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History, current state, and future of linear Fresnel concentrating solar collectors

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Abstract

Linear Fresnel collectors are a type of concentrating solar power technology. In this paper, the technology's technical features and aspects are first described via illustrations of various design concepts; then, the past low- and intermediate-temperature applications of linear Fresnel collectors are reviewed and their state-of-the-art applications in utility-scale electricity generation are presented; finally, the performance, technical challenges, and future outlook of linear Fresnel technology in the context of utility-scale power plants are summarized.

Keywords: Linear Fresnel; Concentrating solar power; Solar thermal

1. Introduction

Concentrating solar power (CSP) is a means to convert solar power into electricity through an indirect process. In general, CSP technologies use large-area mirrors to concentrate sunlight onto a relatively small-aperture receiver. The working fluid inside the receiver can be heated to a high temperature, and then the hot working fluid can be used to either directly run a thermodynamic power cycle or generate another working fluid at high temperature through a heat exchanger to run the cycle to generate electricity. In general, there are four types of CSP technologies (Mills, 2004): parabolic trough, linear Fresnel, central-receiver, and dish/engine. The first three often combine with a utility-scale power cycle such as a Rankine steam cycle to produce electricity and can be enhanced with large-scale thermal storage to increase the dispatchability of a solar power plant; the dish/engine technology uses a compact Stirling or Brayton engine to generate electricity and is more suitable for modular power generation systems (on the order of 1–30 kWe) (SolarPACES, 2012).

Linear Fresnel collectors are one of two viable line-focus CSP technologies, along with the parabolic trough (Price et al., 2002). As shown in Fig. 1, linear Fresnel collectors utilize an array of low-profile, flat or nearly flat primary reflectors and a fixed receiver assembly that includes one or more linear receiver tubes and an optional secondary reflector. The primary reflectors track the sun in the daytime while the receiver assembly remains fixed. The low-profile reflector architecture allows increasing concentration ratio without increasing wind loads, which is otherwise the case for parabolic troughs and large-sized heliostat mirrors for central-receiver systems. This is due to the fact that the wind torque load is roughly proportional to the square of the mirror height.

Because the low-profile architecture provides for great flexibility in the selection of a concentration ratio, linear Fresnel collectors can be readily tailored for different target temperatures to meet varying application needs. Histori-

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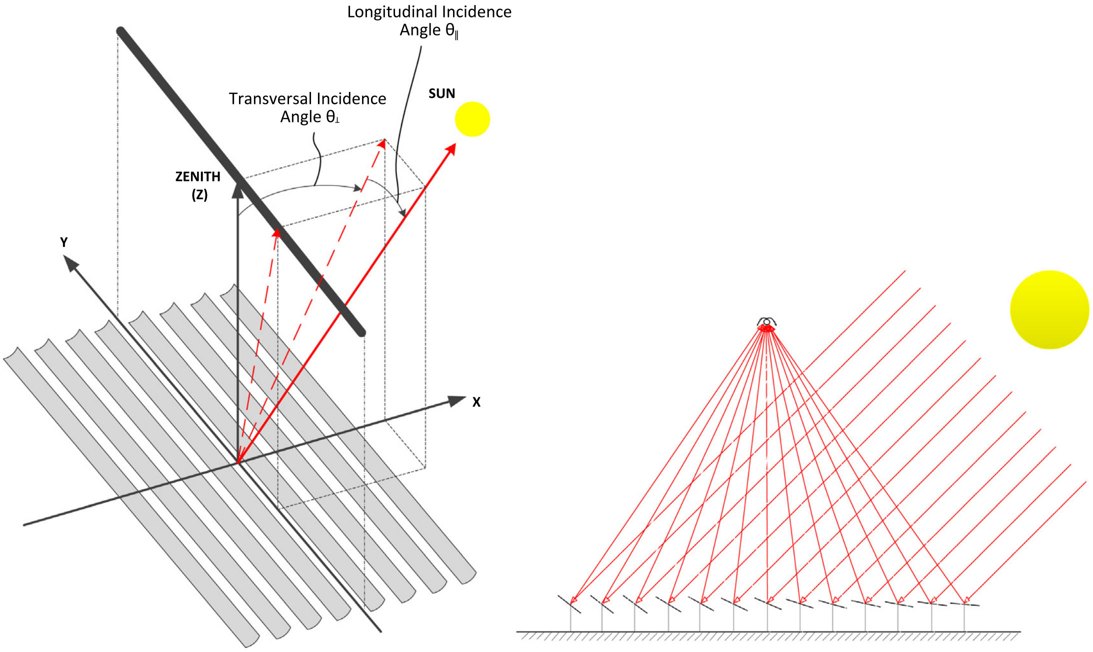

Fig. 1. Schematics of a generic linear Fresnel collector, reprinted from reference Zhu (2012).

cally, most linear Fresnel collectors were used or developed for low- or medium-temperature heat generation. Low- or medium-temperature linear Fresnel has wide applications in building cooling and heating, industrial process heat supply, water treatment, etc. State-of-the-art (SOTA) linear Fresnel collectors are more often designed to produce high-temperature heat for large-scale industrial heat processes or utility-scale electricity generation. This paper reviews the historical and SOTA developments of linear Fresnel collectors/applications and also discusses the possible future directions of high-temperature linear Fresnel technology.

2. Technical aspects of linear Fresnel collectors

A linear Fresnel collector typically includes an array of mirror panels, so its design may differ in terms of the individual mirror dimensions and the overall arrangement. In addition, the fixed nature of the receiver assembly provides considerable design freedom. On the other hand, linear Fresnel collectors have lower optical/thermal efficiency than parabolic troughs because the combination of a fixed receiver and the one-axis tracking mirror panels in a horizontal plane results into greater cosine losses than troughs (Munoz et al., 2011). The lower cost collector components are often required to compensate this optical penalty (Morin et al., 2012).

2.1. Types of linear Fresnel collector configurations

The linear Fresnel concept has been extensively analyzed in the past, and there are numerous types of collector designs. Some of them have proceeded into the prototyping and engineering stages while others were either only for theoretical exploration or are still under conceptual evaluation. In general, linear Fresnel designs differ in receiver assembly design and in the arrangement of the mirror arrays. The receiver assembly may be horizontal, vertical, or triangular in configuration (Negi et al., 1990, 1989; Gordon and Ries, 1993; Abbas et al., 2012a,b), as shown in Fig. 2. In particular, the compact linear Fresnel reflector (CLFR) concept may use two separate receiver towers, as shown in Fig. 3 (Mills and Morrison, 2000). A mirror in the CLFR may track either receiver at a given time of day depending on which tracking choice provides less shading/blocking loss; this may provide better optical efficiency, but it increases the design complexity of the tracking mechanism.

Another interesting linear Fresnel design is called the Etendue-matched CLFR collector (Chaves and Collares-Pereira, 2012; Horta et al., 2011). It incorporates the CLFR concept and further specializes each individual reflector with respect to its height and width in order to maximize the overall optical efficiency. Fig. 4 shows the schematic of this concept, which is currently in the conceptual design phase.

2.2. Types of receiver assembly

A large amount of effort has gone into receiver assembly design in order to increase the collector optical efficiency. As shown in Figs. 5 and 6, an array of receiver tubes instead of a single tube is used to increase the receiver surface, thus leading to an increase in the collector intercept factor. Trapezoidal cavity receivers (Pye et al., 2003; Reynolds et al., 2004; Singh et al., 1999, 2010; Dey, 2004) use non-evacuated receiver (absorber) tubes, and sidewall insulation is added to reduce thermal loss. However, when