Applied Energy 136 (2014) 527–536

Contents lists available at ScienceDirect

Applied Energy

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

Experimental and numerical study on non-concentrating and symmetric unglazed compound parabolic photovoltaic concentration systems

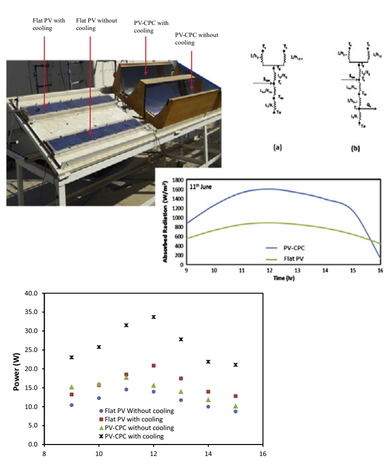
Haitham M. Bahaidarah [a], Bilal Tanweer [b], P. Gandhidasan [b], Nasiru Ibrahim [a], Shafiqur Rehman [c,*]

[a] Center of Research Excellence in Renewable Energy, Research Institute, King Fahd University of Petroleum & Minerals, Saudi Arabia
[b] Mechanical Engineering Department, King Fahd University of Petroleum & Minerals, Saudi Arabia
[c] Center for Engineering Research, Research Institute, King Fahd University of Petroleum & Minerals, Saudi Arabia

HIGHLIGHTS

- Effect of cooling on the efficiency of flat photovoltaic and symmetric compound parabolic concentrator photovoltaic systems.
- Compare modeled results with the experimentally measured values.
- Numerical models are solved using Engineering Equation Solver software.
- For flat PV with cooling, about 49% more power was obtained.
- For PV–CPC with cooling about 100% more power was obtained.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 18 May 2014
Received in revised form 16 August 2014
Accepted 19 September 2014

Keywords:
Flat PV string
CPC system
Cooling
Power output

ABSTRACT

Comparative study on flat photovoltaic (PV) string and symmetric compound parabolic concentrator (CPC) photovoltaic system has been presented in this paper. Two flat PV strings and two unglazed PV–CPC systems are considered. The cells of each of the flat PV and PV–CPC strings are subjected to cooling to reduce temperature. The performance of the two configurations with and without cooling is evaluated numerically and experimentally. The numerical models for the flat PV string and the PV–CPC systems are solved using Engineering Equation Solver (EES) software and the concentration ratio of the CPC system is considered as 2.3X. Absorbed energy is calculated with and without cooling for the PV–CPC and flat PV systems. The absorbed energy is used to solve the energy balance equations on different nodes of the system from which the cell temperature was determined. The results showed that the maximum power output of the flat PV string with cooling was approximately 21 W which gives about 49% more than the power obtained without cooling. The maximum power output of the PV–CPC system with cooling was approximately 34 W which is about twice of the power obtained in the absence of cooling. It was found that the power output of the PV–CPC system is higher than that of the flat PV string with and without cooling by 39% and 23% respectively. Comparison of the numerical results with experimental data showed good agreement for the two configurations. The maximum

* Corresponding author. Tel.: +966 3 8603802; fax: +966 3 8603996.
E-mail addresses: haithamb@kfupm.edu.sa (H.M. Bahaidarah), srehman@kfupm.edu.sa (S. Rehman).

http://dx.doi.org/10.1016/j.apenergy.2014.09.060

percentage differences between the numerical and experimental power output for the flat PV with and without cooling are 5% and 7%, respectively. While those of the PV–CPC system with and without cooling are 9% and 11%, respectively.

Nomenclature

a	air, modified ideality factor
C_p	specific heat capacity
F	control function
G	beam component of radiation
h	height, heat transfer coefficient
$\bar{h}$	truncated height
I	irradiance, current
K	extinction coefficient, incident angle modifier
k	Boltzmann's constant, thermal conductivity
L	glazing thickness
$\bar{\ell}$	truncated opening aperture
M	air mass modifier
$\dot{m}$	mass flow rate
N	number of runs
$\dot{Q}$	rate of heat transfer
S	absorbed radiation
s	width of the PV string
T	temperature
$\overline{T}$	mean temperature
U	overall heat transfer coefficient, top loss coefficient
V	voltage
V_w	speed
$\overline{X}h_r$	truncated distance

Greek symbols

θ	incidence angle
θ_c	half acceptance angle
α	absorbance
β	angle of latitude
ρ	reflectivity
τ	transmittance
ε	product of electron charge and band gap energy
σ	Stefan–Boltzmann constant
μ_{Isc}	Short circuit current temperature coefficient

Subscripts

a	air
b	beam
bs	back sheet
c	cell
cg	solar cell to glass
cbs	cell to backsheet
ga	glass to ambient
bsf	back sheet to fluid
cpc	compound parabolic concentrator
d	diffuse
f	fluid
fa	fluid-ambient
fi	fluid inlet
fo	fluid outlet
g	ground, glass
L	light
mp	maximum power
n	normal incidence
p	plate
r	refraction, radiation
ref	reference state
s	series, sky
sc	short circuit
sh	shunt resistance
t	overall
T	tilted

1. Introduction

Developing sustainable and renewable sources of clean energy is becoming important due to the current increase in world energy demands, greenhouse effects and environmental threats as a result of carbon emissions from fossil fuels. Solar energy offers unlimited potential as a clean renewable source of energy. To exploit the solar energy, a major solution is to convert the solar energy directly into electrical energy. Since the photovoltaic (PV) technology improves and maximizes the photoelectrical conversion rates, it has been extensively employed in the recent years.

The solar PV systems can supply energy without moving parts, operate noiselessly and have minimum maintenance costs. Due to the high initial capital cost of PV systems, their wide-ranging applications are restricted. It is necessary to find ways to reduce the cost of the PV systems considerably and cost reduction can be resolved either by increasing the efficiency of the solar cell or using concentration photovoltaic (CPV). The second strategy strives for reduction in PV module cost with reduced semiconductor material consumption. Semiconductor material is the most expensive part of the PV system. This strategy for reduction in PV module cost with reduced material consumption for semiconductors is called concentrating solar cell technology.

Concentrating PV cells is a complementary approach in which the amount of the expensive photovoltaic cell is reduced by concentrating incident sunlight onto PV cells using cheaper optical components [1,2]. A cost-effective and improved CPV system is obtained by producing the same amount of power by using less number of cells as compared to number of cells in conventional system. The higher concentrating PV systems require less cell area. It is reported that a low concentration photovoltaic system (LCPV) can cut the cost up to 40% as compared to a simple flat PV system [3,4]. Due to their potentials of non-tracking, high liability and low cost, an extensive research has been carried out for the development of various types of LCPV applications [5].

The objective of this study is twofold. First is to study the effect of cooling on the efficiency of flat photovoltaic (PV) string and symmetric compound parabolic concentrator (CPC) photovoltaic systems. Second is to compare the numerically modeled results with the experimentally measured values. The set objectives have been