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Review

Improvement of PV module optical properties for PV-thermal hybrid collector application

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ABSTRACT

Photovoltaic-thermal collectors (or PV-T collector) are hybrid collectors where PV modules are integrated as an absorber of a thermal collector in order to convert solar energy into electricity and usable heat at the same time. In most of the cases, the hybrid collectors are made by the superposition of a PV module on the thermal absorber of a solar collector. In this paper, the approach is different and is to analyze thermal and optical properties related to both PV and solar thermal functions in order to identify an optimum combination leading to a maximum overall efficiency. Indeed, although these two functions do not exploit the same range of radiation wavelengths, thermal and PV functions are not so complementary due to photo-conversion thermal dependency. In this context, an alternative PV cell lamination has been developed with increased optical and thermal performance. The improvements were evaluated around 2 mA/cm^2 in terms of current density in comparison to a standard module encapsulation. Based on this technique, a real size PV-T module has been built and tested at Fraunhofer solar test facilities. The results show a global efficiency of the PV-T collector above 87% (79% thermal efficiency plus 8.7% electrical efficiency, based on the absorber area).

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1. Introduction

In a standard PV module, most of the collected solar irradiation is converted into heat, which is wasted in the environment. Only a relatively small part of incident radiation ends up converted into electricity. This physical effect is directly related to the band energy gap E_{gap} of the PV cell semiconductor material and to the

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Nomenclature

c	light velocity
C_p	water heat capacity (J/kg °C)
E_{gap}	gap energy (eV)
E_{gap}	energy of the incident photons (eV)
EQE(λ)	external quantum efficiency at a wavelength λ
G	irradiation per area unit (W/m^2)
$G(\lambda)$	AM 1.5 solar spectrum as a function of the wavelength λ
h	Planck's constant
J_{sc}	current density (mA/cm^2)
$\dot{m}$	water mass flow rate per area unit (kg/s m^2)
n	refractive index
q	electron load
$R(\lambda)$	reflection as a function of the wavelength
T_{amb}	ambient temperature (°C)
T_{in}	water inlet temperature (°C)
T_m	mean fluid temperature (°C)
T_{out}	water outlet temperature (°C)
λ	wavelength (nm)
α	absorption coefficient
η_{th}	thermal efficiency
τ	transmission

energy of the incident photons E_{photon}. In fact, two main cases can occur. If the photon's energy is lower than the band energy gap of the PV cell ($E_{photon} < E_{gap}$), no light-generated carrier can be created and photon energy is completely dissipated into heat. In the case of crystalline silicon solar cells, due to the low absorption coefficient for wavelengths $\lambda < 1200$ nm, the photons with $E_{photon} < E_{gap}$ are usually mainly absorbed by the rear material of the solar cell. If a photon's energy is greater than the band energy gap of the PV cell ($E_{photon} > E_{gap}$), it will also create only one light-generated carrier, with the excess energy transferred to the crystal lattice as heat [1]. Fig. 1 presents a spectral view of the electrical efficiency based on experimental measurements made on a real mono-crystalline Si (mc-Si) solar cell encapsulated in a typical module made of a glass pane and Ethylene-Vinyl-Acetate (EVA). Approximately 10% of the incoming radiation is reflected by the module, whereas the PV conversion efficiency is only 15.5%. In fact, only a small part of the absorbed radiation is converted into electrical power, whereas most of the absorbed energy is wasted into heat.

For some specific applications such as building component integration, this heat can be recovered and valorised. This is particularly relevant in the context of strong development of high-energy-performance and energy producer buildings. This, in turn, implies that solar devices will be integrated into buildings as surface components in order to respond to the energy needs of electricity, heat and cooling. However, the amount of available building envelope surfaces with suitable orientation is limited at a building scale for energy supply. Therefore, each square meter of surface has to be converted into value and optimized. Thus, the development of multi-energy and multi-functional components like PV-thermal collectors (PV-T) can offer a solution to use the produced heat of PV modules.

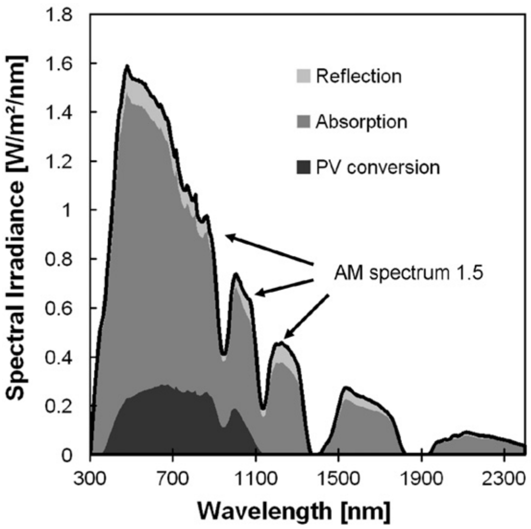

Fig. 1. Spectral representation of the electrical efficiency of a mono-crystalline silicon solar cell encapsulated in a conventional glass/EVA module.

A PV-T collector is a combination of photovoltaic (PV) panels and solar thermal components. A definition of PV-T components was given in the PV-T roadmap written within the IEA Task 35 [2]. In this report, a PV-T component is defined as a device using a PV panel or PV cells as a thermal absorber. The aim of these components is to use the heat generated in the PV panel, and therefore a PV-T device generates not only electrical, but also thermal energy. The development of PV-T collectors can offer a solution to promote the produced electricity and heat from a single collector and have the following advantages:

- Potentially, a high combined (electric and thermal) efficiency and yield (per m^2), especially where only a limited collector area with good solar radiation is available.
- The integration of both technologies into one type of collector may provide for a better esthetic and a better architectural uniformity.
- Collectors may simultaneously cover parts of the demand for electricity and heat at the same location.
- Potential other synergetic effects (e.g. cost reduction) from obtaining both outputs from one device.

The combination of PV and thermal for the co-generation of electricity and heat is not a new concept. In spite of the continuous interest for this concept, there have been no consequent technological breakthroughs that made possible a successful deployment of PV-T collectors on many roof-tops. There is indeed not one main problem to be solved, but rather many different issues that must be investigated to succeed in the development of such devices.

Plenty of PV-T component designs already exist: they differ from each other according to the nature of the PV panel technology (amorphous silicon, crystalline silicon, cadmium telluride, copper indium selenide or III/V technology), the radiation collection (flat plate [3–5] or concentrator [6,7]), whether an additional glass cover is present [8,9], the type of heat transfer fluid (air [10], water [11] or hybrid air/water [12]), the fluid flow in the component (forced [13] or thermosiphon [14]), the heat exchanger configuration (copper serpentine sheet-and-tube [15]), one side flat aluminum absorber [8] or flat-box aluminum absorber [14] and the way the produced heat is used (cooling device, coupling with a system like space heating or domestic hot water systems).

The final application targeted by the present work is a flat plate PV-T collector using crystalline PV cells and using water as