CONCENTRATING SOLAR POWER (CSP) SYSTEMS

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Abstract: As energy-hungry developing nations are engaged in increasing their industrial activity and the more they put pressure on the natural resources, which day-by-day are becoming extinct and jeopardizing the growth. The main roadblock is energy deficiency. “As India strives to raise its annual GDP growth rate from the present 7-8% to over 10%, the ENERGY DEFICIT will only worsen. This may not only retard growth, it could also impose an additional burden in terms of the increased cost of importing oil and natural gas, in a scenario of sharply rising hydrocarbon prices.” This was quoted by MR. MANMOHAN SINGH. India will need an installed capacity of 250 GW of electricity by 2015, against 120 GW available currently. To avoid this power generation must be stepped up. The future lies in efficient use of Renewable Energy. Renewable Energy offers “Clean & Green Energy”. CONCENTRATING SOLAR POWER (CSP) SYSTEMS offers a reliable source of energy.

Solar Energy Basics:
The sun's heat and light provide an abundant source of energy that can be harnessed in many ways. There are a variety of technologies that have been developed to take advantage of solar energy. These include concentrating solar power systems, passive solar heating and day lighting, photovoltaic systems, solar hot water, and solar process heat and space heating and cooling. Solar power can be used in both large-scale applications and in smaller systems for the home. Businesses and industry can diversify their energy sources, improve efficiency, and save money by choosing solar technologies for heating and cooling, industrial processes, electricity, and water heating. Homeowners can also use solar technologies for heating and cooling and water heating, and may even be able to produce enough electricity to operate "off-grid" or to sell the extra electricity to the utilities, depending on local programs. The use of passive solar heating and day lighting design strategies can help both homes and commercial buildings operate more efficiently and make them more pleasant and comfortable places in which to live and work. Beyond these localized uses of solar power, utilities and power plants are also taking advantage of the sun's abundant energy resource and offering the benefits to their customers. Concentrating solar power systems allow power plants to produce electricity from the sun on a larger scale, which in turn allows consumers to take advantage of solar power without making the investment in personal solar technology systems. Solar power technologies, from individual home systems to large-scale concentrating solar power systems, have the potential to help meet growing energy needs and provide diversity and reliability in energy supplies.

Concentrating Solar Power Basics:
This solar concentrator has a fixed-focus faceted dish with a concentration of about 250 suns. This system can be used for large fields connected to the utility grid, hydrogen generation or water pumping.
Credit: Science Applications International Corporation / PIX 13464
Concentrating solar power (CSP) offers a utility-scale, firm, dispatchable renewable energy option that can help meet our nation's demand for electricity. CSP plants produce power by first using mirrors to focus sunlight to heat a working fluid. Ultimately, this high-temperature fluid is used to spin a turbine or power an engine that drives a generator. And the final product is electricity. Concentrating solar power systems can be classified by how they collect solar energy. The following pages discuss and illustrate the basic operation of each of the three main technologies of CSP systems, and they also provide information on thermal storage related to CSP technologies:

- Linear Concentrator Systems
- Dish/Engine Systems
- Power Tower Systems
- Thermal Storage
Stretched-membrane heliostats with silvered polymer reflectors surround the Solar Two power tower in Daggett, California. Credit: Sandia National Laboratories / PIX 00036

Smaller CSP systems can be located directly where the power is needed. Single dish/engine systems can produce 3 to 25 kilowatts of power and are well suited for such distributed applications. Larger, utility-scale CSP applications provide hundreds of megawatts of electricity for the power grid. Both linear concentrator and power tower systems can be easily integrated with thermal storage, helping to generate electricity during cloudy periods or at night. Alternatively, these systems can be combined with natural gas, and the resulting hybrid power plants can provide high-value, dispatchable power throughout the day.

- **Linear Concentrator Systems:**
  Linear concentrating solar power (CSP) collectors are one of the three types of CSP systems in use today. Here you will learn about the basic operations of linear CSP collectors, including the two major types of linear concentrator systems: parabolic trough systems and linear Fresnel reflector systems. Linear CSP collectors capture the sun's energy with large mirrors that reflect and focus the sunlight onto a linear receiver tube. The receiver contains a fluid that is heated by the sunlight and then used to create superheated steam that spins a turbine that drives a generator to produce electricity. Alternatively, steam can be generated directly in the solar field, eliminating the need for costly heat exchangers. Linear concentrating collector fields consist of a large number of collectors in parallel rows that are typically aligned in a north-south orientation to maximize both annual and summertime energy collection. With a single-axis sun-tracking system, this configuration enables the mirrors to track the sun from east to west during the day, ensuring that the sun reflects continuously onto the receiver tubes.

- **Parabolic Trough Systems:**
  A linear concentrator power plant using parabolic trough collectors. The predominant CSP systems currently in operation in the United States are linear concentrators using parabolic trough collectors. In such a system, the receiver tube is positioned along the focal line of each parabola-shaped reflector. The tube is fixed to the mirror structure and the heated fluid—either a heat-transfer fluid or water/steam—flows through and out of the field of solar mirrors to where it is used to create steam (or, for the case of a water/steam receiver, it is sent directly to the turbine). Currently, the largest individual trough systems generate 80 megawatts of electricity. However, individual systems being developed will generate 250 megawatts. In addition, individual systems can be collocated in power parks. This capacity would be constrained only by transmission capacity and availability of contiguous land area. Trough designs can incorporate thermal storage. Parabolic trough plants can also be designed as hybrids, meaning that they use fossil fuel to supplement the solar output during periods of low solar radiation. In such a design, a natural-gas-fired heater or gas-steam boiler/reheater is used. In the future, troughs may be integrated with existing or new combined-cycle natural-gas and coal-fired plants.

- **Linear Fresnel Reflector Systems:**
  A second linear concentrator technology is the linear Fresnel reflector system. Flat or slightly curved mirrors mounted on trackers on the ground are configured to reflect sunlight onto a receiver tube fixed in space above these mirrors. A small parabolic mirror is sometimes added atop the receiver to further focus the sunlight.

  A linear Fresnel reflector power plant.

- **Dish/Engine Systems:**
  The dish/engine system is a concentrating solar power (CSP) technology that produces relatively small amounts of electricity compared to other CSP technologies—typically in the range of 3 to 25 kilowatts. Here you will learn about the basic...
operation of dish/engine systems. A parabolic dish of mirrors directs and concentrates sunlight onto a central engine that produces electricity. The two major parts of the system are the solar concentrator and the power conversion unit.

**Solar Concentrator:**

The solar concentrator, or dish, gathers the solar energy coming directly from the sun. The resulting beam of concentrated sunlight is reflected onto a thermal receiver that collects the solar heat. The dish is mounted on a structure that tracks the sun continuously throughout the day to reflect the highest percentage of sunlight possible onto the thermal receiver.

**Power Conversion Unit:**

The power conversion unit includes the thermal receiver and the engine/generator. The thermal receiver is the interface between the dish and the engine/generator. It absorbs the concentrated beams of solar energy, converts them to heat, and transfers the heat to the engine/generator. A thermal receiver can be a bank of tubes with a cooling fluid—usually hydrogen or helium—that typically is the heat-transfer medium and also the working fluid for an engine. Alternate thermal receivers are heat pipes, where the boiling and condensing of an intermediate fluid transfers the heat to the engine. The engine/generator system is the subsystem that takes the heat from the thermal receiver and uses it to produce electricity. Currently, the most common type of heat engine used in dish/engine systems is the Stirling engine. A Stirling engine uses the heated fluid to move pistons and create mechanical power. The mechanical work, in the form of the rotation of the engine's crankshaft, drives a generator and produces electrical power.

- **Power Tower Systems:**

Power tower systems are one of the three types of concentrating solar power (CSP) technologies in use today. Here you will learn about the basic operation of power tower systems.

In this CSP technology, numerous large, flat, sun-tracking mirrors, known as heliostats, focus sunlight onto a receiver at the top of a tower. A heat-transfer fluid heated in the receiver is used to generate steam, which, in turn, is used in a conventional turbine generator to produce electricity. Some power towers use water/steam as the heat-transfer fluid. Other advanced designs are experimenting with molten nitrate salt because of its superior heat-transfer and energy-storage capabilities. Individual commercial plants can be sized to produce up to 200 megawatts of electricity.

**A power tower power plant.**

Two large-scale power tower demonstration projects have been deployed in the United States. During its operation from 1982 to 1988, the 10-megawatt Solar One plant near Barstow, California, demonstrated the viability of power towers, producing more than 38 million kilowatt-hours of electricity. The Solar Two plant was a retrofit of Solar One to demonstrate the advantages of molten salt for heat transfer and thermal storage. Using its highly efficient molten salt energy storage system, Solar Two successfully demonstrated efficient collection of solar energy and dispatch of electricity. Currently, Spain has several power tower systems operating or under construction. Planta Solar 10 and Planta Solar 20 are water/steam systems with capacities of 11 and 20 megawatts, respectively. Solar Tres will produce some 15 megawatts of electricity and have the capacity for molten-salt thermal storage. Power towers also offer good longer-term prospects because of the high solar-to-electrical conversion efficiency. Additionally, costs will likely drop as the technology matures.

**Storage Systems:**

Several TES technologies have been tested and implemented since 1985. These include the

- Two-tank direct system,
- Two-tank indirect system &
- Single-tank thermocline system.
- Two-Tank Direct System:
Two-tank direct molten-salt thermal energy storage system at the Solar Two power plant.

**Credit: National Renewable Energy Laboratory**

Solar thermal energy in this system is stored in the same fluid used to collect it. The fluid is stored in two tanks—one at high temperature and the other at low temperature. Fluid from the low-temperature tank flows through the solar collector or receiver, where solar energy heats it to the high temperature and it then flows back to the high-temperature tank for storage. Fluid from the high-temperature tank flows through a heat exchanger, where it generates steam for electricity production. The fluid exits the heat exchanger at the low temperature and returns to the low-temperature tank. Two-tank direct storage was used in early parabolic trough power plants (Solar Electric Generating Station I) and at the Solar Two power tower in California. The trough plants used mineral oil as the heat-transfer and storage fluid; Solar Two used molten salt.

- **Two-Tank Indirect System:**

Two-tank indirect thermal energy storage system for AndaSol-1 and -2.

**Credit: FLAGSOL**

This system functions in the same way as the two-tank direct system, except different fluids are used as the heat-transfer and storage fluids. This system is used in plants where the heat-transfer fluid is too expensive or not suited for use as the storage fluid. The storage fluid from the low-temperature tank flows through an extra heat exchanger, where it is heated by the high-temperature heat-transfer fluid.

The high-temperature storage fluid then flows back to the high-temperature storage tank. The fluid exits this heat exchanger at a low temperature and returns to the solar collector or receiver, where it is heated back to the high temperature. Storage fluid from the high-temperature tank is used to generate steam in the same manner as the two-tank direct system. The indirect system requires an extra heat exchanger, which adds cost to the system. This system will be used in many of the parabolic power plants in Spain and has also been proposed for several U.S. parabolic plants. The plants will use organic oil as the heat-transfer fluid and molten salt as the storage fluid.

- **Single-Tank Thermocline System:**

This system stores thermal energy in a solid medium—most commonly silica sand—located in a single tank. At any time during operation, a portion of the medium is at high temperature and a portion is at low temperature. The hot- and cold-temperature regions are separated by a temperature gradient or thermocline. High-temperature heat-transfer fluid flows into the top of the thermocline and exits the bottom at low temperature. This process moves the thermocline downward and adds thermal energy to the system for storage. Reversing the flow moves the thermocline upward and removes thermal energy from the system to generate steam and electricity. Buoyancy effects create thermal stratification of the fluid within the tank, which helps to stabilize and maintain the thermocline. Using a solid storage medium and only needing one tank reduces the cost of this system relative to the two-tank systems. This system was demonstrated at the Solar One power tower, where steam was used as the heat-transfer fluid and mineral oil was used as the storage fluid.
Concentrating Solar Power (CSP) Systems:

Benefits:
Concentrating solar power plants have few environmental impacts; land use is the primary one. Although a CSP plant's “footprint,” or the amount of land it occupies, is larger than that of a fossil fuel plant, the two actually use about the same amount of land. This is true because fossil fuel plants require a significant amount of land for exploration, mining, and road-building purposes. And CSP plants have the advantage that they produce no environmental contaminants or greenhouse gases. However, the fossil fuel component of a hybrid power plant does not have the same benefits.

- One key competitive advantage of CSP systems is that they closely resemble most of the nation's current power plants in some important ways. For example, much of the equipment now used for conventional, centralized power plants running on fossil fuels can also be used for CSP plants. CSP simply substitutes the use of concentrated solar power rather than combustible fossil fuels to produce electricity. This “evolutionary” — in contrast to “revolutionary” or “disruptive” — aspect means CSP can be integrated fairly easily into today's electric utility grid. It also makes CSP technologies the most cost-effective solar option for large-scale electricity generation.
- As Sunlight is the fuel for CSP systems which is abundant and free, these power plants are free from the uncertainties in the prices of natural commodities.
- Also as no raw materials like coal, gas etc are needed transportation costs are saved thus reducing dependence on other factors ensuring smooth operation of the plant.
- CSP systems offer CLEAN & GREEN Energy.
- The future lies in exploring renewable energy as it offers a non-ending, reliable and pollution free energy.
- Potential to create more jobs and boost economy.
- Concentrating solar power is fast approaching commercial viability, and the industry is actively seeking commercial projects.

Financial Considerations:
- Trough systems are commercially available and in use today. However, because of the very low cost of today's fossil fuels, they cannot yet compete on a cost-of-electricity basis with fossil-based systems. A favorable financing arrangement—one likely to be stimulated by green power markets—could enable parabolic troughs to begin to play a role in the marketplace, however. And as global demand for clean energy sources rises, trough systems will become more financially attractive.
- The long-term success of all the concentrating solar power technologies—including dish/engines, which are still in the demonstration phase—depends on continued technological progress.
- It also depends on an increasing desire for, and commitment to, clean energy. With some of the best direct normal solar resources anywhere on Earth.
- America's southwestern states are poised to reap large—though as yet largely uncaptured—economic benefits from this important natural resource. Several states are already taking advantage of this opportunity. California, Nevada, Arizona, and New Mexico are all exploring policies that will nurture the development of their solar industries.

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