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Design and thermal performances of a scalable linear Fresnel reflector solar system

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ABSTRACT

This paper proposes a scalable linear Fresnel reflector (SLFR) solar system. The optical mirror field which contains an array of linear plat mirrors closed to each other is designed to eliminate the inter-low shading and blocking. Scalable mechanical mirror support which can place different number of mirrors is designed to supply different temperatures. The mechanical structure can be inclined to reduce the end losses. Finally, the thermal efficiency of the SLFR with two stage mirrors is tested. After adjustment, the maximum thermal efficiency of 64% is obtained and the mean thermal efficiency is higher than that before adjustment. The results indicate that the end losses have been reduced effectively by the inclination design and excellent thermal performance can be obtained by the SLFR after adjustment.

1. Introduction

It is well known that the energy and environmental crisis has been promoting the development of solar technologies which mainly contains Photovoltaic (PV) panels [1,2] and concentrating solar power (CSP) [3–6]. As a commercial technology, PV technology which generates electricity directly from sunlight has been well developed. Especially building integrated photovoltaic/thermal (BIPV/T) plays a significant role in generating electricity and heat to meet the building energy demands, which is gaining a worldwide acceptance [7–9]. CSP technology has been proven to be a fairly efficient way of converting solar energy into thermal energy or electricity. There are currently four existing CSP technologies, namely parabolic trough collector (PTC) [10–12], linear Fresnel reflector (LFR) [13–15], solar power tower (SPT) [16,17] and parabolic dish systems [18,19]. Among them, LFR technology is regarded as another commercialized type of CSP except PTC. LFR is a type of solar collectors which collects sunlight by using long, narrow, flat or slightly curved mirrors to reflect the sun rays onto a linear receiver. LFR has the advantages of simple production, easy maintenance, and low cost, therefore, it is well developed and extensively applied in solar thermal system [20–23]. However, in LFR solar system, some portion of reflector aperture remains unused due to inter-row shading and blocking and end losses.

In the traditional LFR solar system, shading occurs when incident sun rays are blocked by one reflector and fallen on other reflector. Blocking occurs when reflected sun rays from one reflector are blocked by another reflector [24,25]. Thus the complete reflector-aperture area is not utilized, which affects the efficiency of the LFR solar system. Enlarging the gap between adjacent mirrors has been proposed to eliminate the inter-row shading and blocking, but the ground utilization ratio has been reduced [26]. Increasing the focus length of concentrator can also reduce the inter-low shading and blocking, but it will increase the tracking accuracy requirement and raise the system cost [27]. Stretched parabolic linear Fresnel reflector whose mirrors located at parabolic line and closed to each other have proposed by us, it can effectively eliminate the inter-low shading and blocking [28]. However, the parabolic mechanical structure is very complex. In this paper, the optical mirror field which contains an array of linear plat mirrors located at a straight line has been proposed to eliminate inter-low shading and blocking.

The end losses commonly occur when a portion of reflected rays is not intercepted by the receiver under the condition of the oblique incidence of incoming sunlight, which seriously decreases the efficiency of the LFR solar system [29,30]. In addition, the end losses are even more serious in small-scale LFR solar system. Considering the declined efficiency due to the end losses, much

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Nomenclature

f	focal length of the SLFR [m]
n	number of the mirrors
δ_n	tilt angle of the nth mirror [°]
Q_n	distance between the nth mirror and center [m]
S_n	distance between nth and $(n-1)$th mirror [m]
D	width of the plat mirror element [m]
D_{m1}	width of the layer I mirror element [m]
D_{m2}	width of the layer II mirror element [m]
r	radius of the absorber [m]
r_g	radius of the glass envelope [m]
C	geometrical concentration ratio of the SLFR
l	length of the mirror field [m]
l_r	length of the receiver [m]
φ	adjustable angle [°]
A	total collection area [m^2]
A_1	layer I collection area [m^2]
A_2	layer II collection area [m^2]
N_1	number of layer I mirrors
N_2	number of layer II mirrors
ρ	mirror reflectivity
α	absorptance of the selective absorbing coating
ε	emittance of the selective absorbing coating
η	thermal efficiency
Q_u	useful heat gain (W)
Q	incident radiation (W)
M	mass flow rate of the fluid (kg/s)
T_{in}	inlet temperature of the evacuated tube (°)
T_{out}	outlet temperature of the evacuated tube (°)
C_{in}	fluid's specific heat at constant pressure corresponding to T_{in} (kJ/kg °C)
C_{out}	fluid's specific heat at constant pressure corresponding to T_{out} (kJ/kg °C)
I_{eff}	effective solar radiation intensity (W/m^2)

Abbreviations

SLFR	scalable linear Fresnel reflector
CSP	concentrating solar power
PV	photovoltaic panels
BIPV/T	building integrated photovoltaic/thermal
PTC	parabolic trough collector
LFR	linear fresnel reflector
SPT	solar power tower

effort has been made. For examples, setting a plane mirror at the end of the collector can reduce the end losses [29,31,32], while the very nonuniform focal spot can be caused by the reflection of the plane mirror, and the selective absorbing coating can be destroyed because of the local overheating. Increasing the length of the mirror field can also alleviate the end losses [30], but it will cause much more consumption of materials. In this paper, a mechanical structure which is adjustable to solar altitude angle has been designed to reduce the end losses.

Meanwhile, another remedial measure for the end losses is sunlight area compensation [30]. Whereas, few people studied the changeable sunlight area and the different temperature supplies once the LFR solar system is constructed. Unchangeable focusing multiples and low temperature supplies may limit the practical application of LFR solar system. Therefore, strategies for mitigating the end losses and making the sunlight area adjustable simultaneously are highly required to be proposed.

In this paper, a scalable linear Fresnel reflector (SLFR) solar system is proposed. In this novel SLFR solar system, the optical mirror field which contains an array of linear plat mirrors located at a straight line has been simulated to eliminate inter-low shading and blocking. Mechanical structure has been designed to adjust the solar altitude angle, which can reduce the end losses of the receiver. The changeable numbers of mirrors can be placed in an extend support framework, which makes the LFR solar system scalable and accessible to different focusing multiples and variable temperature application.

2. Design of SLFR solar concentrator

The SLFR design is presented in Fig. 1. The SLFR is oriented to East-West direction and rotated around the horizontal North-South axis. In the mirror field of SLFR, the centers of all plat mirrors are located at the same straight line. The tilt of each mirror is adjusted so that the incoming sunlight reaches to the focus point after a single reflection. The flat mirrors track the sun as a whole, so the inter-row shading and blocking do not need to be considered when the sun is at oblique incidence. An evacuated tube locates at $z = f$, where f is the focal length of the SLFR. The evacuated tube includes a glass envelope of 100 mm diameter and an absorber tube of 70 mm diameter with selective absorbing coating.

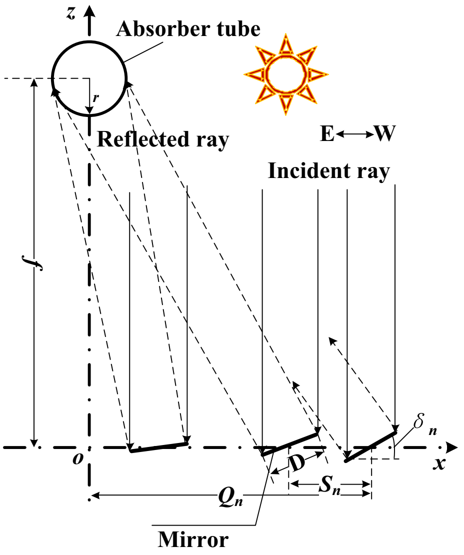

Fig. 1. Schematic design of mirror field layout of SLFR concentrator.

Due to the sun angular subtense (31.98′) is very small, it can be ignored in this paper. Each mirror can be characterized by location (Q_n), tilt angle (δ_n) and the distance of adjacent mirrors (S_n). These parameters can be obtained by the following expressions using simple geometrical optics [33]:

$$\tan 2\delta_n = Q_n/f \tag{1}$$

$$S_n = D/2[(\sin\delta_n + \sin\delta_{n-1})\tan 2\delta_n + \cos\delta_n + \cos\delta_{n-1}] \tag{2}$$

$$Q_n = Q_{n-1} + S_n \tag{3}$$

Here, $n \geqslant 1$.