LOW TEMPERATURE SOLAR POWER PLANT CONNECTED TO A SMART GRID

Didier Haillot, Lucas Poupin, Pierre Urrutti, Christian Lenôtre* and Michel Wohrer

Sophia Antipolis Energie Développement (SAED), Valbonne (France)

*christian.lenotre@sophia-energie.com

1. Abstract

In the context of the PREMIO project, first French smart grid, Sophia Antipolis Energie Développement (SAED) has designed and built a particularly innovative low temperature solar power plant (between 80 and 130°C). The solar collector field is connected to a 5 kW_e Organic Rankine Cycle (ORC) turbine as well as to a sensible heat water storage device of 150 kWh_{th} capacity

Control system is connected to the PREMIO smart grid, providing energy when needed, even in a lack of solar energy thanks to the water storage device.

The low temperature solar plant designed by SAED is operational since November 2010. The major technical data and first experimental results of this technology, in the PREMIO project, will be presented in this communication.

2. Introduction, state of the art

Three thermodynamic solar technologies are currently available commercially or in advanced stages of development. They are distinguished primarily by their solar collector devices:

- Linear concentrator technology uses parabolic trough or Fresnel mirrors to concentrate the solar flux on a focal line. A heat transfer fluid (oil or water / steam) flowing through a tube placed at this focal length and is conveyed to a device for converting heat / electricity from one or more turbines.
- Solar tower technology uses a tracking field of mirrors on two axes (heliostats) to concentrate the radiation at the top of a tower. Receiver allows the conversion of solar flux into heat energy, transferred to a medium (molten salt, steam, air) or directly to the working fluid of the thermodynamic cycle (air).
- Dish Stirling technology uses a parabola that follows the sun on two axes and concentrate the direct radiation onto a receiver at a focal point and serves as a heat source Stirling engine.

These technologies work by concentrating the solar flux and then use the direct sunlight. They are referred to as CSP for "Concentrated Solar Power." CSP principal characteristics are summarized in table 1.

Tab. 1: CSP technology characteristics [Nepveu F., 2009]

	Linear	**Tower**	**Dish stirling**
Working temperature	270-450°C	450-1000°C	600-1200°C
Power plant size	80-300 MW_e	10-100 MW_e	1-200 kW_e

Unlike photovoltaic systems, some of the thermodynamic solar technologies offer the ability to insert a storage form of heat. It is also possible to use hybridization with fossil fuel or biomass. Thermodynamic plants are thus able to overcome the intermittent nature of solar resource.

Thermal energy storage technology for temperature ranges of the CSP, are primarily based on the use of molten salts containing nitrates [Herrmann et al. 2004]. These storage techniques led to difficult economic balances (the storage is 15 to 20% of the investment of a plant and use of these material lead to a problem of competition with other use in industrial and agricultural sectors).

When the heat transfer fluid is water / steam, storage in the form of steam can be considered. Storage tanks must then withstand very high pressures (above 100 bar), resulting in an important cost of the tank [Eck and Steinmann, 2006]. The limitations of this type of storage results in a corresponding dimensioning of the stock over the fluctuations of the solar flux (cloudy) more than as a real temporal phase shift of production (day / night).

Another approach is to use solid media such as concrete high temperature [Laing et al. 2006]. This technology is "simple" and inexpensive but has a limited life time (approximately 10 years), the aging of the concrete causing cracking reducing the capacity charge and discharge energy. In addition, it requires the insertion of large quantity of metal in order to overcome the low conductivity of the material storage. Currently, upstream researches are currently underway to develop alternative storage devices, based on vitrified asbestos [Py et al., 2009].

In addition to the technologies presented above, SAED has developed its own solar power technology which the operating principle is based on low temperatures (between 80 and 130 ° C) to facilitate the establishment of a thermal storage. Solar thermal technology at a low temperature is to our knowledge not yet available on the market worldwide. It also appears that SAED is the only company to have now developed this concept, which puts it in a position to pioneer this technology worldwide.

After a small description of the PREMIO project, the advantages of this technology compared to the CSP and the initial experimental results of the first prototype of the technology involved in PREMIO is presented in the remainder of this paper.

3. PREMIO Project, first French smart grid

The potential benefits of the smart grid include saving energy, increasing amount of renewables and ensuring supply security (Hledik R., 2009). PREMIO (Production REpartie, MDE, Intégrée et Optimisée = Distributed, integrated, optimized energy production and demand response) is a project managed by Capénergies (French cluster on Zero CO2 emission). It aims at driving the energy production and consumption of different kinds, in order to provide the energy operator with peak leveling potential, according to his needs or constraints.

PREMIO is supported by 13 partners and is based on three principles:

- Distribution of small renewable energy production means in different locations such as public buildings and private homes,
- Network energy consumption at the most favorable moment or storage of locally produced energy in order to use it during peak periods,
- Energy consumption reduction or delay during peak periods: this is called peak leveling.

Eight types of distributed resources are includes in the project:

- Thermal storage for industrial and tertiary cooling applications: 1 system,
- Hot water tanks coupled to heat pumps to provide load shifting in houses: 6 systems,
- Individual electric storage units coupled to PV panels: 23 systems,
- Load shedding modules dedicated to residential and small tertiary buildings: 12 systems,
- Load shedding boxes for houses and apartments: 6 systems,
- Adapted LED bases public lighting: 9 systems,
- Solar heat pump combined with hot water storage: 1 system,
- Biomass coupled with electrical heating: 2 systems,
- Solar thermodynamic electricity generation using thermal storage.

The last bullet refers to the $5kW_e$ low temperature power plant developed by SAED.

A control unit optimizes the use of host customers distributed resources. Two types of load reduction services, ‘day-ahead’ (one day prior its implementation) and ‘day of’ (the same day to its application, up to 5-10 min before), are offered to an upstream operator.

4. SAED in PREMIO project: low temperature solar power plant

4.1. Solar collector technology

SAED is an EPC (Engineering, Procurement, Construction) contractor which has developed is own solar collector technology based on four patent. The SAED solar collector technology (figure 1) is composed of heat pipe (figure 2) placed in Dewar type vacuum tubes usually used to generate hot water. These tubes convert solar radiation into heat energy transmitted to a heat transfer fluid flowing through a collector.

Fig. 1: SAED solar collector unit

This type of technology guaranteed very low pressure drops and the risk of leakage practically nil.

The solar collectors are fixed to avoid the costs associated with a tracking system. This concept allows very low operating costs and maintenance costs.

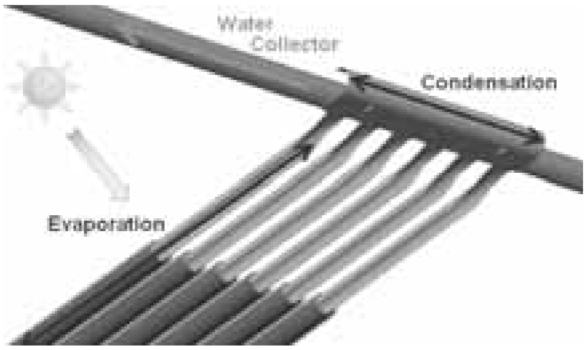

Fig. 2: SAED heat pipe

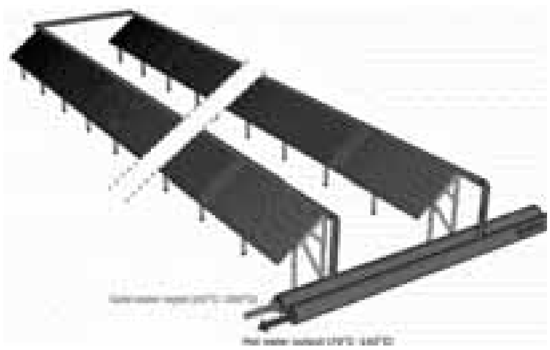

Fig. 3: SAED fields of solar collector

The fields of solar collector developed by SAED (figure 3) consist of the following.

The condenser of the heat pipe is clipped on the surface of the hydraulic water pipes made of black steel pipe (DN 50). Heat pipes are inserted in the vacuum tube, incorporating a selective coating; and fixed on a support. Finally, insulation is placed on water piping to limit heat loss. The support consists of stabilities mounted on the foundation.

Eco-design conception has been pursued, including:

- No toxic chemicals
- Water as heat transfer fluid,
- Materials and components easily available on the market in every country all over the world,
- Restitution of land in the original state when the solar plant is removed after 20 or 30 years of operation.

4.2. System description

Power plants using technology SAED are composed of three main sub-assemblies (Figure 4):

- The solar field: it captures solar radiation (including diffuse radiation) and converts it into heat energy in the form of hot water at a temperature ranging from 80°C to 130°C (pressure about 4 bars).

  The aperture area of the solar field is equal to $81m^2$ representing a thermal power around 45 kW_{th} with a global radiation approximately equal to 900 $W.m^2$.

- The thermal storage tank: it can store heat energy coming from the collectors and then restore it after sunset. The device consists of a stratified sensible heat (water) storage tank which is insulated. It is surrounding by an expansion system. The pressure vessel (<6 bar) is tested to 10 bar.

  The storage tank volume is equal to $6m^3$and represent a 150 kWh_{th} theoretical storage capacity

- ORC Block turbine (Organic Rankine Cycle): The heat from the hot water output of the solar field and / or storage can heat and vaporize an organic fluid, which activates one turbine to produce electricity.

  The power turbine consists of two heat exchangers (hot and cold sources), a turbine driven by an organic fluid in a closed circuit and a power generator (converting mechanical energy into electrical energy). The peak power of the turbine is equal to 5 kW_e.

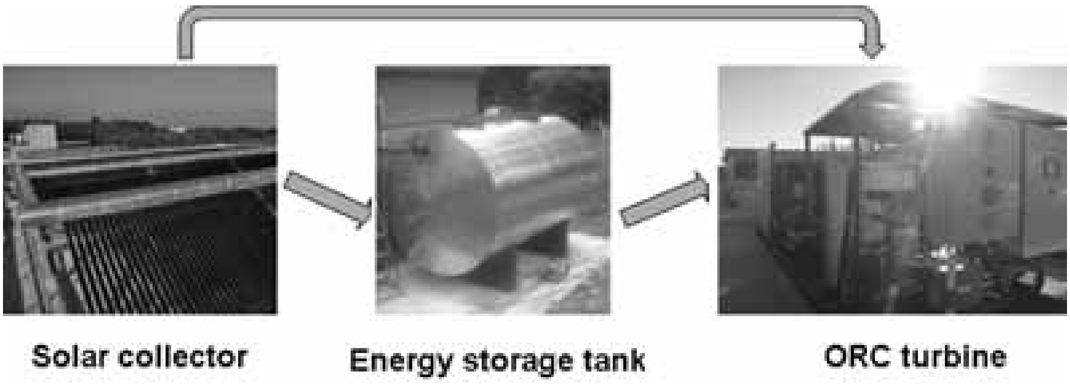

Fig. 4: Concept of the low temperature solar power plant developed in the frame of the PREMIO project

4.3. System performance

The system performance is presented in the two paragraphs below: solar collector efficiency and overall system efficiency

- Solar collector efficiency

Figure 5 presents the experimental results of the solar collector efficiency measurement done in April 2011.

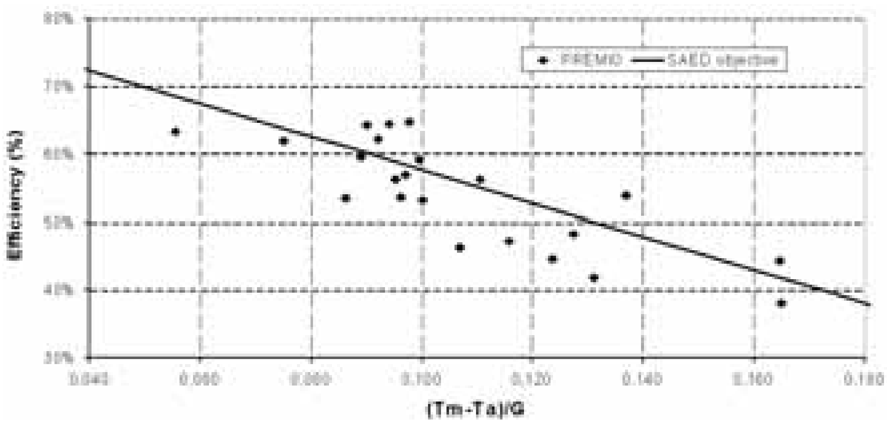

Fig. 5 : Experimental and objective solar collector efficiency

Measurement fits objective with efficiency ranging from 72% to 38% for Tm^* respectively equal to 0.040 and 0.18. At operating temperature and solar radiation conditions (Tm^* approximately equals to 0.1) measured solar collector efficiency ranging from 53 % to 64%.

Error uncertainties are due to the measuring devices precision as well as the system regulation. Several improvements are actually in progress.

- Overall system efficiency

Measurements done allow us to calculate the solar radiation receive by the solar collector, thermal and electrical energy produced.

During the all month of April 2011, horizontal global radiation measured is equal to 13.8 MWh. Energy collected by the solar field during these month is equal to 7.4 MWh_{th}. Thus the overall thermal system efficiency recorded in April is 53.6%. This value match results presented figure 5.

The recorded energy produced by the ORC turbine is equal to 616 kWh_e and represent efficiency equal to 8.32%. The overall system efficiency is thus equal to 4.5%. Out target , next year, is to increase the turbine efficiency from 8 to 11%, thanks to the control system and the strategy, giving rise to an increase of the overall system efficiency up to 6%.

In order to illustrate our system capability to produce energy when needed, solar irradiation, electrical power produced, and thermal energy stored measurements, done 17 and 18 April 2011, are presented figure 6. The stored thermal energy is calculated considering a mean temperature between top and back of the storage tank.

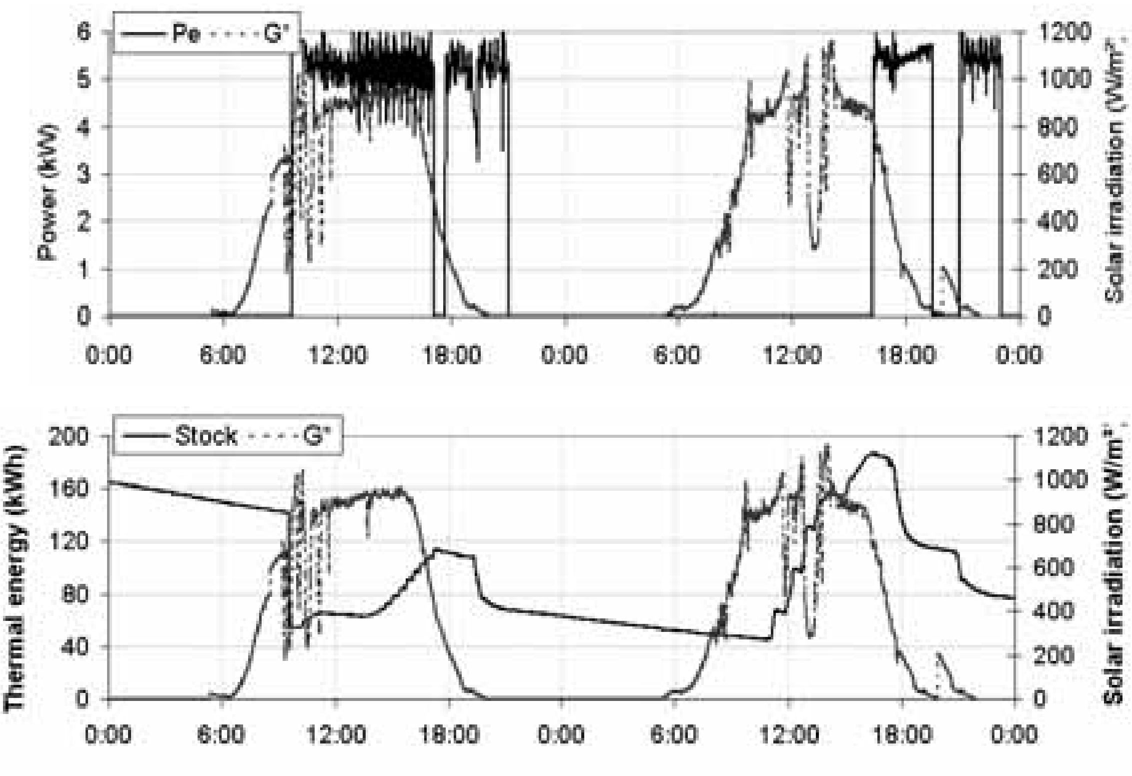

Fig. 6: Experimental low temperature solar power plant results (Top: Power generation and solar irradiation, Bottom: Storage tank thermal energy and solar irradiation) during 17 and 18 April 2011

During day a 5kW_e electric power is produced during all the day. At the end of the day the stored energy is used to produce electricity even in a lack of solar energy.

5. Conclusion

The low temperature solar plant designed by SAED is operational since November 2010. It is the first time that such a system is done and furthermore connected to a smart grid. The overall objective, production on demand (even in a lack of energy), is reached thanks to the thermal energy storage device

The technology principle of the power plant presented here could be applied to larger plant, up to 5MW. This value is between the dish Stirling and other CSP technologies (table 1), making this technology particularly complementary to other thermodynamic solar technologies. Furthermore its ability to use both the direct and diffuse radiation makes a technology particularly suited to coastal regions, and thus the island systems.

Moreover, unlike CSP technologies, the thermal storage system used by SAED, currently based on the sensible heat of water is available and technologically simple to implement. Another solution, based on the use of phase change materials is being studied. These systems (inexpensive, reliable and with highly performance) avoids the intermittent sun, using an environmentally friendly material, water and generate electricity on demand.

6. References

Herrmann U., Kelly B., Price H., 2004. Two-tank molten salt storage for parabolic trough solar power plants, Energy, 29, 883-893.

Hledik R., 2009. How Green Is the Smart Grid?, The Electricity Journal, 22, 29-41.

Laing D., Steinmann W.D., Tamme R., Rishter C., 2006. Solid media thermal storage for parabolic trough power plants. Solar Energy, 80, 1283-1289.

Nepveu F., 2009. Production décentralisée d'électricité et de chaleur par système Parabole/ Stirling : Application au système EURODISH, Thèse de doctorat de l'Université de Perpignan

Py X., Calvet N., Olives R., Echegut P., Bessada C., Jay F., 2009. Thermal storage for solar power plants based on low cost recycled material, Proceding of the Effstock conference, Stockholm, Sweden.

Steinmann Wolf-Dieter, Eck Markus, 2006. Buffer storage for direct steam generation, Solar Energy, 80, 1277-1282.

7. Acknowledgement

This project was financially supported by the French Provence Alpes Cotes d'Azur Region. The authors wish to express acknowledgement to this partner.