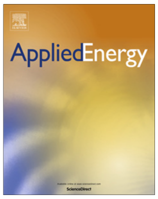
Applied Energy xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy



A comprehensive optical characterization of linear Fresnel collectors by means of an analytic study

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HIGHLIGHTS

- Performance of linear collectors is assessed via the impinging energy on the mirrors.
- Analytic methods are established to design LFCs.
- Innovative designs are proved to increase efficiency with EW orientation.
- Energy effectiveness of LFCs and PTCs are compared for different latitudes and tilts.

ARTICLE INFO

Article history:
Received 27 July 2015
Received in revised form 29 December 2015
Accepted 22 January 2016
Available online xxxx

Keywords:
Linear Fresnel collector
Analytic study
Location latitude
Orientation

ABSTRACT

Linear Fresnel collectors lead to a reduction of investment costs compared to parabolic trough collectors, but it is not yet certain whether this implies a reduction of levelyzed cost of electricity or not. In order to analyze the optical behavior of concentrators ray trace models are often used. However, such methodology leads to time-consuming codes that make difficult to optimize all design variables. In this work an analytic method is used in order to characterize the effect of the design variables on the annual energy impinging onto the reflecting surface, and results for two different locations are compared. The paper leads to the notable conclusion that the ratio of energy impinging onto the reflecting surface of Fresnel collectors is closer to that of parabolic troughs at low latitude locations.

1. Introduction

It is well known that concentrating solar power (CSP) is far from the required maturity level: there seems to be many alternatives to be explored [1–5], although much of the current deployment in countries subsidizing renewable electricity generation is based on standard parabolic trough collectors (PTCs). This is due to the fact that the experience of SEGS plants in California is enough for justifying a project finance with the level of subsidies or feed-in tariffs per kW h in several countries, notably in Spain [6,7].

It is noted by the International Energy Agency (IEA) [8] that "other technologies offer greater prospects for cost reductions but are less mature and therefore more difficult to obtain finance for. In countries with no or little experience of the technology, financing circles fear risks specific to each country". The large number of technologies available in CSP is a drawback to some extent, but it is also an advantage. On the one hand, it is difficult to set-up a priority list in the research budget, and there is a risk of dispersing efforts, without critical mass in any line. But on the other hand, a lot of possibilities remain open, and new proposals can lead to significant advances in the learning curve. In order to decide which are the technologies with higher potential to decrease CSP costs the following properties should be analyzed:

- Safety: The use of synthetic oil, generalized in PTCs, implies safety and environmental issues [9], as they are flammable and toxic.
- Low cost of electricity: PTCs require heavy structures in order to hold nearly 6 m of aperture [10]. In addition, mirrors are notably curved, which is more expensive to manufacture, while those of linear Fresnel collectors (LFCs) are nearly flat [11]. Finally, vacuum receivers are very expensive due the metal-glass seals and the requirement of vacuum in order to conserve the selective coating.
- Operational reliability: Such metal-glass seals are a weak element of PTCs plants due to differences in dilatation between both materials. In addition, the required flexible hoses or rotating joints often drive to oil leakages that reduce the plant reliability.

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http://dx.doi.org/10.1016/j.apenergy.2016.01.065
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Please cite this article in press as: Abbas R, Martínez-Val JM. A comprehensive optical characterization of linear Fresnel collectors by means of an analytic study. Appl Energy (2016), http://dx.doi.org/10.1016/j.apenergy.2016.01.065

Nomenclature

Acronyms

CLFR	Compact Linear Fresnel Reflector
CSP	concentrating solar power
DNI	direct normal irradiance
EW	East–West
HTF	heat transfer fluid
LCOE	levelized cost of electricity
LFC	linear Fresnel collector
MCRT	Monte Carlo Ray Trace
NS	North–South
PTC	parabolic trough collector

Latin symbols

d_{ef}	annual mean distance traveled by the reflected beam
d_r	distance traveled by the reflected beam at a given instant
E_{inst}	impinging solar power per mirror width at a given instant
$E_{\max}$	maximum annual impinging energy per mirror width at a given instant
E_y	annual impinging energy per mirror width at a given instant
E_{rp}	error due to the use of cylindrical mirrors at the reference position
f	focal length of the mirror
f_t	shading and blocking losses factor
p_{sun}	clear-sky probability
t_0	hour of the day when the DNI is sufficiently high for first time in the day
t_{end}	hour of the day when the DNI is no longer sufficiently high for first time in the afternoon
w_r	receiver width
(x_i, z_i)	location of the *i*th mirror
(x_r, z_r)	location of the receiver

Greek symbols

α	angle made by the incident beam with the normal to the reflecting surface
γ_i	angle made by the reflected beam with the normal to the receiver
ϕ_r	diameter of the reflected beam when impinging onto the receiver
$\langle\rho_{\mathrm{tot}}\rangle$	mean square width of the reflected beam
κ	curvature of the mirror
τ_f	field tilt
$\tau_{f_{\mathrm{opt}}}$	optimum field tilt
τ_s	sun typical altitude
η_{Ener}	annual energy effectiveness

- Generation flexibility and regulation: The generation flexibility is given by thermal energy storage. The storage system is more expensive as the temperature difference between the hot and the cold tanks diminishes; this is very relevant in PTCs, where the hot tank temperature is limited by oil's degradation point, below 400 °C.

Therefore, it seems that other technologies than PTC might have a greater prospect to reduce costs in CSP. Both central towers and linear Fresnel collectors use fixed receivers, which implies no limit in the pressures of the heat transfer fluid (HTF) and a more efficient system to drain molten salts.

Many authors have compared linear Fresnel with parabolic trough collectors. Most of them conclude that the performance of LFCs is slightly lower than such of PTCs [10,12–16]. However, central towers also have lower efficiencies than parabolic dish collectors while the latter have not been successful.

Morin et al. [17] identify a potential capital cost reduction of LFCs of 55% compared to PTCs; this can be achieved thanks to reduction of material use of around 20% [18]. The break even point is estimated at costs reductions from 28% to 30% [18] to 54% [13].

Linear Fresnel collectors have additional important operation and maintenance advantages: first, they require up to 3 times less space for the same generating energy than PTCs [12,19]. Second, reflectors are very narrow and with a very small curvature, which implies that they are nearly flat, being cheaper to manufacture and, also, making cheaper its maintenance [20,21] and reducing water use [22]. As a result, the levelized cost of electricity (LCOE) is estimated to be lower for LFCs by some authors [18].

In addition, Zhue et al. [22] identify some advantages of LFCs compared to central towers. First, linear nature of LFCs is conceivably friendly for automatic washing and O&M mechanisms. Mirrors can share the same drive system, as all of them rotate at the same speed. Such single-axis tracking system is much simpler and more cost-effective than for central towers plants, where thousands of heliostats must have their own automated driving/tracking system.

In order to analyze the LFC concentrator some authors prefer the use of analytic studies while others use Monte Carlo Ray Trace (MCRT) techniques [23–25]. If an adequate MCRT is developed or licensed, this method permits the estimation of the optical efficiency of the solar field for a given instant, and thus, annual efficiencies. However, MCRT calculations lead to very long computing times, which make them unsuitable for optimization processes. It must be recalled that LFCs are very flexible in their design, which implies many design variables that must be optimized at once [6]. This could be done via genetic algorithms, but it is not advisable if the computing time of a single function evaluation is very long [26,27].

Therefore, an analytic study of the problem is required in order to minimize the design variables. The present paper is devoted to such analytic study, where all the constrain and design variables are first identified in Section 2. Section 3 is devoted to the study of the effect of the tilt of the field both for NS and EW orientations. Then, the optimum location, tilt and width of the receiver are analyzed in Section 4. Section 5 is devoted to the study, by means of geometrical laws, of the effect of the shape of the mirrors – flat, cylindrical or parabolic – on the point of the receiver where reflected beams would ideally impinge; this leads to an optimum width and an optimum location of mirrors. In Section 7 the energy effectiveness of different LFC designs is obtained for Almería and Aswan; results are also compared to the energy effectiveness of a PTC. Finally, the conclusions of the present work are given in Section 8.

2. Previous considerations to the analytic study

In order to carry out the analytic study some definitions and facts must be first given.

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