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CAI 335 : SOLAR AND WIND ENERGY SYSTEMS

UNIT 5

ALTERNATE ENERGY SOURCES

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Ocean Energy: Overview and Importance

Ocean energy refers to the power derived from the vast amount of energy contained in the world's oceans. It includes various forms of energy that can be harnessed from the sea, such as tidal, wave, ocean thermal, and salinity gradient energy. The oceans are a largely untapped source of renewable energy, with vast potential to help meet global energy demands while reducing reliance on fossil fuels.

Ocean energy is considered a reliable and sustainable form of energy because the oceans offer predictable and consistent sources of energy, unlike solar or wind, which are more intermittent. The technologies to capture ocean energy are still developing, but significant progress has been made in both **offshore** and **onshore** ocean energy conversion systems.

Types of Ocean Energy

Ocean energy can be classified into four main categories:

1. **Tidal Energy**: The energy generated from the rise and fall of tides.
2. **Wave Energy**: The energy generated from the motion of surface waves.
3. **Ocean Thermal Energy**: The energy derived from the temperature difference between the surface water and deep water of the ocean.
4. **Salinity Gradient Energy**: The energy generated from the difference in salinity between freshwater and seawater (also known as **blue energy**).

Offshore and Onshore Ocean Energy Conversion Technologies

Ocean energy conversion technologies can be broadly divided into **offshore** and **onshore** systems, depending on where the energy is captured and the technology is installed. Offshore systems typically harness energy from the deep ocean, while onshore systems may be located along coastlines or in estuaries, closer to shore.

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1. Offshore Ocean Energy Conversion Technologies

Offshore ocean energy technologies are used to harness energy from the deep ocean and typically involve the installation of energy devices at sea. These technologies include tidal stream turbines, wave energy converters, and ocean thermal energy conversion (OTEC) systems.

a) Offshore Tidal Energy Systems

Tidal energy is generated by the gravitational pull of the moon and the sun, causing regular and predictable rises and falls in the sea level. Offshore tidal energy systems capture this energy using tidal stream turbines or tidal range technologies.

- **Tidal Stream Turbines**: These are essentially underwater wind turbines that use the flow of tidal currents to generate electricity. The turbines are installed on the seafloor and are driven by the horizontal movement of water.
    - **Example**: The **Seagen Tidal Turbine** in Northern Ireland is one of the largest tidal stream turbine projects, with two 1.2 MW turbines generating power.
- **Tidal Range Energy**: This system works by capturing the potential energy created by the difference in water level between high and low tides. **Tidal barrage** systems use a dam-like structure across the entrance to an estuary or bay. The water flows through turbines in the barrage when the tide rises and falls, generating electricity.
    - **Example**: The **La Rance Tidal Power Station** in France is one of the most well-known tidal barrage projects.

b) Offshore Wave Energy Systems

Wave energy harnesses the energy produced by the motion of ocean waves. The energy captured from waves can be converted into electricity through various technologies.

- **Point Absorbers**: These floating devices are anchored to the seabed and move with the motion of the waves. They typically consist of a buoy that moves up and down or back and forth in response to wave motion, which drives a generator.
    - **Example**: The **Pelamis Wave Energy Converter** was one of the first wave energy systems designed as a floating snake-like structure, with each segment of the system moving with the waves to generate power.
- **Oscillating Water Columns (OWC)**: These systems use the movement of waves to push air through a turbine. As waves move up and down, the water column inside the structure moves, forcing air through a turbine, which generates electricity.
    - **Example**: The **Oyster Wave Energy Converter** in Scotland is a wave energy device that uses the motion of waves to generate power by driving hydraulic pistons.
- **Attenuators**: These long, floating structures are aligned parallel to the direction of wave movement and are designed to flex as waves pass by. The movement between sections of the device drives hydraulic pumps, which then generate electricity.
    - **Example**: The **Wave Dragon** is a floating wave energy device that works on the principle of capturing and converting wave energy.

c) Ocean Thermal Energy Conversion (OTEC)

Ocean Thermal Energy Conversion (OTEC) uses the temperature difference between warm surface water and cold deep-sea water to generate electricity. This process works through a heat engine, often using ammonia or another working fluid that evaporates and condenses in a closed loop.

- **Closed-Cycle OTEC**: Warm surface water is used to vaporize a working fluid, which then drives a turbine connected to a generator. The fluid is then cooled by cold deep-sea water and condensed to repeat the process.
- **Open-Cycle OTEC**: In this system, warm surface water itself is used as the working fluid. It is evaporated to produce steam, which drives a turbine. The steam is then condensed using cold deep-sea water.
  - **Example**: The **NELHA OTEC Plant** in Hawaii is one of the few operational OTEC plants, demonstrating the potential of this technology.

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2. Onshore Ocean Energy Conversion Technologies

Onshore ocean energy systems are installed on the coastline or in estuaries. These technologies typically involve tidal energy systems, wave energy systems, and salt gradient energy systems. These systems may involve less complexity than offshore systems, as they do not need to withstand harsh deep-sea conditions.

a) Onshore Tidal Energy Systems

Onshore tidal energy systems are similar to offshore tidal technologies but are often smaller and located closer to the shore. They typically involve tidal range systems, such as **tidal lagoons** and **tidal barrage** systems.

- **Tidal Lagoons**: These systems use a natural or man-made lagoon, where the incoming and outgoing tides are trapped and used to drive turbines that generate electricity. A tidal lagoon can be created in estuaries or along the coastline to harness tidal energy.
  - **Example**: The proposed **Swansea Bay Tidal Lagoon** in Wales is a project designed to create a lagoon that will generate electricity from tidal range energy.
- **Tidal Barrages**: These systems are similar to tidal lagoons but use barriers or dams to block off sections of the coastline, creating a difference in water levels that drives turbines. These can be located near shore or in estuaries.
  - **Example**: The **Severn Estuary Tidal Barrage** (a proposed project) aims to harness the tidal range in the Severn Estuary to generate large-scale electricity.

b) Onshore Wave Energy Systems

Onshore wave energy systems are typically smaller and located close to the shore, in places where wave energy is abundant. The technologies often capture the energy of nearshore waves.

- **Overtopping Devices**: These systems are typically installed on the coastline, where waves are directed to flow over a ramp into a reservoir. The water then flows back through turbines to generate power.

- **Example**: The **Wave Dragon** is a device that uses an overtopping technique and could be deployed close to shore.
- **Submerged Pressure Differential Devices**: These systems are installed just below the surface of the water and use the change in pressure caused by the passing waves to drive turbines.
    - **Example**: The **CETO Wave Energy Converter** is a submerged device that uses the movement of waves to generate electricity.

c) Salinity Gradient Energy (Blue Energy)

Salinity gradient energy, or **blue energy**, harnesses the difference in salt concentration between freshwater and seawater. The two main technologies used are **Pressure Retarded Osmosis (PRO)** and **Reverse Electrodialysis (RED)**.

- **Pressure Retarded Osmosis (PRO)**: This process uses a semi-permeable membrane to allow freshwater and seawater to mix. The pressure difference created between the two solutions can be used to drive a turbine to generate power.
- **Reverse Electrodialysis (RED)**: This system uses ion-selective membranes to create a voltage potential between freshwater and seawater. The flow of ions through the membranes generates electricity.

These technologies are still in the research and development phase, but they offer the potential to harness energy from estuaries, rivers, or coastal areas where freshwater meets seawater.

Challenges and Opportunities in Ocean Energy

Challenges:

- **Environmental Impact**: The construction of offshore and onshore ocean energy systems can have environmental impacts on marine life, ecosystems, and local communities. Careful planning and environmental assessments are required to mitigate these effects.
- **High Costs**: The development, installation, and maintenance of ocean energy systems, particularly offshore systems, are expensive due to the harsh operating conditions and technological complexity.
- **Technology Development**: Many ocean energy technologies are still in the research and pilot phase, and large-scale deployment remains a challenge. More research and development are needed to improve efficiency, reduce costs, and scale up production.

Opportunities:

- **Predictable Energy Source**: Unlike solar and wind energy, ocean energy is highly predictable and can offer a reliable power source.

- **Global Potential**: With oceans covering about 70% of the Earth's surface, ocean energy has vast untapped potential to contribute to the global energy mix, particularly in coastal regions.
- **Sustainability**: Ocean energy is a renewable and sustainable source of energy, contributing to the reduction of greenhouse gas emissions and dependence on fossil fuels.

Conclusion

Ocean energy offers significant potential for diversifying the global energy portfolio and contributing to a sustainable energy future. Offshore and onshore ocean energy conversion technologies, such as tidal, wave, ocean thermal, and salinity gradient energy systems, are continuously evolving and becoming more efficient. While challenges such as high costs, environmental concerns, and technological maturity remain, the potential of ocean energy to provide clean, reliable, and predictable energy makes it an exciting area for future development and investment.

Ocean Thermal Energy Conversion (OTEC) Principles: Open and Closed Cycles

Ocean Thermal Energy Conversion (OTEC) is a process that harnesses the thermal energy stored in the ocean. It is based on the principle that there is a significant temperature difference between the warm surface waters and the colder deep waters of the ocean. This temperature gradient can be used to generate electricity by driving a heat engine, much like a traditional power plant uses steam to turn turbines.

OTEC systems typically utilize the temperature difference between the warm surface waters and cold deep-sea water to power a turbine. There are two main types of OTEC systems: **Open-Cycle OTEC** and **Closed-Cycle OTEC**. Both systems rely on this temperature differential but use different methods to convert thermal energy into electrical energy.

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1. Open-Cycle OTEC (OC-OTEC)

Open-Cycle OTEC works by using the warm surface water directly to create steam that drives a turbine. This process is somewhat similar to the way a traditional steam power plant works, but it uses the ocean's warm water as the heat source.

Principle of Operation

1. **Warm Surface Water Evaporates the Working Fluid**:
   In an open-cycle OTEC system, warm surface seawater (typically 25–30°C) is pumped into a low-pressure vessel, often called an **evaporator**. As the warm water enters, it is used to **evaporate a working fluid** (usually ammonia) that has a very low boiling point (about -33°C). This makes the ammonia evaporate easily even at relatively low temperatures.
2. **Turbine Rotation**:
   The **ammonia vapor** (now in gas form) is directed to a **turbine**, where it expands and spins the turbine blades. The turbine is connected to a generator, which produces electricity as the turbine spins.
3. **Condensation**:
   After the ammonia vapor passes through the turbine and loses its energy, it is then cooled using cold water from the deep ocean (around 4–5°C). The cold deep water condenses the ammonia gas back into liquid form.
4. **Recycling**:
   The ammonia liquid is then returned to the evaporator to repeat the cycle. The process relies on the constant availability of warm surface water and cold deep-sea water to keep the cycle running.

Advantages of Open-Cycle OTEC

- **No Need for a Heat Exchanger**: In open-cycle systems, the working fluid (ammonia) is evaporated directly by seawater, so there is no need for a heat exchanger. This can make the system simpler in terms of heat transfer mechanisms.
- **Desalination**: One of the by-products of the process is that the steam used to drive the turbine is pure freshwater, which can be used for desalination purposes, providing fresh water along with electricity.
- **Simple Design**: The design of open-cycle OTEC is relatively straightforward because it directly uses seawater and does not involve complex heat exchangers or multiple fluid cycles.

Challenges of Open-Cycle OTEC

- **Low Efficiency**: The temperature difference between warm surface water and cold deep-sea water is relatively small (usually around 20–25°C), which results in lower thermal efficiency compared to traditional power plants that use higher temperature gradients.
- **High Capital Costs**: Due to the specialized equipment needed (such as large pumps and turbines) and the need for infrastructure to withstand harsh marine environments, open-cycle OTEC systems can be expensive to build and maintain.
- **Environmental Concerns**: The system requires the extraction of large amounts of seawater, which could disrupt local marine ecosystems if not properly managed.

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2. Closed-Cycle OTEC (CC-OTEC)

In **Closed-Cycle OTEC**, the working fluid is contained within a closed loop and does not come into direct contact with the ocean water. This method is more similar to traditional power plants that use a heat exchanger to transfer heat between two fluids, but instead of burning fuel, OTEC uses the temperature difference in ocean water.

Principle of Operation

1. **Warm Surface Water Heats the Working Fluid**:
   In this cycle, warm surface seawater (around 25–30°C) is pumped into a heat exchanger, where it heats up a working fluid with a low boiling point, such as ammonia or refrigerant. Unlike open-cycle systems, the working fluid does not evaporate directly due to seawater; instead, it is heated by the surface water through the heat exchanger.
2. **Expansion of Working Fluid**:
   The working fluid absorbs heat and evaporates, turning into gas. This gas is then directed to a **turbine**, where it expands and rotates the turbine blades connected to a generator, producing electricity.
3. **Cooling via Deep Water**:
   After the working fluid passes through the turbine, it still contains energy but is now in gas form. This gas is then condensed back into a liquid by transferring heat to cold deep-sea water (typically around 4–5°C) via another heat exchanger.
4. **Recycling**:
   Once the working fluid is condensed into a liquid, it is pumped back to the evaporator (heat exchanger) to repeat the cycle. The process continues as long as there is a sufficient temperature difference between the surface water and deep-sea water.

Advantages of Closed-Cycle OTEC

- **Higher Efficiency**: Closed-cycle OTEC systems tend to have higher efficiency than open-cycle systems because the working fluid is contained within a closed loop and the energy extraction process is more controlled.
- **Better Control of Working Fluid**: Since the working fluid is not mixed with seawater, it can be optimized for better performance and efficiency. It also reduces the risk of contamination.
- **No Need for Desalination**: Unlike open-cycle OTEC, closed-cycle systems do not produce freshwater as a by-product, so desalination is not possible with this system.

Challenges of Closed-Cycle OTEC

- **Heat Exchanger Requirements**: The closed-cycle system requires large and efficient heat exchangers to transfer heat between the seawater and the working fluid. These heat exchangers are expensive and need to be very efficient to ensure that the system works effectively.

- **Corrosion Issues**: The harsh marine environment can lead to corrosion of materials, which may increase maintenance costs and reduce the lifespan of the system.
- **Higher Capital Costs**: Closed-cycle systems often involve more complex technology and infrastructure, leading to higher initial capital investment and maintenance costs.

Comparison of Open-Cycle and Closed-Cycle OTEC

Aspect	Open-Cycle OTEC (OC-OTEC)	Closed-Cycle OTEC (CC-OTEC)
Principle	Uses warm seawater to evaporate a working fluid (ammonia)	Uses warm seawater to heat a working fluid in a closed loop
Working Fluid	Directly uses seawater to evaporate ammonia	Uses a low-boiling-point fluid (e.g., ammonia or refrigerant)
Energy Generation	Steam is used to drive a turbine directly	Evaporated working fluid drives a turbine
By-Products	Freshwater (desalinated) from the evaporated seawater	None; only power generation
Efficiency	Lower efficiency due to small temperature gradient	Higher efficiency due to controlled working fluid and heat exchange
Environmental Impact	Minimal, as seawater is directly used	Some environmental concerns due to the use of heat exchangers and working fluids
Capital Cost	Relatively lower, but still expensive	Higher due to complexity and equipment requirements
Desalination	Produces freshwater as a by-product	Does not produce freshwater

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Conclusion

Both **Open-Cycle OTEC (OC-OTEC)** and **Closed-Cycle OTEC (CC-OTEC)** are promising renewable energy technologies that capitalize on the temperature differential between the warm surface waters and cold deep-sea waters. **OC-OTEC** is simpler and can provide both electricity and desalinated water, but it has lower efficiency and is more limited by environmental and capital costs. On the other hand, **CC-OTEC** is more efficient and provides better control over the working fluid, but it requires complex heat exchangers and incurs higher costs. Both technologies have their advantages and challenges, and the choice between them depends on factors such as location, energy demand, environmental considerations, and economic viability.