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Short Communication

High-efficiency photovoltaic technology including thermoelectric generation

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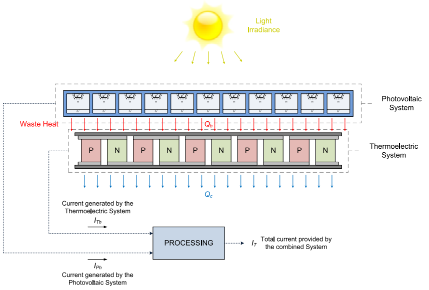
HIGHLIGHTS

- Development of a model which relates photovoltaic technology with thermoelectrics.
- Using temperature gradient to feed a thermoelectric structure for power generation.
- Theoretical and practical increase of overall efficiency under extreme conditions.
- Maximum power is greater when using thermoelectric cells in the system.

GRAPHICAL ABSTRACT



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ABSTRACT

Nowadays, photovoltaic solar energy is a clean and reliable source for producing electric power. Most photovoltaic systems have been designed and built up for use in applications with low power requirements. The efficiency of solar cells is quite low, obtaining best results in monocrystalline silicon structures, with an efficiency of about 18%. When temperature rises, photovoltaic cell efficiency decreases, given that the short-circuit current is slightly increased, and the open-circuit voltage, fill factor and power output are reduced. To ensure that this does not affect performance, this paper describes how to interconnect photovoltaic and thermoelectric technology into a single structure. The temperature gradient in the solar panel is used to supply thermoelectric cells, which generate electricity, achieving a positive contribution to the total balance of the complete system.

1. Introduction

In light of the large current energy demands, solar energy is considered a feasible solution for the future, and an answer to global warming. Furthermore, solar energy is beneficial as it is clean, renewable, and environmental-friendly.

Currently, photovoltaic systems convert solar energy directly into electricity without leading to pollution emissions to the atmosphere. Although since their beginning in 1839 [1] a significant progress has been made, still much work needs to be done in order to increase efficiency and reduce economic costs.

The implementation of a system that combines photovoltaic and thermal technology can be a good way of using residual heat and increasing efficiency. The use of a thermoelectric structure can directly convert residual thermal energy into electrical energy through the temperature difference between the two faces of a solar panel. In addition, a thermal structure has no moving parts

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Nomenclature

T	absolute temperature (K)
Q_c	absorbed heat flow in the thermoelectric system (W)
A	area (m^2)
k	Boltzmann's constant ($J\ K^{-1}$)
m	coefficient of resistance variation (dimensionless)
T_c	cold side temperature in the thermoelectric system (K)
Q_h	dissipated heat flow in the thermoelectric system (W)
q	electrical charge on the electron (C)
I	electrical current in the thermoelectric system (A)
T_{ct}	experimental temperature of the photovoltaic system
R	general resistance (Ω)
T_h	hot side temperature in the thermoelectric system (K)
n	ideality factor of the solar cell model (dimensionless)
R_0	initial value of general resistance (Ω)
V_{oc}	open circuit voltage of the solar cell model (V)
I_λ	photocurrent proportional to the intensity of solar radiation (A)
R_p	resistance that represents the imperfections in the p–n junction (Ω)
T_0	room temperature that surrounds the thermal structure (K)
I_s	saturation current of the p–n junction of the solar cell model (A)
R_s	series resistance of the solar cell model (Ω)
I_{sc}	short circuit electrical current of the solar cell model (A)
$T_{1,2,3,4,5,6}$	temperatures in the different structure interfaces (K)
T_{ts}	temperature difference applied in the experimental thermoelectric system
V_T	thermal voltage (mV)
N	total number of pellets in the thermoelectric structure

Greek symbols

ρ	electrical resistivity (Ω cm)
Δ	Laplace operator
α	Seebeck coefficient ($\mu V\ K^{-1}$)
κ	thermal conductivity ($mW\ cm^{-1}\ K^{-1}$)
κ_{cc}	thermal conductivity of the ceramic cold face ($mW\ cm^{-1}\ K^{-1}$)
κ_{ch}	thermal conductivity of the ceramic hot face ($mW\ cm^{-1}\ K^{-1}$)
κ_m	thermal conductivity of the metal contacts between semiconductors ($mW\ cm^{-1}\ K^{-1}$)
κ_s	thermal conductivity of the semiconductor used ($mW\ cm^{-1}\ K^{-1}$)
κ_0	thermal conductivity on the ceramic surface in contact with air ($mW\ cm^{-1}\ K^{-1}$)

Subscripts

c	cold temperature and heat flow absorbed
h	hot temperature and heat flow rejected
0	initial value
1,2,3,4,5,6	indicates the different internal interfaces of a thermoelectric device
oc	open circuit
sc	short circuit
Ph	related to photovoltaic system
Th	related to thermoelectric system

and is completely quiet and clean, and can be used for years as a complement to photovoltaic systems.

It is interesting to note that the use of nanotechnology in the thermal solar industry is currently seeing a performance boost in these application fields, and therefore the use of these two technologies combined will provide a better efficiency.

2. Typical solar cell

A typical construction of a solar cell is shown in Fig. 1 [2]. It should be noted that the electrical contact to the semiconductor material is always made via a metal n+ (or p+) junction; this is found to be the most convenient way of providing an ohm contact.

The basic electrical equivalent model of the photovoltaic cell is shown in Fig. 2 [3]. The most important parameters of this model are the electrical short-circuit current I_{sc}; the open circuit voltage V_{oc}; the saturation current of the p–n junction of the cell, I_s; the series resistance R_s; the ideality factor n; and the thermal voltage, which depends on absolute temperature T, and can be expressed as $V_T = k \cdot T/q$, with $k = 1.38 \times 10^{-23}\ J\ K^{-1}$; $T = 298.16$ K; and $q = 1.6 \times 10^{-19}$ C.

The photocurrent I_λ proportional to the intensity of solar radiation incident on the device is generated by the current source. The p–n junction solar cell is represented by a direct polarised diode. The resistance R_s represents the internal potential drop to

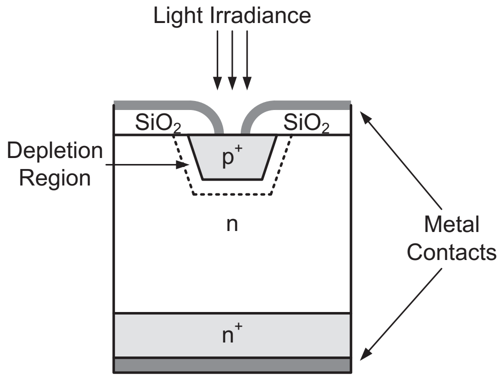

Fig. 1. Typical construction of a solar cell [2].

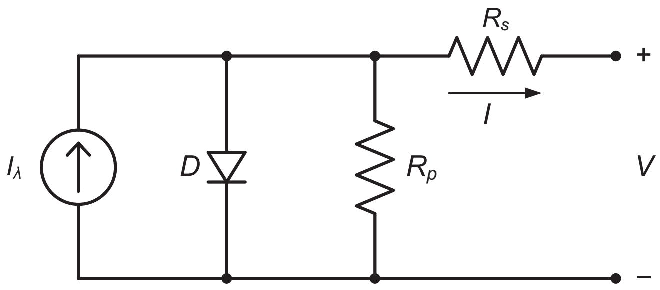

Fig. 2. Solar cell electrical model used in the investigation. R_s and R_p resistors has been included for a more realistic simulation results, by including Joule losses.