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New adaptive method to optimize the secondary reflector of linear Fresnel collectors

Guangdong Zhu

National Renewable Energy Laboratory, 15013 Denver West Parkway, Golden, CO 80401, USA

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ABSTRACT

Performance of linear Fresnel collectors may largely depend on the secondary-reflector profile design when small-aperture absorbers are used. Optimization of the secondary-reflector profile is an extremely challenging task because there is no established theory to ensure superior performance of derived profiles. In this work, an innovative optimization method is proposed to optimize the secondary-reflector profile of a generic linear Fresnel configuration. The method correctly and accurately captures impacts of both geometric and optical aspects of a linear Fresnel collector to secondary-reflector design. The proposed method is an adaptive approach that does not assume a secondary shape of any particular form, but rather, starts at a single edge point and adaptively constructs the next surface point to maximize the reflected power to be reflected to absorber(s). As a test case, the proposed optimization method is applied to an industrial linear Fresnel configuration, and the results show that the derived optimal secondary reflector is able to redirect more than 90% of the power to the absorber in a wide range of incidence angles. The proposed method can be naturally extended to other types of solar collectors as well, and it will be a valuable tool for solar-collector designs with a secondary reflector.

1. Introduction

Linear Fresnel is one of four major concentrating solar power (CSP) technologies, along with parabolic trough, power tower, and dish/engine. As a type of line-focus technology, a linear Fresnel collector is typically composed of an array of one-axis primary reflectors and a fixed receiver assembly. The primary reflectors track the sun and focus sunlight to the receiver assembly. The receiver assembly includes one or multiple absorber tubes and an optional secondary reflector. In the past, linear Fresnel technology was treated as a low-cost, low-concentration option to produce thermal energy at a low or intermediate temperature (Zhu and et al., 2014). Lately, the CSP community has begun to recognize its potential to achieve high concentrations and high temperatures (Zhu and et al., 2014; Mills, 2004; Mills and Morrison, 2000). Commercial direct-steam-generation (DSG) linear Fresnel products exist that can produce steam with a temperature as high as 450 °C (Novatec Solar, Areva Solar), and high-temperature molten-salt linear Fresnel collectors (up to 550 °C) are also an active research topic and under development (Brost and Zhu, 2010, 2009, Areva Solar, US Sandia Labs Join Forces for CLFR Molten-Salt Storage, Morin and et al., 2014; Grena and Tarquini, 2011). The superior feature of molten salt over water/steam is that it not only provides a high-temperature low-vapor-pressure heat transfer fluid (HTF) in the solar field, but also, a low-cost thermal storage media for a utility-scale electricity system using linear Fresnel technologies.

The secondary reflector as part of receiver assembly is used to improve collector performance and—in the cases when non-evacuated absorbers are used—to reduce heat loss of absorbers. Examples of linear Fresnel secondary-reflector shapes include trapezoidal, parabolic, or other profiles defined by a higher-order polynomial, as well as compound parabolic shapes (Novatec Solar, Grena and Tarquini, 2011; Singh et al., 1999, Industrial Solar, Lai and et al., 2011). The trapezoidal shape provides a fabrication-friendly engineering design and facilitates the addition of an insulation layer to reduce heat loss from non-evacuated absorbers (Singh et al., 1999, 2010). The parabolic shape can naturally concentrate the incoming parallel sun rays to its focal point (Grena and Tarquini, 2011), but the reflected light from the primary reflector is not parallel, thus leading to non-ideal optical performance. A higher-order polynomial will provide more design parameters to optimize the secondary profile, but this often requires more intensive computational efforts.

One popular secondary-reflector shape resembles a type of non-tracking collector designs—compound parabolic concentrators

E-mail address: Guangdong.Zhu@nrel.gov

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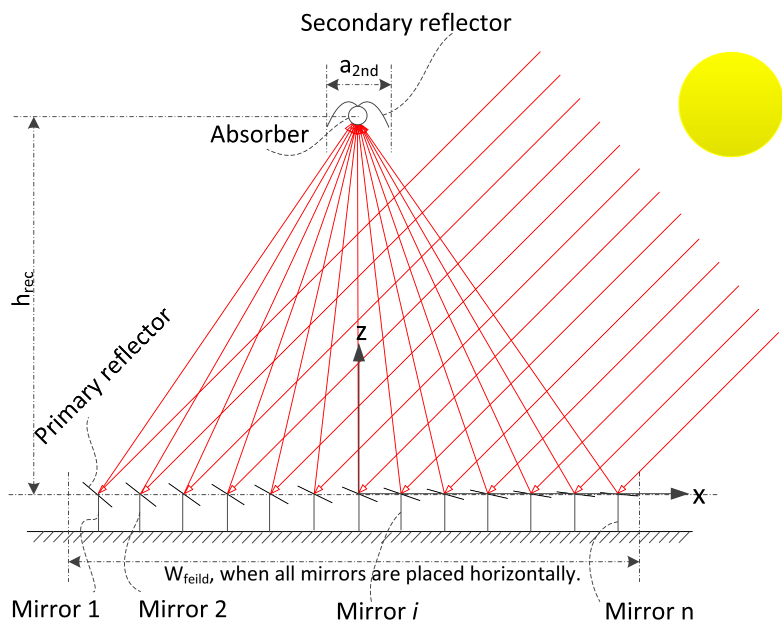
(CPC) Winston et al., 2005; Winston and Hinterberger, 1975. The CPC design is a type of non-tracking solar thermal collector that directly accepts sunlight. In contrast, a linear Fresnel secondary reflector accepts reflected light from primary reflectors, which results into two major differences: (1) the acceptance angle for the secondary reflector is required to cover the whole primary reflector field, and (2) the reflected sun shape becomes widened when reaching the secondary reflector because of the relative long optical path and system optical errors. Thus, the CPC cannot be justified as the optimal solution for a linear Fresnel secondary reflector.

The optimal secondary-reflector profile should be able to achieve the highest optical performance and it will vary with different collector configurations. In this work, a generic optimization methodology is proposed to derive optimal secondary-reflector profiles for a solar collector. Linear Fresnel is selected to illustrate the methodology, but the proposed method can be applied to both line-focus and point-focus collectors. It can also be extended to stationary solar collectors.

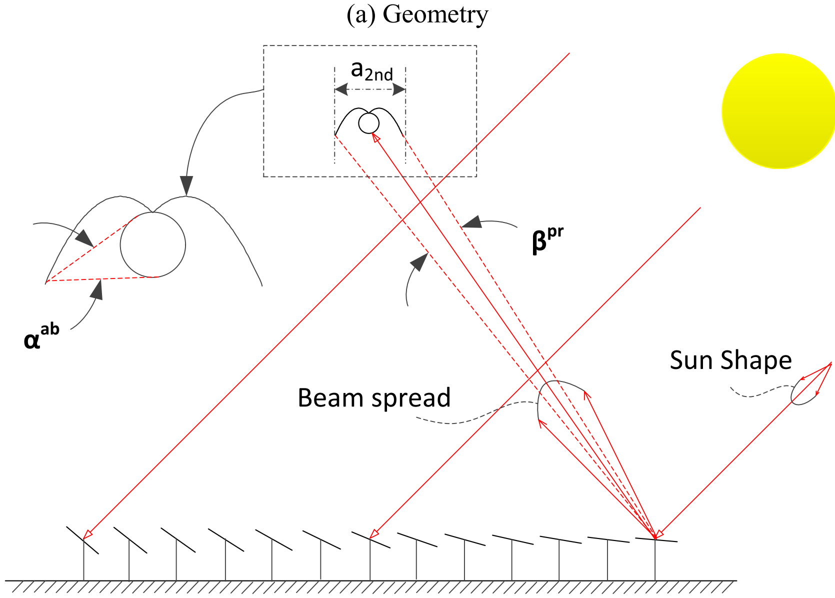
The paper is organized as follows: Section 2 briefly describes key linear Fresnel aspects; Section 3 presents the proposed optimization methodology in detail; Section 4 illustrates the value of the proposed method by selecting an industrial linear Fresnel collector design as a test case; lastly, Section 5 discusses the work presented and its future potential.

2. Linear Fresnel aspects

As shown in Fig. 1, a linear Fresnel collector is characterized by its geometry and system optics. With respect to its geometry, the collector includes an array of primary reflectors and a receiver assembly with a secondary reflector. Primary reflectors track the



(a) Geometry



(b) Optics

Fig. 1. Linear Fresnel collector characteristics: geometry and optics. For the sake of illustration, the sun size, secondary reflector, and absorber are not scaled relative to the size of primary reflectors.