Technology unveiled

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Solar power at its zenith

Unlike photovoltaic systems, which can lose 80% of their power in a matter of seconds during periods of cloud cover, concentrated solar plants have a thermal inertia that curbs intermittent production. They have a possible thermal storage capacity of several hours and, as a result, can be used when no solar energy is available. This storage capability means that the production period can be either extended or shifted, and that the power generation potential can be predicted more reliably. The plants can also be easily hybridised with fossil fuels. Concentrated solar power technologies are currently more expensive than their photovoltaic counterparts and there is little likelihood that costs will decrease in the short term. Consequently, some projects in the United States have been converted into photovoltaic schemes. However, this state of affairs is merely a result of the decision criteria currently associated with the majority of calls for tender, in which only the electricity production cost is taken into consideration. No account is taken of the benefits of storage or hybridisation, or the costs avoided by finding an alternative solution to costly state-of-the-art equipment with high greenhouse gas emissions.

Photo: Linear Fresnel collectors (Areva Solar, SolarPaces 2011)

Concentrated solar power

ONE OF THREE WAYS TO MAKE DIRECT USE OF THE SUN'S ENERGY, OFFERING AN ALTERNATIVE TO THERMAL AND PHOTOVOLTAIC TECHNOLOGIES

Thousands of mirrors, covering an area of more than 100 hectares, follow the movement of the sun and direct its rays to a receiver at the top of a 140-metre tower. This is the scene at a concentrated solar power plant in Andalusia, Spain, where operation began last year. The first commercial plants were commissioned in California between 1984 and 1991, thanks to incentives available during that period, but the oil glut and the gradual withdrawal of financial support finally brought the sector to a halt. However, in 2006, work on new projects resumed in Spain and the United States, and prospects for developing the activity in the medium term indicate that an installed capacity of around 15 to 30 GW would be achievable by 2025 in the arid and semi-arid regions of the 'solar belt'.

Concentrated solar power plants can be grouped into three families, distinguished by their energy collection and concentration methods: linear focusing systems (parabolic troughs or linear Fresnel collectors), solar power towers and dish-Stirling systems.

Robert Soler, senior researcher at EDF R&

Full sun ahead for EDF

The EDF Group has recently identified concentrated solar power as a potential area for development in the renewable energies sector. A study of the market and suitable geographic areas indicates that it may pursue projects in the United States or China. Several projects are currently being examined in the Maghreb and the Middle East.

HOW CONCENTRATED SOLAR POWER PLANTS WORK

The fairest mirrors of them all

CONCENTRATED SOLAR POWER PLANTS TURN SOLAR ENERGY INTO HEAT AT HIGH TEMPERATURE AND THEN CONVERT THE HEAT INTO ELECTRICITY

First, the solar radiation needs to be concentrated, based on one of a wide variety of configurations. Concentrated solar power systems can be classified into four technological approaches: parabolic troughs, Fresnel collectors, central receivers (towers) and dish-Stirling systems. These technologies, which only exploit the direct component of solar radiation, involve devices for monitoring the sun's trajectory and mirrors for concentrating its rays.

Parabolic troughs

This technology is by far the most mature. TThis technology is by far the most mature. These plants use parabolic mirrors, ranging from 100 to 800 m2 in size, which concentrate the sun's rays on tubes containing a heat transfer fluid, placed at the focal axis of the concentrator. The concentrator follows the course of the sun by turning on an axis. The heat transfer fluid, usually a synthetic oil, is heated as it moves along the pipes, circulating through a series of heat exchangers to produce steam heated to a temperature of 390°C under a pressure of 100 bars. This provides the heat source for a conventional steam cycle with reheat. All units built to date are hybridised with at least 12 to 15% natural gas. A thermal storage capacity of several hours in molten salt means that power generation can be better adapted to demand, although adding this system, and extending the solar field as a result, do increase the investment cost. The collector field can also be integrated with a fossil fuel plant to augment the steam cycle. The maximum solar-electric efficiency in the best case scenario is around 25%, while the net annual efficiency is 15%.

The footprint is around 3.25 ha/MW for plants without storage capacity. However, this technology does have its disadvantages. One particular drawback is that a flat, rectangular piece of land is required, with a maximum slope of 3%. The thermal oil also poses problems, as it chemically degrades when it reaches 400°C, restricting the efficiency of the thermodynamic cycle due to the limitation on the temperature of the heat source; it solidifies at 12°C, so the use of fossil fuel may be required at night or in winter for the sole purpose of keeping it fluid. Finally, the oil is flammable and, therefore, presents an environmental risk. In France, this product is Seveso-classified in the quantities required for solar power plants. Research is currently under way on the possibility of using other heat transfer fluids, particularly molten salts, or a direct steam generation method, but these options carry their own operational risks.

Photo: Gemasolar tower plant in Andalusia

KEY FACTS

221-213 BC Archimedes concentrates the sun's rays to destroy the enemy fleet at Syracuse.

1878 Augustin Mouchot's solar furnace is presented at the Universal Exhibition in Paris.

1912 Sun Power's 55 kW steam generation plant opens near Cairo, using cylindrical parabolic collectors of 62 metres in length.

1970-80 Experiments with three different approaches: cylindrical parabolic troughs, solar power towers and Stirling parabolic dishes.

1983 THEMIS solar power tower plant operated by EDF and the French National Centre for Scientific Research (CNRS). Power output of 2.5 MW with 5 hours of molten salt storage capacity.

1985-1991 California: nine commercial SEGS plants with parabolic troughs collectors. Capacity of 354 MW.

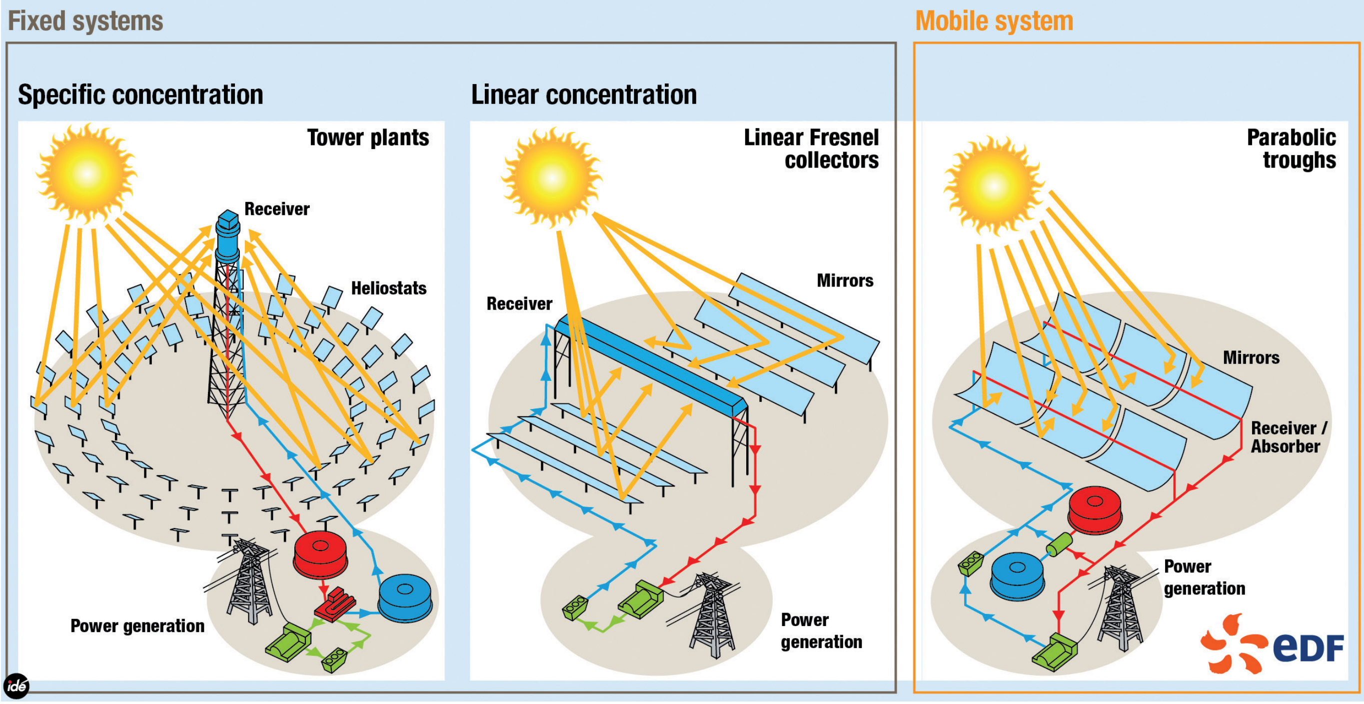
1991 Luz International (SEGS plants) files for bankruptcy. Commercial development stops for 15 years.

2006 Nevada Solar One plant in Boulder City, Nevada. The sector resumes.

2007 First commercial solar power tower plant near Seville: PS10.

2011 Gemasolar tower plant commissioned. Use of molten salt.

THREE MAIN TYPES OF CONCENTRATED SOLAR POWER SYSTEMS



DID YOU KNOW ?

The Gemasolar tower plant, commissioned in Ecija (Andalusia) in 2011, has a power output of 19.9 MW. It has 2,650 heliostats spread over 185 ha, concentrating the sun's rays at the top of a 140-metre tower. It has a molten salt storage capacity of 15 hours, allowing it to operate 24 hours a day in summer and to generate 110 GWh per year (enough to supply 25,000 homes). The plant uses 8,500 tonnes of salt, which took 9 months to melt during construction.

Fresnel collectors

This method is simple and inexpensive. The collectors are in the form of mirrors, arranged in flat, parallel rows close to the ground, which concentrate the sun's rays on fixed receiver pipes. Water is supplied at 100 bars and 500°C to be used as the heat transfer and working fluid. This technology is still at the demonstration stage. It operates on a similar principle to the parabolic trough approach, but uses flat or slightly curved mirrors, which are less expensive than parabolic reflectors. This method has the lowest optical performance and the lowest net annual solar-electric efficiency (10%) but its footprint is only 1.5 ha/MW, less than 60% of the area needed for plants with cylindrical parabolic troughs. The mirrors can be cleaned automatically. However, there is no mature storage solution. Hybridisation applications with conventional power plants, as well as industrial heat generation, are of great interest for this activity. The ground must be reasonably flat, with a maximum slope of 5%.

Solar towers

This technology is the most flexible to use and costs are expected to reduce significantly. Heliostats follow the sun and concentrate its rays on a receiver at the top of a tower. Two technologies are involved: direct steam generation, at a relatively low cost, and the use of molten salt, which can serve as a heat transfer fluid and a thermal storage medium. Mature technologies use a steam cycle with reheat, similar to that at a coal-fired power plant (with steam at 150 bars and 550°C). Storage is three times more efficient than with the cylindrical parabolic trough approach. The maximum efficiency for Rankine cycle tower plants is around 22% and the net annual efficiency is around 16%. The footprint without storage is 4 ha/MWe and the heliostats can be installed on sloping ground. The good thermodynamic performance limits the required cooling water power and the amount of water consumed.

Dish-Stirling systems

This method is very costly and is currently unable to progress to the commercial stage.

Outlook

Parabolic trough technology is the first technology to reach the commercial operation stage on a significant scale. Solar Energy Generating Systems (SEGS), making up a group of nine units with a total capacity of 354 MWe, were built in the second half of the 1980s and the beginning of the 1990s in Southern California. This technology currently dominates the market, but there are no real prospects for lowering its cost. Manufacturers believe that the future of this approach lies in the use of molten salt, but this does pose operational risks due to the need to maintain the temperature above the salt melting point inside kilometres of pipes. In direct competition with parabolic trough systems is the more recent Fresnel technology. Design engineering companies, such as ABB and Areva Solar, are now offering the turnkey delivery of power plants generating superheated steam. Pilot plants with capacities of just a few MWe have already been built in Spain, the United States and Australia, and several commercial projects are currently under construction. Pilot projects emerged in the 1980s and, from 1983 to 1986, EDF and the CNRS operated the THEMIS solar power plant at Targassonne in the Pyrénées Orientales. The first commercial projects saw the light of day in 2007. Current developments largely suggest that significant progress will be made in Fresnel technologies, molten salt towers and superheated steam towers, and that these approaches will eventually form the basis for industrial decisions. However, finding reliable and innovative storage solutions is becoming crucial. Hybridisation with combined cycle or fossil-fired plants will offer one way to develop solar thermal technologies, while minimising the risks and reducing the plants' greenhouse gas emissions. However, in the short- and medium-term, we can expect to see a fall in component costs, improved efficiency and the development of new storage methods for pressurised air and direct steam generation.

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> for further information

La centrale expérimentale Thémis: bilan et perspectives (The experimental Thémis plant: assessment and outlook). B. Bonduelle, B. Rivoire and A. Ferriere. Revue Phys. Appl. 24, pp 453-461. April 1989.

Power from the sun: http://www.powerfromthesun.net/
ESTELA: http://www.estelasolar.eu/

Torresol Energy: http://www.torresolenergy.com/TORRESOL/planta-gemaso-lar/es

Helioscsp: http://www.helioscsp.com/

List of terms

Watt (W): uinternational unit of power. This corresponds to the amount of energy consumed or generated over a given unit of time (one joule per second). The power corresponds to a flow of energy.

kWh: one kWh (kilowatt hour) equates to 3.6 MJ (megajoules) and is equivalent to the power used by a 1,000-watt electrical device over a one-hour period.

Heat transfer fluid: a fluid (such as a molten salt mix), which absorbs, transports and transfers heat.

Fossil-fired plant: electrical power generating plant that uses heat released by the combustion of fossil energies (coal, gas or fuel oil). This heat converts water into steam, resulting in a pressure reduction, which turns a turbine driving a generator to produce electricity.

Gas combined cycle: electricity generation technology used in a fossil-fired power plant operating on natural gas. A cycle consists of one or more combustion turbines and a steam turbine (for increased efficiency). The synthetic gas is sent to the combustion turbine, which generates electricity and very hot exhaust gases (fumes). The heat from the fumes is recovered by a boiler, which then produces steam. Some of this steam is used by the steam turbine to produce additional electricity.

Heliostat: a remote-controlled adjustable mirror, which follows the trajectory of the sun and concentrates its radiation on a receiver installed at the top of a tower.

Molten salt: a mix of nitrate salts (sodium nitrate, potassium nitrate, etc.), which melts at 220°C and chemically degrades at temperatures above 600 to 650°C. This has a good specific heat capacity (1.5 J/K.kg, compared to 4.2 J/K.kg of water); it is a liquid at atmospheric pressure, and is non-flammable and non-toxic.

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