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Parameters effect analysis of a photovoltaic thermal collector: Case study for climatic conditions of Monastir, Tunisia

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ABSTRACT

PV/T solar collector is an energy system designed to provide both thermal and electrical energies at the same time. In this paper, the dynamic simulation of a photovoltaic thermal collector is presented. The effect of different parameters, such as meteorological, design and optical parameters are investigated. Furthermore, evaluation and comparative economic analyses among different designs of PV/T sheet-tube collectors, conventional thermal solar collector and PV module is conducted under Monastir (Tunisia) climatic conditions. Numerical results show that the thermal and electrical efficiencies significantly depend on the studied parameters. It is also found that, in terms of economy, the uncovered PV/T collector yield the best performance among others.

1. Introduction

The PV/T hybrid collectors convert simultaneously solar energy into electricity and heat. Many and theoretical and experimental studies and have been made to improve the thermal and electrical performance of the collector [1–12]. Bergene and Lovvik [1], proposed a detailed model of the flat-plate collector through integrating solar cells. They show numerically that the efficiency of PV/T collector ranges from 60% to 80%. Sandnes and Rekstad [2] used an analytical model to study a PV/T system. They built pasting single crystal silicon PV cells on a polymer thermal absorber. A 10% decrease in the energy is observed due to the low optical absorption in the solar cells compared a classic black absorber. Zondag et al. [3] studied numerically the behavior of PV/T. For that, they compared the results obtained by a three-dimensional dynamic model and those obtained by three other stationary models (1D, 2D, 3D). Their numerical results were also confirmed experimentally, where a maximum error of 5% was observed. Chow [4] proposed an explicit dynamic model. He studied the effect of some parameters, like mass flow rate and conduction heat transfer coefficients between the absorber and the PV module, on thermal and electrical efficiencies. Santbergen et al. [5] studied numerically sheet and tube PV/T with one cover. They showed that the thermal efficiency could be improved by using low emissivity coating and that the electrical efficiency could be improved by applying the anti reflective coating. Cristofari et al. [6] proposed a detailed model of a PV/T solar system. They studied the effect of thermal stratification in storage tank on its performance. The results showed that the thermal stratification increase the thermal efficiency-of PV/T system. Ibrahim et al. [7] have carried out a comprehensive review about water-heating systems. They observed that PV/T solar systems improved the energy performance per unit area. Bhattarai et al. [8] compared a photovoltaic thermal system with a conventional solar system, numerically and experimentally. They found that the primary energy-saving efficiency of PV/T-sheet and tube collector was higher than that of a conventional solar system. Dupeyrat et al. [9] conducted an experimental study to improve properties of PV/T thermal collector. The results showed a global efficiency of the PV-T collector above 87% (79% as thermal efficiency and 8.7% as electrical efficiency). Touafek et al. [10] carried out an experimental study of a PV/T collector and a conventional PV one. They observed an improvement of electric efficiency of the PV collector due to the presence of the thermal system. They also showed that the thermal efficiency of the PV/T collector could be improved by adding glazing however, electrical efficiency decreases in this case. Therefore, a compromise between the two efficiencies should be found.

The literature review indicates that the modeling of thermal conventional PV plate, and PV/T collector have been investigated separately. Bhattarai et al. [8] studied numerically and experimentally a thermal conventional and PV/T collector for South Korea (Chuncheon) climatic conditions. To our knowledge no studies, investigating and comparing between different designs of PV/T sheet-tube collectors, with a conventional thermal solar collector

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Nomenclature

A	surface area (m^2)
T	temperature (K)
C_p	specific heat (J kg^{-1} K^{-1})
M	mass (kg)
E	electrical power output (W/m^2)
k	thermal conductivity (W m^{-1} K^{-1})
C_{el}	electrical energy cost (US$/kW h)
C_{th}	thermal energy cost (US$/kW h)
N	payback period
P	total cost US ($)
Pac	packing factor
H	solar power (W h m^{-2})
G	solar irradiation (W m^{-2})
h	heat transfer coefficient (W m^{-2} K^{-1})
Nu	Nusselt number
Ra	Rayleigh number
R	radius (m)
B	collector control function
Pr	Prandtl number
Pe	perimeter (m)
t	time (s)
$\dot{m}$	mass flow rate (kg s^{-1})

Greek

β	solar cell temperature coefficient (K^{-1})
δ	thickness (m)
α	absorption coefficient
σ	Stefan Boltzmann constant, 5.670×10^{-8} (W m^2 K^{-4})
θ	incident angle
υ	kinematic viscosity (m^2 s^{-1})
ρ	density (kg m^{-3})
η	efficiency
τ	transmittance
ε	emissivity

Subscripts

amb	ambient
env	environment
g	glazing
PV	photovoltaic module
pab	absorber plate
tu	tube
w	water
i	insulation
$cond$	conduction
$conv$	convection
$elec$	electrical
out	outlet
ad	adhesive
In	inlet
f	fluid
c	collector
l	load
th	thermal
Wi	wind
a	air gap

and PV module under Tunisia climatic conditions (a semi-arid climate with hot summer and mild to warm winter) have been reported in the literature. The main objectives of this paper are to examine the influence of meteorological, design and optical parameters on thermal and electrical efficiencies. An evaluation and a comparative economic analysis between different designs of PV/T sheet-tube collectors, conventional thermal solar collector and PV module under Monastir (Tunisia) climatic conditions have been conducted.

2. Mathematical model

2.1. PV/T collector one cover

The PV/T solar collector, considered in this study (Fig. 1), 2 m^2 area, has been connected to a stratified water storage tank which has an advantage that the return temperature to the side of collector is reduced. A lower inlet to in the collector is likely to increase the thermal and electrical efficiencies. The different components of the collector are depicted in Fig. 2. It consists of a glazing, a PV sheet which converts sunlight into electrical energy and a copper plate which absorbs sunlight. Ten copper tubes were fixed to the absorber plate. The coolant fluid (water) circulate into the copper tubes. The absorber plate and tubes were insulated on the back side. The design and optimization of PV/T system require the knowledge and the comprehension of heat transfer within the collector components and the hot water storage tank. A transient mathematical model is presented to simulate the collector and the water storage tan behavior.

In order to simplify the model, some assumptions have been taken into consideration:

- Thermo-physical properties of the collector components are constant.
- The water flow rate in the tubes is assumed uniform.
- The temperature of the tube and the working fluid vary along in the y direction.
- The sky is assumed as a black body.

With regard to these assumptions, the energy balance equations in the PV/T collector components are described as follows:

2.1.1. Glazing

$$\rho_g \delta_g C_g \frac{dT_g}{dt} = \alpha_g G + h_{ray,g\rightarrow env}(T_{sky} - T_g) + h_{wi}(T_{amb} - T_g) + (h_{ray,pv\rightarrow g} + h_{conv,pv\rightarrow g})(T_{pv} - T_g) - k_g \delta_g \left(\frac{\partial^2 T_g(x,y)}{\partial x^2} + \frac{\partial^2 T_g(x,y)}{\partial y^2} \right) \quad (1)$$

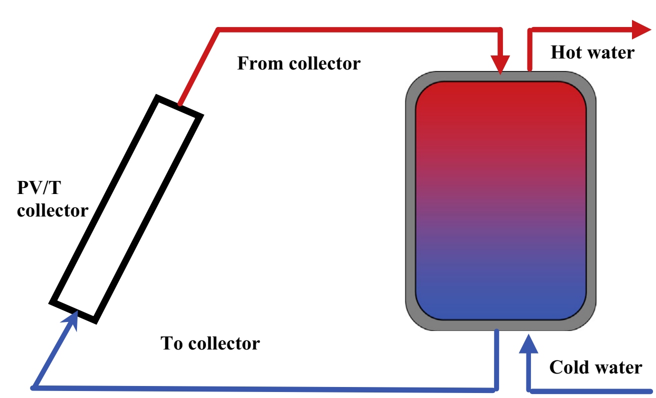

Fig. 1. PV/T system using water storage tank.