Energy 94 (2016) 633–653

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Effects of shading and blocking in compact linear fresnel reflector field

Vashi Sharma*, Sourav Khanna, Jayanta K. Nayak, Shireesh B. Kedare

Dept. of Energy Science and Engineering, Indian Institute of Technology Bombay, Powai, Mumbai 400076, India

ARTICLE INFO

Article history:
Received 12 June 2015
Received in revised form
5 October 2015
Accepted 23 October 2015
Available online 15 December 2015

Keywords:
Compact linear fresnel reflector
Shading
Blocking
Cost of electricity

ABSTRACT

In a compact linear fresnel reflector field, ‘s’ number of reflector-rows lying between two receivers can be configured in 2^s ways. Each possible configuration will lead to different energy loss, electricity generation and cost of electricity. The variations in energy losses, energy collection by fluid, electricity generation and cost of electricity with length (L) and width (w) of aperture of a reflector-row, spacing between adjacent reflector-rows (p), number of reflector-rows (2n), receiver-height (H), collector-configuration and location have been studied. It is found that the collector configuration has no significant effect on annual shading. However, it affects annual energy losses due to cosine effect, blocking and the factors τ and α significantly. As a result, the cost of electricity can be improved significantly by varying collector configuration. The cost of electricity decreases with increment in p/w and later on, it starts increasing. The best p/w ratio corresponding to minimum cost of electricity is 1.44 for H/nw = 0.3 and 1.85 for H/nw = 0.7. The energy collection by fluid increases rapidly with increment in H/nw initially. However, beyond H/nw about 0.7, further increase in H/nw does not lead to significant increase in energy collection.

1. Introduction

Generally an LFR (Linear Fresnel Reflector) field in a solar power plant consists of a number of collectors. Each collector has a number of reflector-rows (placed parallel to each other) and a linear receiver, the reflectors directing sun rays towards the receiver as shown in Fig. 1 [1]. Mills and Morrison [2] have proposed that, if the collectors are close enough, the reflector-rows lying between two receivers have an extra degree of freedom to direct the incident rays towards either of the receivers. The solar field having such flexibility is called CLFR (Compact Linear Fresnel Reflector) field. Thus, a CLFR field can be interpreted as a combination of a number of LFR collectors placed close to each other.

In an LFR collector, the complete reflector aperture cannot be utilized due to the following reasons: (i) the reflected rays from some portion of reflector are not intercepted by receiver during non-zero angle of incidence of sun rays in axial direction (known as end losses), (ii) some portion of reflector gets shaded by adjacent reflectors (known as shading), (iii) the reflected rays from some portion of reflector gets blocked by adjacent reflectors (known as blocking). In addition to end effect, shading and blocking, cosine effect [3], cleanliness factor (c), reflectivity of reflectors (ρ), intercept factor of receiver (γ), transmissivity of receiver cover (τ), multiple reflectance of secondary reflector (if used) (R), absorptivity of absorber tube (α) and thermal losses from receiver also contribute to energy losses. In an LFR collector, energy losses get affected by the latitude of the place, day of the year, time of the day, length and width of aperture of reflector-row, spacing between adjacent reflector-rows, number of reflector-rows, receiver height, collector orientation and receiver's dimensions and material-properties.

Several studies on LFR collectors are available for calculating the optical losses (losses due to end effects, shading, blocking and effects of c, ρ, γ, τ, R and α), thermal losses, the energy collected by fluid, the generated electricity and the cost of electricity. In all the studies, the combined effect of variations in shading, blocking and effective product of c, ρ, γ, τ, R and α is treated as variation in optical efficiency. It is estimated by using ray tracing software and termed as IAM (Incident Angle Modifier). IAM is usually captured as the product of its longitudinal and transversal components. Zhu [4] has found that the splitting of IAM slightly underestimates the optical efficiency.

Heimsath et al. [5] have computed the energy received by the absorber tube considering CPC (Compound Parabolic Concentrator) shaped secondary reflector for various collector orientations. Barale et al. [6] have studied the effect of spacing, curvature of reflectors,

* Corresponding author.
E-mail address: vashimant.sharma@gmail.com (V. Sharma).

http://dx.doi.org/10.1016/j.energy.2015.10.098
0360-5442/

Nomenclature

a_b	fraction of aperture area of a reflector-row experiencing blocking
A_b	area of the blocked part of the aperture of a reflector-row (m^2)
a_{end}	fraction of aperture area of a reflector-row experiencing end effect
A_{end}	area of the part of the aperture of a reflector-row that remains unused due to end effect (m^2)
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 experiencing shading
A_s	area of the shaded part of the aperture of a reflector-row (m^2)
c	cleanliness factor of reflector-rows
C	geometrical concentration ratio
C_{coll}	cost of collector per unit collector-aperture area ($/$m^2$)
C_{invest}	total plant investment cost ($)
C_{land}	cost of land per unit area ($/$m^2$)
$C_{O\&M,a}$	annual cost for operation and maintenance ($)
C_{PB}	cost of the power block per “We” of power rating ($/We)
D_{abs}	diameter of absorber tube (m)
dir_i	variable giving the information that whether i^{th} row directs the sun rays towards eastern receiver or western. (E for Eastern Receiver, W for Western Receiver)
E_{abs}	energy absorbed by the receiver of a collector (J)
E_{avl}	energy available from the collector considering end effect, shading and blocking (J)
E_{b_loss}	energy loss due to blocking in a collector (J)
E_{col}	energy collected by fluid in a collector (J)
E_{cos_loss}	energy loss due to cosine effect in a collector (J)
E_{el}	electricity generation by a collector (J)
$E_{el,a}$	annual electricity generation by a collector (kWh/year)
E_{end_loss}	energy loss due to end effect in a collector (J)
E_{inc}	energy incident on the collector without considering end losses, shading and blocking (J)
E_{s_loss}	energy loss due to shading in a collector (J)
E_{th_loss}	energy loss due to thermal loss in a collector (J)
$E_{c\rho\gamma\tau R\alpha\_loss}$	energy loss due to factors c, ρ, γ, τ, R and α in a collector (J)
$f_{avail,\ plant}$	factor for plant availability
f_{EPC}	factor representing surcharge for 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 (m)
L	length of each row (m)
L_b	length of blocked area of a reflector-row (m)
L_{end}	length of the aperture area of a reflector-row that remains unused due to end effect (m)
L_s	length of shaded area of reflector-row (m)
2n	total number of rows in a collector
N	number of equal intervals in which the time period [t_1, t_2] is divided
p	pitch (spacing) i.e. centre to centre distance between two consecutive rows (m)
P_{gross}	turbine gross power (We)
q_{pipe}	pipe losses per unit collector-aperture area (W/m^2)
r	expected project's internal rate of return
R	effective reflectivity of secondary reflector (accounting multiple reflections)
s	number of rows lying between the receivers
t	time (s)
T_a	ambient temperature (°C)
$T_{abs,l}$	temperature of absorber tube over a small length of “dl” (°C)
T_f	fluid temperature (°C)
$U_{L,l}$	overall loss coefficient of absorber tube over a small length of “dl” (W/m^2-K)
w	width of the aperture of reflector-row (m)
w_b	width of blocked area of a reflector-row (m)
w_{end}	width of the aperture area of a reflector-row that remains unused due to end effect (m)
w_s	width of shaded area of reflector-row (m)
Y	life span of the power plant (year)

Subscripts

a	annual
avg	average
b	blocking
cos	cosine effect
end	end effect
i	i^{th} reflector-row
inlet	inlet of absorber tube
i, j	on i^{th} row due to j^{th} row
j	j^{th} row
k	k^{th} time interval
l	length
max.	maximum
min.	minimum
outlet	outlet of absorber tube
r	r^{th} collector configuration
s	shading
t	t^{th} instant of time
th	thermal loss

Greek symbols

α	absorptivity of absorber tube
α_o	absorptivity of absorber tube at $\theta_{g,lo} = 0°$
β	tracking angle of a row i.e. angle between aperture normal 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 (°)
δ_g	thickness of glass cover (m)
Δt	time interval within which values of all the parameters are assumed to remain constant (s)
ε	extinction coefficient (/m)
$\eta_{th\text{-}el}$	thermal to electricity conversion efficiency of power block
θ	angle of incidence of sun rays at reflector aperture (°)
θ_{rim}	rim angle of trough (°)
θ_g	angle of incidence of reflected rays at glass cover (°)