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Comparison of line focusing solar concentrator fields considering shading and blocking

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Abstract

The performance of line focusing solar collectors [Parabolic Trough Concentrator (PTC), Linear Fresnel Reflector (LFR) and Compact Linear Fresnel Reflector (CLFR)] is affected by many factors. Due to end effect, inter-row shading and blocking (for LFR and CLFR), the complete aperture of the collector cannot be utilized. Besides, the cosine effect, reflectivity of reflectors, intercept factor, transmissivity of receiver cover, absorptivity of absorber tube and thermal losses are the other major contributors to the energy losses. In the current work, PTC, LFR and CLFR fields are compared in terms of energy losses, net energy collection by fluid, electricity generation and cost of electricity. The ratio of collector aperture area to land area is named as land coverage ratio. The appropriate values of land coverage ratio are found out corresponding to minimum cost of electricity for different technologies. The corresponding annual energy collection by fluid and the annual electricity generation have also been calculated. It is seen that there is no significant difference in the performance of LFR and CLFR fields. For low values of receiver height to collector width ratio, the LFR field results in the largest levelised cost of electricity and the PTC field results in the lowest.

Keywords: Parabolic trough; Linear Fresnel reflector; Shading; Blocking

1. Introduction

Electricity generation using line focusing collectors is one of the economically feasible renewable technologies. Electricity generation depends on the energy collection by the collectors. Some collectors are good at energy collection but costlier. However, some are not so good at energy collection but quite cheaper (Morin et al., 2012). Thus, for specific applications, these collectors have to be compared in terms of energy collection, electricity generation and cost of electricity. Parabolic Trough Concentrator (PTC) field and Linear Fresnel Reflector (LFR) field refer to line focusing technologies.

A Parabolic Trough Concentrator (PTC) field consists of parallel rows of collectors. A part of collector-aperture area can't be used due to end effects (also known as end losses) and inter-row shading (Morin et al., 2012). End losses occur when a portion of reflected rays is not intercepted by the receiver due to non-zero angle of incidence of sun's rays in axial direction at collector-aperture. Shading occurs when one collector-row blocks the incident rays falling on other collector-row. Thus, the complete aperture area of the collector is not utilized. Besides, cosine effect, optical parameters (such as reflectivity of reflectors, intercept factor, transmissivity of receiver cover, absorptivity of absorber tube) and thermal losses from the absorber also affect the energy collection. Moreover, day of the year, time of the day, the latitude of the place, length (L) and width (W) of aperture of collector-row, spacing between adjacent

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Nomenclature

A	total aperture area of a reflector-row (m^2)
a_b	fraction of aperture area of a reflector-row experiencing blocking
a_{end}	fraction of aperture area of a reflector-row or collector-row experiencing end effect
A_{PB}	land area required by power block per "We" of power rating (m^2/We)
a_s	fraction of aperture area of a reflector-row or collector-row experiencing shading
C	geometrical concentration ratio
C_{coll}	cost of collector per unit collector-aperture area ($/$m^2$)
C_{land}	cost of land per unit area ($/$m^2$)
C_{PB}	cost of the power block per "We" of power rating ($/We)
d	centre to centre distance between the ith reflector-row of kth collector-row and jth reflector-row of mth collector-row (m)
E_{avl}	energy available considering end effect, shading and blocking (J)
E_{b_loss}	energy loss due to blocking (J)
E_{col}	energy collected by fluid (J)
E_{cos_loss}	energy loss due to cosine effect (J)
E_{el}	electricity generation (J)
$E_{el,a}$	annual electricity generation (kWh/year)
E_{end_loss}	energy loss due to end effect (J)
E_{ibn}	beam normal radiation energy on an aperture having area NnwL (J)
E_{inc}	energy incident without considering end losses, shading and blocking (J)
E_{s_loss}	energy loss due to shading (J)
$E_{\rho\gamma\tau R\alpha\_loss}$	energy loss due to factors ρ, γ, τ, R and α (J)
F	focal length of parabolic trough collector (m)
$f_{avail,plant}$	factor for plant availability
f_{EPC}	factor representing surcharge for Engineering, Procurement and Construction (EPC), project management and risk
$f_{ins,a}$	fraction of total plant investment cost used as annual insurance rate
$f_{O\&M,a}$	fraction of total plant investment cost used as annual operational and maintenance cost
H	height of receiver above the reflector level (m)
I_{bn}	instantaneous beam normal radiation (W)
L	length of each reflector-row or collector-row (m)
L_b	length of the aperture area of a reflector-row experiencing blocking (m)
L_{end}	length of the aperture area of a reflector-row or collector-row that remains unused due to end effect (m)
L_s	length of the aperture area of a reflector-row or collector-row experiencing shading (m)
n	number of reflector-rows in a collector-row
N	number of collector-rows in a field
P_{gross}	turbine gross power (We)
r	expected project's internal rate of return
R	effective reflectivity of secondary reflector (accounting multiple reflections)
s	centre to centre distance between two consecutive reflector-rows (m)
S	centre to centre distance between two consecutive collector-rows (m)
t	time (s)
T_a	ambient temperature (°C)
T_{abs}	temperature of absorber tube (°C)
T_f	fluid temperature (°C)
U_L	overall loss coefficient of the receiver (W/m^2 K)
w	width of the aperture of a reflector-row (m)
W	width of the aperture of a collector-row (m)
w_b	width of the aperture area of a reflector-row experiencing blocking (m)
w_s	width of the aperture area of a reflector-row experiencing shading (m)
Y	life span of the power plant (year)

Subscripts

a	annual
b	blocking
cos	cosine effect
end	end effect
i, k	ith reflector-row of kth collector-row
i, k, j, m	on ith reflector-row of kth collector-row due to jth reflector-row of mth collector-row
inlet	inlet of absorber tube
k	kth collector-row
outlet	outlet of absorber tube
s	shading
t	tth instant of time

Greek symbols

α	absorptivity of absorber tube
β	tracking angle i.e. angle between normal to aperture and local vertical (°)
γ	intercept factor i.e. fraction of the reflected radiation intercepted by the receiver
γ_s	solar azimuth angle; due south is zero and positive in anticlockwise direction in plan view (°)
γ_{sur}	surface azimuth angle; due south is zero and positive in anticlockwise direction in plan view (°)
δ	solar declination angle (°)
$\eta_{th\text{-}el}$	thermal to electricity conversion efficiency of power block
θ	angle of incidence of sun rays at aperture (°)
θ_{rim}	rim angle of trough (°)
θ_z	zenith angle (°)