Concentrated Solar System

Concentrated photovoltaic (CPV) technology uses optics such as lenses or curved mirrors to concentrate a large amount of sunlight onto a small area of solar photovoltaic (PV) cells to generate electricity. Compared to non-concentrated photovoltaics, CPV systems can save money on the cost of the solar cells, since a smaller area of photovoltaic material is required. Because a smaller PV area is required, CPVs can use the more expensive high-efficiency tandem solar cells. To get the sunlight focused on the small PV area, CPV systems require spending extra money on concentrating optics (lenses or mirrors), solar trackers, and cooling systems. Because of these extra costs, CPV is far less common today than non-concentrated photovoltaics. However, ongoing research and development is trying to improve CPV technology and lower costs. CPV also competes with concentrated solar thermal. CPV turns the sunlight directly into electricity, while solar thermal turns the sunlight into heat, and then turns the heat into electricity. Solar thermal is far more common than CPV, although the two technologies are sometimes combined. CPV systems operate most efficiently in concentrated sunlight, as long as the solar cell is kept cool through use of heat sinks. Diffuse light, which occurs in cloudy and overcast conditions, cannot be concentrated. To reach their maximum efficiency, CPV systems must be located in areas that receive plentiful direct sunlight.

The design of photovoltaic concentrators introduces a very specific optical design problem, with features that makes it different from any other optical design. It has to be efficient, suitable for mass production, capable of high concentration, insensitive to manufacturing and mounting inaccuracies, and capable to provide uniform illumination of the cell. All these reasons make nonimaging optics the most suitable for CPV.

Concentrated photovoltaics and thermal (CPVT), also sometimes called combined heat and power solar (CHAPS), is a cogeneration or micro cogeneration technology used in concentrated photovoltaics that produces both electricity and heat in the same module. The heat may be employed in district heating, water heating and air conditioning, desalination or process heat. CPVT systems are currently in production in Europe, with Zenith Solar developing CPVT systems with a claimed efficiency of 72%.

Efficiency : All CPV systems have a concentrating optic and a solar cell. Except for very low concentrations, active solar tracking is also necessary. Semiconductor properties allow solar cells to operate more efficiently in concentrated light, as long as the cell Junction temperature is kept cool by suitable heat sinks. Efficiency of multi junction photovoltaic cells developed in research is upward of 40% today, with the potential to approach 50% in the coming years. Also crucial to the efficiency (and cost) of a CPV system is the concentrating optic since it collects and concentrates sunlight onto the solar cell. For a given concentration, nonimaging optics combine the widest possible acceptance angles with high efficiency and, therefore, are the most appropriate for use in solar concentration. For very low concentrations, the wide acceptance angles of nonimaging optics avoid the need for active solar tracking. For medium and high concentrations, a wide acceptance angle can be seen as a measure of how tolerant the optic is to imperfections in the whole system. It is vital to start with a wide acceptance angle since it must be able to accommodate tracking errors, movements of the system due to wind, imperfectly manufactured optics, imperfectly assembled components, finite stiffness of the supporting structure or its deformation due to aging, among other factors. All of these reduce the initial acceptance angle and, after they are all factored in, the system must still be able to capture the finite angular aperture of sunlight.

For thermodynamic solar systems, the maximum solar-to-work (ex: electricity) efficiency can be deduced by considering both thermal radiation properties and Carnot's principle.[23] Indeed, solar irradiation must first be converted into heat via a solar receiver with an efficiency ; then this heat is converted into work with Carnot efficiency . Hence, for a solar receiver providing a heat source at temperature TH and a heat sink at temperature T° (e.g.: atmosphere at T° = 300 K) :

$$\eta = \eta_{\text{Receiver}} \cdot \eta_{\text{Carnot}}$$

Where

$$\eta_{\text{Carnot}} = 1 - \frac{T^0}{T_H} \qquad \eta_{\text{Receiver}} = \frac{Q_{\text{absorbed}} - Q_{\text{lost}}}{Q_{\text{solar}}}$$

where Q_{solar}, Q_{absorbed}, Q_{lost} are respectively the incoming solar flux and the fluxes absorbed and lost by the system solar receiver.

For a solar flux I (e.g. I = 1000 W/m^2) concentrated C times with an efficiency η_{Optics} on the system solar receiver with a collecting area A and an absorptivity α:

$$Q_{\text{solar}} = \eta_{\text{Optics}} ICA,$$

$$Q_{\text{absorbed}} = \alpha Q_{\text{solar}},$$

For simplicity's sake, one can assume that the losses are only radiative ones (a fair assumption for high temperatures), thus for a reradiating area A and an emissivity ϵ applying the Stefan-Boltzmann law yields:

$$Q_{\text{lost}} = A\epsilon\sigma T_H^4$$

Simplifying these equations by considering perfect optics (η_{Optics} = 1), collecting and reradiating areas equal and maximum absorptivity and emissivity (α = 1, ϵ = 1) then substituting in the first equation gives

$$\eta = \left(1 - \frac{\sigma T_H^4}{IC}\right) \cdot \left(1 - \frac{T^0}{T_H}\right)$$

Concentrated photovoltaic (CPV) technology utilizes three technological approaches for positioning to get the solar heat from the SUN: Trough systems, Power tower systems, and Dish/engine systems.

(A). **Trough Systems:** Trough systems use large, U-shaped (parabolic) reflectors (focusing mirrors) that have oil-filled pipes running along their center, or focal point, as shown in Figure 1. The mirrored reflectors are tilted toward the sun, and focus sunlight on the pipes to heat the oil inside to as much as 750°F. The hot oil is then used to boil water, which makes steam to run conventional steam turbines and generators.

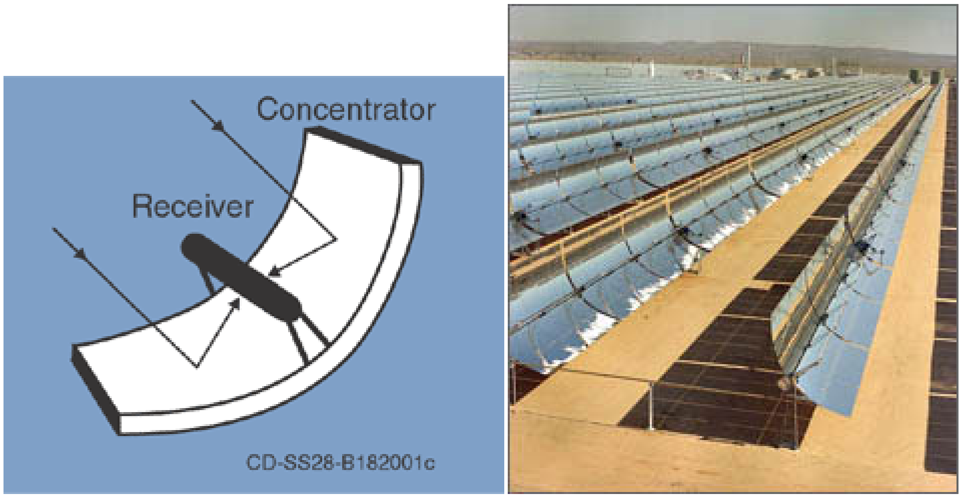

Fig 1 : Parabolic Trough System Schematic Diagram & Parabolic trough system

(B). **Power Tower Systems**: Power tower systems also called central receivers, use many large, flat heliostats (mirrors) to track the sun and focus its rays onto a receiver. As shown in Figure 2, the receiver sits on top of a tall tower in which concentrated sunlight heats a fluid, such as molten salt, as hot as 1,050°F. The hot fluid can be used immediately to make steam for electricity generation or stored for later use. Molten salt retains heat efficiently, so it can be stored for days before being converted into electricity. That means electricity can be produced during periods of peak need on cloudy days or even several hours after sunset.

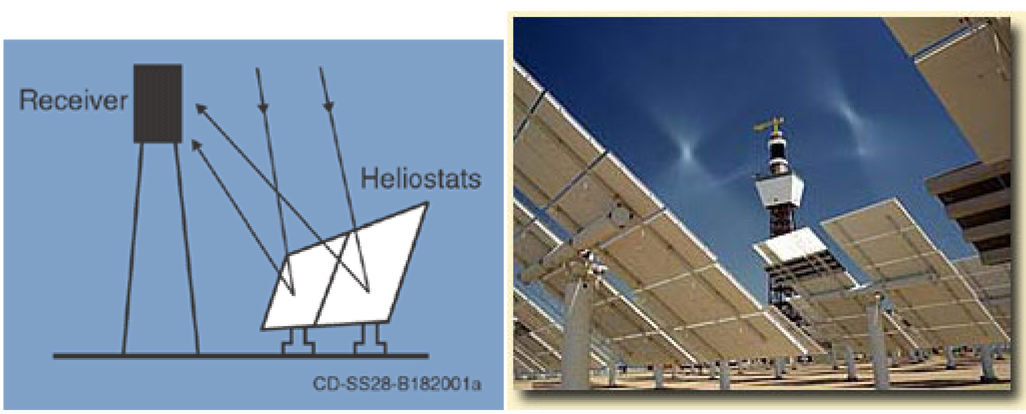

Fig 2 : Power Tower Schematic Diagram & Power tower system

(C). Dish Engine Systems : Dish/engine systems use mirrored dishes (about 10 times larger than a backyard satellite dish) to focus and concentrate sunlight onto a receiver. As shown in Figure 3, the receiver is mounted at the focal point of the dish. To capture the maximum amount of solar energy, the dish assembly tracks the sun across the sky. The receiver is integrated into a high-efficiency "external" combustion engine. The engine has thin tubes containing hydrogen or helium gas that run along the outside of the engine's four piston cylinders and open into the cylinders. As concentrated sunlight falls on the receiver, it heats the gas in the tubes to very high temperatures, which causes hot gas to expand inside the cylinders. The expanding gas drives the pistons. The pistons turn a crankshaft, which drives an electric generator. The receiver, engine, and generator comprise a single, integrated assembly mounted at the focus of the mirrored dish.

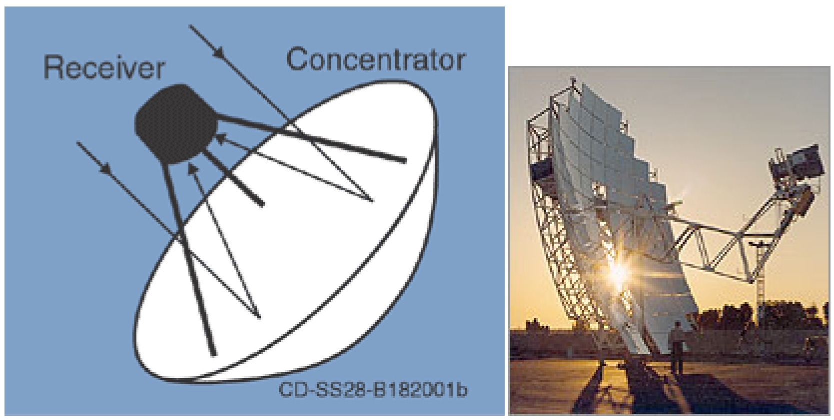

Fig 3 : Dish/engine System Schematic Diagram & Solar dish-engine system.