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# End losses minimization of linear Fresnel reflectors with a simple, two-axis mechanical tracking system

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ABSTRACT

In order to compensate for end losses in linear solar concentrators (which can account for 33% of the optical losses), a mechanically simple two-axis tracking system was designed and analyzed. In the proposed system, a standard linear Fresnel reflector (LFR) with east-west rotational tracking was placed on north-south rails and driven by a linear actuator. By keeping the receiver fixed, end losses can be eliminated when the reflector slides along the rails. The relative optical efficiency improvement of this design was studied in detail though a combination of theory, numerical simulation, and experimentation. The results show that the annual average optical efficiency of an LFR can be improved by 8–50%, depending on the normalized collector length and local latitude. The optimal sliding distance limit, $d_{s,\mathrm{lim}}$, and the LFR geometries where this design is most techno-economically beneficial were also investigated. It was found that the proposed tracking system is most applicable to solar-driven, industrial process heat systems where rooftop or ground space is limited.

## 1. Introduction

Solar energy represents a key solution in the campaign to sustainably meet world energy demand due to the fact that it is clean, freely available, and abundant in most countries [1,2]. Although non-concentrating solar thermal technologies are cheaper per square meter, concentrating solar thermal technologies can obtain higher temperature and be applied to higher value, yet under-developed, markets such as industrial processing heat, thermal driven refrigeration and air-conditioning, and displacing coal use in power plants [1,3]. Among the concentrating solar technologies, linear Fresnel reflectors (LFR) represent an emerging, commercially viable technology for these applications [4]. For electrical generation, there are already several commercial LFR plants in operation worldwide – e.g. the Puerto Errado 2 (30MWe) plant in Spain, the Kimberlina plant (5MWe) in the USA, the Liddell power station (9.3 MWth) in Australia [5], and the Rajasthan (125 MW) plant in India [6].

LFR systems are typically installed with one-axis east-west rotational tracking, which inevitably results in cosine losses, end losses, and shading losses due to changes in the sun's position [7]. Therefore, improving the optical efficiency of LFR systems has been the subject of numerous investigations in recent decades.

In order to reduce the shading created by adjacent reflectors, Mills and Morrison invented a compact LFR which utilizes interleaving in a multi-absorber system for large-scale solar thermal power plants [8,9]. Mathur et al. proposed an optimal design for sizing the width of the primary mirror [10]. Xie [11], Ahmed [12] and Yu [13] all investigated the effect of receiver position and absorption ratio on optical efficiency.

At smaller scales (1–100 kW), LFR systems are suitable for rooftop installations since they have lower wind loading than parabolic troughs, although both technologies can suffer from end losses [14]. Hongn et al. and Eck et al. both stated that optical end losses and their influence on the energy performance were crucial issues to be dealt with for LFR systems [15,16]. The end losses factor, defined by illuminated fraction of receiver length, can even approach 0 when the normalized receiver length (receiver length divided by receiver height) is low enough [15]. Elmaanaoui et al. developed mathematical equations to predict end losses in LFRs [17]. Barbón et al. optimized the length and position of the absorber tube in small-scale linear Fresnel concentrators by taking the end losses and the spillage into account [18] and later proposed a frontal and lateral design method to help minimize these losses [5]. Boito and Grena optimized the Fresnel linear collector as a function of mirror width, spacing, and focal length based on a target function of the ratio between the plant cost and the collected radiation [19]. Muthusivagami also investigated end losses, but for parabolic trough collectors (PTC) [20].

Aside from the geometric optimization techniques mention above, only a few researchers have proposed solutions for the end loss

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**Nomenclature**

| | |
|---|---|
| $\theta_{in}$ | incident angle [°] |
| $\theta_{re}$ | reflection angle [°] |
| $\theta_1$ | projection of incident angle [°] |
| $\theta_2$ | projection of reflection angle [°] |
| $\alpha_s$ | solar altitude [°] |
| $\gamma_s$ | solar azimuth [°] |
| $\gamma$ | local latitude [°] |
| $\alpha$ | angle between reflected ray and XOY plane [°] |
| $\psi$ | azimuth angle of LFR [°] |
| $\beta$ | tilt angle of LFR [°] |
| $L_{oel}$ | instantaneous non-illuminated length [m] |
| $L_{oel,av}$ | average non-illuminated length [m] |
| $L_{oel,d}$ | daily average of optical end losses [m] |
| $L_{oel,a}$ | annual average of optical end losses [m] |
| $\widetilde{L}_{oel}$ | a relative non-illuminated length [m] |
| $H$ | receiver height [m] |
| $f$ | the focal length of the mirror [m] |
| $\overline{f}$ | average of the focal distance [m] |
| $W$ | width of the mirrors |
| $L$ | length of Fresnel reflector |
| $x_{c,i}$ | mirror location [m] |
| $d_s$ | sliding distance of reflectors [m] |
| $d_{s,lim}$ | limit of sliding distance [m] |
| $d_{s,lim,opt}$ | optimal sliding distance limit [m] |
| $(L/H)_{lim}$ | the upper limit of $L/H$ |
| $\rho_1$ | mirror reflectivity |
| $\rho_2$ | receiver reflectivity |
| $\eta$ | optical efficiency |
| $\eta_{oel}$ | the end loss factor |
| $\eta_d$ | daily average optical efficiency |
| $\eta_a$ | annual average optical efficiency |
| $\kappa$ | the effective mirror width coefficient |
| $n$ | number of mirrors |
| $n_d$ | day number |
| $t$ | solar time |
| $t_1$ | startup time |
| $t_2$ | shutdown time |

*Abbreviations*

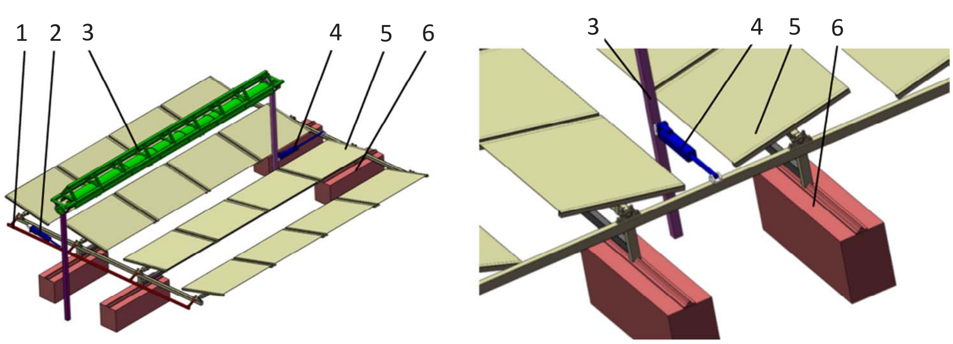
| | |
|---|---|
| LCOH | levelized cost of heat |
| LFR | linear Fresnel reflector |
| PTC | parabolic trough collectors |
| LEF | low efficiency system |
| HEF | high efficiency system |

problem. Li et al. presented a fan-shaped end plane mirror which redirect light which would normally be lost from the ends of PTCs [1]. Xu [21] and Buie [22] have proposed tilting and elongating the reflectors. However, tilting a long linear collector will considerably increase the cost, complexity, and the wind loading (particularly for a rooftop system). Zhu [14] presented a 'stretched' movable collector which also was able to reduce the end losses of LFR. It should be noted that reflector elongation works on the assumption that the reflector is significantly cheaper than the receiver and that by attempting to avoid extra heat losses from extending the receiver length.

Due to the ease of integration with factory rooftops, small-scale linear solar concentrators have been recently considered for industrial process heat systems [23,24], such as the commercialized Chromasun micro-concentrator [25], the PolyTrough-1200, and others [26]. As mentioned above, end losses of a small-scale solar concentrator become critical when the collection length is reduced – e.g. limited by the available, unshaded north-south dimension of the rooftop or site.

To address this issue, a new tracking system is proposed here to minimize the end losses of a standard LFR. This design assumes that the receiver remains stationary and that the reflector rotates east-west as normal. The new part is in how the reflector and its supporting structure mount on V-shaped slide rails, which are in turn driven by a linear actuator to track solar elevation angle changes, as shown in Fig. 1. Compared to the 'stretched' movable collector proposed by Zhu [14], the optical performance of the proposed design is similar. However, the approach of this paper is differentiated by three key aspects:(i) For movable reflectors, the receiver/support structure and – importantly – the pressurized piping and connections with receiver can be fixed. This is beneficial for improving reliability and installation costs; (ii) The moving receiver concept comes with the risk of exposing the driving mechanism to concentrated sunlight and elevated temperatures, both of which can shorten the life of electro-mechanical systems; (iii) The drive mechanism of a moving reflector can be located on the ground where it can more easily be maintained and linked to neighboring elements to enable cost savings.

The optical performance of the proposed LFR was analyzed theoretically, via ray tracing (numerically), and with experiments to determine the extent to which end losses can be reduced. Then it was investigates *when* and *where* such a design would be suitable through a theoretical analysis of optical performance as well as an analysis of the levelized cost of heat.




(a) The overall view (b) The local view

**Fig. 1.** Schematic of the proposed two-axis tracking LFR (1 – crank-rod mechanism; 2 – linear actuator; 3 – receiver and its supporter; 4 – linear actuator; 5 – reflector and its supporter; 6 – slide rails and pedestals).