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CAI 335 : SOLAR AND WIND ENERGY SYSTEMS

UNIT 2

SOLAR CONCENTRATING COLLECTORS AND PV TECHNOLOGY

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Solar Thermal Power Stations: Principles and Applications

A **solar thermal power station** (also known as a **concentrated solar power (CSP)** plant) is a facility that generates electricity by converting solar energy into heat, which is then used to drive a turbine connected to an electricity generator. Unlike photovoltaic (PV) systems that directly convert sunlight into electricity, solar thermal power stations rely on the collection of solar radiation and its conversion into thermal energy, which can then be used to produce electrical power.

Principles of Solar Thermal Power Stations

The core principle behind solar thermal power stations is **concentrating sunlight** to generate high temperatures, which are then used to heat a working fluid. This heated fluid is typically used to produce steam that drives a turbine, which generates electricity.

1. Solar Energy Collection

- The first step in solar thermal power generation is the collection of sunlight. Solar thermal systems typically use **optical concentrators** (mirrors or lenses) to focus sunlight onto a smaller receiver. This increases the intensity of solar radiation, allowing the system to achieve much higher temperatures than direct sunlight would produce.
- The main types of concentrating collectors used in solar thermal power stations include **parabolic troughs**, **central tower receivers (heliostats)**, and **parabolic dishes**.

2. Heat Transfer and Storage

- Once the sunlight is focused onto the receiver, it is absorbed by a **working fluid** (often a heat transfer fluid like synthetic oil, molten salt, or water). The fluid is heated to high temperatures (typically between 300-1000°C, depending on the system).
- Some systems incorporate **thermal energy storage** to store excess heat for later use. This is often done using molten salt, which has excellent thermal storage capabilities. The stored heat can be used to produce power during periods without direct sunlight (such as nighttime or cloudy weather), providing consistent and reliable power output.

3. Power Generation

- The heated working fluid is transferred to a **steam generator** or **heat exchanger**. In systems using water as the working fluid, the heat turns the water into steam. In other systems, such as molten salt or synthetic oil, the heat is used to generate steam indirectly.
- The steam drives a **turbine**, which is connected to an electricity generator. The turbine converts the thermal energy of the steam into mechanical energy, which is then converted into electrical energy by the generator.

4. Cooling

- After passing through the turbine, the steam is cooled and condensed back into water. The cooling process typically takes place in a **cooling tower** or through **dry cooling** systems, depending on the plant design and environmental conditions.
- The condensed water is then pumped back into the system to be reheated, continuing the cycle.

Types of Solar Thermal Power Stations

Solar thermal power stations can be classified into different types based on the method of concentrating sunlight and the technology used to convert thermal energy into electricity. The three most common types of solar thermal power stations are:

1. Parabolic Trough Systems

- **Design**: Parabolic trough systems use long, curved mirrors shaped like parabolas to focus sunlight onto a receiver tube placed along the focal line of the parabola. These systems typically use a heat transfer fluid, such as synthetic oil, which flows through the receiver tube.
- **Operation**: The heated fluid is used to generate steam, which drives a turbine to produce electricity.
- **Advantages**: This is one of the most established CSP technologies, and it is relatively cost-effective for medium-scale power generation. Parabolic trough systems are also modular, meaning they can be expanded as needed.
- **Applications**: Often used for commercial-scale CSP plants in sunny regions.

2. Central Receiver Systems (Heliostat Towers)

- **Design**: In central receiver systems, also known as **heliostat systems**, large, flat mirrors (heliostats) track the sun and focus the sunlight onto a central receiver located at the top of a tower.
- **Operation**: The receiver absorbs the concentrated solar radiation and transfers the heat to a working fluid (such as molten salt). The heated fluid is used to produce steam for electricity generation.
- **Advantages**: This technology can achieve very high temperatures and is suitable for large-scale power plants. The use of thermal energy storage (e.g., molten salt) allows these systems to provide power even when the sun isn't shining.
- **Applications**: Used for large-scale power generation in areas with high direct sunlight, such as deserts or arid regions.

3. Dish Stirling Systems

- **Design**: Dish Stirling systems use a parabolic dish to concentrate sunlight onto a receiver at the focal point. The receiver absorbs the heat and transfers it to a **Stirling engine** (a type of heat engine) that converts the thermal energy into mechanical power.
- **Operation**: The Stirling engine drives a generator that produces electricity. These systems are often used for smaller-scale power generation compared to other CSP technologies.
- **Advantages**: High efficiency due to the direct conversion of heat to mechanical energy. The systems are also compact and modular, making them suitable for distributed generation.
- **Applications**: Primarily used for small-scale electricity generation and off-grid applications.

4. Linear Fresnel Reflector Systems

- **Design**: Linear Fresnel reflectors use a series of flat mirrors to focus sunlight onto a receiver located above the mirrors. The mirrors are arranged in parallel rows, and they concentrate sunlight onto the receiver in a linear fashion.
- **Operation**: The receiver absorbs the concentrated sunlight and transfers heat to a working fluid, which is then used to produce steam and generate electricity.
- **Advantages**: Fresnel systems are simpler and less expensive to build compared to parabolic trough systems, but they may have lower optical efficiency.
- **Applications**: Suitable for medium-scale power generation and areas where cost is a key consideration.

Applications of Solar Thermal Power Stations

Solar thermal power stations are used primarily for electricity generation, especially in regions with abundant sunlight. However, they also have a variety of applications in both the industrial and residential sectors.

1. Electricity Generation

- **Utility-Scale Power Generation**: CSP plants can generate electricity on a large scale, providing power to the grid. Some CSP systems, such as central receiver systems, can be combined with thermal energy storage, allowing for the generation of electricity even during the night or cloudy periods.
- **Distributed Power Generation**: Smaller systems, such as dish Stirling systems, can be used in off-grid or remote locations to generate electricity in areas without access to the main power grid.

2. Industrial Heat

- Solar thermal power stations can provide **process heat** for various industrial applications. This includes industries like cement production, food processing, desalination, and chemical manufacturing, where high-temperature heat is needed.
- By using solar thermal systems to provide heat, industries can reduce their reliance on fossil fuels, leading to cost savings and a reduction in greenhouse gas emissions.

3. Water Desalination

- In regions with limited freshwater resources, solar thermal power stations can be used for **desalination** of seawater. The heat generated by the solar thermal system is used to produce steam that powers the desalination process, providing clean, potable water for communities and industries.

4. Solar Thermal for District Heating

- Solar thermal plants can also be used to provide **district heating** in urban areas. In this application, solar thermal energy is used to heat water or other fluids, which are then distributed to residential and commercial buildings for space heating and hot water.

Advantages of Solar Thermal Power Stations

1. **Renewable Energy Source**: Solar thermal power plants rely on solar energy, a clean and renewable resource, reducing dependence on fossil fuels.
2. **Low Emissions**: Since solar thermal systems do not burn fossil fuels, they produce little or no direct greenhouse gas emissions, making them environmentally friendly.
3. **High Efficiency**: Concentrating solar power systems can achieve high thermal efficiencies, especially when combined with thermal energy storage.
4. **Energy Storage**: Some solar thermal power stations, especially central receiver systems, can incorporate **thermal storage** (like molten salt), which allows power to be generated even when the sun isn't shining.
5. **Scalable**: Solar thermal power stations can be scaled up or down depending on the size of the facility and the demand for electricity.

Challenges of Solar Thermal Power Stations

1. **High Initial Costs**: The construction of solar thermal plants requires a significant upfront investment, especially in terms of land, equipment, and infrastructure.
2. **Location Dependency**: Solar thermal power stations require large areas with high direct sunlight, making them most suitable for regions like deserts or areas near the equator.
3. **Water Usage**: Some CSP plants, particularly those that use steam turbines, require large amounts of water for cooling, which can be a concern in arid regions.

4. **Intermittency**: Although thermal energy storage helps mitigate this issue, solar thermal plants still rely on the availability of sunlight, making them intermittent during cloudy periods or at night.

Conclusion

Solar thermal power stations play an important role in the transition to renewable energy by harnessing the power of the sun to generate high-temperature heat, which is then used to produce electricity and provide process heat for industrial applications. With their ability to store energy and produce electricity even after the sun sets, they offer a promising solution for large-scale power generation. While they face challenges such as high initial costs and site-specific requirements, advances in technology, cost reductions, and increased interest in renewable energy are helping to make solar thermal power stations a key player in the future energy mix.