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Dynamic thermal model for hybrid photovoltaic panels

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Abstract

Photovoltaic technology is a consolidated solution for electricity production in residential, commercial and industrial facilities. Despite that, the solar-to-electrical energy conversion is still low and many efforts are still needed in order to increase the panel efficiency. Since the photovoltaic modules performance decreases when the cell temperature increases, solutions have been investigated to cool down the panel with a refrigerated thermal plate installed on the PV rear surface. In standard applications, the photovoltaic thermal panel (PV/T) systems can produce both thermal and electrical energy and they are typically used for domestic hot water (DHW) production. Moreover, hybrid solar panels must be coupled with a heat pump system at the evaporator side, realizing a photovoltaic solar assisted heat pump (PV-SAHP) plant. Generally, a careful design of these integrated systems must involve accurate control strategy to optimize energy savings during operation. In fact, the behavior of the PV/T panels is heavily influenced by the very quick variation of the external conditions during daytime (mainly due to solar irradiation), affecting the working conditions of the other equipment. Therefore, models able to reproduce the dynamic behavior of the PV/T panels represent a flexible tool for developing innovative and user-adapted system control criteria, in a global system optimization perspective. In this context, the aim of the present paper is to describe a simplified numerical model able to reproduce the short time dynamic behavior of the PV/T panel. The model has been validated using experimental data which have been collected during outdoor tests conducted at the University of Genoa using a prototype realized by retrofitting a commercial PV collector. Several simulations have been performed by comparing the PV/T outlet temperature provided by the numerical model against experimental data.

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Keywords: Energy Efficiency, Hybrid panel; Retrofitting; PV/T; Dynamic models; Experimental tests

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Nomenclature

Roman letters

A	Module area [m^2]
C	Thermal capacitance [$J\ K^{-1}$]
c_p	Water specific heat [$J\ kg^{-1}\ K^{-1}$]
G	Solar radiation [$W\ m^{-2}$]
h_{tot}	Global heat transfer coefficient [$W\ m^{-2}\ K^{-1}$]
$\dot{m}$	Mass flow rate [$kg\ s^{-1}$]
P	Electrical power output [W]
Q	Heat flow rate [W]
R	Thermal resistance [$K\ W^{-1}$]
T	Temperature [K]

Greek letters

α	Absorbance
β	Temperature coefficient [K^{-1}]
η_{el}	Electrical efficiency
η_{ref}	NOCT efficiency
τ	Time
τ_v	Glass transmission coefficient

Subscripts

c	PV cell
el	Electrical
f	Fluid
g	Glass
p	Absorber plate
ref	Reference state
u	Useful

1. Introduction

The efficiency of the standard photovoltaic panels (PV) is relatively low, making them less of an economical system solution for producing electrical energy. Considering the decrease in electrical efficiency of the photovoltaic modules as a consequence of its temperature increase, cell cooling was proposed to increase the overall conversion efficiency [1, 2], realizing hybrid thermal photovoltaic panels (PVTs).

In the last years, many researchers focused their attention on the hybrid photovoltaic panels performing a lot of theoretical [3] and experimental [4,5,6] studies in order to analyze their thermal and electrical performances (an exhaustive review on PV/T systems is presented by Charalambous et al. [7] and Ibrahim et al. [8]). Moreover, in order to optimize the PV/T configuration, several authors investigate the thermal and fluid-dynamic issue of PV-T panel with the aim to achieve the best cooling effect [9,10] and to develop numerical model to predict the thermal performance of these systems [11]. In fact, considering the strong variation of the working conditions of the PV/T systems, the development of simplified numerical model able to reproduce their dynamic behavior, assumes a relevant role in order [12]:

- to realize useful tools able to perform more reliable external tests respect to ones adopted to the common standard [13];
- to support the energy system design for both preliminary and executive stages;
- to optimize regulation strategies, especially for complex systems in which several energy sources are coupled together.