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CAI 335 : SOLAR AND WIND ENERGY SYSTEMS

UNIT 5

ALTERNATE ENERGY SOURCES

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Tidal Energy: High and Low Tides

Tidal energy is the energy generated by harnessing the rise and fall of tides, which are caused by the gravitational forces exerted by the moon and the sun on Earth's oceans. Tides occur in predictable cycles and are an important source of renewable energy. The movement of water from high to low tide (and vice versa) creates potential energy, which can be converted into mechanical or electrical energy using various technologies.

Tidal energy systems utilize the natural ebb (outgoing) and flow (incoming) of tides, and they can be classified based on how the energy is captured, such as **tidal range** and **tidal stream** systems. The efficiency and power generated by these systems depend heavily on the magnitude of high and low tides.

Understanding High and Low Tides

The **tides** are the periodic rise and fall of sea levels caused by the combined gravitational pull of the moon and the sun, along with the centrifugal force of Earth's rotation. The height of the tide changes throughout the day and depends on several factors, including the position of the moon relative to Earth, the sun's position, and geographical features such as coastlines, bays, and estuaries.

1. **High Tide (Flood Tide)**:
    - **High tide** occurs when the water level reaches its highest point during the tidal cycle. This typically happens twice a day in most coastal areas, although in some places there may be variations such as **semidiurnal** tides (two high tides per day) or **diurnal** tides (one high tide per day).
    - High tide occurs when the moon is either directly above or below a particular point on Earth, creating a **bulge** in the ocean due to the gravitational pull. This bulge causes the water level to rise.
2. **Low Tide (Ebb Tide)**:
    - **Low tide** is when the water level reaches its lowest point during the tidal cycle. It typically occurs twice a day, opposite to the high tide. Low tide happens when the point on Earth is not in alignment with the moon's gravitational pull, and the water level recedes.
    - Low tide is the result of the gravitational forces exerted by the moon being weaker at that point on Earth, causing water to retreat from the shore.

The difference in height between high and low tide is called the **tidal range**, and it is a critical factor in determining the potential for tidal energy generation in a given location. Areas with a **high tidal range** have a greater difference between high and low tides, making them ideal for energy generation.

Tidal Energy Technologies and Their Relationship to High and Low Tides

Tidal energy can be harnessed using two main approaches: **tidal range** systems and **tidal stream** systems. Both types of systems are heavily influenced by the variation between high and low tides.

1. Tidal Range Energy Systems (Tidal Barrages)

A **tidal range energy system** makes use of the difference in water level between high and low tides to generate electricity. The greater the difference in height between the two, the more potential energy is available to be captured.

- **Tidal Barrage**:
    - A **tidal barrage** is a dam-like structure built across the entrance to an estuary or a bay. This system traps water during high tide and releases it during low tide, using turbines to generate power.
    - During **high tide**, the water level inside the barrage is higher than the water outside. When the tide starts to go out (ebbing tide), the water inside the barrage is released through turbines that generate electricity. Conversely, during **low tide**, the water outside the barrage is higher, and the turbines are used to release water to generate power as the tide comes in.
    - **Power Generation Cycle**:
        1. **Flood Cycle (High Tide)**: When the tide is rising, the sluice gates of the barrage are closed, trapping the water at the higher level. The turbines are not used yet.
        2. **Ebb Cycle (Low Tide)**: As the tide recedes, the sluice gates are opened, and the water flows through the turbines, generating power.
        3. **Repeat Cycle**: The process repeats every 12.5 hours (for semidiurnal tides), depending on the tidal schedule in the region.
    - **Example**: The **La Rance Tidal Power Station** in France is one of the most famous tidal barrage projects. It has been in operation since 1966 and generates around 240 MW of power.
    - **Advantages**:
        - Can generate a significant amount of power in areas with large tidal ranges (over 5 meters).
        - The technology is mature and proven in practice.
    - **Challenges**:
        - High initial capital cost and complex infrastructure.
        - Potential environmental impact, such as disrupting local marine ecosystems and sediment transport.
        - Suitable only for locations with significant tidal ranges.

2. Tidal Stream Energy Systems (Tidal Turbines)

Tidal stream energy systems use the kinetic energy of moving water (caused by the tides) to generate electricity. These systems are similar to underwater wind turbines, with turbines placed in areas with strong tidal currents to capture the energy from the flow of water.

- **Tidal Stream Turbines**:
  - These turbines are installed in areas where the flow of tidal water is strong, such as narrow channels, straits, or between islands where tidal currents are concentrated.
  - As the tide rises (high tide) and falls (low tide), the water flows through the turbines, causing them to rotate and generate electricity.
  - Tidal stream systems work during both high and low tides as the water flow is what drives the turbines, rather than relying on the change in water level like tidal range systems.
  - **Example**: The **Seagen Tidal Turbine** in Northern Ireland is a leading example of tidal stream technology, capable of generating up to 1.2 MW from the tidal currents of Strangford Lough.
  - **Advantages**:
    - Tidal stream turbines can be deployed in areas with relatively smaller tidal ranges but high tidal velocities.
    - Less intrusive and environmentally impactful compared to tidal barrage systems, as they do not involve large-scale barriers.
  - **Challenges**:
    - Suitable locations for tidal stream turbines are limited to areas with strong tidal currents.
    - The technology is still in the development and pilot phase, with efficiency and cost issues remaining to be addressed.

Tidal Range and Its Effect on Power Generation

The **tidal range**, which is the difference between high and low tide, directly impacts the power generation capacity of tidal energy systems, particularly tidal range (barrage) systems. Locations with a larger tidal range have more energy available for capture, while those with a smaller tidal range will have lower energy potential.

High Tidal Range (Large Difference Between High and Low Tides)

- **Ideal for Tidal Range Systems**: A larger tidal range creates a greater difference in water levels, which increases the potential energy that can be harnessed. High tidal ranges, often found in coastal areas with deep, narrow bays or estuaries, are the best sites for tidal barrage systems.

- **Example Locations**: The **Bay of Fundy** (Canada) is famous for having the world's highest tidal range, with variations of up to 16 meters between high and low tides. This provides enormous potential for tidal energy generation.

Low Tidal Range (Small Difference Between High and Low Tides)

- **Less Suitable for Tidal Range Systems**: Locations with a smaller tidal range (less than 2 meters) are less suited for tidal barrage systems, as the energy potential from the height difference is too small to generate significant amounts of electricity.
- **Potential for Tidal Stream Systems**: Areas with low tidal ranges but strong tidal currents can still be suitable for tidal stream turbines. Tidal stream technology is based on the kinetic energy of moving water rather than the height difference, so it can work effectively in areas with strong tidal flows, even if the tidal range is small.

Conclusion

Tidal energy is a promising renewable energy source that relies on the gravitational forces between the Earth, moon, and sun, which cause the periodic rise and fall of tides. The difference between **high tides** and **low tides** creates significant energy potential that can be harnessed using **tidal range systems** (e.g., tidal barrages) or **tidal stream systems** (e.g., tidal turbines). High tidal ranges are ideal for tidal range systems, which exploit the change in water height, while low tidal ranges can still support tidal stream turbines that capture energy from the motion of water. Despite challenges such as high capital costs and potential environmental impacts, tidal energy offers a reliable and predictable source of renewable power.

Tidal Power and Tidal Energy Conversion

Tidal power or **tidal energy** is a form of renewable energy that uses the natural rise and fall of ocean tides, caused primarily by the gravitational forces of the moon and the sun, to generate electricity. This type of energy has the potential to be highly reliable because tidal movements are predictable, unlike solar or wind energy, which can fluctuate based on weather conditions.

Tidal energy is one of the oldest and most promising sources of renewable energy, with the main idea being to harness the movement of tidal waters to turn turbines or generate electricity using various technologies. There are several methods of converting tidal energy into usable electricity, each suited to different coastal and tidal conditions.

How Tidal Power Works

The process of converting tidal energy into electricity generally involves capturing the energy from the motion of tidal water or the difference in water height between high and low tides (tidal range). Tidal power can be generated using two main approaches: **tidal range** (also called tidal barrage) and **tidal stream**.

1. Tidal Range (Tidal Barrage)

A **tidal barrage** is a type of dam built across the entrance of an estuary, bay, or river, where there is a significant difference in water level between high and low tides. This system uses the tidal range (the difference in water height between high and low tides) to generate electricity.

- **Principle of Operation**:
  1. **High Tide (Flood Tide)**: When the tide comes in, the water level rises, and sluice gates or locks are closed to trap the water at high tide behind the barrage. The water is stored behind the dam, creating potential energy.
  2. **Low Tide (Ebb Tide)**: As the tide goes out, the water level outside the barrage becomes lower than the water inside the barrage. The trapped water is then released through turbines in the barrage, generating electricity as it flows out and turning the turbines.
  3. **Power Generation**: The turbines connected to generators are powered by the flow of water, which drives the turbines and produces electrical energy. This process works during both the incoming (flood) and outgoing (ebb) tides, but more energy can be generated during the ebb tide.
- **Advantages**:
  - Predictable and reliable energy generation because tides follow a regular cycle.
  - Large potential for energy generation in areas with high tidal ranges.
  - Dual benefit: can also help with flood control and navigation in some cases.
- **Challenges**:
  - Significant capital investment for building the infrastructure.
  - Environmental impact, as the barrage could disrupt local ecosystems and migration patterns of marine life.
  - Suitable only for locations with large tidal ranges (over 5 meters).
- **Example**: The **La Rance Tidal Power Station** in France is the most famous example of a tidal barrage. It generates up to 240 MW of electricity and has been operational since 1966.

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2. Tidal Stream Power (Tidal Turbines)

Tidal stream energy captures the kinetic energy from the flow of water during the rise and fall of tides. This method is similar to wind energy generation, but instead of air, it uses water currents to turn turbines. These turbines are placed underwater in locations where tidal currents are strong.

- **Principle of Operation**:
    1. **Tidal Flow**: Tidal stream turbines are placed in areas with strong tidal currents, such as narrow channels, straits, or coastal areas with high tidal flow.
    2. **Turbine Rotation**: As the tide flows in (flood tide) and out (ebb tide), it moves the turbines. The movement of water turns the blades of the turbines, which are connected to a generator.
    3. **Electricity Generation**: The kinetic energy from the moving water turns the turbines, and the generator produces electricity. These systems can generate power continuously as long as the tidal currents are flowing.
- **Advantages**:
    - Less intrusive than tidal barrage systems as they do not require large structures like dams.
    - Can be deployed in deeper waters and more locations than tidal barrages.
    - Lower environmental impact compared to tidal barrages because turbines are placed on the seabed and can be removed or relocated.
- **Challenges**:
    - Efficiency is dependent on the strength of tidal currents, so the best sites are limited to locations with powerful tidal flows.
    - Still a relatively new technology, and large-scale commercial deployment is limited.
    - The turbine infrastructure must be able to withstand harsh marine conditions, which can increase costs.
- **Example**: The **Seagen Tidal Turbine** in Northern Ireland is one of the first commercial-scale tidal stream turbines, generating electricity from the tidal currents of Strangford Lough.

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3. Dynamic Tidal Power (DTP)

Dynamic Tidal Power is a relatively new concept that combines the principles of tidal barrage and tidal stream technology. It involves building large dams or barriers in the open sea, extending into areas where tidal currents are strong but the tidal range is low.

- **Principle of Operation**:
    - Large barriers or structures are built in areas where tidal currents are strong. The idea is that the interaction between tidal currents and the barrier generates water flow through turbines, even in regions with small tidal range.
    - DTP does not rely on the difference in water height (tidal range) but on the movement of tidal currents that occur around the structure.
- **Advantages**:
    - Can be used in areas with low tidal range.
    - Provides a more stable source of energy because it harnesses the movement of water rather than relying on fluctuating water levels.
- **Challenges**:
    - Very large scale construction is required, leading to high costs.

- The technology is still in the experimental phase and has not been deployed on a large scale yet.

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4. Overtopping Devices

Overtopping devices are another form of tidal energy conversion that works on the principle of capturing the incoming tide. These systems are similar to tidal barrage systems but do not involve building large dams.

- **Principle of Operation**:
    - An overtopping device works by capturing the incoming tidal water in a reservoir or basin located above sea level. The water is collected during high tide and released through turbines as the tide recedes.
    - The energy is generated as the water flows back into the ocean through turbines, turning them and producing electricity.
- **Advantages**:
    - Can be more environmentally friendly because the system does not need a full-scale barrage.
    - Can be used in a variety of coastal settings with a moderate tidal range.
- **Challenges**:
    - Still experimental and not yet widely deployed.
    - Requires significant construction and infrastructure, though typically smaller than tidal barrage systems.

Key Considerations for Tidal Energy

- **Location**: The most important factor for tidal energy generation is location. Areas with high tidal ranges or strong tidal currents are ideal for generating energy. This includes areas like the Bay of Fundy (Canada), the Bristol Channel (UK), and parts of Northern Europe.
- **Environmental Impact**: While tidal energy is a renewable and clean energy source, the construction of large-scale tidal barrage systems can affect local ecosystems. Fish migration, sediment transport, and water quality can be impacted. Proper environmental assessments are needed before the construction of tidal energy plants.
- **Cost and Infrastructure**: Tidal power systems, especially tidal barrages, require large upfront investments in infrastructure. Maintenance costs for underwater turbines and other marine equipment can also be high. However, operational costs are generally lower once the systems are up and running.
- **Predictability**: One of the major advantages of tidal power is its **predictability**. Unlike solar or wind power, tidal energy can be predicted accurately years in advance because tidal patterns follow a regular cycle, making it a highly reliable energy source.

Conclusion

Tidal power is a promising renewable energy source that harnesses the energy from the rise and fall of ocean tides to generate electricity. The most common methods for converting tidal energy into power include **tidal range** systems (such as tidal barrages), **tidal stream** turbines, and newer technologies like **dynamic tidal power**. Tidal power has a number of advantages, including high predictability and low environmental impact in some cases, but it also faces challenges such as high capital costs, site limitations, and environmental concerns. As technology advances, tidal energy could play an important role in the global transition to renewable energy, especially in regions with strong tidal movements.