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Photovoltaic and thermoelectric indirect coupling for maximum solar energy exploitation

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Advanced photovoltaic devices with a high performance/cost ratio is a major concern nowadays. In the present study, we investigate the energetic efficiency of a new concept based on an indirect (instead of direct) photovoltaic and thermoelectric coupling. Using state-of-the-art thermal transfer calculations, we have shown that such an indirect coupling is an interesting alternative to maximize solar energy exploitation. In our model, a concentrator is placed between photovoltaic and thermoelectric systems without any physical contact of the three components. Our major finding showed that the indirect coupling significantly improve the overall efficiency which is very promising for future photovoltaic developments.

1. Introduction

The design of advanced photovoltaic (PV) systems with high electricity generation efficiency and low total development cost is of importance for harvesting solar energy. In this context, enormous work has already helped increasing the charge mobility of photoelectric compounds [1–4] and improving the absorption of solar radiation [5]. As far as the performance/cost ratio is concerned, huge progress has been made to improve the efficiency [6–12] but the latter is still seriously suffering from phenomena such as reflection, transmission and thermalization. One way of overcoming such obstacles, a hybrid system that directly interconnects photovoltaic (PV) and thermoelectric (TE) systems was proposed in the literature [5,12]. Indeed, this PV-TE combination is an interesting alternative since the excess heat (or thermalization) in the PV system can though be transferred to the TE system where it is converted to an electric energy. The TE system has in addition another role that consists in reconverting the transmitted irradiation from the PV system to an additional electric energy. Currently, many efforts are devoted to develop this novel hybrid system [13–18]. Unfortunately, it was noticed that such a concept tends to increase the temperature of the PV module (rather than reducing it) due to the low thermal conductivity of the used thermoelectric material [19–22]. Therefore a negative effect is obtained on the overall performance.

These results motivated us to investigate the energetic efficiency of a new concept based on an indirect (instead of direct) PV-TE coupling using state-of-the-art thermal transfer calculations [12]. All along our investigation, comparison with direct coupling performances will be made.

2. Model and thermal transfer method

2.1. Presentation of general model

In this part, we propose a new hybrid system that couples PV and TE systems to overcome the PV thermalization issue. We performed the coupling through two models; direct and indirect (see Fig. 1). Both models contain the same elements but differ in the coupling manner of the components. The elements are coupled as follows from top to bottom: a protective glass, photovoltaic system, a concentrator and a thermoelectric system. For the direct coupling (Fig. 1a), all components are physically connected, while in the indirect coupling (Fig. 1b), the concentrator is integrated without any direct physical contact with PV and TE systems. It is

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Nomenclature

A	area of the hybrid system (m^2)
C	concentrator coefficient
E_g	bandgap of silicon material (eV)
e	elementary charge 1.6×10^{-19} (C)
h_1, h_1'	heat transfer coefficient for the bottom surface (W/m^2 K)
h_3, h_5	heat transfer coefficient for the top surface (W/m^2 K)
I	electrical current in thermoelectric module (A)
k	Boltzmann constant ($J\,K^{-1}$)
k_{TE}	thermal conductivity of the thermoelectric module (W/m K)
k_{sub}	thermal conductivity of the substrate in solar cells (W/m K)
k_g	thermal conductivity of the glass layer in solar cells (W/m K)
n	number of p–n pairs in the thermoelectric module
Q	heat flow (W)
P_J	energy of Joule heating (W)
P_{pv}	power output of photovoltaic solar cells (W)
P_{TE}	power output of thermoelectric module (W)
r_{eq}	equivalent resistance equal to the sum external and internal resistances of thermoelectric module circuit (Ω)
RT	room-temperature (°C)
S	Seebeck coefficient of thermoelectric module (μV/K)
S_c	solar irradiance (W/m^2)
S_c'	transmitted solar irradiation (W/m^2)
$T_1, \ldots, T_5$	nodal temperatures at node $1, \ldots, 5$ (K)
T_a	temperature of the ambient air (K)
T_h	temperature of the hot side for thermoelectric module (K)
T_c	temperature of the cold side for thermoelectric module (K)
T_{water}	temperature of the cooling water (K)
T_{env}	temperature of the surroundings (K)
V_{TE}	voltage of the thermoelectric module circuit (V)
Δz_{TE}	half thickness of the thermoelectric module (m)
Δz_{sub}	half thickness of the substrate (m)
Δz_g	half thickness of the glass layer (m)
Δz_β	half thickness of the concentrator layer (m)
a, b	constants related to bandgap
ε	emissivity of the protective glass layer
ρ	reflectivity of the protective glass layer
σ	Stefan–Boltzmann constant ($5.67 * 10^{-8}$ $W/(m^2 K^4)$)
η_{PV}	efficiency of the photovoltaic system
η_{TE}	efficiency of the thermoelectric system
η_{hyb}	efficiency of the hybrid system

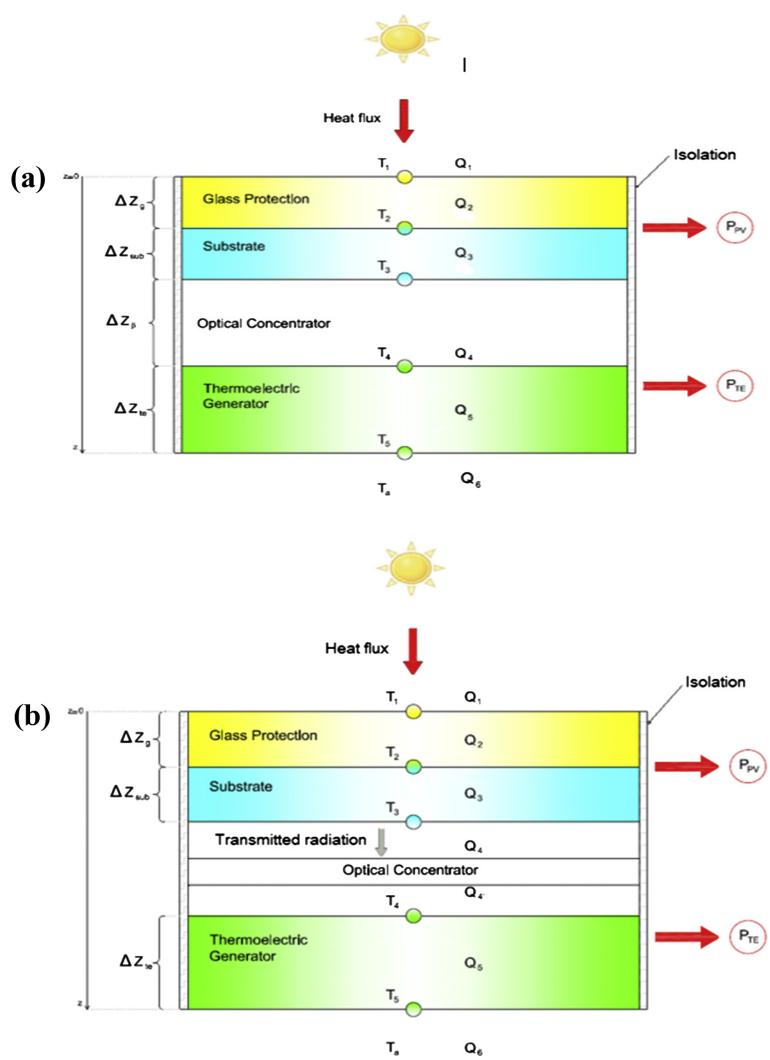

Fig. 1. Sketch of PV-TE hybrid system model for (a) direct and (b) indirect coupling.