Energy Conversion and Management 159 (2018) 371–380

Contents lists available at ScienceDirect

Energy Conversion and Management

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

Performance investigation of a hybrid photovoltaic/thermoelectric system integrated with parabolic trough collector

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ARTICLE INFO

Keywords:
Thermoelectric
Photovoltaic
Parabolic trough collector
Efficiency

ABSTRACT

In this study, a non-dimensional model of a tri-generation unit consisting parabolic trough solar collector, integrated with solar cell and thermoelectric generator is presented. In order to obtain the effects of solar irradiance and ambient temperature on the performance of the system, a set of functions were coded in the MATLAB software. Eight nonlinear algebraic equations were derived and solved via the iterative Newton-Raphson technique. The thermal and electrical efficiencies, the electrical characteristics of the thermoelectric and photovoltaic modules, and the thermal and electrical power of the hybrid device were analyzed in this study. The results have reflected some improvements on the electrical efficiency by placing thermoelectric module and solar cell on the lateral area of the absorber tube. Furthermore, an electrical power of 22.714 W could be reached at the solar concentration of 998 W/m^2. In order to validate the results of the mathematical model, two research works have been utilized. The evaluation of the obtained results shows a good agreement with the results in the literature.

1. Introduction

Photovoltaic is recognized as the promising approach to exploit solar energy. However, the main part of solar energy is transformed into waste heat and the temperature increase of photovoltaic leads to diminish its electrical efficiency. An appropriate method to moderate the effects of this problem, is the integration of PV module with a converter of heat-to-electricity in the form of thermoelectric generator (TEG) [1]. To obtain this goal, it is necessary to heat one side, while keeping the other side cold. The temperature difference across the TEG provides energy for charging barriers (electron, hole) to depart from the hot side to the cold side of a thermoelectric element.

Many research works have focused on the combination of thermoelectric modules with solar systems [2–4]. Miljkovic and Wang [5] numerically evaluated the performance of a hybrid solar thermoelectric system. They investigated the effects of three various types of thermoelectric materials on the efficiency of the system. They presented an energy-based model of the hybrid device to evaluate the overall performance. The effects of environmental parameters on the efficiency of a parabolic trough/TE unit were investigated by Li et al. [6]. They observed that rising the solar insolation, ambient temperature and wind velocity, increased the thermal losses of the system.

Many researchers have investigated the effects of using thermoelectric material on the efficiency of photovoltaic systems [7–10]. Su et al. [11] presented an electrical and thermal model for a dye-sensitized PV hybrid thermoelectric generator. They studied the temperature effects on the efficiency of the solar cell. The results indicated that the hybrid system could be used as a promising configuration to exploit solar energy. Lamba et al. [12] proposed a thermodynamic model for a concentrated photovoltaic cell and a thermoelectric module. The effects of some characteristics such as solar flux, PV current and TE current on the overall efficiency and total power were discussed. The results proved that the overall power of the hybrid system was reduced by 0.7% and 4.78% at the solar concentrations of 1 and 5, respectively. Hajji et al. [13] studied the efficiency of an indirect PV/TE coupling device. They placed a concentrator between the photovoltaic and thermoelectric modules. Their findings demonstrated that their design enhanced the overall efficiency of the hybrid PV/TE system.

Studying the simultaneous use of thermoelectric cooler and solar cell has been received wide attention. Najafi et al. [14] investigated the application of thermoelectric cooler to control the solar cell temperature. They computed the required power to run the thermoelectric cooler, and applied genetic algorithm to optimize the thermoelectric current. It was found that using thermoelectric cooler dropped the temperature of solar cell. Kane et al. [15] utilized a thermoelectric tile

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https://doi.org/10.1016/j.enconman.2017.12.091
Received 19 September 2017; Received in revised form 26 December 2017; Accepted 27 December 2017

Nomenclature

L	length (m)
D	diameter (m)
W	width (m)
α	seebeck coefficient (V/K)
k	thermal conductivity (W/m·K)
R	electrical resistance (Ω)
R_0	load resistance (Ω)
Z	figure of merit for TEG
T	temperature (°C)
ΔT_{Max}	temperature gradient across TEG (°C)
$\dot{m}$	mass flow rate (kg/s)
G	solar irradiance ($W{\cdot}m^{-2}$)
t	time (hour)
I_{Max}	maximum current of TEG (A)
V_{Max}	maximum voltage of TEG (V)
P	power (W)
Q	thermal energy (W)
e	error

Subscripts

PV	photovoltaic
FF	fill factor
TEG	thermoelectric generator
H	hot side of the TEG
C	cold side of the TEG
f	fluid
ref	reference condition
aper	aperture area
amb	ambient
air	air
Sky	sky
Sol	solar
go	outside area of glass envelope
gi	inside area of glass envelope
co	outer surface of the PV
ci	inner surface of the PV
pi	inner surface of absorber tube
po	outer surface of absorber tube
M	mean
env	envelope
Max	maximum
in	input flow
out	output flow
The	thermal
ele	electrical
tot	total

Greek Symbols

α	absorptance
λ	molecular mean free path
β	angle of inclination
η	efficiency (%)
τ	transmittance
θ	incidence angle
ρ	reflectance
σ	Stephan Boltzmann constant (5.67×10^{-8} kg s^{-3} K^{-4})
ε	emissivity

to reduce the temperature of solar cell. They stated that the TE modules were able to operate at the optimal temperature of solar cell. The results showed that the electrical efficiency of the solar cell was increased in the range of 1–18% for the solar irradiation range of 800–1000 $W{\cdot}m^{-2}$ and the temperature range of 25–45 °C.

The integration of photovoltaic cell and solar collector is accounted as a novel design for improving the efficiency of hybrid systems. Some investigations have been conducted to improve the performance of

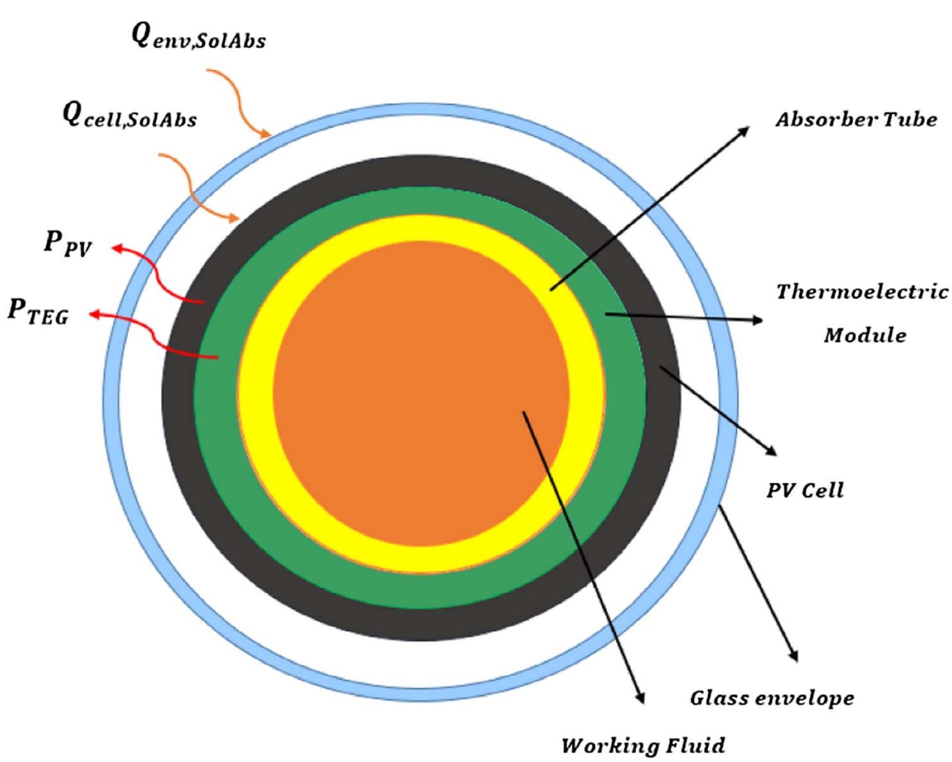

Fig. 1a. Cross-sectional view of the evacuated tube.