435-24

Analysis of the operation of a Fresnel solar plant through experimental tests: Energy production and efficiency

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Abstract

To mitigate the lack of information on the actual performance of linear Fresnel technology in industries with thermal demand, numerous daily operational tests were carried out on a 105.6 m^2 Fresnel solar plant in Spain. An analysis was conducted covering all months of the year and including real direct radiation data. The tests were classified according to their characteristics, and the available solar energy, energy production, and efficiency were calculated. The use of actual data measured at the plant provided information on Fresnel systems under real operating conditions.

1. Introduction

Despite major efforts to reduce CO_2 emissions, the penetration rate of renewable energies in industries is still low. Fresnel concentrating solar technology has some favorable characteristics for heat generation in medium and low-temperature industrial processes. However, there are almost no experimental analyses focusing on the actual long-term operation of Fresnel installations in real plants. Most studies are based on simulations and very few rely on experimental data from full-size real plants.

Fig. 1.

In this work, a real 105.6 m^2 Fresnel solar plant was analyzed through different operational tests over several years. The plant has a NW-SE orientation, and it is fully automated to register minute data of various variables, including direct radiation.

The tests were classified and selected according to working time and radiation, and average energy production and efficiency were evaluated for every month of the year. Long-term monitoring of the plant's performance will contribute to the development and integration of Fresnel technology in existing industrial processes.

2. Materials and methods

The Fresnel solar plant, whose characteristics are described in Table I, produces steam via an indirect system using pressurized water as HTF and a kettle reboiler steam generator. The control system is automated, supports remote monitoring of the main variables (pressure, flow, temperature, energy, radiation), and provides minute data.

Table I. Main characteristics of the solar plant [1]

Location	Latitude	Longitude	Collectors	Mirror area	Orientation
Cáceres (SW Spain)	39.646º N	6.386º W	4 Fresnel collectors with 10 mirror rows	105.6 m^2	-42.3º (NW-SE)

[1] M. T. Miranda et al., "Prototype plant for indirect low-pressure steam generation with Fresnel solar collectors: Sizing and commissioning tests", Energy Conversion and Management: X (2024). Vol. 21, p. 100513, doi: 10.1016/j.ecmx.2023.100513.

The following parameters were defined to classify the daily tests performed from 2020 to 2023 and identify days with the plant inactive, days with operating errors that put the system out of service, and days valid for the analysis:

- **Theoretical duration of days ($T_{theor\text{-}day}$):** Time between sunrise and sunset, calculated theoretically using the solar equations.
- **Time with global radiation above 200 W/m² ($T_{real\text{-}GHI}$):** The plant only works when global radiation (GHI) measured at the site exceeds this minimum level.
- **Ratio between $T_{real\text{-}GHI}$ and $T_{theor\text{-}day}$ ($T_{real\text{-}GHI}/T_{theor\text{-}day}$)**
- **Real plant operating time ($T_{real\text{-}test}$):** According to the real operating data.

The monthly average values of the variables defined below were also calculated:

- **Daily energy production (E_{day}):** Real value measured in the primary circuit.
- **Daily solar energy:** Using actual direct radiation data. $E_{solar} = \Sigma_i\, DNI_i \cdot S_{Fresnel}$
- **Average daily efficiency:** $\eta_d = E_{day}/E_{solar}$
- **Average theoretical optical efficiency (η_{opt}):** Based on the manufacturer's data [1].

3. Results

The daily files with minute data of the plant variables were classified as shown in Table II. Part of the days with the plant inactive coincided with the worst solar radiation conditions. Constant monitoring and maintenance is required to ensure proper operation and avoid faults as pressure drops in the primary circuit, mechanical errors, or communication failures. In well-functioning days, the duration of tests coincided with the time with GHI above 200 W/m².

Table II. Classification of days

Total days with data			
679 (during 30 months)			
Days inactive	Days with plant operation		
139	540		
	Operat. errors	Valid days	
	72	468	
		Incompl. days	Well-funct. days
		118	350

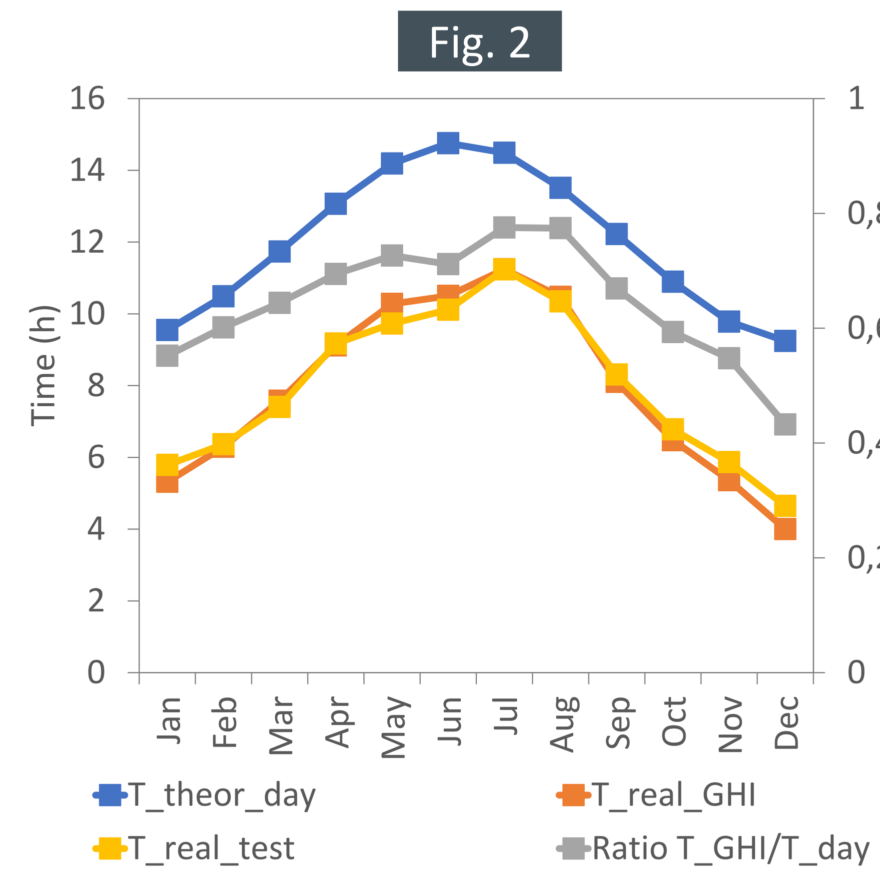
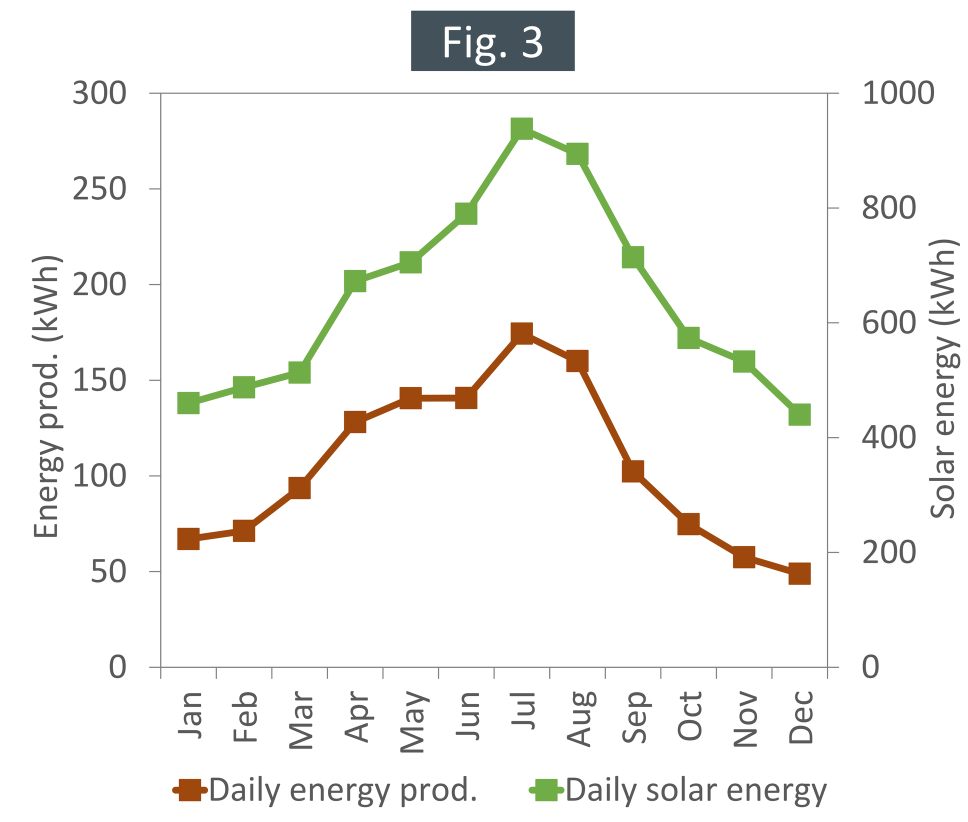
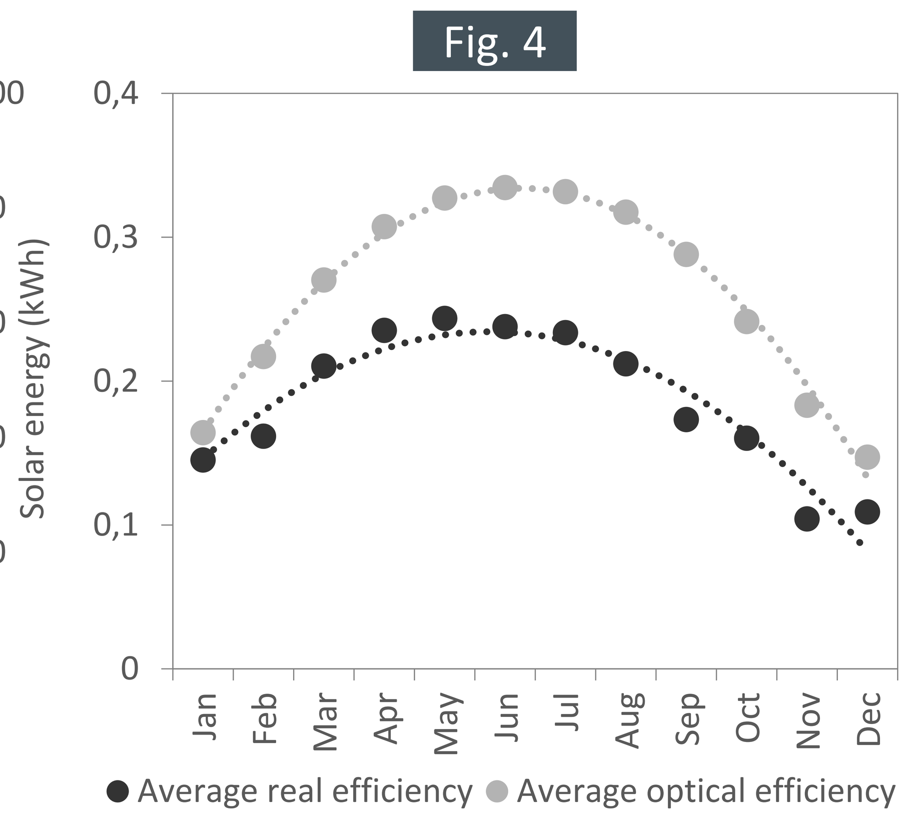


Fig. 2 shows the monthly average values of the parameters defined. Theoretical duration of days had a maximum value in June, coinciding with the summer solstice. Meanwhile, other variables are influenced by the local climate. July had the longest time with GHI over the minimum value of 200 W/m². The ratio $T_{real\text{-}GHI}/T_{theor\text{-}day}$ showed that the solar plant could operate between 43% and 77.5% of the time, with an annual average of 64%, an acceptable value compared to other studies. December was the worst month in all cases. $T_{real\text{-}GHI}$ was a good predictor of the average real operating time ($T_{real\text{-}test}$).

The months with the highest solar energy values were those between April and September, as shown in Fig. 3. July and August had the best average energy production, 174.3 and 160 kWh. April, May and June went from 128 to 140 kWh, and winter months didn't exceed 100 kWh. The plant performance was better in spring than in autumn: April and May had higher energy production, although solar energy was higher in September.

The theoretical optical efficiency shown in Fig. 4 was calculated using equations based on the incidence angle modifier [1]. June had the highest average value at 33.4%. The real efficiency was lower, as it represents the actual performance of the plant and includes thermal losses. The maximum values were 24.4% in May and 23.8% in June. The lowest were 10.4% in November and 10.9% in December. The highest average efficiency values were observed around the spring months, with decreases in the final months of the year. Plant orientation, radiation levels and other factors could be the cause of this behavior.





4. Conclusions

Many daily performance tests of a Fresnel solar plant were classified and analyzed. Experimental data from several years under real working conditions were used. Only half of the days with data were valid for the study. July had the highest average duration of tests, solar energy and daily production (174 kWh), while June had the best optical efficiency and May the highest real efficiency (24.4%). The plant could operate 64% of daylight hours, and the system behaved better in spring than in autumn. Future work with new tests will further evaluate the influence of parameters like the plant's orientation.

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