The other technology, Concentrated solar power

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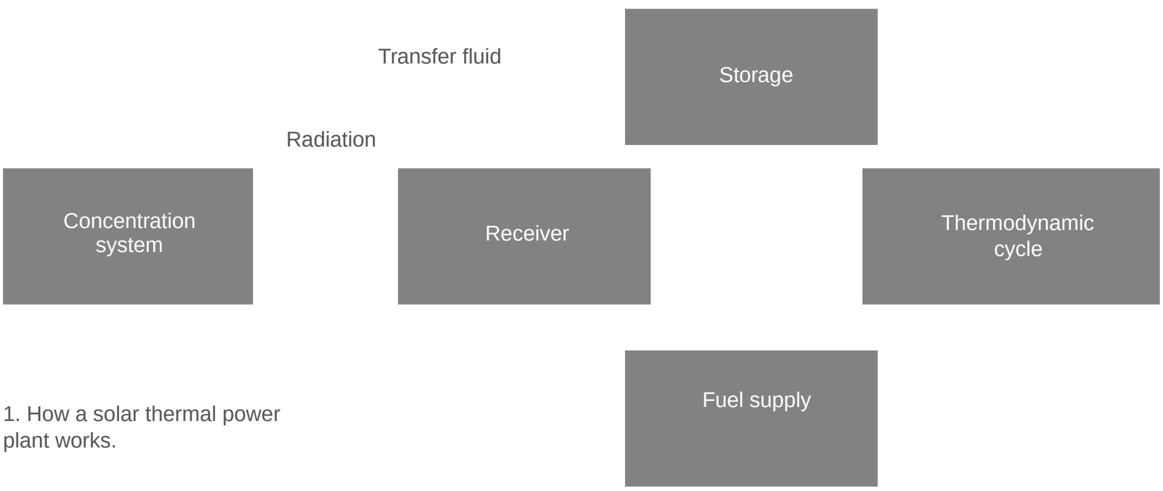
Concentrating solar power is used to heat a heat transfer fluid to a high temperature. The heat obtained can either be used directly, or converted into electrical energy using a thermodynamic cycle. One advantage of solar power plants is that they can be coupled with thermal storage systems to improve the ability to regulate production according to demand.

This article gives a brief overview of the current performance and future prospects of these plants.



1. How a solar thermal power plant works.

Principle and state of the art

Concentrating the direct component of solar radiation produces high-temperature heat. This heat can be used either directly in an industrial process, or to generate mechanical energy or chemical energy carriers using thermochemical processes. In the case of electricity generation (Fig. 1), solar energy is transferred to a heat •|èRƒ' |MÒ"3 M 3| "Jè•3 receiver. A set of heat exchangers •/ RMèJJ\®ƒM•/3ƒM/ è•M •\M•|èRƒ' |M3•ƒM/ è•M•\ which converts this thermal energy into mechanical energy via a thermodynamic cycle. This heat can also be stored to shift production to periods of high consumption (generally evenings in Europe). Finally, a generator coupled to this motor cycle produces electricity. The second part of this conversion chain is identical to that of a conventional thermal power plant, but in the case of solar thermal power plants, the primary energy source is solar energy. As a result, a solar thermal power plant can be hybridised with an additional fuel source.

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THE THEMIS SOLAR POWER PLANT [1]

Box 1

Thémis is a solar energy research centre located in the commune of Targasonne (Pyrénées-Orientales), in a region where the weather conditions (sunshine, altitude, etc.) are very favourable. It is managed by the Conseil départemental des Pyrénées-Orientales.

After the 1973 oil crisis, the French government decided in 1977 to develop the use of solar energy and to set up in the Pyrénées-Orientales, a power station to convert this energy into electricity by concentrating solar radiation. Built by EDF and the CNRS, the Thémis plant was inaugurated in 1983, but the fall in the price of oil led EDF to abandon its financing in 1986. In 2004 , the Conseil départemental des Pyrénées-Orientales decided to relaunch the Thémis solar power plant, the electricity from which would be sold back to EDF and to develop a research and technological development centre for solar energy production on the site. The first kWh were produced at the end of 2007.

The 102-hectare site (fig. E1a) features a field of 200 heliostats (moving flat mirrors), which follow the path of the sun to reflect its rays and concentrate them towards the top of a 101 m high concrete tower (fig. E1b), a building for businesses and tourist visits, and offices.

Since 2014, the facility has been divided into two experimental zones. In the first zone, operated by the CNRS's PROMES laboratory, 107 heliostats and the solar tower power the thermodynamic solar power plant. The second zone, with around a hundred heliostats, is reserved for innovative projects (including the Thémis-PV operation).

a

E1. The Thémis solar power plant.
(a) The Thémis site in 2015.
(b) Tests on a fluidised particle solar receiver at the top of the Themis tower.

b

How the concentrated solar power plant works

Heliostats concentrate the sun's rays towards the top of the tower, which houses a solar receiver containing a heat transfer fluid (initially molten salts at 350°C). Heated by the sun's rays, the fluid transfers its energy to a water circuit. The steam then formed drives a turbine that produces electricity.

As part of the European next-CSP programme (2016-2020), the Thémis power plant has been equipped with a new 1.2 MW_{el} turbine and uses solid particles heated to 800°C (for greater thermodynamic conversion efficiency) as a heat transfer fluid and for thermal storage.

Projects

The European POLYPHEM project has made it possible to prototype the components of a small-scale concentrating solar power plant, which could prove ideal for small isolated entreprises or developing countries.

Engie PV Thémis is planning to build a photovoltaic power plant on the Thémis site, using 80 heliostats and producing more than 800 MWh a year. Projects include the use of new thin-film or microcrystalline silicon cells, and the installation of systems for concentrating the light energy reaching the photovoltaic cells.

1• www.promes.cnrs.fr .

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The optical systems used are mirrors producing either linear concentration (parabolic trough and Fresnel linear concentrators) or point concentration (paraboloid and tower concentrators). The corresponding concentration factors range from a few dozen to a few thousand. Solar furnaces that use the principle of \“ J M | Ò •3\RMè| M| ƒ

At the end of 2019, the world's installed solar thermal capacity reached ã#àNBÆ$M(R |è•3R(Mè| More than a hundred solar power plants are in operation, with unit èyè 3•3 ƒM|èR(3R(M'|\Q In Spain, the installed capacity is ß#àN BÆ$M QèG3R(M 3•M has most developed this technology commercially. Other countries with such plants include the United States, Morocco, South Africa, Chile, some Middle Eastern countries (Dubai, Abu Dhabi, etc.), India and China. Since 2016, China has been developing a number of demonstration projects using different technologies. In France, research is being carried out on the Thémis solar power plant (Box 1, p. 64).

As concentrating solar power systems only exploit the direct component of solar radiation, it is generally accepted that the minimum annual resource required to make a solar y\® |M yJèR•M y|\Ñ•è J M ÞåÝÝM èR M ßÝ² year. In Europe, Spain, Portugal, Greece and certain regions of southern Italy and France meet this criterion. However, for industrial heat production, this threshold can be considerably lower, which explains the development of such applications in certain Nordic countries such as Denmark.

Large-scale thermal storage capacity an asset

The integration of thermal storage gives solar thermal power plants a quality that is much appreciated by grid regulators: the ability to regulate production according to demand (dispatchability). Storage increases the load factor. The load factor is the ratio between the electrical energy actually produced over a given period and the energy that a power plant would have produced if it had been operating at its nominal power during the same period. Generally (except for power plants operating at peak load), the energy needed to charge the storage is provided by increasing the surface area of the mirrors compared with the surface area needed for production at nominal power. The criterion for qualifying this increase is known as the "solar multiple". Typical values for the solar multiple are between Þ#âNèR Mß#â$M®/3 /M storage time of between 6 and ÞâN /\“|ƒM '\|M y|\ “ •3\RM è•M '“JJM power. Power plants with more than 8 hours' storage generally have a load factor in the 50-65% range. Installed storage capacities amount to several GWh.

Performance, cost and impact

¥/ |Q\ ´RèQ3 M \R- |ƒ3\RM Ð3-ciency varies from 37% to 42% depending on the concentration technology, since point concentration allows cycle temperatures of 550°C to be reached instead of 390°C for linear concentration systems. Taking into account operational losses (concentrator) and thermal J\ƒƒ ƒM4| 3- |5$M•/ M\- |èJJM Ð3 3 R ´M of converting solar energy into electricity is around 20%. The average èRM'èJM®\-R|MJJM Ð3 3 R ´M 3ƒM ÞåM•\M 17%. Developments in technology should make it possible to implement •/ |Q\ ´RèQ3 M ´ J ƒM®3•/MèRM Ð3-ciency of 50%.

The discounted cost of electricity produced by solar thermal power plants has fallen by 47% between 2010 and 2019. The learning curve for concentrated solar power is very similar to that for photovoltaics [2, 3]. In the United States, the current cost of electricity produced by a molten salt tower power plant with storage 3ƒMRÞÝÝ0iÆ$M *US Department of* -R |(´LƒM•è|(•M'\|MßÝàÝM3ƒMRåÝ0iÆ/M for base load plants with 12 hours of ƒ•\|è($M èR MRÞÝÝ0iÆ/M '\|M yJèR•ƒM designed for peak production.

Life-cycle analysis of parabolic trough and tower solar power plants shows that emissions are 26-38 g CO_2 {0GÆ/$M• RM•3Q ƒMJ ƒƒM•/èRMeMRe•“|èJM (èƒ<Ñ| MyJèR•#M¥/ M R |(´Myé è GM time is around 1 year [5].

Future

Current research focuses in particular on increasing the operating temy |è•“| M\'My\® |MyJèR•ƒM4Ñ(#N-Þ 5M and reducing the cost of components such as thermal storage. The production of solar heat (in 2014, industry used 32% of global energy consumption and heat accounted for 74% of industrial energy consumption) and hydrogen are also very active areas of research and innovation. ■

1• IEA (2020), "Renewables 2020, Analysis and forecast to 2025", IEA, Paris. https://cutt.ly/iea_renewable2020, License: CC BY 4.0.

2• IRENA (2020), "Renewable power generation costs in 2019", International Renewable Energy Agency, Abu Dhabi. ISBN 978-92-9260-244-4.

3• J. Lilliestam et R. Pitz-Paal, "Concentrating solar power for less than USD 0.07 per kWh: finally the breakthrough?" *Renewable Energy Focus*, 26 (2018) 17-21.

4• C. Murphy *et al.*, "The Potential Role of Concentrating Solar Power within the Context of DOE's 2030 Solar Cost Targets", National Renewable Energy Laboratory Technical Report, NREL/TP-6A20-71912 (2019).

5• J. J. Burkhardt *et al.*, "Life Cycle Greenhouse Gas Emissions of Trough and Tower Concentrating Solar Power Electricity Generation", *Journal of Industrial Ecology*, 16 (2012) 93-109.

6• O. Behar *et al.*, (2020). "Design and performance evaluation of a modular solar power plant using a gas turbine combined cycle with fluidized particle-in-tube receiver and direct thermal storage", *Energy Conversion & Management*, 220 (2020) 11310.

Low-temperature solar heat

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T/ Mè|•3 J M ´MB#MAJèQèR•M4y#Nãà5M deals with the use of solar energy to transfer high-tempe- |è•“| M/ è•M•\MèMÒ“3 M“ƒ M•\My|\ “ M electricity. Another use of the sun is to take advantage of the low-temperature heat it accumulates in the earth, air or water. It can be used 3| •J´M•\M/ è•MèMÒ“3 M•/è•M 3| “Jè• ƒM between a panel and a reservoir of heated water. Many Mediterranean countries have roofs full of such installations to produce a large proportion of their domestic hot water.

Solar thermal power plants use the sun's energy to produce centralised hot water, which is then distributed to consumers via a heating network (Fig. 1). These plants currently account for a very marginal share of the solar thermal market worldwide.

Heat can also be recovered from the ground to heat a home using a heat pump (PAC): deep geothermal energy (the real thing) consists of recovering the heat generated deep down by the earth's radioactivity. This heat pump technique is also used to recover heat from the ambient air to heat a home or a hot water tank (thermodynamic tank). These electrically-powered installations are characterised by an energy performance \ Ð3 3 R•M 4 t‘5$M •/ M the total thermal energy supplied and the pump's electricity consumption: typical values are 3 or 4 .

There is a great deal of solar heat available, and in principle it could be used to heat many properly insulated homes. The limitations are due to the cost of installation, their lower Ð3 3 R ´M “|3R(My |3\ ƒM\'M cold when heat is extracted from the è3|$M •/ M(| è• |M 3Ð3 “J•´M \ M 3QyJ - mentation in densely built-up areas (large surface areas are required for surface geothermal systems), and the problems with neighbours that can be caused by the noise of heat pump compressors in dense areas. They are also due to the fact that, despite some possibilities for public support for air-water heat pumps in the residential sector, most incentives are concentrated on photovoltaic solar energy. ∎

1. The Cellcius solar thermal park in Creutzwald, Moselle, the largest in France, inaugurated on 15 October 2020, is made up of 379 flat 16 m^2 glazed aluminium collector panels, giving a collector surface area of over 6,000 m^2. The heat-carrying liquid is transported through extruded cells running the length of the panels. At the far end is the 2,000 m^3 buffer tank, which stores the heat produced in summer by the solar thermal park in the form of hot water at 85°C. The plant produces 2.7 GWh a year, equivalent to the heating needs of 190 homes.
Source: Le Républicain Lorrain.

> “Another way of using the sun is to take advantage of the low-temperature heat it accumulates in the earth, air or water.”