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Energy Procedia 30 (2012) 1 – 7

Energy
Procedia

SHC 2012

Thermal-electrical optimization of the configuration a liquid PVT collector

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Abstract

The study focuses on the optimal thermal and electrical configuration of hybrid Photovoltaic-Thermal (PVT) collectors. The electrical production of a PVT system is, in fact, highly affected by the temperature of the PV cells. In a PVT collector a temperature gradient exists along the absorber, so not all cells may be able to operate with the same electrical characteristics due to their temperature coefficient. In order to evaluate temperature distribution on solar cells, thermal analysis has been carried out with computational fluid dynamic (CFD) software. The study was focused on two absorbers types, characterized by different designs: a serpentine tube absorber and a parallel tubes absorber.

Starting from the thermal analysis, alternative electrical configurations were simulated in order to define the best solution to maximize as much as possible the photovoltaic performance.

Keywords: PVT collectors; solar thermal; CFD analysis

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doi:10.1016/j.egypro.2012.11.002

1. Introduction

In recent time, due to the increasing energy demand in building sector a number of initiatives have been taken all over the world to promote R&D activities on new technologies for generating energy from renewable sources. Among these, one that has grown very vastly is the photovoltaic (PV) technology. The improvement of the energy performance of PV can be reached by combining PV system with solar thermal system, keeping the PV cells at lower temperatures and recovering thermal energy otherwise wasted.

A photovoltaic-thermal hybrid system (PVT) produces both electricity and heat by means of one integrated component, in which cells are applied on the thermal absorber. The increase in PVT research since 90's is also the result of the growing interest of the construction industry towards the building-integrated-photovoltaic (BiPV) options. In fact, PVT collectors can provide architectural uniformity and are considered aesthetically better than the two separated arrays of PV and solar thermal collectors being placed side by side. Moreover, considering average thermal and electrical performances and typical PVT system costs, the application of hybrid systems could become even more affordable than that of the two solar technologies separately [1].

Many efforts have therefore been carried out to increase thermal and electrical performance of PVT components [2,3] with the aim to optimize their overall efficiency.

Among other factors, thermal performance of a PVT collector is strongly influenced by the flow distribution through the absorber pipes, which can also cause boiling in the absorber [4-8]. The electrical efficiency of PV cells is on the other hand affected by their temperature and consequently by the temperature distribution on the underlying absorber plate. In fact when a temperature gradient exists, not all cells may be able to operate in the same manner (i. e. at their maximum power point) at the same time, causing parallel-series mismatches. More in detail, cells temperature has only a very small effect in series connections (efficiency loss about 1%), but a considerable effect in parallel connections, with about 17% loss [9].

2. Methodology

The aim of this work is to theoretically investigate on electrical efficiency in function of the temperature distribution in a PVT collector, taking into account two different configurations of solar absorbers (serpentine and harp pipes). Since roll-bonding is a well established large-scale industrial process which is mainly applied for the production of evaporators of refrigerators, in last years it has been successfully used to produce high-efficiency solar absorbers at low-cost [10]. As a consequence, in the present study two different roll-bond configurations are presented, as described hereafter. In detail, a glass-covered PVT collector was analyzed, and different thermal and electrical performances were simulated by varying the design of the absorber.

The applied methodology is described hereafter in detail, illustrating the simulation procedure that has been used to carry out the thermal analysis and the mathematical model for the estimation of electrical efficiency of the PVT module, according to different connections of the photovoltaic cells applied on the absorber plates.

2.1. PVT system configuration

The investigated PVT solar collector is the size of 1640 × 990 mm; this represents a common dimension of a commercial 60-cells PV module. In detail, the collector consists of an aluminum roll-bond absorber [11] with channels section as shown in Fig 1, above which 60 photovoltaic cells of 150 × 150 mm are superposed. Each cell has the electrical characteristics summarized in Tab. 1, referred to MPP (Maximum Power Point) conditions.

Table 1. Main electrical characteristics of considered polycrystalline PV cell

Peak power (W)	4.092
I_{MPP} (A)	0.528
V_{MPP} (V)	7.75
Temperature coefficient on current (A/°C)	0.0027
Temperature coefficient on voltage (V/°C)	-0.0019

The PV absorber is placed under a selective tempered-glass, with absorption coefficient of 8 m^{-1}, which forms an air gap of 2 cm, to limit the heat losses towards the outside.

A general scheme of the proposed collector is shown in Fig 2.

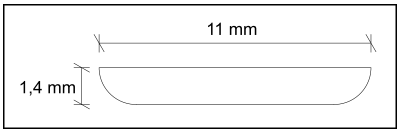

Fig. 1. Absorber channels cross section

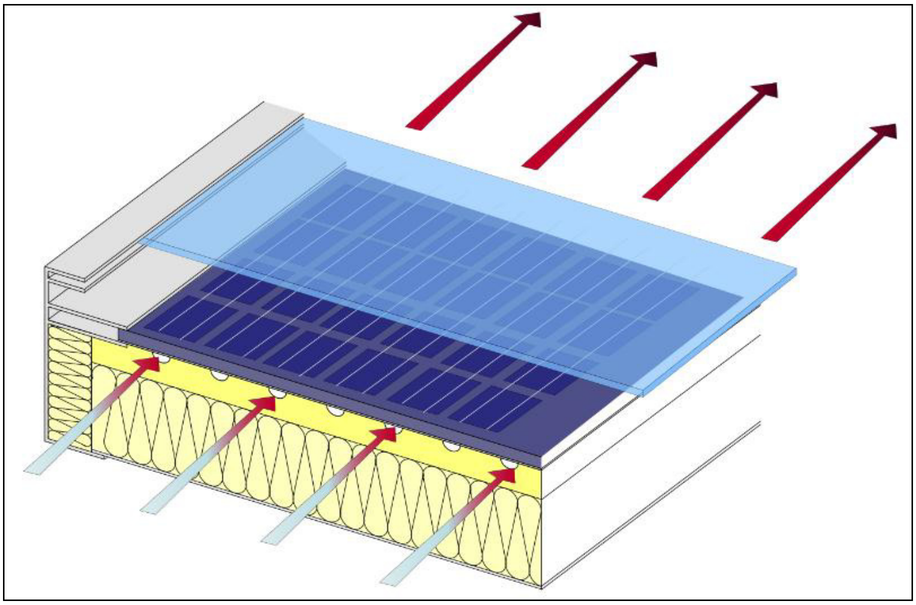

Fig. 2. Glass-covered liquid PVT collector with roll-bond absorber general scheme

As introduced, in order to compare most widely used configurations of absorbers [6,10,11], it was decided to carry out the study on two plates with different representative layout: the first one is configured with a serpentine pipe and the second one with harp (parallel pipes) connected with two manifolds.

In order to correctly compare the two configurations, the overall length of the tubes is the same for both heat exchangers. Moreover, the W/D ratio (ratio between spacing and diameter of the tubes) is also equivalent for the two absorbers, and is equal to 7.1, a value in agreement with literature [12]. Two pipes are placed behind each PV cell, in both evaluated cases.

The two described layouts are shown in Fig 3.

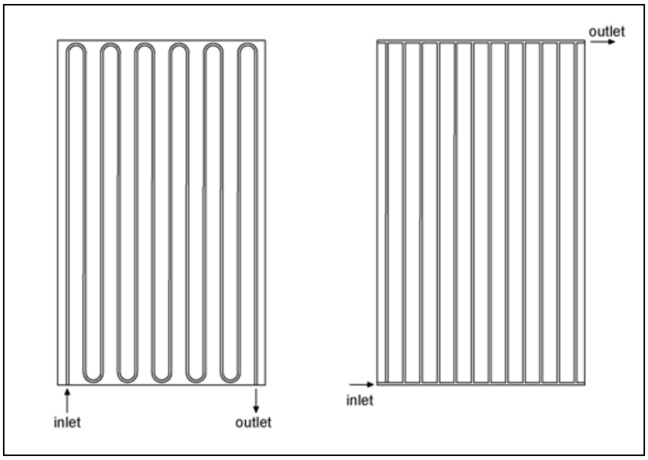

Fig. 3. Serpentine pipe and harp pipe solar absorbers

According with several works [13,14] in order to avoid unnecessary consumption due to the circulation pump, a flow rate of 25 kg/m^2h was set for the serpentine pipe. However, considering that harp configuration is characterized by lower pressure drop, an higher flow rate was set equal to 50 kg/m^2h. The inlet temperature of water to the hybrid collector was assumed constant and equal to 14 °C.

The collector thermo-electrical performance was evaluated supposing a stabilized operating pattern. Boundary conditions were defined according to the NOCT conditions, in respect of which the Nominal Operating Cells Temperature of the module is calculated. It is common to use NOCT as an indicator of module temperature; in fact, this parameter is defined as the mean solar cell junction temperature within an open-rack mounted module in Standard Reference Environment (SRE), represented by a tilt angle at normal incidence to the direct solar beam at local solar noon, a total irradiance of 800 W/m^2, an ambient temperature of 20°C and a wind speed of 1 m/s. NOCT could be considered a main parameter in module characterization, since it is a reference of how the module works when operating in real conditions [15].

2.2. Simulation tools

The heat transfer in the PVT collectors were studied by means of computational fluid dynamics (CFD) calculations though the FLUENT 13.0 software.

A simplified model was built to simulate the PVT collectors described above, where absorber, pipe and air gap are fully modeled, while heat loss from the glass is represented in a simplified way by convection boundary conditions. The temperature distribution on the collector's plate is investigated with heat transfer model, Discrete Ordinate (DO) model of radiation with solar ray tracing and buoyancy performed with Boussinesq approximation.

The simulations were performed in steady state conditions to avoid unnecessarily heavy and time expensive analyses. In this respect it is worth to be mentioned that some works report only 0.2% of difference between simulations carried out under steady state and under dynamic conditions [16].

3. Thermal simulation result and discussion

By analyzing the simulation results it is possible to observe how the flow rate and its sharing between pipes influence the heat transfer fluid temperature and the absorber temperature distribution.

In particular, in Fig. 4 the two absorbers' temperature distributions are shown.

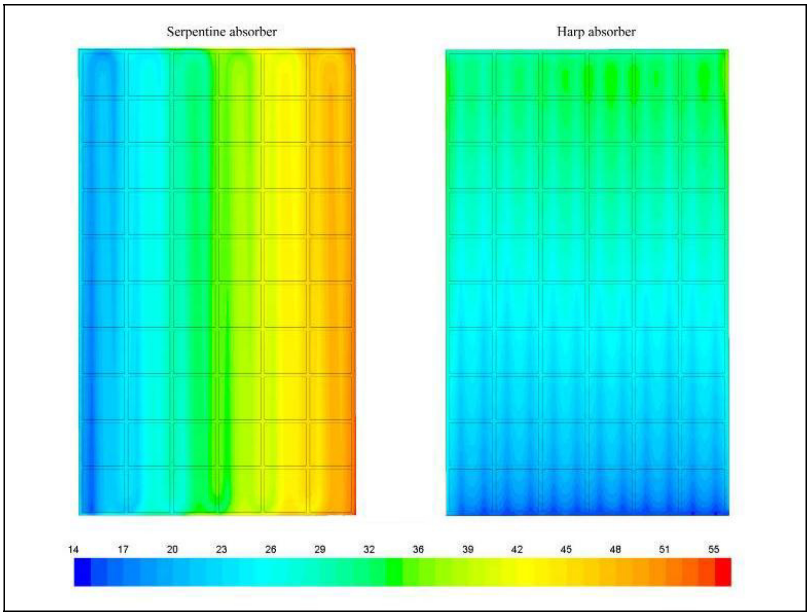

Fig. 4. Absorber temperature distributions

As can be seen, temperature distribution through the pipes is not uniform in both cases: temperature increases from left to right in first case, and from the bottom to the top in the second one. As a consequence, each PV cell placed on a specific portion of the absorber will have a different temperature and, thus, a different electrical performance.

Furthermore, serpentine absorber reaches higher temperature gradient than the harp configuration.

4. Electrical simulation result and discussion

In order to analyze the different influence that the two temperature distributions in the absorber can have on PV conversion efficiency, electrical simulation were carried out considering four different configurations of PV cells' electrical wirings, as reported in Fig. 5.

In detail, the electrical layouts, which can be considered consistent with standard manufacturing practices of PV modules, are described hereafter:

a) two strings of 30 cells each, connected from bottom to top in series.
b) two strings of 30 cells each, connected from bottom to top in parallel.
c) two strings of 30 cells each, connected from left to right in series.
d) two strings of 30 cells each, connected from left to right in parallel.

Subsequently, each electrical layout was coupled with both the before-calculated thermal distributions on absorber plates, obtaining the specific working temperature of each of the 60 PV cells.

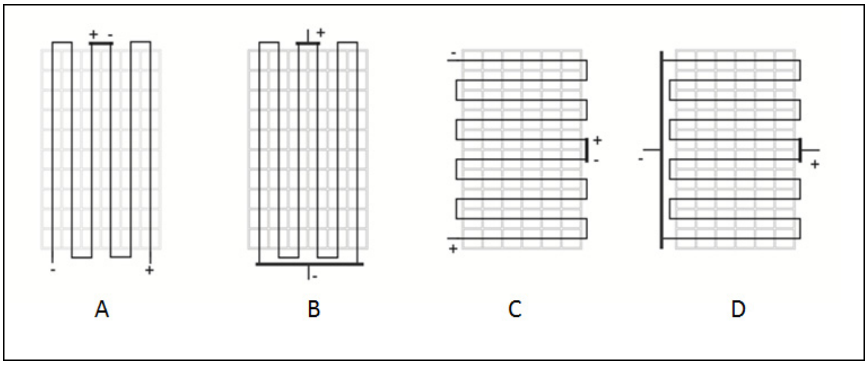

Fig. 5. Analyzed electrical configurations of the PV cells on the absorber

The main difference among series and parallel connection is the values of voltage and current obtained and the related losses due to the temperature coefficients on the voltage and current of the PV cell.

In particular, as it can be observed, the first and the third configurations connect all 60 cells in series, so total module voltage will be double that of B and D configurations, which on reverse have higher current values.

Consequently, different values of the PVT module's voltage, current and power at MPP conditions were calculated for each combination of electrical configuration and temperature distribution. Moreover, the maximum theoretical power of each configuration, calculated as the sum of the maximum achievable power of each PV cell in its specific thermal condition, was evaluated.

Obtained results are summarized in Tab. 2.

Table 2. Main electrical performance parameters of each analyzed PVT module configuration

	A		B		C		D	
	Serpentine	Harp	Serpentine	Harp	Serpentine	Harp	Serpentine	Harp
I_{mpp} (A)	7.72	7.72	15.50	15.45	7.72	7.72	15.46	15.48
V_{mpp} (V)	30.67	31.65	14.84	15.82	30.67	31.65	15.33	15.5
P_{max} (W)	238.39	245.27	238.39	245.27	238.39	245,27	238.39	245.27
P_{real} (W)	236.88	244.40	230.03	244.40	236.88	244,40	236.86	239.84

Previously calculated performance parameters demonstrate that harp absorber, thanks to a more homogeneous thermal distribution and to lower average temperatures is more suitable for PVT application than serpentine absorber. Moreover, among all analyzed electrical layouts, A, B and C assure same performances if coupled with harp plates. In detail, a 244.4 W_p total peck power is achievable, with a very low reduction (-0.35%) compared with the total maximum theoretical power of all PV cells of the module, equal to 245.27 W_p.

Anyway, considering ohmic losses due to high current densities, A and C configurations have to be preferred since they assure lower output currents of the module.

5. Conclusions

A PVT collector is a very peculiar component, which cannot be treated as conventional solar systems (PV or ST). Opposite requirements occur with respect to the thermal and especially electrical performance. In order to optimize the overall efficiency it is necessary to perform accurate and multi-objective assessments, taking into account all the variables involved.

This study shows that it is possible to optimize PVT productivity by appropriately choosing the collector's thermo-electric configuration. As can be observed from obtained results, harp absorber guarantees better performance that serpentine absorber in all electrical configurations analyzed.

Further developments of the presented research are foreseen in the future to carry out experimental analyses on the simulated components.

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