool), the water level is maintained above that in the other, the low basin (or low pool).
- In this system the turbines are located in between the two adjacent basins.
- At the beginning of the flood tide, the turbines are shut down, the gates of upper basin A are opened and those of the lower basin B are closed.
- The basin A is thus filled up while the basin B remains empty.
- As soon as the rising water level in A provides sufficient difference of head between the two basins, the turbines are started.
- The water flows from A to B through the turbines, generating power.
- The power generation thus continues simultaneously with the filling up the basin A.
- At the end of the flood tide when A is full and the water level in it is the maximum, its sluice gates are closed.
- When the ebb tide level gets lower than the water level in B, its sluice gates are opened whereby the water level in B starts falling with the ebb.
- With the next flood tide the cycle repeats itself.

❖ Advantages of Tidal Power

- Tidal power is available freely, and in abundance.
- It is free from pollution and noise.
- It is superior to hydro-power plants, as it is totally independent of rain, which always fluctuates year to year. Therefore, there is certainty of power supply as the tide cycle is very definite.
- It has a unique capacity to meet the peak power demand effectively when it works in combination with thermal or hydroelectric system.
- It can provide better recreational facilities to visitors and holiday makers, in addition to the possibility of fish farming in the tidal basins.
- It is highly economical as the initial investment and maintenance costs are minimum.

❖ Limitations of Tidal Power

- These power plants can be developed only if natural sites are available.
- The sites are available on the bay, which will be always far away from the load centers, hence the power generated must be transported to long distances. This makes the cost of production expensive.
- The supply of power is not continuous, as it depends upon the timing of tides.
- The capital cost of the plant (Rs. 5000 per kW) is considerably large as compared to the conventional power plants, such as the hydroelectric plant.
- Sedimentation and siltation of the basins are some of the problems with the tidal power plant.

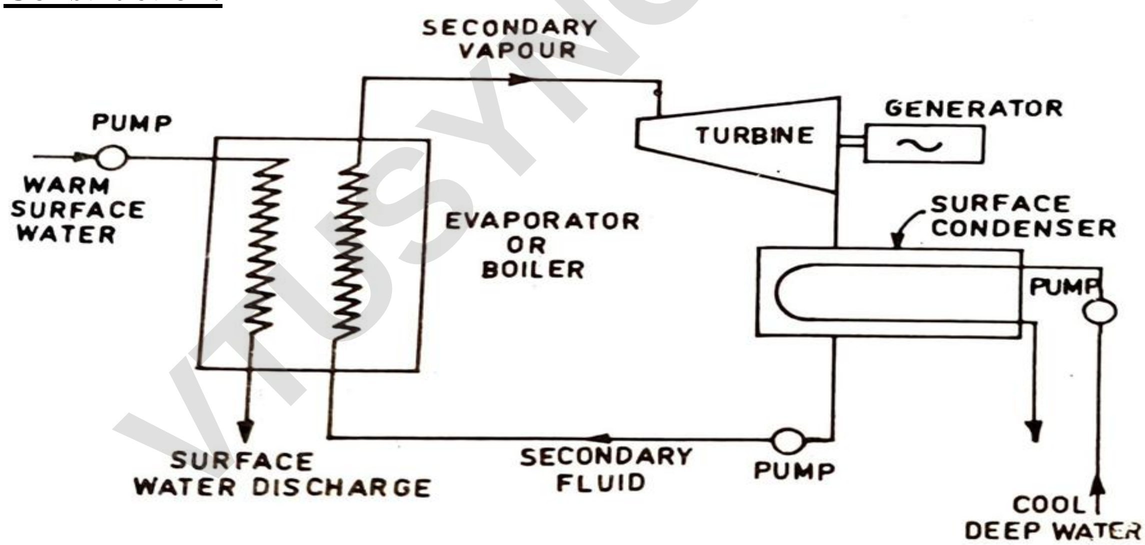
Ocean Thermal Energy Conversion

- OTEC or ocean thermal energy thermal conversion is a technology which converts solar radiation absorbed by the oceans to electric energy. The oceans can be considered as the world's largest solar energy collector as it covers two thirds of the earth surface.
- There are different temperatures in the different layers of the oceans. This is because of the heat input from the sun at the surface of the ocean. The surface at the top of the oceans is the warmest and gradually the temperature decreases with the depth. But in the polar regions the temperature at the surface of the ocean is low, so there is no gradual change in temperature.

➢ Principle of Working of OTEC:

- The water at the surface of the ocean is warmer than the water at deeper depths. This temperature difference can be used by Ocean Thermal Energy Conversion (OTEC) systems to generate electricity.

❖ Construction:



- **Warm water intake:** OTEC requires a large amount of warm surface seawater to drive the heat engine. The temperature of this water should be around 20-25°C (68-77°F) or higher, depending on the specific OTEC design.
- **Cold water intake:** OTEC also requires a large amount of cold deep seawater to condense the working fluid of the heat engine. The temperature of this water should be around 5-10°C (41-50°F) or lower, depending on the specific OTEC design.
- **Heat exchanger:** The heat exchanger is the component that transfers heat from the warm seawater to the working fluid, which is typically a low-boiling-point fluid such as ammonia.
- **Turbine:** The working fluid vaporizes as it is heated and expands through a turbine, which generates electricity.
- **Condenser:** The working fluid is then cooled and condensed back to a liquid state using cold seawater in the condenser, ready to be used again in the heat exchanger.

❖ Working:

- In an OTEC plant, the energy of warm surface water is used to convert low boiling point liquid ammonia into a gaseous state.
- The vapor of ammonia at high pressure is used to rotate the turbines & generators converting the Ocean thermal energy to electricity.
- The used vapor ammonia passes through the condenser where cold water, pumped from the deeper parts of the ocean condenses ammonia vapor back into a liquid.
- This process is repeated again and again, to get continuous production of electricity.

❖ Types of Ocean Thermal Energy Conversion Systems:

▪ Open Cycle OTEC System:

- The open cycle OTEC systems, also known by the name Claude system, are a practically feasible system to convert ocean thermal energy into useful electrical energy. It makes use of the sea water as the working medium. It is termed open cycle, since the condensate of the working medium is not recycled. The principle of operation of an open OTEC system is shown in Fig. 7-6.

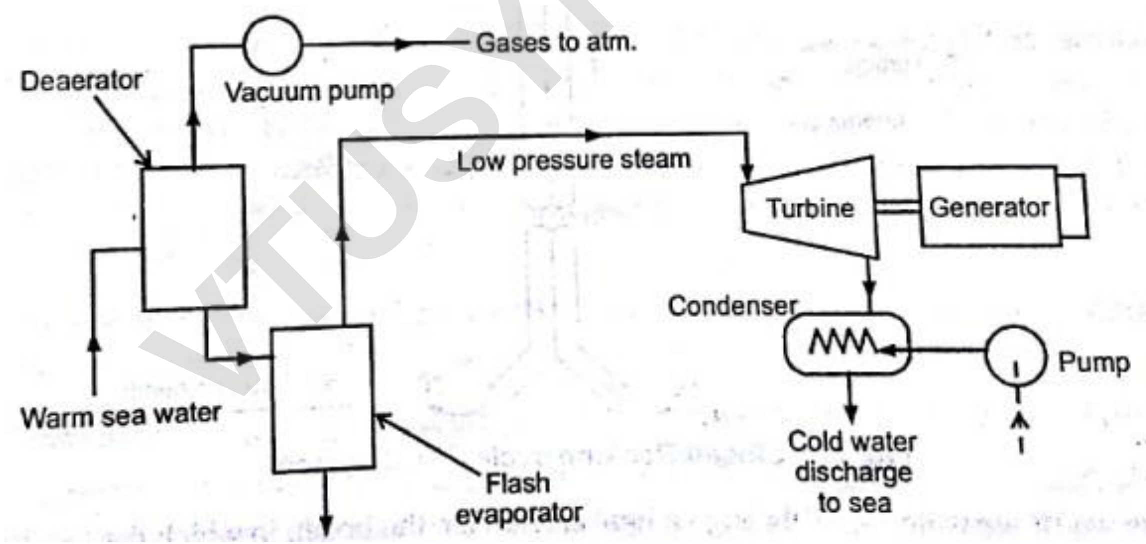


Fig: Open cycle OTEC system

- In this the warm water at the top layer of the sea is passed through a deaerator, and flash evaporated under partial vacuum. The vacuum pump removes the non-condensate and exhausts to the atmosphere. The flash evaporated water is converted into a low-pressure steam, which is used to run a steam turbine. The exhaust steam is cooled in a condenser and the condensate is discharged back to the sea. The turbine is coupled to a generator to generate electric energy. In this fashion, ocean thermal energy is converted into electric energy in open OTEC system

❖ Closed Rankine Cycle OTEC System:

- The closed Rankine cycle OTEC power plant operates with a low boiling fluid like propane as the working medium (the other low boiling fluids that can be used are ammonia, R-12, R-22, etc.). The schematic representation of this system is shown in Fig.

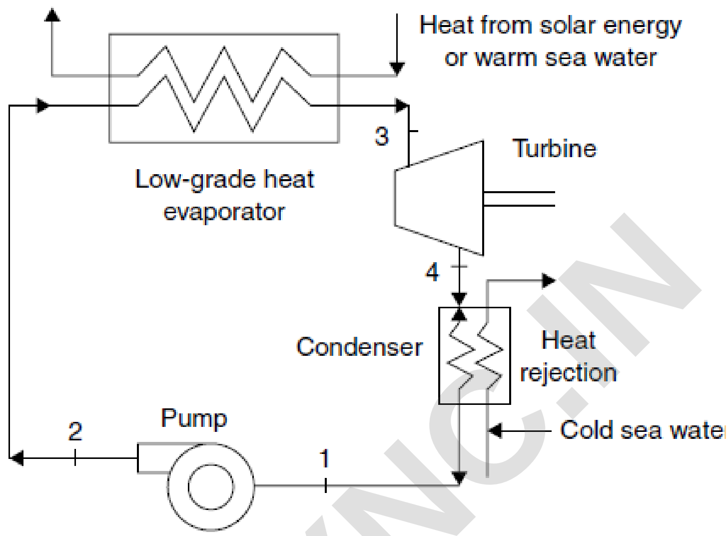


Fig: Closed Rankine Cycle OTEC system

- Warm ocean surface water flows into the evaporator which is the high-temperature heat source. A fluid pump is utilized to force the fluid in a heat evaporator where liquid fluid vaporizes.
- Then, the vapor of boiling fluid enters the turbine expander coupled with an electrical generator to generate electrical power.
- The vapor released from the turbine enters into condenser where it condenses. The cold deep-sea water is pumped through the condenser for heat rejection from vapor fluid and condenses it as liquid fluid.
- The liquid fluid is again pumped through evaporator and cycle repeats. As temperature difference between high- and low-temperature ends is large enough, the cycle will continue to operate and generate power.

❖ OTEC Power Stations in The World

- Ocean Thermal Energy Conversion (OTEC) power stations are still in the experimental stage and there are currently only a few small-scale demonstration plants in operation around the world.
- OTEC theory was first developed in the 1880s and the first bench size demonstration model was constructed in 1926. Currently operating pilot-scale OTEC plants are located in Japan, overseen by Saga University, and Makai in Hawaii.
- NELHA OTEC Demonstration Plant, Hawaii, USA
- Makai Ocean Engineering OTEC Pilot Plant, Hawaii, USA
- Japan Agency for Marine-Earth Science and Technology (JAMSTEC) OTEC Test Facility, Okinawa, Japan
- Seascape OTEC Pilot Plant, Martinique, France
- Deep Ocean Water Utilization Center, Okinawa, Japan

❖ Problems Associated with OTEC

- Conversion efficiency is very low about 3-4% due to the small temperature difference between the surface water and deep water.
- OTEC power generation system gives less efficiency.
- High capital cost and maintenance cost makes them uneconomical for small plants.
- Energy required to pump the sea water from depths may be huge, which otherwise needs a diesel generator.
- Construction of OTEC plants and pipes in the ocean may cause damage to onshore marine ecosystems and reefs.
- As this technology has been tested only in small-scale, it is not feasible for an energy company to invest in this project.
- Electricity produced from OTEC would currently cost more than that produced from fossil fuels.

Wind Energy

❖ Properties of Wind Energy

- Wind is due to differences in air pressure in the atmosphere. Wind at high pressure tends to move to areas at low air pressure, greater the pressure difference faster will be the flow of air.
- In meteorology, winds are often referred to according to their strength, and the direction from which the wind is blowing.
- Wind is characterized by two parameters. They are wind speed and wind direction.
- Wind Power occupies very little space.
- Excellent conversion efficiency.
- The environmental impact is minimal.
- Wind power is good solution in remote areas, wherever they may be isolated areas.

❖ Availability of Wind Energy In India

- The total installed capacity of wind power in India as on March 2017 is around 32 GW.
- Wind power generation capacity in India has significantly increased in recent years.
- As of 28 February 2021, the total installed wind power capacity is 38.789 GW, the fourth largest installed wind power capacity in the world.
- The potential is far from exhausted. Indian Wind Energy Association has estimated that with the current level of technology, the 'on-shore' potential for utilization of wind energy for electricity generation is of the order of 65,000 MW.
- Wind in India are influenced by the strong south-west summer monsoon, which starts in May-June, when cool, humid air moves towards the land.

- **Wind velocity** refers to the speed and direction of the movement of air, typically measured in meters per second (m/s) or kilometers per hour (km/h). It is a vector quantity, meaning it has both a **magnitude** (speed) and a **direction**.
- **Wind power** is the process of generating electricity by harnessing the energy of the wind. This is typically done using **wind turbines**, which convert the kinetic energy of the wind into mechanical energy that drives a generator to produce electrical power.

❖ Major Problems Associated with Wind Power:

- **Intermittent Supply:** Wind power depends on wind availability, which is variable and unpredictable.
- **High Initial Cost:** Installation of wind turbines requires significant upfront investment.
- **Noise Pollution:** Wind turbines produce noise, which can disturb nearby residents.
- **Visual Impact:** Large wind farms may affect landscape aesthetics and face public opposition.
- **Wildlife Impact:** Turbines can pose risks to birds and bats in their flight paths.
- **Space Requirement:** Wind farms need large open areas, which may not be available near demand centers.

❖ Basic Components of Wind Energy Conversion Systems (WECS):

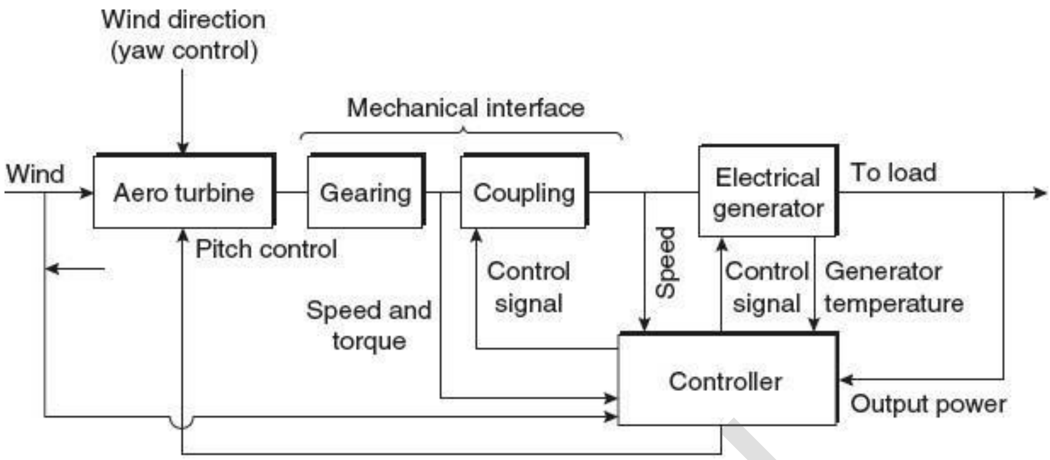
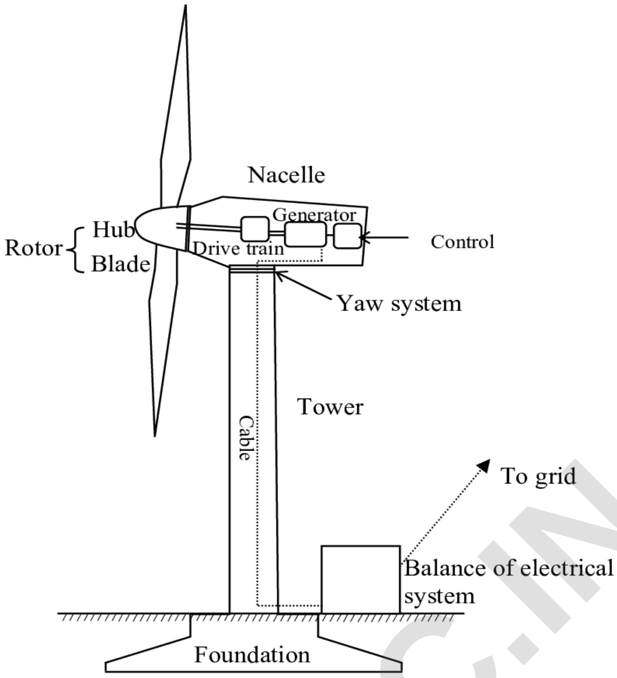


Fig. *Basic Components of a Wind Electric System*

➢ The main components of a WECS

- **Aero turbines** convert energy in moving air to rotary mechanical energy. In general, they require pitch control and yaw control (only in the case of horizontal or wind axis machines*)* for proper operation.
- **A mechanical interface** consisting of a step-up gear and a suitable coupling transmits the rotary mechanical energy to an electrical generator.
- **The yaw control mechanism** comprises a motor and drive. The main purpose of this arrangement is to move the nacelle and blades according to the wind direction. It enables the wind turbine to capture the maximum available wind.
- The purpose of the **controller** is to sense wind speed, wind direction, shafts speeds and torques at one or more points, output power and generator temperature as necessary and appropriate control signals for matching the electrical output to the wind energy input and protect the system.
- **Rotors:** two types of rotors are Horizontal axis rotor and Vertical axis rotor. One advantage of vertical-axis machines is that they operate in all wind directions and thus need no yaw adjustment.
- **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. 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.
- **Generators:** The generator of choice is the synchronous unit for large aero generator systems because it is very versatile and has an extensive database. Either constant or variable speed generators are a possibility, but variable speed units are expensive and/or unproved.
- **Towers.** Four types of supporting towers deserve consideration, these are:
    1. the reinforced concrete tower
    2. the pole tower.

❖ Horizontal Axis Wind Mill:



- A **Horizontal Axis Wind Turbine (HAWT)** is the most common type of wind turbine, designed to convert kinetic energy from the wind into mechanical energy, which is then converted into electrical energy. It has a rotor that spins on a horizontal axis, meaning the blades rotate around an axis that is parallel to the ground.

❖ Construction of Horizontal Axis Wind Turbine

1. **Tower:**
- The **tower** is the main support structure for the turbine, and it elevates the rotor and other components to a height where wind speeds are higher and more consistent. Towers are typically made of steel, concrete, or sometimes hybrid materials.
- The height of the tower varies, but it typically ranges from 50 meters to 150 meters, depending on the design and location.
2. **Nacelle:**
- The **nacelle** is the housing that sits atop the tower. It contains the key components that enable the turbine to generate electricity. It includes:
- **Gearbox (in some designs):** A mechanical device that increases the rotational speed of the rotor to match the generator's requirements. However, some newer designs use direct-drive generators that eliminate the need for a gearbox.
- **Generator:** Converts the mechanical energy from the spinning rotor into electrical energy.
- **Brake system:** Used to slow or stop the rotor in case of high wind speeds or for maintenance purposes.
- **Yaw mechanism:** This system allows the nacelle to rotate horizontally to face the wind direction, ensuring the rotor is aligned with the prevailing wind.

3. **Rotor Blades:**

- The **blades** are the most critical part of the turbine. They capture the kinetic energy of the wind and convert it into rotational energy. The number of blades can vary, but most modern HAWTs have **two or three blades**.
- The shape and length of the blades are designed to maximize efficiency by increasing the amount of wind energy they can capture. Blade materials are typically fiberglass or carbon composites for strength and lightness.

4. **Hub:**

- The **hub** connects the blades to the rotor shaft and is located at the center of the rotor assembly. It transfers the rotational motion from the blades to the shaft.

5. **Main Shaft:**

- The **main shaft** connects the hub to the gearbox or generator (depending on the turbine design). It transmits the rotational energy from the rotor to the mechanical components inside the nacelle.

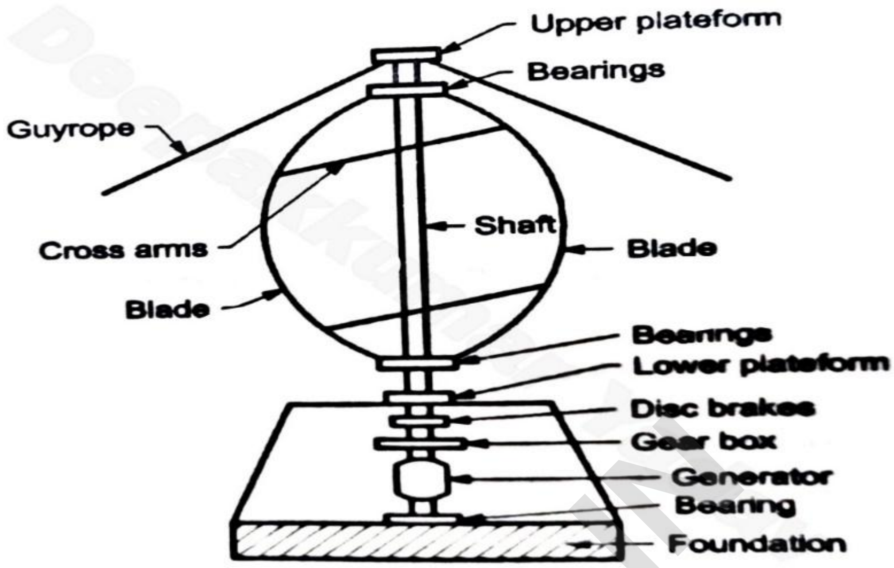
6. **Yaw Mechanism:**

- The **yaw system** ensures that the wind turbine is always facing into the wind. This system allows the nacelle to rotate horizontally on the tower in response to changes in wind direction. Yawing is typically achieved using a small electric motor, and the system uses sensors to detect the wind's direction.

➢ Working Principle

- The horizontal axis wind mill operates on the principle of aerodynamic lift and drag.
- It consists of blades mounted on a horizontal shaft, similar to a propeller. When wind flows over the blades, it creates a difference in air pressure on either side due to their curved shape.
- This pressure difference generates a lift force that causes the rotor to spin. The rotating motion of the shaft is transferred to a gearbox, which increases the rotational speed and drives a generator to produce electricity.

❖ Vertical Axis Wind Mill



Vertical Axis Darrieus Type Wind Turbine

➢ Construction of Vertical Axis Wind Turbine

1. **Rotor Blades:**
- These are the parts of the turbine that interact with the wind. In the Darrieus design, the blades are typically aero foil-shaped and are mounted vertically.
2. **Shaft (Vertical Axis):**
- The central vertical shaft, which is the axis around which the turbine rotates.
- The shaft transmits the mechanical power generated by the wind into usable electrical energy.
3. **Support Structure:**
- The structure supports the rotor and shaft assembly.
- It often consists of a metal frame that holds the entire turbine upright and in place.
4. **Generator:**
   The generator is connected to the shaft, and it converts the rotational mechanical energy of the turbine into electrical energy.
5. **Bearings:** Bearings are used to support the rotating shaft and reduce friction.

➢ Working of Vertical Axis Wind Mill

- The vertical axis wind mill operates on the principle of wind energy conversion through drag and lift forces acting on the blades, which are mounted vertically around a central shaft.
- The vertical axis design allows the turbine to capture wind from any direction, eliminating the need for a yaw mechanism. As wind flows across the blades, it creates a pressure difference that generates lift or drag, depending on the blade design.
- This force causes the rotor to spin around the vertical axis. The rotational energy is then transferred to a generator, which converts it into electrical energy.

❖ Coefficient of Performance (Cp) of a Wind Mill Rotor

- The **Coefficient of Performance (Cp)** of a wind turbine rotor (often referred to as the **power coefficient**) is a measure of the efficiency with which the turbine converts the kinetic energy of the wind into mechanical energy (or electrical energy).
- It is defined as the ratio of the actual power extracted by the rotor to the total available power in the wind.

$$C_p = \frac{P_{actual}}{P_{theoretical}}$$

❖ Advantages of Wind Energy

- It is a renewable and inexhaustible source of energy.
- Environmentally friendly – no pollution or greenhouse gas emissions.
- Low operating and maintenance costs after installation.
- Reduces dependence on fossil fuels like coal and oil.
- Wind farms can be built on existing agricultural land without disturbing farming.

❖ Disadvantages of Wind Energy

- Wind is unpredictable and not available all the time.
- High initial setup and installation costs.
- Wind turbines can be noisy and cause disturbance.
- May harm birds and bats flying near turbines.
- Some people consider wind turbines unattractive in landscapes.

❖ Applications of Wind Energy

- Generating electricity for homes, schools, and industries.
- Pumping water in rural and agricultural areas.
- Providing power to remote and off-grid locations.
- Used in hybrid systems with solar or diesel for stable supply.
- Powering wind-powered ships and innovative green transport systems.

❖ Site selection for Wind Power Plant

- Site selection for a wind power plant is the process of choosing the best location to build wind turbines in order to generate electricity efficiently. Here are the key factors to consider.

➢ **Wind Speed and Consistency**
  - The site must have strong and steady winds, ideally above 6–7 m/s at turbine hub height.
  - Wind maps, meteorological data, and on-site measurements help determine wind potential.

➢ **Terrain and Land Characteristics**
  - Flat or gently sloping terrain is preferable to reduce turbulence and increase efficiency.
  - Avoid areas with forests, buildings, or hills that obstruct wind flow.

➢ **Land Availability and Spacing**
  - A large open area is needed to install multiple wind turbines with proper spacing.
  - Sufficient distance between turbines prevents wake effects and improves performance.

➢ **Proximity to Transmission Lines**
  - The site should be near power grid infrastructure to reduce transmission losses and connection costs.
  - A feasibility study is conducted to assess grid capacity and stability.

➢ **Environmental Considerations**
  - The location should not harm wildlife, especially birds and bats.
  - Environmental Impact Assessments (EIA) ensure compliance with regulations and sustainability.

➢ **Accessibility and Infrastructure**
  - Good road access is necessary for transporting turbine components and carrying out maintenance.
  - The availability of water, workforce, and communication facilities is also important.

➢ **Legal and Regulatory Compliance**
  - Government permits, land leases, and zoning approvals must be secured.
  - Incentives or subsidies from renewable energy policies may benefit the project.

➢ **Community and Social Acceptance**
  - Local communities should be engaged to address concerns about land use, noise, and aesthetics.
  - Compensation and benefits can help gain public support.

➢ **Climatic and Natural Disaster Risks**
  - Avoid areas prone to earthquakes, extreme storms, lightning, or floods.
  - Long-term climate data should be analysed to predict future wind patterns.