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Simulation of Electricity Production by a Solar Tower Power Plant with Thermal Storage System in Algeria

IKHLEF Khaoula[#1], LARBI Salah[#2]

[#]*Ecole Nationale Polytechnique d'Alger (ENP), Laboratoire de Génie Mécanique et Développement (LGMD)*
10, Avenue Hassen Badi, BP182, El Harrach, Alger, Algérie
[1]khaoula.ikhlef@g.enp.edu.dz
[2]salah.larbi@enp.edu.dz

Abstract— **Concentrating solar tower power plant with thermal storage system has received particular attention among researchers, power-producing companies and policymakers according to its bulk electricity generation ability by overcoming the intermittency of solar energy. The parabolic trough collector and solar tower are the two dominant CSP systems which are either operational or in the construction stage.**
The aim of this paper is to study the production of electricity by a solar tower power plant with thermal storage system (type PS10). The power plant capacity is 150MWe and it is located in Hassi R'mel (south region of Algeria). The purpose is to highlight the importance of developing concentrating solar thermal technologies in Algeria.
Concentrating solar thermal technologies belong to an engineering field, which can significantly contribute to the delivery of clean, stainable energy worldwide.

Keywords—**Solar Tower Power Plant, Thermal Storage System, Simulation, System Advisor Model.**

Abbreviations

CCGT	Combined Cycle Gas Turbine
CDSEP	Crescent Dunes Solar Energy Project
CF	Capacity Factor
CRS	Central Receiver Systems
CSP	Concentrating Solar Power
DNI	Direct Normal Irradiation
DSG	Direct Steam Generation
HTF	Heat Transfer Fluid
ISEGS	Ivanpah Solar Electric Generating System
LFR	Linear Fresnel reflector
PD	Parabolic Dish
PTC	Parabolic Trough Collector
SAM	System Advisor Model
SM	Solar Multiple
SPT	Solar Power Tower

I. INTRODUCTION

In order to take up the global challenges of clean energy, climate change and sustainable development, it is necessary to boost the development of environmentally friendly energy technologies. In this context, concentrating solar power plants (CSP) are increasingly relevant because of the need to reduce carbon dioxide emissions in electricity production and heat generation required to reach the goal of limiting climate change to 2°C above the pre-industrial levels.

CSP power plants are gaining in popularity with advances in technology. There is a type of concentrating solar thermal technologies available nowadays, being solar thermal collectors the major component of solar power systems. As previously stated, these collectors receive the incoming radiation and concentrate solar rays to heat a fluid, which then directly or indirectly drives a turbine and converted mechanical energy into electricity through a generator. The concentration of sunlight allows the fluid to reach working temperatures high enough to ensure affordable efficiency in turning the heat into electricity, while limiting heat losses in the receiver. The four main commercial CSP technologies are distinguished by the way they focus the sun's rays and the technology used to receive the solar energy (Fig. 1): parabolic trough collector (PTC), solar power tower (SPT), linear Fresnel reflector (LFR) and parabolic dish (PD). The basic principles of concentrated CSP systems are covered in previous reference works such as [1], [2], [3], [4] and [5].

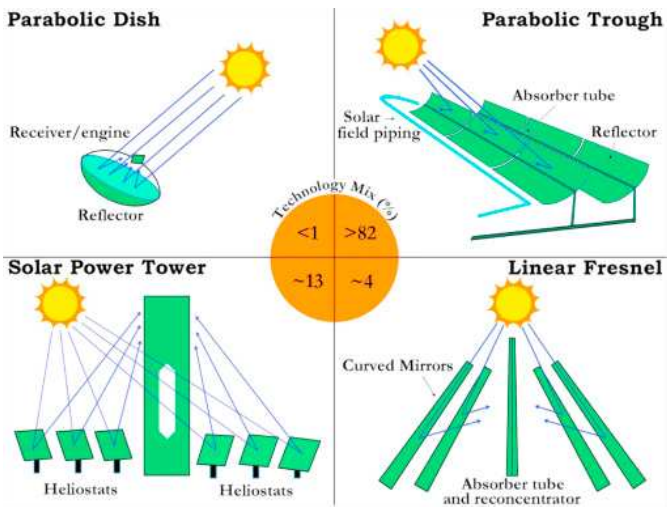

Fig. 1 Categories of CSP technologies.

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In the SPT plants (see Fig. 2), also called central receiver systems (CRS) or power tower, a large number of computer-assisted mirrors (heliostats) track the sun individually over two axes. Heliostats are less expensive than trough mirrors because they used standard flare glass, instead of glass that is manufactured at specific curves. They concentrate the solar radiation onto a single receiver at the top of a central tower where the solar heat drives a thermodynamic cycle and generates electricity. SPT plants can achieve higher temperatures than PTC and LFR systems because they have higher concentration factors. The SPT can use water-steam (DSG), synthetic oil or molten salt as the primary heat transfer fluid [6].

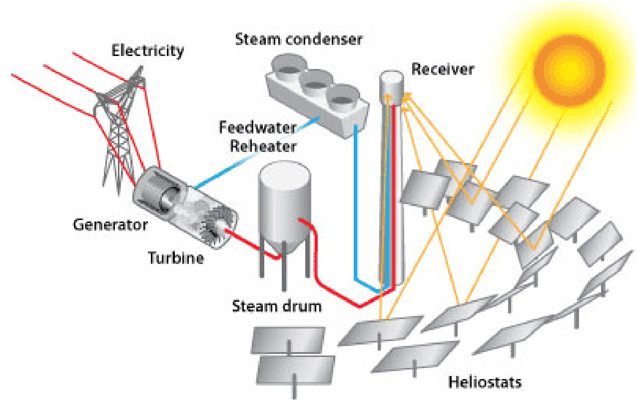

Fig. 2 Schematic of a Solar Tower Power Plant.

The number of existing CSP SPT plants of significant size is very limited, and the time they have been operational is also minimal. Additionally, not all the data needed are publicly available. Hence, the full potential of the SPT technology is not shown by the surveys of plants. In the list of the SPT plants of [7], there are only 34 CSP SPT plants worldwide. Only 3 above 20 MW of capacity are operational, ISEGS of 377 MW capacity since 2014, Crescent Dunes Solar Energy Project (Tonopah) of 110 MW capacity since 2015, and Khi Solar One of 50MW capacity since 2016. The 377 MW ISEGS plant only producing 703,039 MWh/year (2016), the output of a medium to small scale CCGT plant, has the best data set covering 3 years.

Recently, there has been a particular interest to solar tower power technology, as is evident from the fact that there are several companies involved in planning, designing and building utility size power plants. This is an important step towards the ultimate goal of developing commercially viable plants. There are numerous examples of case studies of applying innovative solutions to solar power [8].

II. Results and Discussions

The solar power tower simulation is performed using the System Advisor Model (SAM) simulator. The meteorological data of the selected site are taken by METEONORM 7 software with period data (1991-2010) for numerical simulation. Some important design parameters used in the simulation are given by tables, I, II and III.

TABLE I
HELIOSTAT FIELD

Total heliostat reflective area	Heliostats number	Mirror washing
1269055 m^2	8790	0.70L/m^2 and 63 washes per year

TABLE II
POWER CYCLE

Solar multiple	Capacity	Cycle	Condenser type
2	**150 MWe**	**Rankine**	**Air-cooled**

HTF type	HTF temperature	HTF mass flow rate
Salt (60% $NaNO_3$, 40% KNO_3)	**Hot: 574°C Cold: 290°C**	**850.9 kg/s**

TABLE III
THERMAL STORAGE

Type	Full load hours	Tank volume	Hot tank heater capacity
Two tank	6	11087 m^3	30MWe

Figures 3, 4 and 5 illustrate the meteorological data of Hassi R'Mel site.

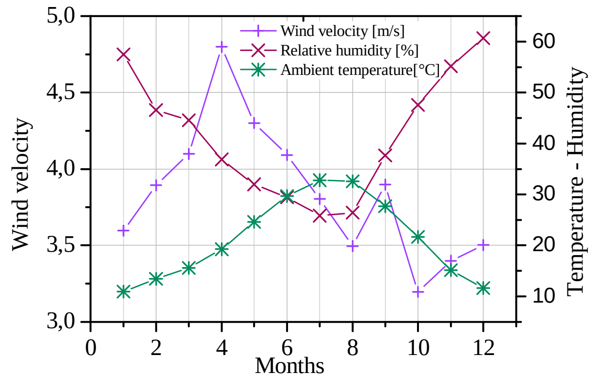

Fig. 3 Wind velocity, temperature and humidity.

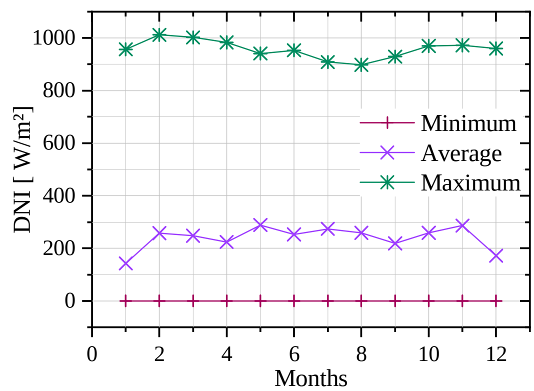

Fig. 4 Direct normal irradiation.

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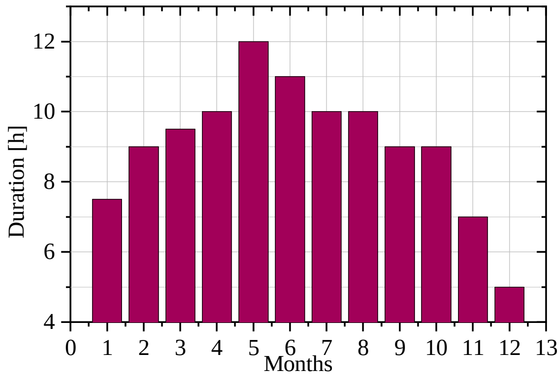

Fig. 5 Hours of sunshine.

The hours of sunshine are the hours whose DNI is greater than 300W/m² the threshold of deliverability of the plant.

Figure 6 illustrates the changes in the monthly averages of the production capacity of the power plant. Notice that the production varies proportionally to the DNI. Thus, the decrease in the production capacity from the incident radiation to the net power produced is caused by the optical, thermal and parasitic losses generated in the installation.

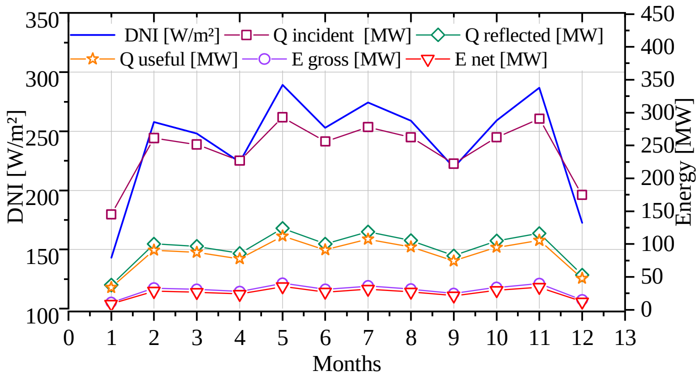

Fig. 6 Average monthly production capacity of the solar power plant.

The net hourly production capacity of the different months is given by figure 7.

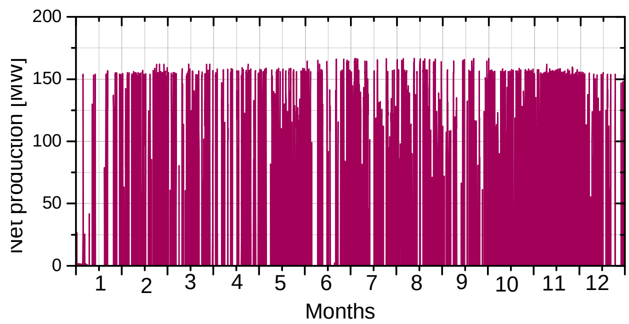

Fig. 7 Hourly production capacity of the solar power plant.

According to this figure, the best production is reached in the summer period, which records values that exceed 150 MW, where the plant works in an overcapacity.

Figures 8 and 9 show the monthly average daily production of the plant with a storage system that actually starts from a DNI greater than 300W/m² for the two typical days in May and January.

For the typical day of May, the energy incident, absorbed and reflected by the solar field follow the same shape as the DNI. The other energies (useful, gross and net) follow the variation of the DNI until 18h where they continue to be generated despite the disappearance of the DNI (null DNI). This generation of energy is provided by the storage tanks.

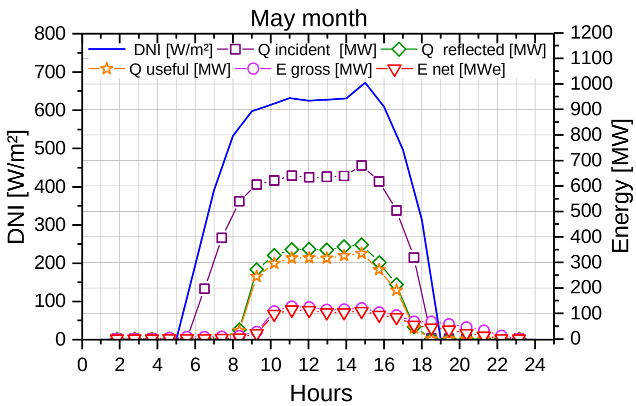

Fig. 8 Monthly average daily production of the power plant (21May).

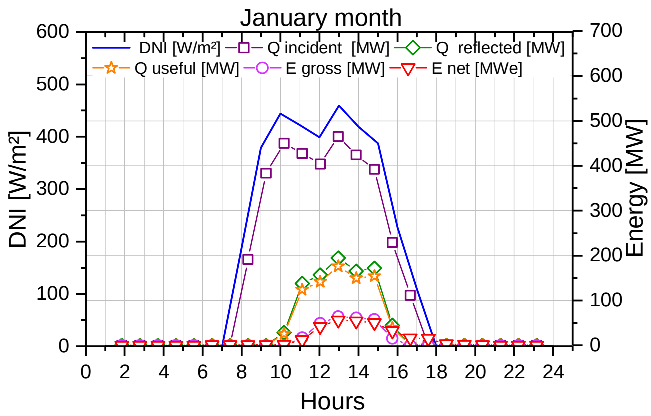

Fig. 9Monthly average daily production of the power plant (21January).

For the typical day of January, all energies follow the same shape as the DNI. The production of electricity starts when the DNI exceeds 300W/m². The power plant operates approximately one-third of its capacity.

A. Validation

To validate the results of our simulations, the Crescent Dunes Solar Energy Project is chosen. The project has a capacity of 125MWe [9] and 1.1 GW-hours of energy storage [10]. The site is located closely to Tonopah at approximately 310km from northwest of Las Vegas [11, 12]. It is the first utility-scale CSP plant with a solar tower and advanced molten salt energy storage technology from Solar Reserve. Results comparison between theoretical and experimental data are illustrated on table IV.

TABLE IV
RESULTS COMPARISON

	CDSEP [13]	Our simulation
Capacity	125MWe	150MWe
Storage system	10h	6h
Total collector area	1200000 m^2	1269055 m^2
Site resource	2685 $kWh/m^2/yr$	2828 $kWh/m^2/yr$
CF	more than 50%	57,9%
Annual net output	196 GWh (2018)	223,11GWh

III. CONCLUSIONS

The CSP STP plant technology is still far from the standards of conventional power plants in the power industry, where the actual costs and performances are usually close to the planned values. More experience must be gathered to proper develop a technology that appears to be still in its infancy. The different alternatives that are presently under study at different stages of development may only progress slowly, benefiting from real world experiences requiring time rather than simulations or laboratory experiments. This paper illustrates a simulation of a solar power tower with a capacity of 150MWe with heat storage system and the importance of installing such power plant in Algeria.

The main conclusions are presented as follows:

1) The parameters that have a great influence on the energy produced are the DNI and the duration of sunshine.

2) Thermal energy storage system plays a positive role in annual electricity generation and system capacity factor.

3) The results of this study were compared with those of the CDSEP power plant. Good agreement is observed between theoretical results and experimental data.

To make these technologies competitive with conventional fossil-based technologies, a reduction in the cost of production must be sought in the years to come.

This objective will be achieved on one hand, thanks to the technological innovations brought by the research and development work on solar sectors and their components (mirrors, panels, receivers, fluids and storage) and on the other hand by the massive construction of these power plants around the world.

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