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Innovative thermal storage strategies for Fresnel-based concentrating solar plants with East-West orientation

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HIGHLIGHTS

- An innovative three-tank thermal storage system is proposed for East-West Fresnel-based solar plants.
- Storage management strategies can increase annual efficiency by 12% in East-West Fresnel-based solar plants.
- Proposed storage management strategies are more effective when low quality receivers are used.
- High latitude locations using this system provide a better annual performance.

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ABSTRACT

A novel proposal to drive forward linear Fresnel technology within the solar market competitiveness is presented in this paper. It consists of two innovative storage strategies conceived for the management of a flexible three-tank thermal storage system of molten salts, which seeks the enhancement of part-load plant efficiency in alternative East-West oriented Fresnel solar plants. A consistent methodology has been developed in order to assess quantitatively this new proposal by means of annual performance simulations of a global model. This allows the comparison of the aforementioned approach of Fresnel-based plant with reference parabolic trough collectors (PTC) and linear Fresnel collectors (LFC), which are equipped with state-of-the-art two-tank thermal storage of molten salts and North-South solar field orientation. Results show an increase of more than 10% in annual plant efficiency compared to conventional North-South Fresnel plants based in high latitude locations, i.e. Almería (Spain). This boost in LFC performance would imply narrowing the gap with PTCs, where expensive high optical quality receivers are used. Findings in this paper state that the proposed innovative strategies are proven to be more effective when low quality receivers are used and when the solar fields are located far from tropics.

1. Introduction and background

The price of concentrating solar power (CSP) has dropped sharply during the last year, becoming competitive with conventional power plants in locations with very high annual solar irradiations [1]. Furthermore, CSP technologies have important advantages when compared to photovoltaics in terms of grid stability [2] and plant dispatchability due to thermal energy storage [3]. In addition, CSP technology has a major effect on local industry, which is of especial interest when the sun source is mainly in developing countries [4].

There are four main concentrating solar power (CSP) technologies depending on weather the receiver is fixed or not and the concentrator dimension (lineal or punctual). The most mature technology is parabolic trough collector (PTC) [2], although central towers have become more important during the last decade [5,6]. Among all CSP technologies, linear Fresnel collectors (LFCs) have a great potential for cost reduction as mirrors are easier to manufacture, their structure is lighter, wind effects are relatively low and the receiver is fixed, which eliminates the need of rotating joints [7–9]. As a result, potential capital cost of LFCs is the lowest of all CSP technologies [10] and expected levelized cost of energy (LCOE) is as low as for central towers [11].

Nevertheless, the total LFC capacity installed in the world is still very low compared to central towers and, most notably, to PTCs. This is mainly due to its low maturity level, as most of scientific work carried out during the last decades, especially during the 70–80s, was concentrated on PTCs and central towers. This is well known by international agencies such as the IEA, which advices that financing circles fear risks when the technology is not mature, even when it has a higher cost-

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Nomenclature

E	energy (J)
h	specific enthalpy (kJ/kg)
$\dot{m}_s$	steam mass flow (kg/s)
M	total HTF mass (kg)
N	number of elements (#)
P	power intensity (kW/m^2)
q	absorbed linear energy (J/m)
T	temperature (K)
w_i	mirror width (m)
W	power (W)
x_m	dimensionless mass fraction (–)

Acronyms

2D	Two-dimensional
BH	Boiler
CSP	Concentrating Solar Power
CT	Cold tank
D1	Dual 1 strategy
D2	Dual 2 strategy
DNI	Direct Normal Irradiance
EW	East-West
HQ	High quality
HT	Hot tank
HTF	Heat transfer fluid
HTX	Heat exchangers
IT	Intermediate tank
LFC	Linear Fresnel collector
MCRT	Monte Carlo ray trace
MQ	Medium quality
NS	North-South
PH	Preheater
PTC	Parabolic trough collector
RH	Reheater
S	Single strategy
SH	Superheater

Greek letters

α_{hp}	dimensionless bleed steam mass (–)
Γ	terminal temperature difference (°C)
ΔL	length subdivision (m)
Δp	pressure loss (Pa)
Δt	time step (min)
ϵ_t	receiver tube emissivity (–)
η	component efficiency (–)
κ_q	tube emissivity coefficient
ρ	fluid density (kg/m^3)
ϕ_p	dimensionless pumping coefficient (–)

Subscripts

$1-6, p$	energy states
dc	drain cooling
e	electricity
$Forr.$	Forristal
h	hot
hp	high pressure
i	intermediate
lp	low pressure
op	optical
p	pump
pb	power block
s	steam
t	turbine
th	thermal receiver
x	exchangers

reduction potential [12].

It must be recalled that the optical design of LFCs includes the optimization of many design variables, which include the number of mirrors, their width, the shift between mirrors, the orientation, the location of the receiver and the receiver technology, mainly multitube or secondary reflector receiver [13]. There are many studies that analyze the effect of different design variables on the optical performance of the collector. Those studies might be analytic or based in Monte Carlo Ray Trace (MCRT) method. The former are less time-consuming in terms of computing time and, thus, they are customary used to obtain a preliminary design of the collector [14–16].

However, analytic works are not adequate to obtain the solar flux intensity distribution at the receiver, which is required in order to estimate the thermal performance of the receiver. Numeric methods such as MCRT are used for this task both for LFCs and PTCs [17–21], whereas other studies analyze the optical performance of LFCs for different designs, including the effect of the field orientation [22–25]. It has been concluded in [26] that East-West (EW) embodiments seem to be more interesting for latitude far from the tropics, while Fresnel collectors oriented North-South (NS) achieve higher efficiencies when the solar field is closer to the tropics.

Observing flux intensity maps given for LFCs with NS and EW orientation by some studies [25,26] one can conclude that, although EW embodiments are able to achieve similar solar intensity fluxes along the whole year at midday, its value is always very low during the morning and afternoon due to cosine effect. This results in a lower operation time compared to NS embodiments, especially during summer months. In order to solve this problem an innovative storage design has been patented [27]. It consists in the use of three molten salts tanks in order to reduce the receiver mean temperature when the flux intensity is low.

The present study is unique as a comprehensive methodology has been especially developed to assess the novel thermal storage design patented for LFCs plants with EW orientation. Due to its novelty, there are not any actual solar plant constructed with the layout needed to obtain experimental data. Hence, this work aims at obtaining the first preliminary results of the proposed storage system. Although other innovative storage systems with a medium temperature tank have been studied before [28], none of these works has examined thoroughly energy management strategies for maximizing EW oriented LFCs performance. Besides, the methodological approach allows the comparison with reference PTC and LFC plants equipped with state-of-the-art two-tank thermal storage and NS orientation in order to assess in a comparative manner the effects of the proposed storage system. Many works have compared the performance of PTCs and LFCs in locations such as Spain [29,30], USA [31,29,30], Egypt [32] and Italy [33]. These studies conclude that the efficiency of LFC is lower to that of PTC, which is an expected result. However, the difference in efficiency differs importantly from one study to other, with break even costs from 28% to 79%. Thus, results in this paper not only contribute to assess the gap between LFC an PTC, but also suggest an innovative plant layout with particular operation strategies to drive forward LFC technology within the solar market competitiveness.

The effect of the aforementioned innovative storage system on the EW oriented LFCS performance is analyzed in depth in this work. First, the proposed thermal energy storage design is described in Section 2. Then, Section 3 is devoted to the description of the methodology