CBCS SCHEME

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BME654B

Sixth Semester B.E./B.Tech. Degree Examination, June/July 2025
Renewable Energy Power Plants

Time: 3 hrs. Max. Marks: 100

Note: 1. Answer any FIVE full questions, choosing ONE full question from each module.
2. M : Marks , L: Bloom's level , C: Course outcomes.

			M	L	C
		Module – 1			
Q.1	**a.**	Explain briefly different renewable and non-renewable energy sources.	10	L2	CO1
	b.	Explain environmental benefits and challenges of renewable energy sources.	10	L2	CO1
		OR			
Q.2	**a.**	Explain extra-terrestrial radiation and special distribution of extra terrestrial radiation.	10	L2	CO1
	b.	Explain solar radiation at the earth's surface.	10	L2	CO1
		Module – 2			
Q.3	**a.**	Explain pyranometer with neat sketch.	10	L2	CO2
	b.	Explain pyrheliometer with neat sketch.	10	L2	CO2
		OR			
Q.4	**a.**	Explain PV system components and their functionalities.	10	L2	CO2
	b.	What are the design considerations for solar power plants.	10	L2	CO2
		Module – 3			
Q.5	**a.**	Explain horizontal wind energy power plant with diagram.	10	L3	CO3
	b.	Explain the parameters effecting the energy extraction through wind.	10	L2	CO1
		OR			
Q.6	**a.**	Explain with schematic diagram the working of a dry steam geothermal power plant.	10	L3	CO3
	b.	What are the problems associated with geothermal conversion.	10	L2	CO3
		Module – 4			
Q.7	**a.**	Explain different ways to extract energy through tides with neat diagram.	10	L3	CO4
	b.	Explain different ways to extract energy through waves with neat diagram.	10	L2	CO4
		OR			
Q.8	**a.**	Describe OTEC and working principle with neat sketch.	10	L2	CO4
	b.	What are the problems associated with OTEC.	10	L2	CO4
		Module – 5			
Q.9	**a.**	Explain fixed dome biogas power plant with diagram.	10	L2	CO5
	b.	Explain gasification with diagram.	10	L2	CO5
		OR			
Q.10	**a.**	Explain Hydrogen Production Technology (Electrolysis method).	10	L2	CO5
	b.	Describe advantages of hydrogen energy.	10	L2	CO5

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Renewable Energy Power Plant (BME654B)

Solutions

Q.1

a)

Renewable energy resources are those that can be naturally replenished over time and are sustainable for long-term use. Examples include:

- **Solar Energy:** Energy harnessed from sunlight using solar panels to generate electricity or heat.
- **Wind Energy:** Produced by converting wind flow into electricity using wind turbines.
- **Hydropower:** Generated from the kinetic energy of flowing or falling water to produce electricity.
- **Geothermal Energy:** Comes from the Earth's internal heat, used for electricity generation or heating.
- **Biomass Energy:** Derived from organic materials like plants and waste, converted into fuel or heat.

Non-renewable energy resources are finite and deplete over time as they cannot be replenished within a human lifespan. Examples include:

- **Fossil Fuels:** Coal, oil, and natural gas formed from ancient organic matter, widely used for electricity, heating, and transportation.
- **Nuclear Energy:** Produced by splitting atoms (usually uranium), which is a limited resource with concerns over waste disposal.

b)

Renewable energy sources offer significant environmental benefits but also face some challenges.

Environmental Benefits of Renewable Energy:

- **Reduced Greenhouse Gas Emissions:** Renewable sources like wind, solar, and hydropower emit little to no greenhouse gases during operation, helping mitigate climate change and global warming.
- **Improved Air Quality:** They produce minimal air pollutants compared to fossil fuels, reducing respiratory illnesses and improving public health.
- **Conservation of Natural Resources:** Renewable energy reduces dependence on finite fossil fuels, preserving them and reducing environmental degradation from extraction.
- **Lower Water Usage:** Many renewables require less water than conventional power plants, conserving water resources.
- **Habitat Protection:** By reducing pollution and destruction caused by mining and drilling, renewables help protect ecosystems and biodiversity.

Challenges of Renewable Energy:

- **Intermittency:** Sources like solar and wind fluctuate with weather and time of day, requiring energy storage or backup systems to ensure reliability.
- **Land and Resource Use:** Large-scale renewable installations can demand significant land area which may impact wildlife and natural habitats.
- **Material and Waste Concerns:** Manufacturing solar panels, batteries, and turbines involves mining rare materials and can result in waste management issues.
- **Infrastructure Costs:** High initial investment cost and the need for new grid infrastructure can hinder deployment.
- **Location Limitations:** Renewable resources are region-specific, requiring optimal siting and transmission solutions.

Q.2

a)

Extraterrestrial Radiations: Extraterrestrial radiation refers to the solar radiation that reaches the outer surface of the Earth's atmosphere, before any interaction with the atmosphere occurs. It is essentially the solar energy incident on a surface perpendicular to the sun's rays at the top of the atmosphere. This radiation provides the baseline solar energy available and is not affected by atmospheric absorption, scattering, or reflection. Its intensity varies slightly throughout the year due to the elliptical orbit of the Earth around the Sun, causing changes in the Earth-Sun distance. The average value of extraterrestrial radiation, also called the solar constant, is approximately 1361 W/m². The spectral distribution peaks in the visible range, with contributions also in ultraviolet and infrared regions.

Spectral Distribution of Extraterrestrial Radiation:
The radiation covers a broad spectrum of wavelengths emitted by the sun:

- Ultraviolet (UV) radiation (about 8%)
- Visible light (about 46%)
- Infrared (IR) radiation (about 46%)

The intensity is highest near 0.48 micrometers in the visible range, following the sun's blackbody radiation characteristics. This radiation is the source for all solar energy applications and is essential for understanding Earth's energy balance and designing solar energy systems.

Special Distribution of Extraterrestrial Radiations:
The distribution of extraterrestrial radiation depends on several factors:

- **Time of Year:** Due to Earth's elliptical orbit, radiation intensity changes periodically. It reaches a maximum when Earth is closest to the Sun (perihelion) and a minimum when farthest (aphelion).
- **Solar Angles:** The angle of incidence changes with latitude and time of day, affecting the intensity received on different surfaces.
- **Solar Constant Variations:** Minor fluctuations in solar output cause variations (~ ±1.5%) in radiation.

b)

Solar radiation at the Earth's surface is the solar energy that has passed through the Earth's atmosphere and reaches the ground. It is composed of:

- **Direct beam radiation:** Solar rays that travel straight from the Sun to the surface without scattering.
- **Diffuse radiation:** Solar rays scattered by molecules and particles in the atmosphere reaching the surface indirectly.
- **Reflected radiation:** Solar rays reflected from the ground, buildings, and other surfaces.

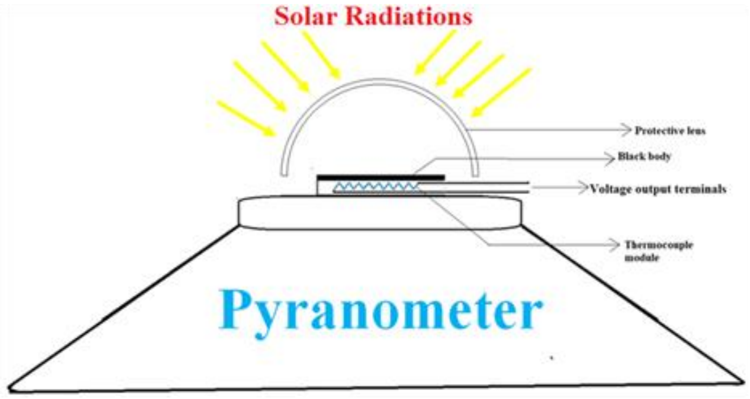
As solar radiation passes through the atmosphere, it is affected by absorption, scattering, and reflection by air molecules, water vapor, clouds, and pollutants, which reduce the intensity that reaches the surface. Typically, the maximum power of direct solar radiation at the Earth's surface on a clear day is about 1000 W/m².

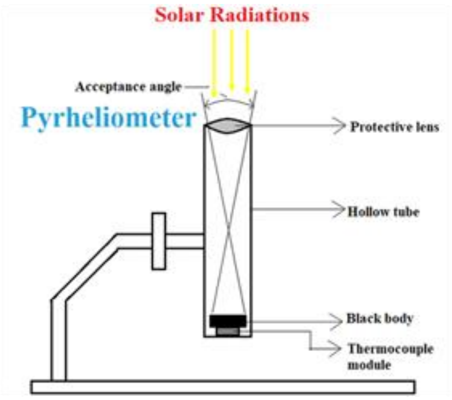
The amount of solar radiation received depends on factors such as:

- Geographic location (latitude)
- Time of day and season (solar angle)
- Atmospheric conditions, including cloud cover and pollution
- Local landscape and terrain features

Q.3

a) A **pyranometer** is an instrument used to measure solar irradiance, which is the power of sunlight received per unit area on a flat surface, expressed in watts per square meter (W/m²). It measures the combined solar radiation coming from the entire hemisphere above the sensor, including both direct sunlight and diffuse sky radiation. The device typically consists of a sensor covered by one or two glass or quartz domes that allow sunlight to reach the sensor while protecting it from environmental factors. The sensor converts the incident solar radiation into an electrical signal proportional to the radiation intensity. Pyranometers are designed with a "cosine response," meaning their sensitivity varies with the angle of incoming sunlight, accurately measuring radiation regardless of the sun's position in the sky. This ensures maximum response when sunlight strikes the sensor perpendicularly and decreases as the angle changes. They are widely used in meteorology, climatology, solar energy systems, and environmental science to monitor solar radiation for performance evaluation and research purposes. Pyranometers are also classified into various types based on their sensor technology and accuracy levels.





b)

A **pyrheliometer** is an instrument used to measure the **direct beam solar irradiance**, which is the amount of solar energy per unit area received directly from the sun on a surface perpendicular to the sun's rays. It measures the solar radiation that comes in a straight line from the sun without being scattered or diffused by the atmosphere.

How it works:

- Sunlight enters the pyrheliometer through a quartz glass window.
- The radiation is focused onto a black absorber plate.
- The absorber heats up, producing heat which is converted into an electrical signal by a thermopile sensor.
- The electrical signal is proportional to the intensity of the solar radiation and is measured in watts per square meter (W/m^2).

Key features:

- Typically mounted on a solar tracker that keeps the instrument aligned with the sun's position throughout the day.
- Measures only direct normal irradiance (DNI).
- Has a limited field of view to exclude scattered sunlight.

Applications:

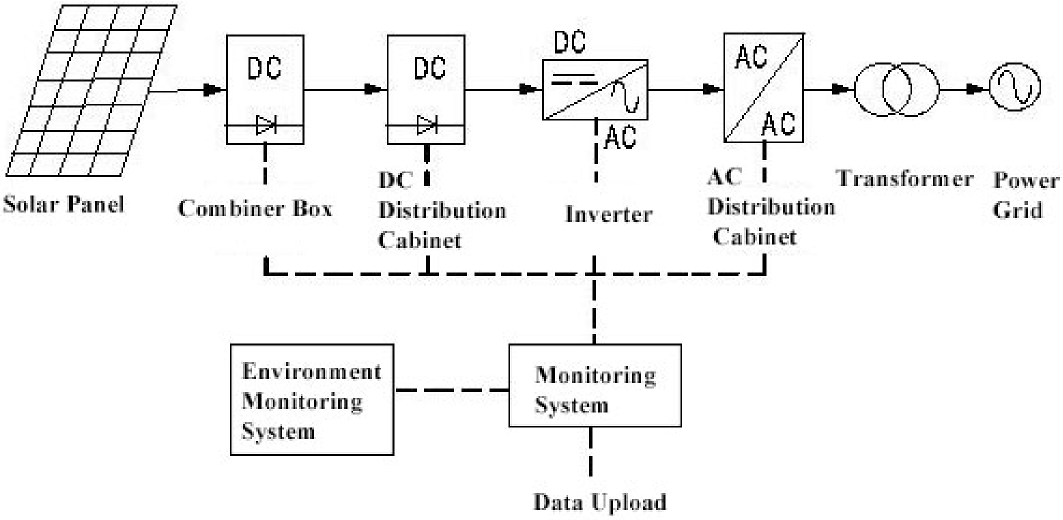
- Used in meteorological studies.
- Solar energy system performance assessments.
- Climate research and solar resource assessments.

Q.4

a) A photovoltaic (PV) system consists of several key components, each serving a specific function to convert sunlight into usable electrical energy:

1. **Solar PV Panels (Solar Array):** Composed of multiple solar cells, these panels capture sunlight and convert it into direct current (DC) electricity through the photovoltaic effect.
2. **Inverter:** Converts the DC electricity produced by the solar panels into alternating current (AC), which is compatible with household appliances and the electricity grid.
3. **Battery Bank (optional):** Stores excess electricity generated during the day for use during nighttime or periods without sunlight, providing energy autonomy.
4. **Charge Controller:** Regulates the charging of batteries to prevent overcharging or deep discharge, thereby extending battery life and ensuring safe operation.

5. **Mounting Structures:** Securely hold the solar panels in place, ensuring the optimal tilt and orientation to maximize sunlight absorption.
6. **Wiring and Electrical Connections:** Connect all system components for safe and efficient power transfer, including connectors, switches, and safety devices.
7. **Utility Meter (in grid-tied systems):** Monitors power flow between the solar system and the grid, enabling net metering and energy management.



b) Key design considerations for solar power plants include:

1. **Site Selection:** Choose locations with high solar irradiance, minimal shading, flat terrain, and suitable soil stability. Proximity to grid infrastructure reduces transmission costs.
2. **Solar Panel Orientation and Tilt:** Optimize panel angle and direction (usually facing true south in the Northern Hemisphere) to maximize sunlight capture throughout the year.
3. **Solar Technology and Modules:** Select high-efficiency, durable solar panels. Consider options like bifacial panels that capture sunlight from both sides for greater output.
4. **Energy Storage:** Incorporate batteries or other storage solutions to supply power during low sunlight or nighttime, improving reliability.
5. **System Layout and Spacing:** Design row spacing to prevent shading, ensure airflow, and maximize land utilization without compromising efficiency.
6. **Electrical Design:** Properly configure wiring, inverters, transformers, and protective devices to reduce losses and ensure safety.
7. **Monitoring and Maintenance:** Install real-time monitoring systems to detect faults and optimize performance. Plan for regular maintenance to extend system life.
8. **Environmental and Regulatory Compliance:** Conduct environmental impact assessments, secure permits, and adhere to local regulations to ensure smooth project execution.
9. **Structural and Civil Engineering:** Design mounting structures to withstand local climate and weather conditions, including wind and snow loads.
10. **Economic Feasibility:** Account for capital costs, operational expenses, incentives, and return on investment to ensure the project's financial viability.

Q.5

a) A **Horizontal Axis Wind Energy Power Plant** primarily uses Horizontal Axis Wind Turbines (HAWTs) to convert wind energy into electrical power. These turbines have their main rotor shaft and blades aligned horizontally and typically face into the wind for efficient energy capture.

Components and Working:

- **Rotor Blades:** Usually, three blades shaped like airplane wings that rotate when pushed by the wind, converting kinetic energy to mechanical energy.
- **Hub and Shaft:** The blades are attached to a hub connected to a main shaft that transfers mechanical energy.
- **Gearbox:** Increases the rotational speed from the slow-turning rotor shaft to a faster speed suitable for the generator.
- **Generator:** Converts mechanical rotation into electrical energy.
- **Nacelle:** Houses the gearbox, generator, and control systems; mounted on top of the tower.
- **Tower:** Supports the nacelle and blades at a height where wind speeds are stronger and more consistent.
- **Yaw System:** Rotates the nacelle to keep the turbine facing the prevailing wind.
- **Controller:** Starts, stops, and regulates turbine functions based on wind speed and safety.

The wind drives the rotor blades, rotating the shaft inside the nacelle. The gearbox steps up the rotation speed to the generator, which produces electrical power fed into the grid. The yaw system aligns the turbine with wind direction, optimizing energy capture.

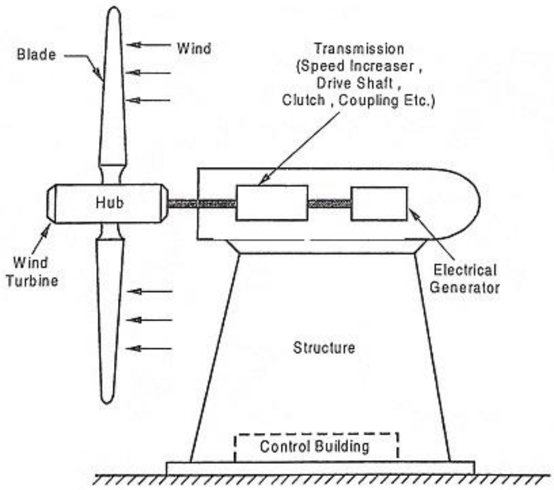


Fig:4.28 Wind - Electric Generating Power Plant.

b) The energy extraction through wind turbines depends on several key parameters:

1. **Wind Speed (V):** The power extracted varies with the cube of the wind speed, meaning even small increases in wind speed significantly raise power output. High and consistent wind speeds are essential for efficient energy harvest.
2. **Air Density (ρ):** Power is directly proportional to air density, which varies with altitude, temperature, and humidity. Denser air contains more kinetic energy to convert into mechanical energy.
3. **Swept Area (A):** The area swept by the turbine's blades (proportional to the square of the blade length) determines how much wind energy can be captured. Larger blades capture more energy.
4. **Power Coefficient (Cp):** Represents the efficiency of a turbine in converting kinetic wind energy into mechanical energy. Theoretical maximum Cp is 0.592 (Betz Limit), practical turbines have Cp values from 0.3 to 0.5.
5. **Blade Tip Speed Ratio (λ):** The ratio of blade tip speed to wind speed affects aerodynamic efficiency. Optimal λ balances lift and drag for maximum power.
6. **Blade Pitch Angle (β):** Adjusting the angle of blades controls the power output and helps protect turbines at high wind speeds.
7. **Number of Blades:** Affects torque and rotational speed; typical turbines have 2-3 blades for optimal balance between efficiency and mechanical stability.
8. **Turbulence and Wind Shear:** Variations in wind speed and direction due to obstacles or terrain can reduce turbine performance and increase mechanical stress.
9. **Operational Parameters:** Cut-in and cut-out wind speeds, yaw mechanism efficiency, and control systems also influence energy extraction.

Q.6

a) A dry steam geothermal power plant works by directly using steam from an underground geothermal reservoir to drive a turbine connected to a generator, producing electricity. The steam is extracted from the earth through production wells, passed through filters to remove debris, then directed onto turbine blades which spin the turbine. The generator coupled with the turbine produces electricity. After passing through the turbine, the steam is condensed back into water in a condenser and then re-injected into the reservoir to sustain the resource.

Working Steps with Schematic Explanation

- **Steam Extraction:** Steam is brought up directly from the dry steam geothermal reservoir through production wells.
- **Filtration:** The steam passes through filters that remove rocks or debris to protect the turbine blades.
- **Turbine Rotation:** The high-pressure steam strikes the turbine blades causing the turbine to rotate.
- **Electricity Generation:** The turbine shaft drives the generator to produce electricity.
- **Condensation:** Exhaust steam from the turbine goes to a condenser where it is cooled into water.
- **Re-injection:** The condensed water is pumped back into the earth through injection wells to maintain reservoir pressure and sustainability.

Main Components

- **Production Well:** Well drilled into the geothermal reservoir to extract steam.
- **Steam Separator:** (If necessary) separates steam from any remaining water.
- **Filters:** Mesh filters to clean steam before turbine.
- **Turbine:** Converts steam's kinetic energy into mechanical energy.
- **Generator:** Converts mechanical energy from turbine into electrical energy.
- **Condenser:** Cools down exhaust steam to water.
- **Injection Well:** Returns condensed water back underground.

Schematic Diagram Description

- The schematic generally shows steam rising from the underground dry steam reservoir via production wells, moving through filters into the turbine. The turbine shaft connects to the generator. Exhaust steam from the turbine flows to a condenser. Condensed water is then injected back underground. Cooling towers may be present to assist condensation.
- This plant operates on a simple principle by directly using steam without any water flashing process, typically requiring steam at about 150°C or higher.

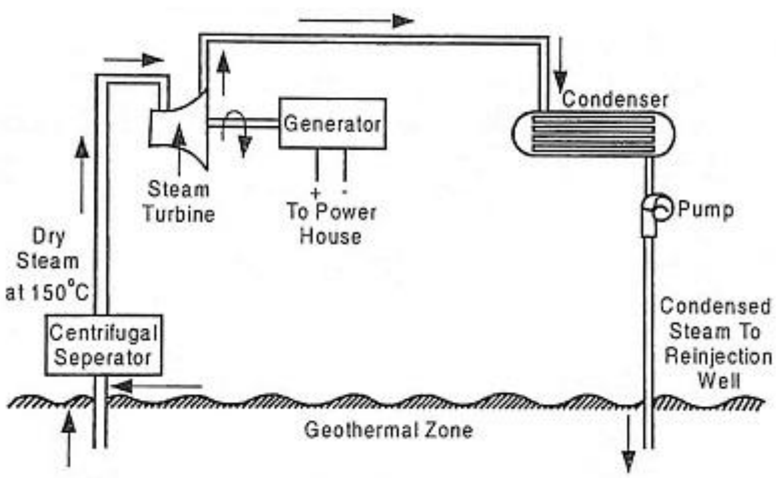


Fig. 4.48 Dry Steam Open System

b) The main problems with geothermal conversions include the following:

1. Location Specificity: Geothermal energy can only be effectively harnessed in certain geologically active regions, limiting its availability and usefulness in many areas, especially urban centers far from these sites. This restricts widespread adoption.
2. High Initial Costs: Setting up geothermal systems, especially residential heat pumps or large power plants, involves significant upfront investments, which can be a financial barrier for many.
3. Environmental Concerns: Geothermal processes may release gases like hydrogen sulfide and carbon dioxide, although these emissions are far lower than fossil fuels. Also, disposal of geothermal fluids, which may contain toxic materials, poses environmental challenges.
4. Induced Seismicity: The drilling and injection activities involved can alter underground pressures and stresses, sometimes causing small earthquakes or tremors (induced seismicity), which is a notable risk and public concern.
5. Resource Depletion Risk: Geothermal reservoirs can cool down or steam pressure can diminish over time if heat extraction is not managed sustainably, leading to a decline in energy production.
6. Infrastructure Limitations: There is limited existing infrastructure for geothermal energy extraction and distribution, and such energy typically serves as baseload power that cannot be easily moved across grids, posing challenges for integration.
7. Technical Challenges: The drilling process can be difficult and costly due to the high temperatures underground and wear of equipment. Retrofitting existing buildings to use geothermal heat can be complex and expensive.

Q.7

a) There are mainly three different ways to extract energy through tides, each utilizing the potential or kinetic energy of tidal waters:

1. Tidal Barrage

- This method exploits the **potential energy** created by the difference in height (hydraulic head) between high and low tides.
- A dam-like structure (barrage) is built across the mouth of a tidal basin or estuary.
- During high tide, water flows into the basin through sluice gates. When the tide starts to fall, the stored water is released back to the sea via turbines in the barrage.
- The falling water drives turbines to generate electricity.
- Modes of operation include ebb generation, flood generation, and two-way generation.
- This is the oldest and most established tidal energy extraction method.

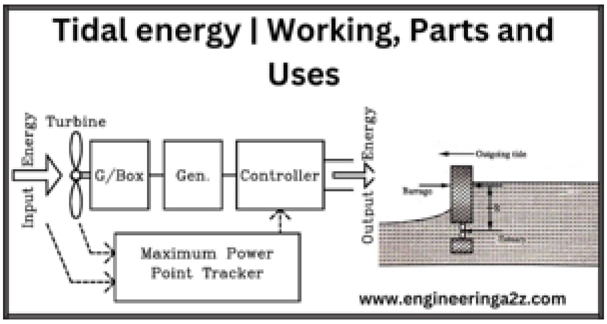
2. Tidal Stream Generators

- These devices capture the **kinetic energy** of moving tidal waters (tidal currents).
- Similar to underwater wind turbines, turbines are placed in fast-flowing tidal streams, straits, or channels with strong tidal currents.
- Turbines can be horizontal-axis or vertical-axis and may be mounted on the seabed or floating.
- As water flows past, it turns the turbine blades, generating electricity.
- This method is less ecologically disruptive and can be sited in various locations with strong tidal flows.

3. Dynamic Tidal Power (DTP)

- A newer concept involving building a long dam-like structure perpendicular to the coast without enclosing an area.
- This creates a difference in water height on either side of the dam due to tidal phase differences.
- Turbines installed in the dam convert this potential energy into electricity.
- DTP aims to combine the advantages of tidal barrage and tidal stream methods.

Each method has pros and cons. Barrages can generate large amounts but impact ecosystems; tidal stream generators are less intrusive but depend on strong currents; DTP is promising but unproven on large scale.



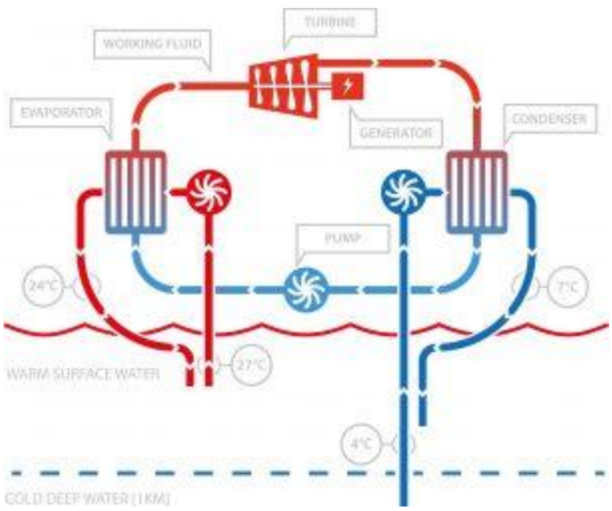
b) There are several different ways to extract energy from ocean waves, using various wave energy converter (WEC) technologies. The main methods include:

1. Wave Profile Devices (Point Absorbers):
- These devices capture energy from the oscillating vertical movement of waves.
- Example: Buoy-like floating absorbers that rise and fall with the waves.
- Mechanical or hydraulic systems convert this motion into electricity.
- Typically moored offshore with a heavy reaction mass or anchored to the sea floor.

2. Oscillating Water Columns (OWC):
- These devices use the wave-induced rise and fall of water inside a chamber to compress and decompress air.
- The moving air drives an air turbine connected to a generator.
- The chamber is usually built onshore or nearshore with a partially submerged opening.

3. Wave Capture Devices (Overtopping Devices):
- These devices raise the waves higher than their normal level by a ramp or funnel mechanism.
- The elevated water is collected in a reservoir.
- Its potential energy is converted back into electricity using a low-head turbine as the water flows back to the sea.

4. Surface Attenuators:
- Long floating structures aligned perpendicular to wave direction.
- They flex and bend as waves pass, and this motion drives hydraulic pumps or generators.



Q. 8

a) Ocean Thermal Energy Conversion (OTEC) is a renewable energy technology that generates electricity by exploiting the temperature difference between warm surface seawater and cold deep seawater in tropical oceans.

Working Principle of OTEC:

OTEC operates on a thermodynamic cycle that converts thermal energy from the ocean into mechanical energy, which is then converted into electricity. The key requirement is a temperature difference of about 20°C or more between the warm surface water (around 25°C) and cold deep water (around 5°C).

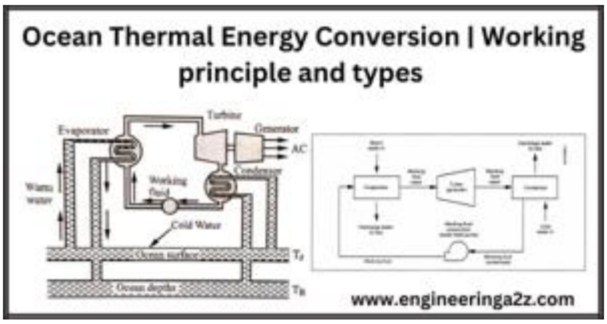
There are mainly two types of OTEC systems:

1. **Closed-Cycle OTEC:**
    - Warm surface seawater flows through a heat exchanger (evaporator) where it transfers heat to a working fluid with a low boiling point, such as ammonia or freon.
    - The working fluid vaporizes and the high-pressure vapor drives a turbine connected to a generator that produces electricity.
    - The vapor then passes through a condenser where cold seawater from the deep ocean cools it back to liquid form.
    - The liquid working fluid is pumped back to the evaporator to continue the cycle, all within a closed loop.
2. **Open-Cycle OTEC:**
    - Warm seawater is pumped into a low-pressure container (vacuum chamber) where it boils and produces steam directly.
    - The steam drives a turbine connected to a generator.
    - After the turbine, the steam is condensed back to water by cold deep seawater in a condenser.
    - The condensed freshwater can be collected for use, making this method capable of desalination as well.

Key Points: Closed-cycle Ocean Thermal Energy Conversion (OTEC) system diagram

- OTEC utilizes renewable thermal gradients in tropical oceans.
- It can provide continuous (baseload) power unlike intermittent sources.
- Closed-cycle systems use an intermediate working fluid; open-cycle systems use seawater as the working fluid.
- Can also be used for freshwater production through desalination in open-cycle systems.

This conversion process exemplifies how ocean temperature differences can be harnessed for clean energy generation efficiently in suitable tropical locations.



b) The problems associated with Ocean Thermal Energy Conversion (OTEC) include:

1. High Initial Cost: The equipment purchase and installation for OTEC plants are expensive, making the technology less accessible for many countries and electricity providers.
2. Location Specificity: OTEC requires a significant temperature gradient (~20°C) between warm surface water and cold deep water, which occurs mainly in tropical regions near coastlines. This limits its applicability to a few suitable geographic locations, excluding many nations.
3. Low Energy Conversion Efficiency: The small temperature difference severely limits the thermodynamic efficiency of the OTEC cycle, generally around 3-5%, making power generation economically challenging.

4. Technical Challenges: Large, efficient heat exchangers and cold-water pipes that reach deep into the ocean (2-3 km) are needed, making engineering complex and costly. The size and durability of turbines and components are also major issues.
5. Environmental Impact: The installation of deep-water pipes and pumps can interfere with marine ecosystems, potentially harming small marine organisms and affecting shipping routes in some locations.
6. Limited Scalability and Infrastructure: OTEC plants currently face problems scaling up to commercial capacities. Transmission of electricity from offshore plants to the mainland grid also poses logistical challenges.
7. Competition with Other Renewables: OTEC competes with more mature and cost-effective renewable technologies like solar and wind, which may limit its adoption

Q.9

a) A fixed dome biogas power plant is a type of biogas plant where the digester and the gas holder are combined in a single, fixed, dome-shaped structure. It is designed for the anaerobic digestion of organic waste, such as cattle dung mixed with water, to produce biogas primarily composed of methane.

Components of Fixed Dome Biogas Plant:

- **Digester Tank**: An underground, airtight chamber usually made of brick and cement with a dome-shaped roof. The dome acts as a gas holder.
- **Inlet Pipe and Mixing Tank**: Where slurry (a mix of cattle dung and water) is prepared and fed into the digester.
- **Outlet or Overflow Tank**: Where the digested slurry (spent slurry) is displaced as biogas accumulates.
- **Gas Outlet Pipe**: At the top of the dome, leading biogas to external use with a gas valve controlling flow.

Working Principle:

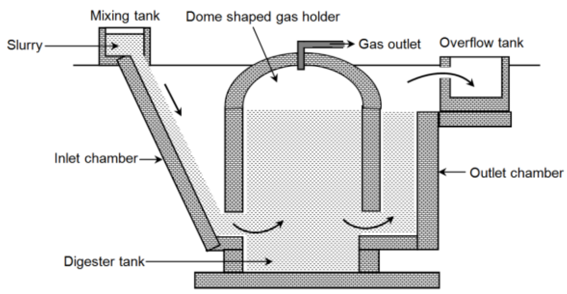
- Organic waste mixed with water is fed into the digester.
- Anaerobic microorganisms break down the waste in the absence of oxygen, producing biogas.
- The biogas accumulates in the dome-shaped roof, increasing gas pressure.
- As gas accumulates, it displaces the digested slurry into the overflow tank.
- Biogas is withdrawn through the outlet pipe for use in cooking, heating, or power generation.
- The spent slurry removed from the overflow tank is nutrient-rich and used as organic fertilizer.
- This process is continuous with daily feeding of fresh slurry and removal of spent slurry.

Advantages:

- Low construction cost due to simple design.
- No moving parts and no corrosion-prone steel parts, ensuring long life (20+ years).
- Underground construction protects from external damage and temperature fluctuations.

Disadvantages:

- Gas pressure fluctuates, affecting gas delivery consistency.
- Construction requires skilled supervision to ensure gas-tightness and avoid leaks.
- Fixed volume design limits plant size (usually up to 20 m^3).



b) Gasification is a thermochemical process that converts carbonaceous materials such as biomass or coal into a combustible gas mixture called syngas (synthesis gas) through partial oxidation at high temperatures with limited oxygen.

Working Principle of Gasification:
The gasification process involves several key stages inside a gasifier reactor:

1. **Drying:** The moisture in the feedstock is evaporated as the temperature rises to about 100°C.
2. **Pyrolysis:** At 200–300°C, the solid biomass decomposes into volatile gases and solid char.
3. **Combustion:** Partial oxidation of fuel with a controlled amount of oxygen generates heat and produces CO2 and CO.
4. **Reduction:** The char reacts with CO2 and steam at high temperatures to produce carbon monoxide (CO), hydrogen (H2), and methane (CH4).
5. **Cracking:** Large complex hydrocarbons (tars) break down into simpler gases under high temperature.

The syngas generated mainly consists of CO, H2, CO2, CH4, and nitrogen.

Q.10

a) Hydrogen production by the electrolysis method involves using electricity to split water (H2O) into hydrogen (H2) and oxygen (O2) gases. This process takes place in an electrolyzer, which consists of an anode and a cathode separated by an electrolyte.

Working Principle:

- When electric current is passed through water, electrochemical reactions occur at the two electrodes.
- At the **anode** (positive electrode), water molecules lose electrons (oxidation) to produce oxygen gas and hydrogen ions (protons).

  Anode reaction: $2H_2O \rightarrow O_2 + 4_H + + 4e^-$

The hydrogen ions move through the electrolyte to the **cathode** (negative electrode).

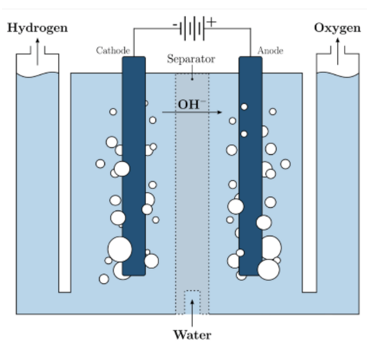
- At the cathode, hydrogen ions gain electrons (reduction) to form hydrogen gas.

  Cathode reaction: $4H^+ + 4e^- \rightarrow 2H_2$

- The overall chemical reaction is: $2H_2O(l) \rightarrow 2H_2(g) + O_2(g)$

Types of Electrolysis:

1. **Alkaline Electrolysis**: Uses a liquid alkaline electrolyte, commonly potassium hydroxide (KOH). Electrodes are submerged in the electrolyte solution.
2. **Proton Exchange Membrane (PEM) Electrolysis**: Uses a solid polymer electrolyte membrane that allows only protons to pass through, separating the hydrogen and oxygen gases.
3. **Solid Oxide Electrolysis**: Operates at high temperatures with a ceramic electrolyte conducting oxygen ions.



b) The advantages of hydrogen energy are:

1. **Clean and Zero Emissions**: Hydrogen fuel produces only water and heat when used in fuel cells, with no greenhouse gases or pollutants, improving air quality and reducing carbon footprint.
2. **High Energy Efficiency**: Hydrogen fuel cells convert chemical energy directly into electrical energy with efficiencies greater than 60%, surpassing traditional combustion engines.
3. **Energy Storage and Flexibility**: Hydrogen can store excess renewable energy (solar, wind) for later use, helping stabilize power grids and providing energy on demand.
4. **Versatility**: Hydrogen fuel can be used in various sectors, including transportation, industrial processes, stationary power generation, and portable devices.
5. **Energy Security and Local Production**: Hydrogen can be produced domestically from diverse sources (water, biomass, natural gas), reducing dependence on imported fossil fuels.
6. **Supports Renewable Energy Integration**: It helps balance intermittent renewables by serving as a clean energy carrier and fuel.
7. **Job Creation and Economic Growth**: The emerging hydrogen economy has the potential to create millions of jobs and stimulate economic development globally.
8. **Lightweight and Long-Range Applications**: Hydrogen's high energy density benefits heavy-duty transport and long-distance travel better than batteries.