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Optical performance of an azimuth tracking linear Fresnel solar concentrator

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Abstracts

In this paper, a linear Fresnel solar concentrator installed on a solar azimuth tracker is studied. Based on the integration of the effective source distribution for a reflection point and the whole reflector area, we develop an analytical model to calculate the intercept factor of the concentrator and analyze its performance over a year. The prediction of our analytical optical model agrees pretty well with that of the ray tracing program SolTRACE. Then we study the effects of the main design parameters on the performance of the system. The results show that annual mean total efficiency of 61% can be obtained in optimized design when the operational temperature of the receiver is 400 °C. The performance of the azimuth tracking linear Fresnel solar concentrator (ATLFSC) is compared with that of the parabolic trough collector. It is found that the cosine factor, intercept factor and total efficiency of the ATLFSC are better than those of parabolic trough collector, showing that the ATLFSC may have great potential for solar energy utilization.

Keywords: Linear Fresnel reflector; Azimuth tracking; Intercept factor; Ray trace

1. Introduction

Since Francia had constructed the first linear Fresnel solar concentrator pilot plant (Francia, 1968), the company Solarmundo built a prototype in Liège, Belgium (Häberle et al., 2002), Mills raised a compact linear Fresnel reflector (CLFR) near Liddell Power plant in Australia (Mills et al., 2004) and 5 MW pilot one in Bakersfield, California, and Novatec Solar put up a commercial linear Fresnel concentrator PE1 in Puerto Errado of Spain (Novatec-Solar, 2011). The solar energy collected by the linear Fresnel reflector can be used by solar cells (Tkachenko et al., 1990), fossil fuel power plants (Morin et al., 2004; Popov, 2011) and refrigeration systems (Velázquez et al., 2010). Compared to the parabolic trough solar collector, although the efficiency of the linear Fresnel reflector is lower (Buie et al., 2002), the cost of its reflectors and structure is also lower (Ford, 2008) as well as the maintenance and operation cost (Häberle et al., 2002), showing great potential of cost reduction (Dersch et al., 2009).

In 1980s and 1990s, Negi et al. carried out some experiments (Choudhury and Sehgal, 1986; Singhal et al., 1986) to investigate the optical and thermal performance of the linear Fresnel solar concentrator employing the receivers with the black and selective absorptive coatings, presented the variation in efficiency of solar energy to net heat and overall heat loss coefficient of those absorbers with temperature based on experiments (Negi et al., 1989; Negi and

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Nomenclature

a, b, c	parameters to calculate reflectivity
A, C	edge of the receiver
A_1C_1	line through B and perpendicular to BR
ATLFSC	**Azimuth Tracking Linear Fresnel Solar Concentrator**
$B(\delta)$	radial distribution of the solar radiation (W m^{-2} sr^{-1})
B	center of the receiver
$B_{eff}(\theta)$	normalized distribution of the effective reflected solar brightness (W m^{-2} rad^{-1})
$B_{guasseff}(\theta)$	distribution of the reflected solar brightness in Gaussian form (W m^{-2} rad^{-1})
B_{linear}	transverse distribution of the solar incidence brightness (W m^{-2} rad^{-1})
c_i	simulation coefficient of $B_{eff}(\theta)$
D	width of reflector aperture (m)
D_1, D_2, D_3, D_4	lower and upper limit of the integration of η_{optn} (m)
d_n	distance between the vertex of the nth reflector and the center of the receiver (m)
DNI	direct normal insolation (W m^{-2})
D_P	distance of point P to the axis of the nth reflector (m)
E_{fyear}	solar energy collected per unit reflector area (J m^{-2})
f_n	real focus length of the nth reflector (m)
H	receiver height associated with concentrate base (m)
h	solar altitude (°)
ht	BQ_1 (m)
I_{in}	incident solar energy at point P (W m^{-2})
I_p	solar energy captured by the receiver for point P (W m^{-2})
I_{sc}	solar constant (W m^{-2})
m	air mass
n	the highest degree of polynomial of $B_{eff}(\theta)$, the number of the reflector or the number of a day in the year from Jan.1st
nr	the total number of the reflector
nx	ratio of the actual DNI to the DNI calculated from the clear day model at t
O	origin of the coordinate
p	atmospheric transparency with $m = 2$
P	any point on the reflector
Q	the incident ray from the center of the sun after reflection striking at Q in plane AC
Q_1	the central incident ray after reflection striking at Q_1 in plane A_1C_1
q_{loss}	heat loss per unit receiver area (W m^{-2})
$Q_{netyear}$	annual net energy collected by the system per unit reflector area (J m^{-2})
R	vertex of the nth reflector
r	corrected coefficient
r_n	optimal radius of the nth reflector (m)
T	working temperature (°C)
t	time (s)
W	width of receiver (m)
x	the horizontal level
x_n	location of the vertex of the nth reflector on the concentrator base (m)
y	vertical direction
α	absorptivity of the reflected ray striking on the receiver
β	angle between AB and A_1B (°)
γ	instantaneous intercept factor of the whole system
γ_n	instantaneous intercept factor of the nth reflector
γ_P	instantaneous intercept factor of point P
γ_{year}	annual mean intercept factor
δ	angle between the ray from the center of the sun and any incidence ray (rad)
$\delta_\perp$	transverse δ (rad)
$\delta_{\amalg}$	longitudinal δ (rad)
ΔD_1, ΔD_2	calculated from D_1, D_2, D_3, D_4
η_{cosn}	instantaneous cosine factor of the nth reflector
η_{coss}	instantaneous cosine factor of the system
η_{cyear}	annual mean cosine factor of the system
η_{opts}	instantaneous optical efficiency of the system
η_{optn}	instantaneous optical efficiency of the nth reflector
η_p	instantaneous optical efficiency for point P
η_{ryear}	annual receiver efficiency
η_{sbn}	instantaneous shading and blocking factor of the nth reflector
η_{sbs}	instantaneous shading and blocking factor of the system
η_{sbyear}	annual mean shading and blocking factor
η_{tyear}	annual solar energy to net heat efficiency
θ	angle of any reflected ray associated with the central reflected direction for each point on the reflector (rad)
θ_{p1}, θ_{p2}	APQ, QPC (rad)
μ_n	transverse incidence angle of the nth reflector (°)
μ_{nm}	maximum incidence angle of the nth reflector during a year (°)
μ_{ns}	minimum incidence angle of the nth reflector during a year (°)
ρ	reflectivity of point P
ρ_n	instantaneous reflectivity of the nth reflector
ρ_s	instantaneous reflectivity of the system
ρ_{year}	annual mean reflectivity efficiency
σ_{ontour}	mirror contour error in the transverse direction (mrad)
σ_{optic}	total optical error (mrad)
$\sigma_{specular}$	specular error (mrad)