MODULE-4

HYDROELECTRIC PLANTS

HYDROPOWER

Hydropower is the generation of electricity using the energy of flowing or falling water. Modern hydropower plants convert the kinetic energy of water into mechanical energy using turbines, which then generate electricity.

Advantages & Disadvantages of Water Power

Advantages of Hydroelectric Power:

1. **Renewable Energy Source:**
    - **Sustainability:** Water power is a renewable energy source as it relies on the natural water cycle, which is constantly replenished by precipitation.
2. **Low Operating Costs:**
    - **Economical:** Once a hydroelectric plant is constructed, the operational and maintenance costs are relatively low compared to other energy sources.
3. **Clean Energy:**
    - **Environmentally Friendly:** Hydroelectric power produces no direct emissions of greenhouse gases or pollutants, making it a clean source of energy.
4. **Reliable and Efficient:**
    - **Consistent Power Supply:** Hydroelectric plants can generate electricity continuously, providing a reliable power supply.
    - **High Efficiency:** Hydroelectric power plants typically have high efficiency rates, converting over 90% of available energy into electricity.
5. **Energy Storage and Management:**
    - **Pumped Storage:** Hydroelectric plants can be used for energy storage through pumped-storage methods, which help balance supply and demand by storing excess energy during low demand periods and releasing it during high demand periods.

6. **Flood Control and Water Supply:**

    - **Multipurpose Use:** Dams used for hydroelectric plants can also provide benefits such as flood control, irrigation, and water supply for domestic and industrial use.

7. **Long Lifespan:**

    - **Durability:** Hydroelectric plants generally have long operational lifespans, often exceeding 50 years, providing a long-term energy solution.

Disadvantages of Hydroelectric Power:

1. **Environmental Impact:**

    - **Ecosystem Disruption:** The construction of dams and reservoirs can disrupt local ecosystems, affecting fish migration, water quality, and wildlife habitats.
    - **Sedimentation:** Reservoirs can accumulate sediments over time, which can reduce water storage capacity and affect aquatic life.

2. **High Initial Costs:**

    - **Capital-Intensive:** The construction of hydroelectric plants requires significant upfront investment, including costs for dam construction, infrastructure, and land acquisition.

3. **Dependence on Water Availability:**

    - **Climate Dependence:** Hydroelectric power generation depends on water availability, which can be affected by seasonal variations, droughts, and climate change.

4. **Displacement of Communities:**

    - **Social Impact:** The creation of reservoirs can lead to the displacement of local communities and the loss of arable land and cultural sites.

5. **Limited Suitable Locations:**

    - **Geographic Constraints:** Suitable sites for hydroelectric plants are limited to areas with sufficient water flow and topographical features, such as rivers and valleys.

6. **Potential for Catastrophic Failure:**

    - **Dam Safety:** Dam failures, although rare, can have catastrophic consequences, including loss of life, property damage, and environmental destruction.

7. **Alteration of Natural Water Flow:**

   - **Flow Regulation:** The regulation of river flow for hydroelectric power can affect downstream water availability and quality, impacting agriculture and local water users.

Storage and Pondage in Hydroelectric Power

Storage:

1. **Definition:**

   - Storage refers to the capability of a hydroelectric power plant to store water in a reservoir created by damming a river. This stored water can be used to generate electricity as needed.

2. **Purpose:**

   - **Regulation of Water Flow:** Storage allows for the regulation of river flow, ensuring a consistent supply of water for power generation even during periods of low rainfall or drought.
   - **Load Balancing:** Stored water can be released to meet peak electricity demand, providing a stable and reliable energy supply.
   - **Flood Control:** Storage reservoirs can help manage flood risks by capturing and controlling excessive water flow during heavy rainfall.

3. **Types of Storage:**

   - **Seasonal Storage:** Water is stored over long periods, such as from one season to another, to ensure a steady supply throughout the year.
   - **Daily Storage:** Water is stored and used within a short period, typically to balance daily fluctuations in electricity demand.

4. **Advantages:**

   - **Energy Security:** Provides a reliable source of energy that can be managed and controlled.
   - **Economic Benefits:** Helps in stabilizing electricity prices by balancing supply and demand.

   - **Multiple Uses:** Storage reservoirs can serve additional purposes, such as irrigation, water supply, and recreation.

5. **Challenges:**

- **Environmental Impact:** Large storage reservoirs can disrupt local ecosystems and displace communities.
- **Evaporation Losses:** Stored water can be lost to evaporation, especially in hot and dry climates.

Pondage:

1. **Definition:**

- Pondage refers to the small-scale storage of water for short-term use, typically on a daily or weekly basis, to manage fluctuations in electricity demand.

2. **Purpose:**

- **Short-Term Regulation:** Provides the ability to quickly adjust water flow and electricity generation to match short-term variations in demand.
- **Peak Load Supply:** Ensures that sufficient water is available to meet peak electricity loads.

3. **Characteristics:**

- **Smaller Scale:** Unlike large storage reservoirs, pondage involves smaller water bodies or ponds created by diversion structures or small dams.
- **Rapid Response:** Enables quick adjustments in power generation, making it suitable for handling sudden changes in electricity demand.

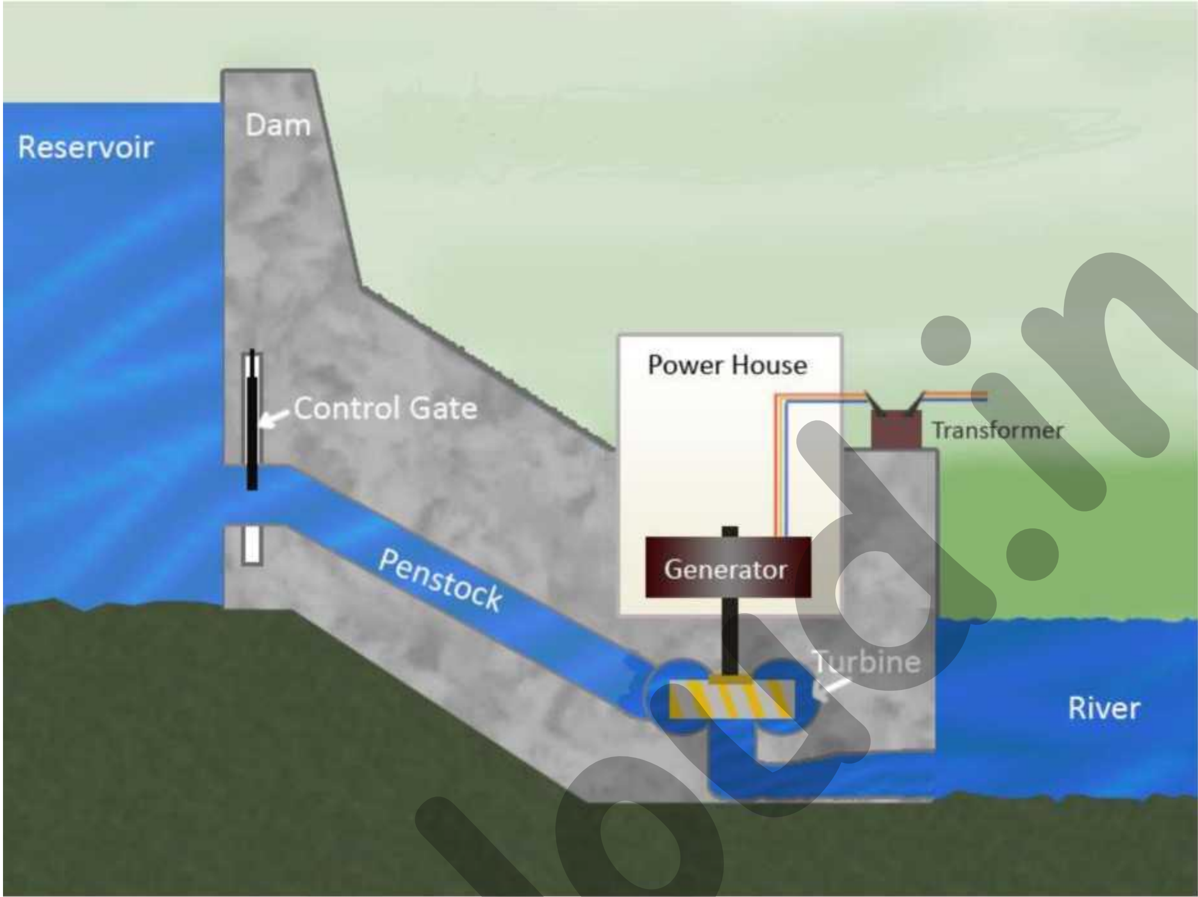
4. **Advantages:**

- **Flexibility:** Provides the flexibility to respond to daily and weekly changes in electricity demand.
- **Reduced Environmental Impact:** Smaller scale than large reservoirs, leading to fewer environmental and social impacts.

5. **Challenges:**

- **Limited Capacity:** Smaller storage capacity compared to large reservoirs, making it less effective for long-term water management.
- **Dependence on Regular Inflows:** Relies on consistent water inflow to maintain sufficient levels for power generation.

Layout and Working of Hydroelectric Power Plant



The above image shows the typical layout of a hydroelectric power plant and its basic components.

a. **Dam and Reservoir:** The dam is constructed on a large river in hilly areas to ensure sufficient water storage at height. The dam forms a large reservoir behind it. The height of water level (called as water head) in the reservoir determines how much of potential energy is stored in it.

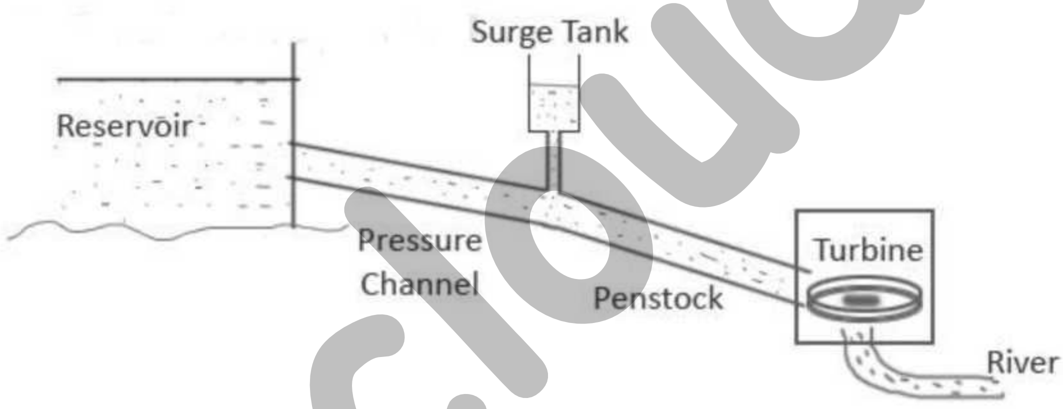
b. **Control Gate:** Water from the reservoir is allowed to flow through the penstock to the turbine. The amount of water which is to be released in the penstock can be controlled by a control gate. When the control gate is fully opened, maximum amount of water is released through the penstock.

c. **Penstock:** A penstock is a huge steel pipe which carries water from the reservoir to the turbine. Potential energy of the water is converted into kinetic energy as it flows down through the penstock due to gravity.

d. **Water Turbine:** Water from the penstock is taken into the water turbine. The turbine is mechanically coupled to an electric generator. Kinetic energy of the water drives the turbine and consequently the generator gets driven. There are two main types of water turbine; (i) Impulse turbine and (ii) Reaction turbine. Impulse turbines are used for large heads and reaction turbines are used for low and medium heads.

e. Generator: A generator is mounted in the power house and it is mechanically coupled to the turbine shaft. When the turbine blades are rotated, it drives the generator and electricity is generated which is then stepped up with the help of a transformer for the transmission purpose.

f. Surge Tank: Surge tanks are usually provided in high or medium head power plants when considerably long penstock is required. A surge tank is a small reservoir or tank which is open at the top. It is fitted between the reservoir and the power house. The water level in the surge tank rises or falls to reduce the pressure swings in the penstock. When there is sudden reduction in load on the turbine, the governor closes the gates of the turbine to reduce the water flow. This causes pressure to increase abnormally in the penstock. This is prevented by using a surge tank, in which the water level rises to reduce the pressure. On the other hand, the surge tank provides excess water needed when the gates are suddenly opened to meet the increased load demand.



Surge Tank in Hydro Power Plant

Advantages of a Hydroelectric Power Plant

1. No fuel is required as potential energy is stored water is used for electricity generation
2. Neat and clean source of energy
3. Very small running charges - as water is available free of cost
4. Comparatively less maintenance is required and has longer life
5. Serves other purposes too, such as irrigation

Disadvantages

1. Very high capital cost due to construction of dam
2. High cost of transmission - as hydro plants are located in hilly areas which are quite away from the consumers

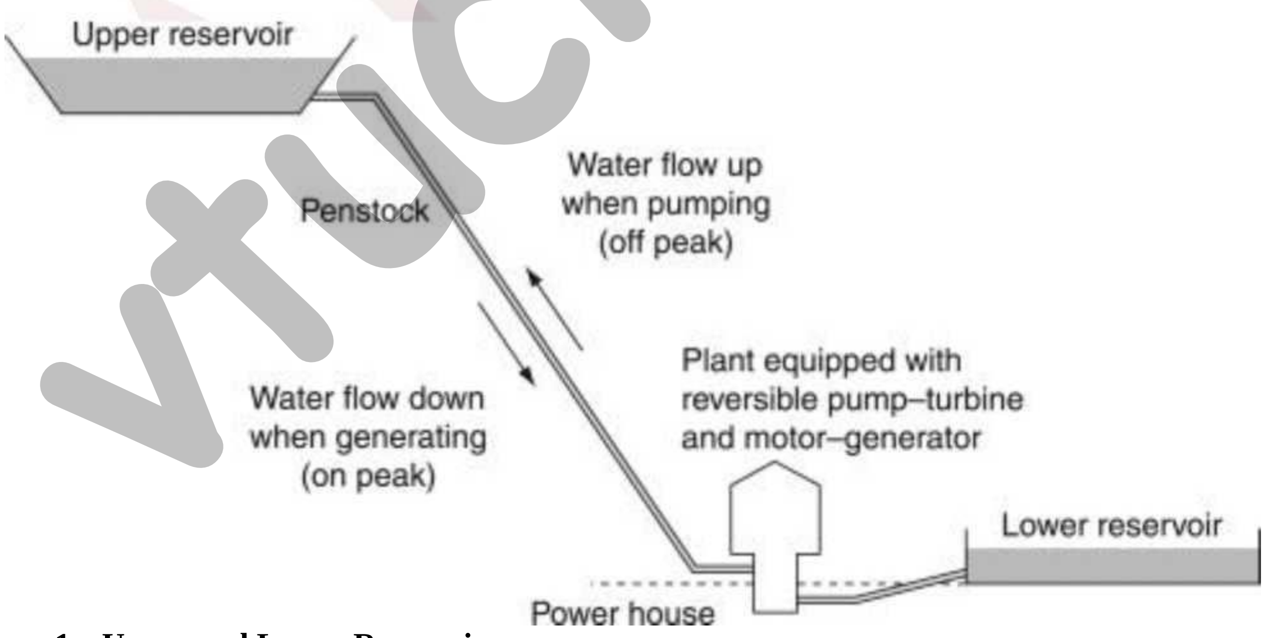
Pumped Storage Plants

Pumped storage plants are a type of hydroelectric power generation facility that can store and generate electricity to meet varying demand. They use two water reservoirs at different elevations to store and generate energy by moving water between them.

How Pumped Storage Plants Work?

1. **Pumping Mode:**
   - **Low-Demand Periods:** During times of low electricity demand, excess power (often from renewable sources like wind or solar) is used to pump water from the lower reservoir to the upper reservoir.
   - **Storage of Energy:** This process effectively stores energy in the form of gravitational potential energy in the water stored at the higher elevation.
2. **Generation Mode:**
   - **High-Demand Periods:** During peak electricity demand, the stored water is released from the upper reservoir, flowing down through turbines to generate electricity.
   - **Electricity Generation:** The falling water turns the turbines, converting the potential energy back into electrical energy, which is then fed into the grid.

Components of Pumped Storage Plants



1. **Upper and Lower Reservoirs:**
   - **Upper Reservoir:** Stores water during low-demand periods.
   - **Lower Reservoir:** Receives water during the generation process and serves as the

source for pumping water back up.

2. **Pumping/Turbine Units:**
   - **Reversible Pumps/Turbines:** These units can function both as pumps (to move water to the upper reservoir) and as turbines (to generate electricity when water flows back down).

3. **Penstocks:**
   - **Conduits:** Large pipes or tunnels that carry water from the upper reservoir to the turbines and from the turbines to the lower reservoir.

4. **Powerhouse:**
   - **Facility:** Houses the reversible pump-turbine units and generators, controlling the operation of the plant.

Advantages of Pumped Storage Plants

1. **Energy Storage:**
   - **Grid Stability:** Provides a reliable way to store excess energy from intermittent renewable sources, helping to stabilize the grid.
   - **Peak Shaving:** Reduces the need for expensive and less efficient peaking power plants by supplying energy during peak demand periods.

2. **Flexibility and Reliability:**
   - **Quick Response:** Can quickly switch between pumping and generating modes, making it highly responsive to changing electricity demands.
   - **Load Balancing:** Helps balance supply and demand on the grid, ensuring a stable electricity supply.

3. **Efficiency:**
   - **High Efficiency:** Typically has an overall efficiency of 70-80%, making it one of the most efficient large-scale energy storage options.

Disadvantages of Pumped Storage Plants

1. **High Initial Costs:**

   - **Construction Costs:** Building the reservoirs, penstocks, and powerhouses involves significant capital investment.
   - **Site Requirements:** Suitable sites with the necessary elevation differences and water availability are limited.

2. **Environmental Impact:**

   - **Ecological Disruption:** Construction and operation can affect local ecosystems, water quality, and wildlife habitats.

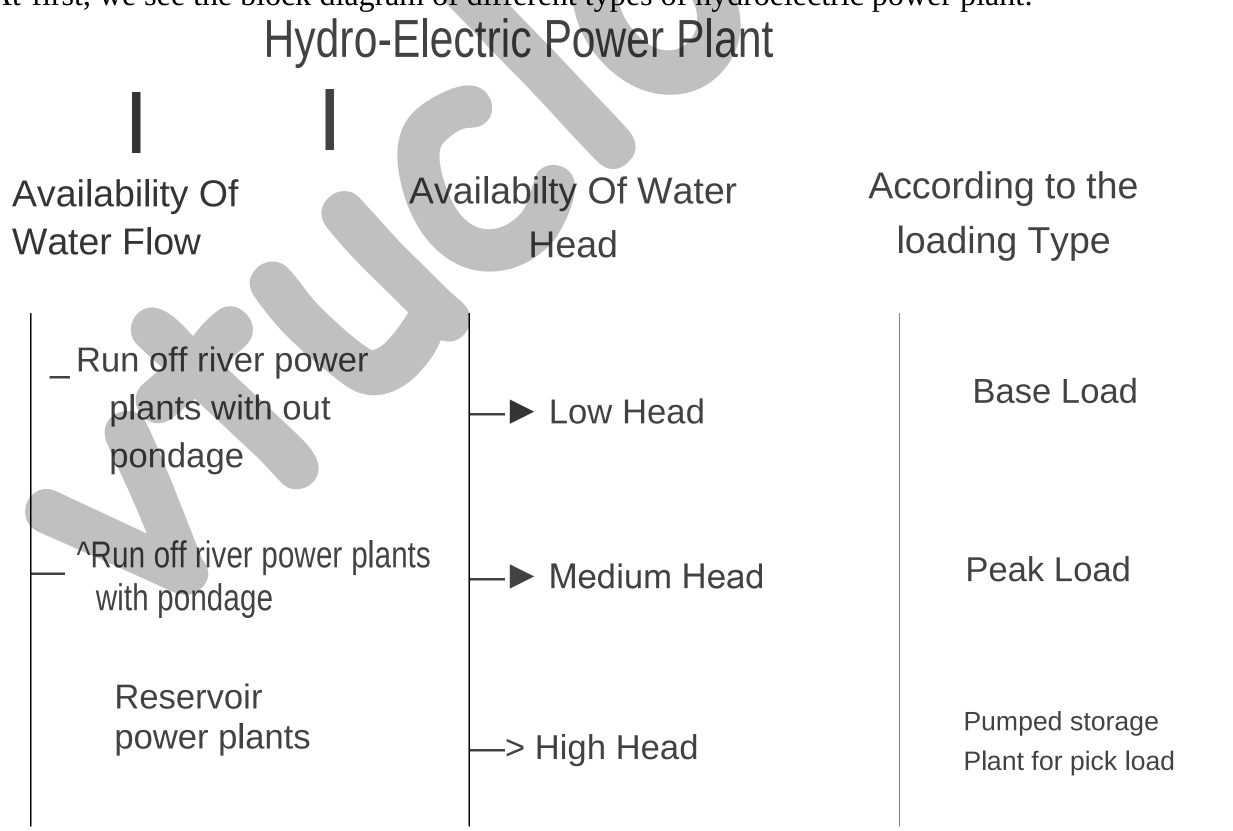
   - **Land Use:** Requires substantial land for reservoirs and infrastructure, potentially leading to displacement and land-use changes.

3. **Dependency on Water Availability:**

   - **Water Resource Management:** Efficient operation depends on the availability of water, which can be affected by seasonal and climatic variations.

Detailed Classification of Hydroelectric Plants

At-first, we see the block diagram of different types of hydroelectric power plant:



1. According to the extent of water flow regulation available:

According to the extent of water flow regulation, hydroelectric power plant may be classified into three categories:

- **a.** Run off river power plants without pondage
- **b.** Run off river power plants with pondage
- **c.** Reservoir power plants

a. Run off river power plants without pondage

This type of hydroelectric power plant, water is not available all the time. So this type of power station is not suitable for constant steady load. There is no pondage or storage facility available in such type of power plant. Plant is placed in such an area, where water is coming directly from the river or pond. This type of hydroelectric power plant is called run off power plant without pondage. Plant produces hydroelectricity only when water is available. This type of plan cannot use all the time. During high flow and low load period, water is wasted and the lean flow periods the plan capacity is very low. Power development capacity of this type of plan is very low and it produces power incidentally. The development cost of such a plant is relatively cheaper than full-time power development hydroelectric power plant. Though it is not used for constant steady load supply, it's objective is to generate electricity by using excessive flow of water during flood or rainy season or whatever flow is available to save some sort of our natural resource of energy such as coal, diesel etc.

b. Run off river power plants with pondage

This type of plant is used to increase the capacity of pond. The pond is used as a storage water of hydroelectric power plant. Increased the pond size means more water is available in the plant, so such type of hydroelectric power plant is used fluctuating load period depending on the size of pondage. On a certain limitation, this type of power plant can be a part of load curve and it is more reliable than a hydro plant without pondage. Such type of plant is suitable for both base load and peak load period. During high flow period, this plant is suitable for base load and lean flow period it may be used to supply peak loads only. During high flood period, one thing should keep in mind that floods should not raise tail-race water level. Such types of power plant save conservation of coal.

c. Reservoir power plants

Most hydroelectric power plant in the world is reservoir power plant. This type of plant, water is stored behind the dam and water is available throughout the year even in dry season. This type of power plant is very efficient and it is used both base and peak load period as per requirement. Most importantly, it can also take a part of load curve in grid system.

2. According to the availability of water flow

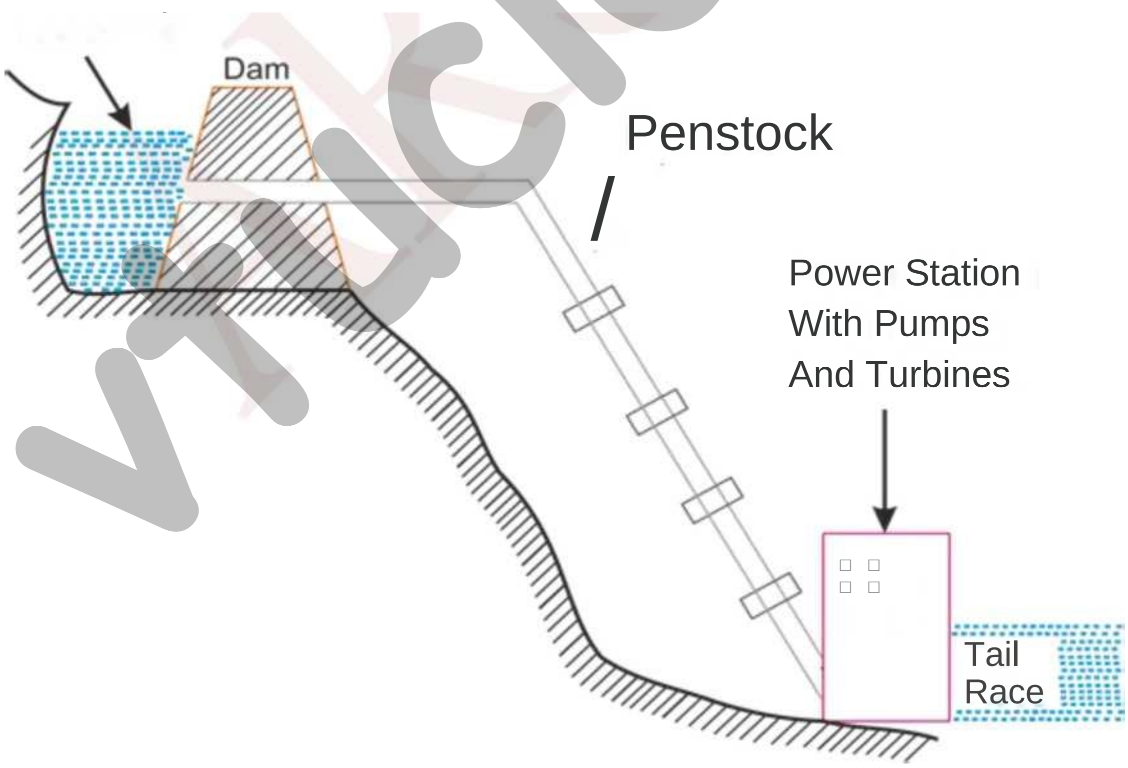
As per height of water or water head, hydroelectric power plant can be divided three categories:

- **a.** Low Head
- **b.** Medium Head
- **c.** High Head

Low head, medium head, high head. Though there is no rule regarding water head height but below 30 meters is considered as low head, above 30 meters to 300 meters is called medium head and above 300 meters is known as high head hydroelectric power plant.

a. Low head hydroelectric power plant

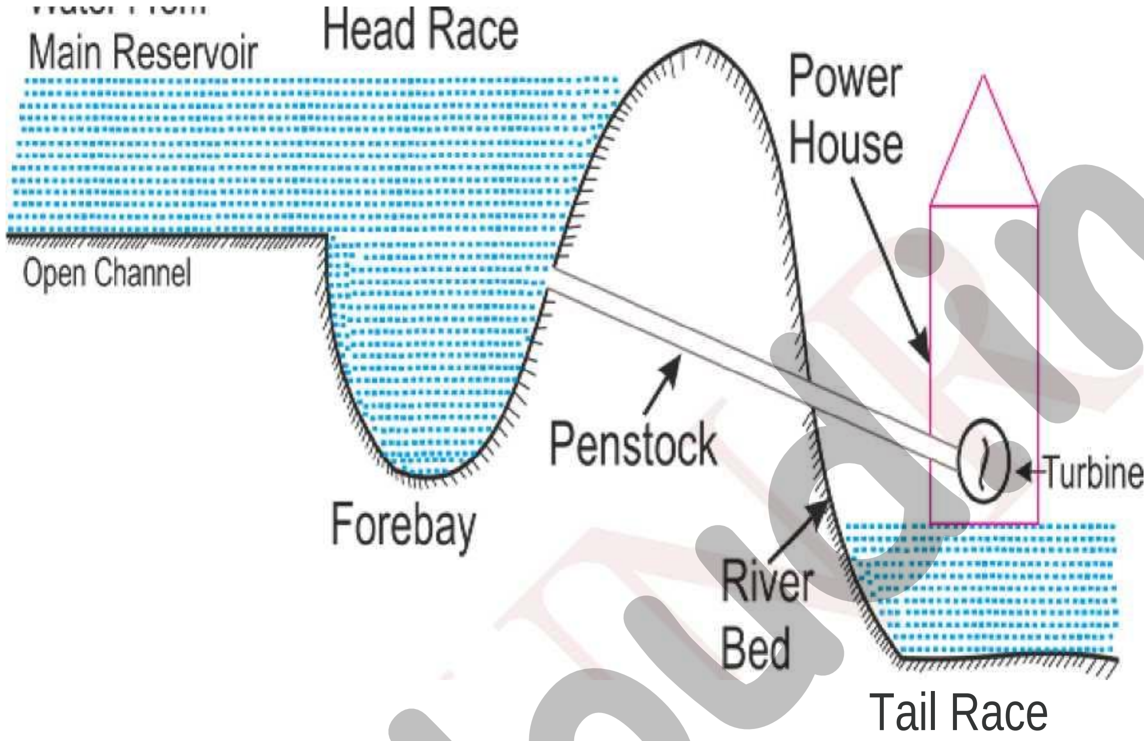
Francis, Kaplan or propeller turbines are used for this type of hydroelectric power plant. To create a low head, dam construction is essential. Water resource level i.e. River or pond is placed just behind the dam to create a necessary water head level. Water is led to the turbine through the penstock. This type of hydro plant is located just below the dam and it creates a useful water level as well. No surge tank is required for this plant, dam itself discharge the surplus water from the river. Science head is low, huge amount of water is required for desire output. That's why large diameter and low length pipe is used for this plant. Such types of power plant use low speed and large diameter type generators.
The block diagram of low head hydroelectric power plant is given in fig:



b. Medium head hydroelectric power plant

Block diagram of medium head hydroelectric power plant is shown below:

Water Frnm

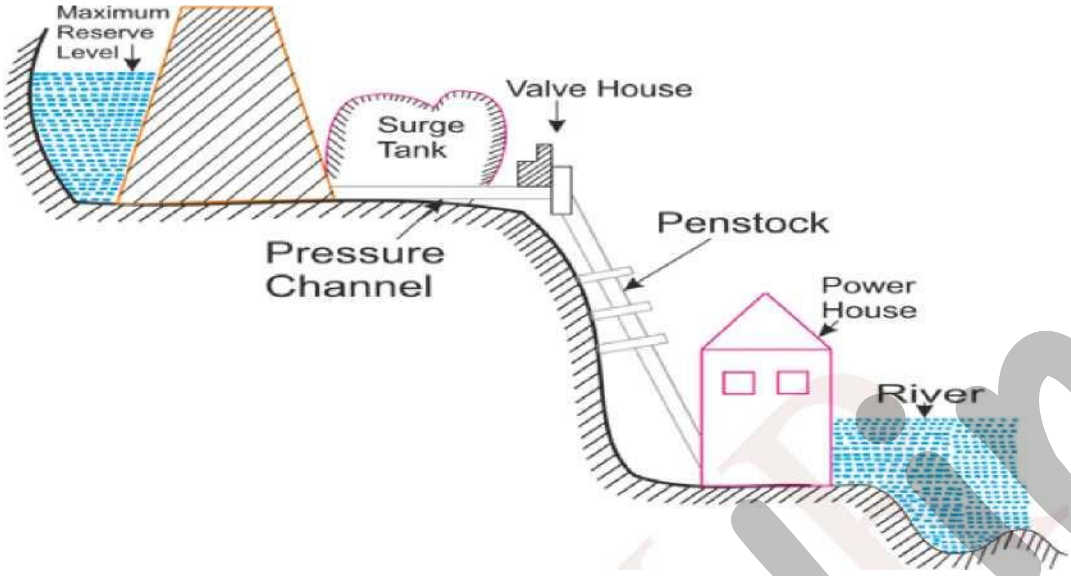


A fore-bay is used for medium head hydroelectric power plant. This fore-bay is worked as a surge tank. Fore-bay is tapped with the river and water is led to the turbine via penstock. Fore-bay is just beginning of penstock. For low head plant fore-bay, it serves as a surge tank.

c. High head hydroelectric power plant

The head of this power plant is more than 300 meters. A dam is constructed such level that maximum reserve water level is formed. A pressure tunnel is constructed which is connected to the valve house. Water is coming from reservoir to valve house via this pressure tunnel and it is the starting of penstock. A surge tank is also constructed before valve house which reduces water hammering to the penstock in case of sudden closing of fixed gates of water turbine. Surge tank also store some extra water which is useful for pick load demand because it will serve extra water to the turbine. Valve house consists of a main valve sluice valves and automatic isolating valves, which operate on bursting of penstock and cut off further supply of water to penstock. The penstock is a connecting pipe which supplies water from valve house to turbine. For high head more than 500 meters, Pelton is used and for lower head Francis turbine is useful.

Dam



3. According to the types of load supply

- **a.** Base Load
- **b.** Peak Load
- **c.** Pumped storage plants for the peak load

a. Base load hydroelectric power plant

This is a large capacity power plant. This plant work as a base portion of load curve of power system, that's why it is called base load plants. Base load plant is suitable for constant load. Load factor of this plant is high and it is performed as a block load. Run off river plants without pondage and reservoir plants are used as base load plants.

b. Peak load hydroelectric power plant

This plant is suitable for peak load curve of power system. When demand is high, this type of plant does their job very well. Run off river plants with pondage can be employed as peak load plants. If water supply is available, it generates large portion of load at a peak load period. It needs huge storage area. Reservoir plants can be used as peak load plants. This type of plant can serve power throughout the year.

c. Pumped storage hydroelectric power plant for the peak load

This is unique design of peak load plants. Here two types of water pond is used, called upper head water pond and tail water pond. Two water ponds are connected each other by a penstock. Main generating pumping plant is lower end. During the off load period, surplus energy of this plant is utilized to pumping the lower head pond water to upper head pond water. This extra water is used to generate energy at pick load periods. By doing this arrangement, same water is used again and again. Extra water is required only to take care of evaporation and seepage.

TIDES AND WAVES AS ENERGY SUPPLIERS

Harnessing the energy from tides and waves offers a promising source of renewable energy. These energy sources exploit the natural movement of water to generate electricity, providing a reliable and sustainable alternative to fossil fuels.

TIDAL ENERGY

Mechanics of Tidal Energy

Tidal energy is derived from the gravitational interactions between the Earth, Moon, and Sun, which cause the periodic rise and fall of ocean levels. There are two primary methods to harness tidal energy:

1. **Tidal Stream Generators:**

Function: These devices are similar to underwater wind turbines. They are placed in tidal streams where the flow of water spins the turbine blades, generating electricity.

Advantages: Can be installed in various locations with strong tidal currents, less intrusive to marine life compared to other methods.

2. **Tidal Barrages:**

Function: Barrages are dam-like structures built across the entrance of a tidal basin. Gates and turbines within the barrage allow water to flow through during high and low tides, turning turbines to generate electricity.

Advantages: Can generate a significant amount of power and also provide flood protection and act as bridges.

Disadvantages: High construction costs and potential environmental impacts on estuarine ecosystems.

Advantages of Tidal Energy

1. **Predictability:** Tidal patterns are highly predictable, providing a reliable source of energy.
2. **Longevity:** Tidal energy systems can have long operational lifespans, often exceeding 100 years.
3. **Low Operating Costs:** Once installed, the operating and maintenance costs are relatively low.

Disadvantages of Tidal Energy

1. **High Initial Costs:** The construction of tidal energy systems, particularly barrages, requires substantial capital investment.

2. **Environmental Impact:** Can affect marine habitats and sedimentation patterns, potentially impacting local ecosystems.
3. **Geographical Limitations:** Suitable sites for tidal energy installations are limited to coastal regions with significant tidal ranges.

WAVE ENERGY

Mechanics of Wave Energy

Wave energy harnesses the kinetic and potential energy of ocean waves. There are several types of wave energy converters, including:

1. **Point Absorbers:**

Function: These floating structures move with the waves, and the mechanical movement is converted into electricity using hydraulic pumps or other mechanisms.

Oscillating Water Columns:

Function: Waves enter a chamber, causing the water column to rise and fall. This movement pushes air through a turbine, generating electricity.

2. **Attenuators:**

Function: Long, articulated devices that float on the water surface and move with the waves. The movement at the hinges is converted into electrical power.

Advantages of Wave Energy

1. **Abundant Resource:** Oceans cover over 70% of the Earth's surface, providing vast areas for wave energy exploitation.
2. **Consistency:** Waves are more consistent than wind, providing a more reliable energy source.
3. **Environmental Benefits:** Wave energy systems have a smaller visual impact and can coexist with marine activities like fishing and shipping.

Disadvantages of Wave Energy

1. **Technological Maturity:** Many wave energy technologies are still in the experimental or early commercial stages, requiring further development.
2. **Maintenance Challenges:** Marine environments are harsh, and devices must withstand extreme conditions, leading to higher maintenance costs.
3. **Environmental Concerns:** Potential impacts on marine ecosystems, navigation, and sediment transport need to be carefully managed.

Fundamental Characteristics of Tidal Power

Tidal power harnesses the energy from the natural rise and fall of ocean tides, driven by the gravitational forces of the moon and the sun, to generate electricity. Here are the fundamental characteristics of tidal power:

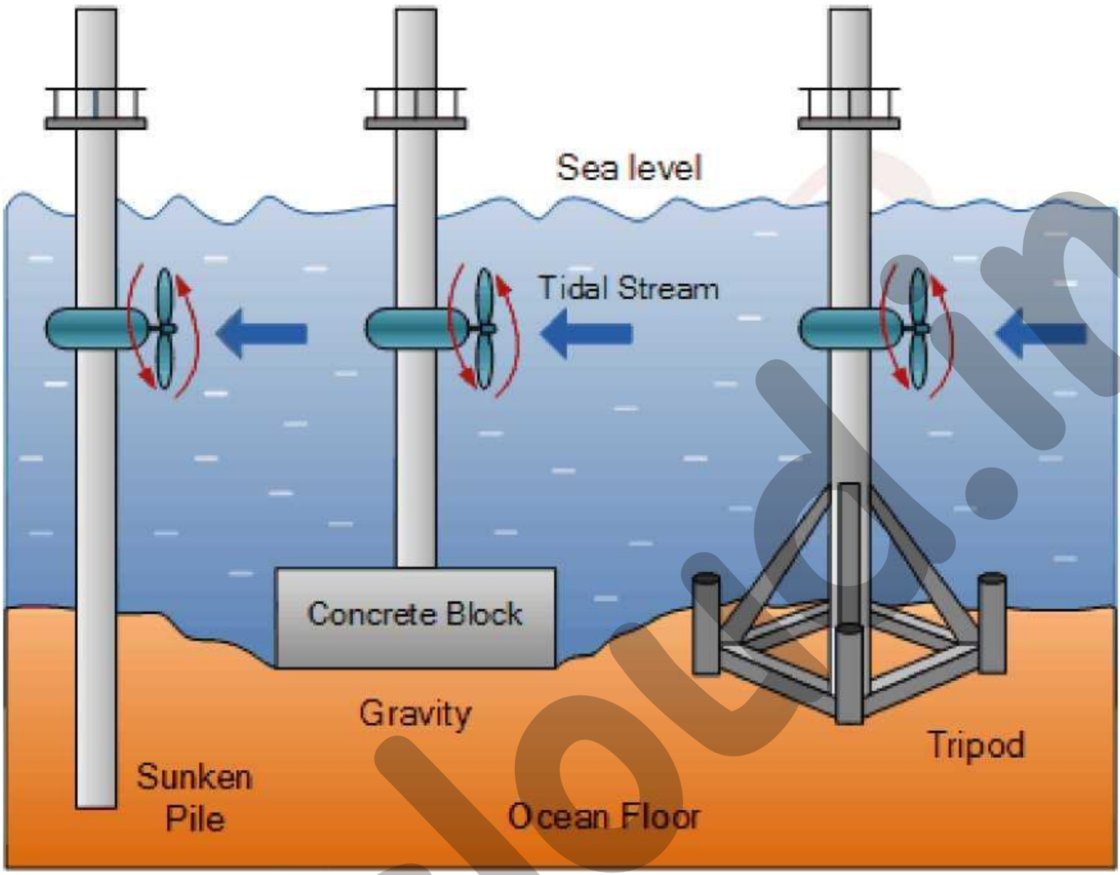
1. **Predictability**
   - **Reliable and Predictable:** Unlike solar and wind energy, tidal patterns are highly predictable, allowing for accurate forecasting of energy production. Tides follow a regular and cyclical pattern due to the gravitational interactions of the Earth, moon, and sun.
2. **Energy Density**
   - **High Energy Density:** Tidal power has a higher energy density compared to other renewable sources. The density of water is much higher than air, making tidal turbines more efficient at capturing kinetic energy.
3. **Environmental Impact**
   - **Minimal Greenhouse Gas Emissions:** Tidal power is a clean energy source with negligible greenhouse gas emissions during operation.
   - **Potential Environmental Concerns:** Tidal installations can impact marine ecosystems, fish migration patterns, and sediment transport. Careful site selection and environmental impact assessments are essential.
4. **Operational Characteristics**
   - **Bilateral Energy Production:** Tidal systems, especially barrages and lagoons, can generate electricity during both the rising and falling tides, providing two periods of energy production each day.
   - **Long Lifespan:** Tidal power plants can have long operational lifespans, often exceeding several decades, which can offset the initial high capital costs.
5. **Cost and Economic Factors**
   - **High Initial Investment:** The construction of tidal power systems, especially barrages, requires substantial capital investment.
   - **Low Operating Costs:** Once operational, tidal power plants typically have low operating and maintenance costs.
6. **Geographical Limitations**
   - **Site-Specific:** Suitable locations for tidal power installations are limited to regions with significant tidal ranges and strong tidal currents, such as coastal areas with narrow straits, estuaries, and bays.
7. **Scalability and Grid Integration**
   - **Scalability:** Tidal power projects can range from small-scale installations for local use to large-scale projects supplying significant amounts of electricity to the grid.
   - **Grid Integration:** Due to the predictability of tidal patterns, integrating tidal power into the energy grid can help stabilize and balance energy supply.

Harnessing Tidal Energy

Tidal energy is a form of hydropower that converts the energy from the natural rise and fall of tides into electricity. The harnessing of tidal energy involves capturing the kinetic and potential energy of tides using various technologies. Here's an overview of the methods and technologies used to harness tidal energy:

Methods of Harnessing Tidal Energy

A. Tidal Stream Generators:

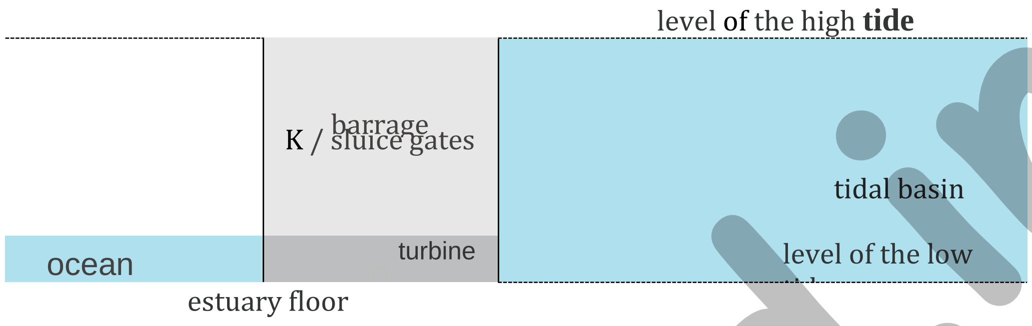


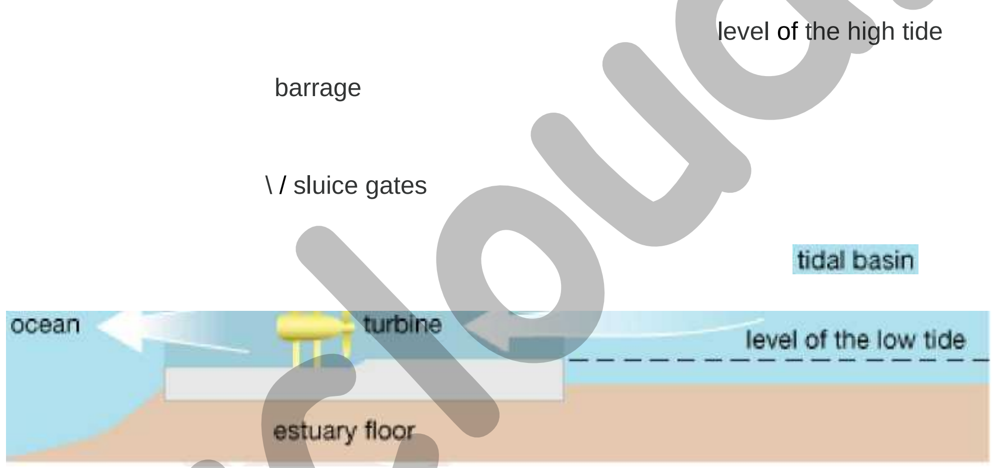
1. **Description:** These devices work similarly to underwater wind turbines. They are placed in areas with strong tidal currents where the kinetic energy of moving water can turn the turbine blades.
2. **Technology:** Horizontal-axis turbines, vertical-axis turbines, and oscillating hydrofoils are common types of tidal stream generators.
3. **Advantages:** Minimal environmental impact, modular and scalable, can be placed in existing marine traffic lanes.
4. **Challenges:** Corrosion and biofouling in the marine environment, impact on marine life, and high installation costs.

B. Tidal Barrages:

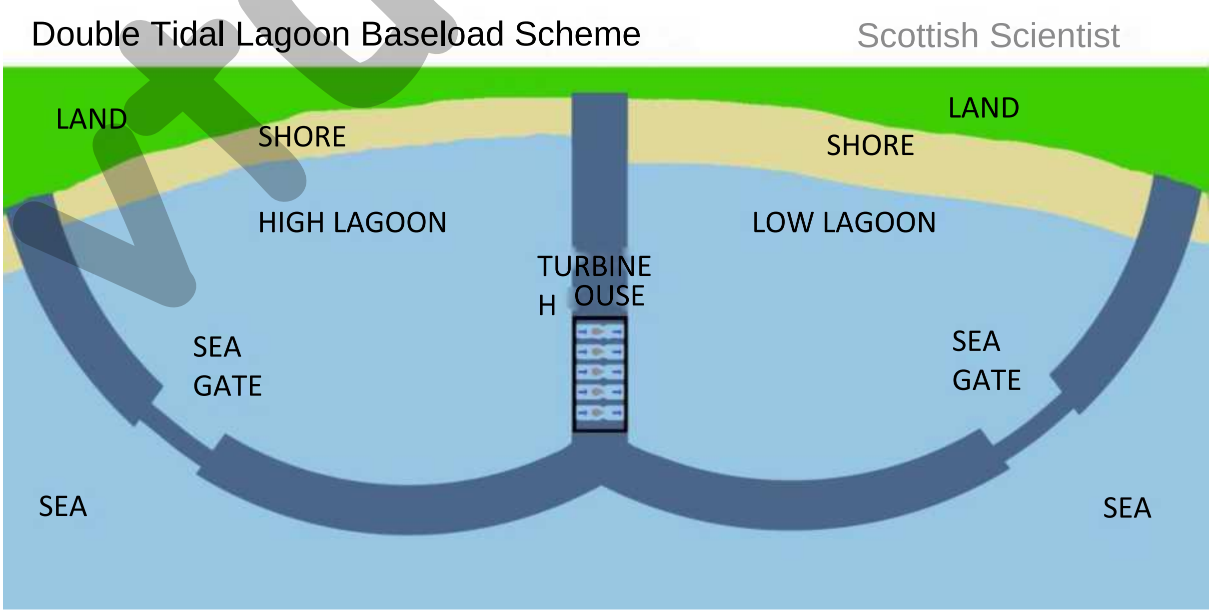
1. **Description:** Tidal barrages are large dams built across estuaries or bays. They capture the potential energy of the difference in water height (head) between high and low tides.

2. **Technology:** Gates and turbines within the barrage allow water to flow in and out, generating power during both the incoming and outgoing tides.
3. **Advantages:** High energy output, predictable energy generation, and can provide flood protection and improved navigation.
4. **Challenges:** High initial costs, significant environmental impact on estuarine ecosystems, and displacement of local communities.





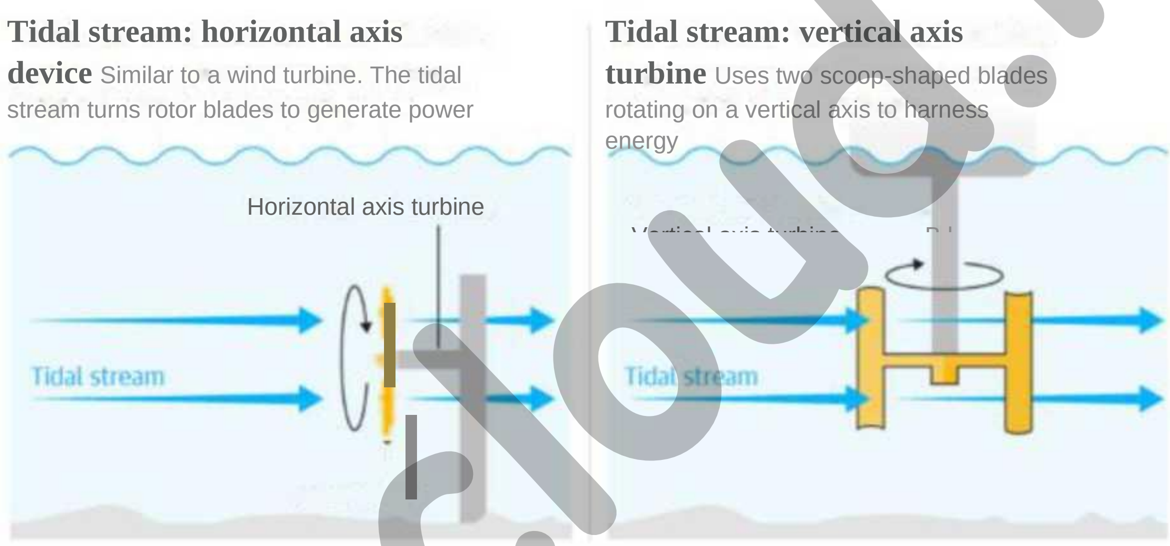
C. Tidal Lagoons:



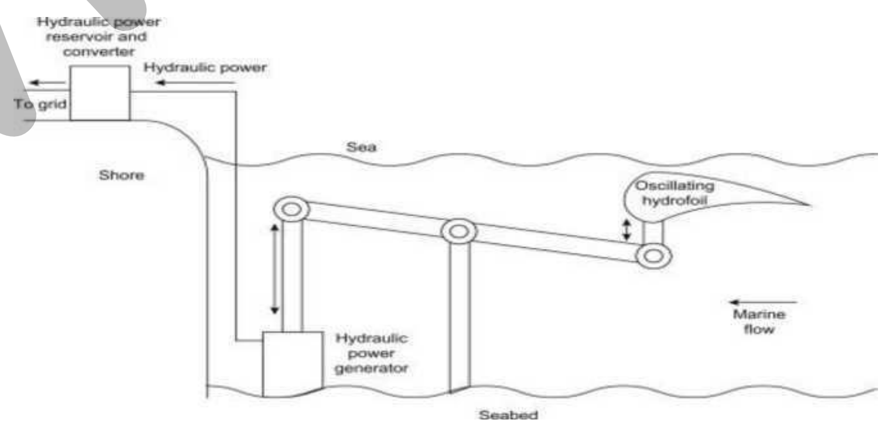
1. **Description:** Tidal lagoons are similar to tidal barrages but create artificial enclosed areas along the coast. Turbines are installed in the barriers to generate power from tidal movements.
2. **Technology:** Water is allowed to flow in and out of the lagoon through turbines, harnessing both incoming and outgoing tides.
3. **Advantages:** Less environmental impact than barrages, can be built to scale, and provide recreational and conservation benefits.
4. **Challenges:** High construction costs, site-specific feasibility, and potential ecological impact.

Key Technologies in Tidal Energy

1. **Turbines:**



a. **Horizontal-Axis Turbines:** Similar to wind turbines, these have blades that rotate around a **horizontal axis.**
b. **Vertical-Axis Turbines:** These have blades that rotate around a vertical axis and can capture energy from tides flowing in multiple directions.
c. **Oscillating Hydrofoils:** These use a wing-like structure that moves up and down in the water to generate energy.



2. **Energy Conversion Systems:**
   a. **Generators:** Convert the mechanical energy from turbine movement into electrical energy.
   b. **Power Electronics:** Manage the flow of electricity to ensure a stable and reliable supply to the grid.

3. **Structural Components:**
   a. **Foundations:** Secure the turbines and other structures to the seabed or riverbed.
   b. **Support Structures:** Include towers, monopiles, or gravity-based structures to support the turbines.

4. **Environmental and Economic Considerations**
   a. **Environmental Impact:** Tidal energy projects can affect marine ecosystems, sediment transport, and water quality. Environmental impact assessments are crucial to mitigate negative effects.
   b. **Economic Viability:** High initial costs can be offset by low operational and maintenance costs. Government incentives and advancements in technology can improve economic feasibility.
   c. **Energy Output:** Tidal energy is predictable and can provide a stable source of renewable energy, reducing reliance on fossil fuels and contributing to energy security.

Limitations of Tidal Energy

1. It is site specific and the tidal energy can be recovered economically on the locations where the tidal range is 5m or more.
2. The availability of tidal energy is variable thus the power generation is highly fluctuating in nature.
3. Turbines are needed which can operate with fluctuating heads.
4. The marine life and ecology is affected in the region where the tide plants are located . It also affects the navigation system.
5. In order to handle large volume flow rates of tidal water at low heads , tidal plants need to operate with several turbines in parallel.
6. Sea water is corrosive.

WAVE ENERGY

Wave Energy Basics: Wave energy is a renewable energy source that utilizes the power of ocean waves to generate electricity. Unlike tidal energy, which relies on the rise and fall of tides, wave energy harnesses the vertical movement of surface water to produce power. This energy is captured using equipment placed on the ocean's surface, converting the mechanical energy of wave movements into electrical energy.

How Wave Energy is Generated?

1. **Wind and Waves:**

    - Solar power heats the Earth's atmosphere unevenly, causing air to move from hotter to cooler regions, creating wind.
    - As wind blows across the ocean's surface, it transfers kinetic energy to the water, forming waves.
    - Waves are essentially energy moving across the ocean's surface, not the water itself.

2. **Energy Capture:**

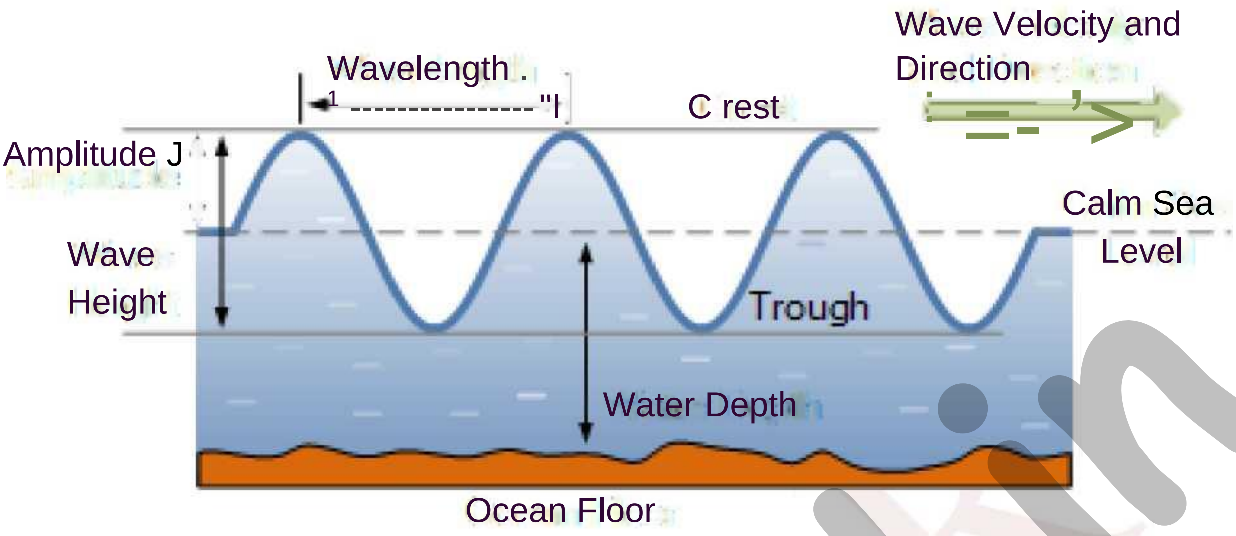
    - Waves can travel long distances with minimal energy loss. As they approach shorelines, they slow down and increase in size, releasing kinetic energy when they crash onto the shore.
    - The potential energy of waves varies based on geographic location and time of year, influenced mainly by wind strength and the distance wind travels over the sea (fetch).

Wave Energy Conversion:

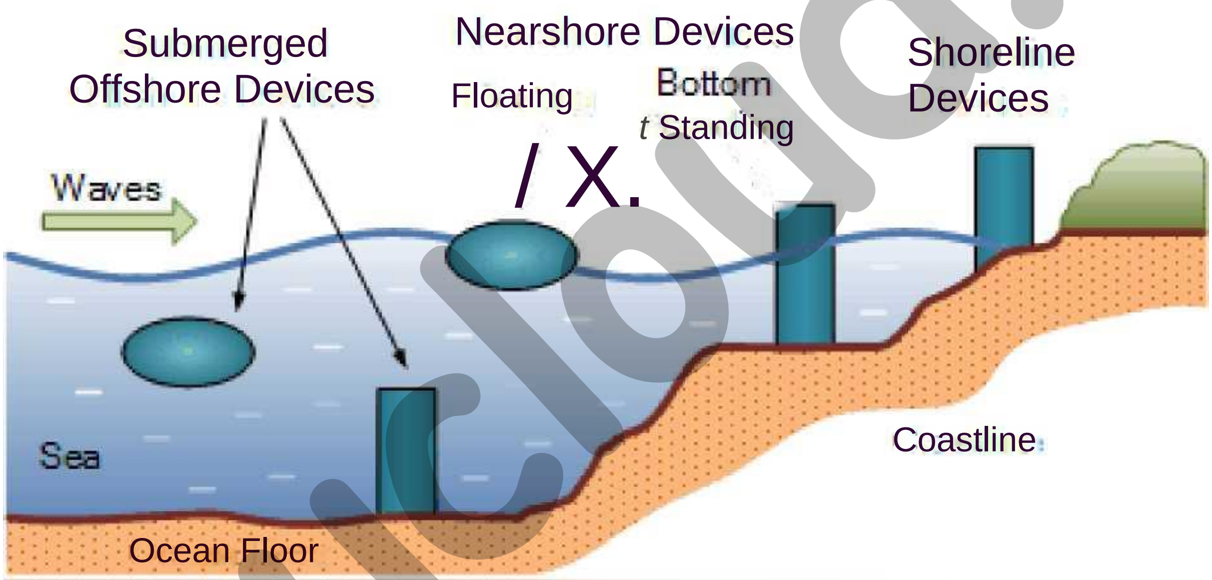
- **Technology:** Similar to tidal and hydroelectric power, wave energy technology captures wave movement to generate electricity.
- **Process:** The kinetic energy from waves turns a turbine connected to a generator, producing electricity.
- **Challenges:** The ocean environment is harsh, often leading to damage or destruction of wave energy devices.

Wave Characteristics:

- **Wave Motion:** Waves exhibit an up-and-down vertical movement, creating high points (crests) and low points (troughs).
- **Amplitude:** The height difference between the crest and trough is the peak-to-peak amplitude, representing the wave's energy potential.



Wave Power Devices

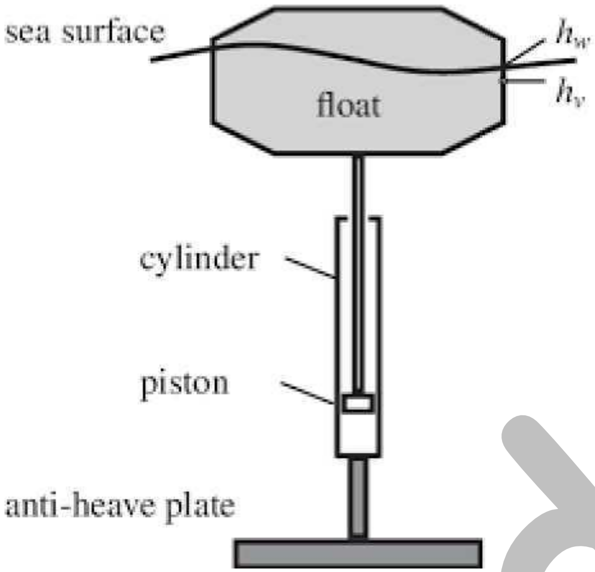


1. **Shoreline devices** are wave energy devices which are fixed to or embedded in the shoreline, that is they are both in and out of the water.
2. **Nearshore devices** are characterised by being used to extract the wave power directly from the breaker zone and the waters immediately beyond the breaker zone, (i.e. at 20m water depth).
3. **Offshore devices** or deep water devices are the farthest out to sea and extend beyond the breaker lines utilising the high-energy densities and higher power wave profiles available in the deep water waves and surges. One of the advantages of offshore devices is that there is no need for significant coastal earthworks, as there is with onshore devices.

Wave Energy Capture Methods

Wave energy is harnessed using four primary methods, each converting the energy of ocean waves into electricity through different mechanisms:

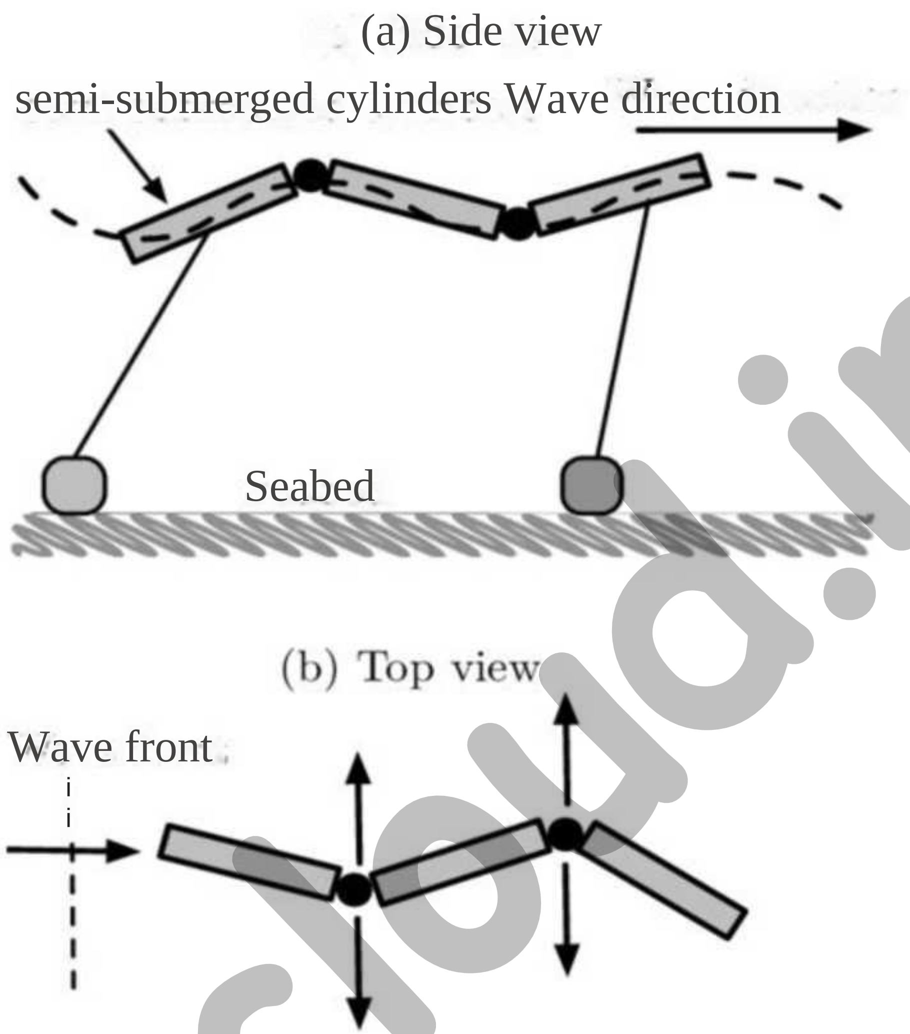
1. **Point Absorbers:**



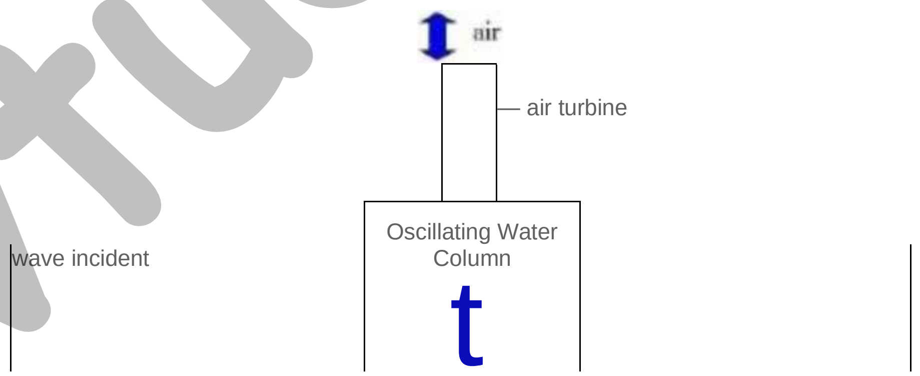
- **Description:** These devices are either fixed to the ocean floor or tethered via a chain, absorbing wave energy from all directions.
- **Mechanism:** They generate electricity from the bobbing or pitching motion of floating devices such as buoys, floating bags, ducks, and articulated rafts.
- **Advantage:** Can be deployed in deeper waters where wave energy is higher.

2. **Wave Attenuators:**

- **Description:** Also known as linear absorbers, these are long, horizontal, semi-submerged snake-like devices oriented parallel to the waves.
- **Mechanism:** Comprised of linked cylindrical sections with flexible joints, they convert wave-induced motion into hydraulic pressure. This pressure turns a hydraulic turbine generator to produce electricity.
- **Example:** Cylindrical sections rotate and yaw, pressing a hydraulic piston (ram) that generates electricity through high-pressure oil.



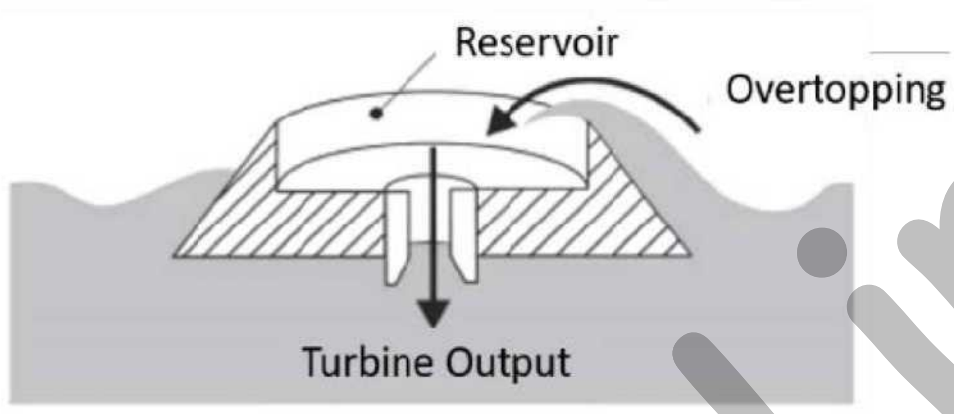
3. **Oscillating Water Column:**



- **Description:** A partly submerged chamber fixed at the shoreline, converting wave energy into air pressure.
- **Mechanism:** The vertical motion of waves within the chamber moves the water column, acting like a piston on the air above. This compressed and decompressed air is channeled through a wind turbine generator to produce electricity.
- **Structure:** Can be a natural cave with a blowhole or a man-made chamber

perpendicular to waves.

4. **Overtopping Devices:**



- **Description:** Fixed or floating structures with ramps and tapered sides positioned perpendicular to waves.
- **Mechanism:** Waves are driven up the ramp, spilling over into a reservoir 2-3 meters above sea level. The potential energy of trapped water is released back to the sea through a Kaplan turbine generator, producing electricity.
- **Disadvantage:** Low power output and only suitable for sites with a deep water shoreline and low tidal range.

Wave Energy Advantages

1. Wave energy is an abundant and clean energy resource as the waves are generated by the wind.
2. Pollution free as wave energy generates little or no pollution to the environment compared to other green energies.
3. Reduces dependency on fossil fuels as wave energy consumes no fossil fuels during operation.
4. Wave energy is relatively consistent and predictable as waves can be accurately forecast several days in advance.
5. Wave energy devices are modular and easily sited with additional wave energy devices added as needed.
6. Dissipates the wave's energy protecting the shoreline from coastal erosion.
7. Presents no barriers or difficulty to migrating fish and aquatic animals.

Wave Energy Disadvantages

1. Visual impact of wave energy conversion devices on the shoreline and offshore floating

buoys or platforms.

2. Wave energy conversion devices are location dependent requiring suitable sites were the waves are consistently strong.
3. Intermittent power generation as the waves come in intervals and do not generate power during calm periods.
4. Offshore wave energy devices can be a threat to navigation that cannot see or detect them by radar.
5. High power distribution costs to send the generated power from offshore devices to the land using long underwater cables.
6. They must be able to withstand forces of nature resulting in high capital, construction and maintenance costs.