Available online at www.sciencedirect.com
ScienceDirect
Solar Energy 105 (2014) 147–156
SOLAR ENERGY
www.elsevier.com/locate/solener

Energy and thermo-fluid-dynamics evaluations of photovoltaic panels cooled by water and air

Natale Arcuri, Francesco Reda *, Marilena De Simone

Department of Mechanical, Energy and Management Engineering, University of Calabria, 87036 Rende, Italy

Received 2 September 2013; received in revised form 23 December 2013; accepted 27 March 2014
Available online 4 May 2014

Communicated by: Associate Editor Brian Norton

Abstract

The main limit of photovoltaic (PV) systems is the low conversion efficiency of cells, which is strongly influenced by their operating temperature. As the temperature increases the short circuit current (I_{sc}) increases moderately, while the open circuit voltage (V_{oc}) decreases considerably. The cell temperature reduction is a useful methodology that could be used in order to improve the PV panels performance of both new and already installed as well. This solution is interesting especially for high irradiation level locations with high external air temperature range along the daytime, because the maximum producibility occurs when the irradiation is high and therefore, as a consequence, the cell temperature increases. Furthermore, the proposed solution could be integrated with many PV typologies, already installed as well. Thus, it represents an alternative to PVT (Thermal–Photovoltaic) systems, which need DHW consumers for supplying the heat produced, otherwise the performance of the system will decrease. Various solutions adopting respectively a cooling water system and an airflow lapping the back of the panels in an open circuit is investigated to individuate the best cooling solution. Finite element software that describes with extreme detail the thermal exchange between the PV cells, the external environment and the cooling system is used in order to assess the reached temperature of the cells with different cooling system configurations calculating for each considered cases the overall thermal losses coefficient. Regarding the air cooling system configuration, which results less invasive, a comparison between the simulated and the measured, by laboratory tests, air speed has been conducted. Hourly energy simulations for the best configurations using the software TRNSYS are carried out to evaluate the annual performances.

Keywords: Photovoltaic panel; Efficiency; Cooling system; Energy analysis

1. Introduction

Low efficiency of photovoltaic (PV) arrays is due to non-linear variations of output current and voltage as a function of solar radiation levels, operating temperature and load current. Hiyama et al. (1995) and Hua et al. (1998) described the interactions of those phenomena and overcame these problems using online or offline tracking algorithms in order to reach the maximum operating power point of PV systems forcing the system operating point toward the optimal condition. Furthermore, the main limit of PV system is the variation of the efficiency as a function of the operating. There are available in the literature various correlations showing both the electrical efficiency and the related power output of a PV module as a linear

* Corresponding author. Address: Department of Mechanical, Energy and Management Engineering, University of Calabria, P. Bucci 44/C, 87036 Rende, (CS), Italy. Tel.: +39 3471996839.
E-mail address: francesco.reda@unical.it (F. Reda).

http://dx.doi.org/10.1016/j.solener.2014.03.034
0038-092X/

Nomenclature

A	cross section area, m^2
c	air speed, m/s
C_t	specific heat capacity, J/m^2 K
G_T	incident solar radiation, W/m^2
h_c	convective heat exchange coefficient between PV external surfaces and external air, W/m^2 K
I_{sc}	short circuit current A
k_{EVA}	thermal EVA conductivity, W/m K
k_g	thermal glass conductivity, W/m K
k_s	thermal Silicon conductivity, W/m K
k_{PET}	thermal PET conductivity, W/m K
k_{ted}	thermal Tedlar conductivity, W/m K
NOCT	nominal operating cell temperature, °C
s_{EVA}	thermal EVA conductivity, W/m K
s_g	glass thickness, m
s_s	silicon thickness, m
s_{PET}	PET thickness, m
s_{ted}	Tedlar thickness, m
Q_{el}	specific electricity production, W/m^2
Q_{loss}	specific thermal power losses, W/m^2
Qr_{ad}	specific collected solar power, W/m^2
T_{env}	external air temperature, K
U_{pan}	overall heat loss coefficient, W/m^2 K
$U_{pan\text{-}system}$	overall heat loss coefficient of PV-cooling system, W/m^2 K
V_{mp}	tension at maximum power, V
V_{oc}	open circuit tension, V
α	solar absorption coefficient, -
η	conversion efficiency, %
λ	thermal conductivity, W/m K
ρ	density, kg/m^3
τ	solar transmission coefficient, -

function of the cell operating temperature for PV modules or PV arrays mounted on free-standing frames, for PV/thermal collectors and for BIPV arrays, respectively (Skoplaki and Palyvos, 2009). As Fig. 1 shows, the output power of a single-crystalline silicon solar cell decreases as its temperature increases. Usually the temperature coefficient of the maximum output power for crystalline silicon PV operating above 25 °C is −0.65%/K (Raziemska, 2003), in accordance to the efficiency reference value reported in literature that is approximately 0.06 in absolute value per kelvin degree increase (Joshi, 1994). Malik (2003) analyzed the outdoor performance of a PV system; the results show that cold temperatures produce more efficient photo conversion for monocrystalline solar cells. Therefore, in tropical regions keeping as low as possible the PV module temperature is paramount to optimize PV performance (Ye et al., 2013).

Studies showing the benefits of PV modules cooled by both air and water have been carried out by many scientists. As regard air as working fluid, many studies were

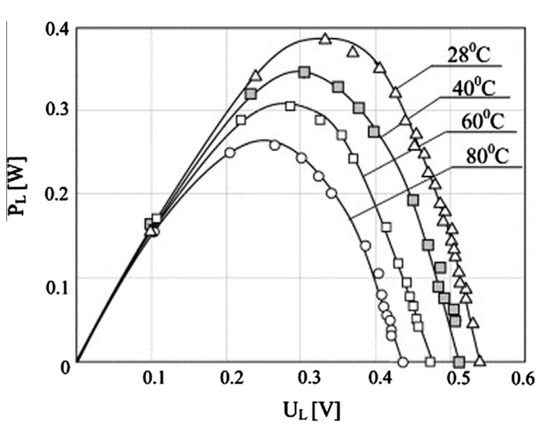

Fig. 1. Output power versus voltage of a single-crystalline silicon solar cell at various temperatures (Raziemska, 2003).

done (Bambrook and Sproul, 2012; Brinkworth et al., 1997), especially concerning building integration purposes (Yun et al., 2007; Ghani et al., 2012a, 2012b; Yin et al., 2013). Instead regarding water as working fluid, studies of hybrid concepts were done (Assoa et al., 2007; Anderson et al., 2009; Mishra and Tiwari, 2013) but focused on enhancing PV performance as well, indeed Amery and Abdolizadeh (2009) investigated the effect of spraying water upon the PV cells in terms of cells temperature variation and reflection losses showing an increase in cells efficiency on average of 3.26% and an increase in optical performance of 1.8% compared with standard operating mode. (Krauter, 2004) examined a cooling strategy consisting of a flowing film of water on the PV module front; the results showed an improvement of the optical performance by 1.5% and an increment of the electrical energy yield over the whole considered day by 10.3% compared to the same PV system without cooling. In conclusion the previous studies show the convective effect of air and water improves the working condition of the PV system as a consequence of decreasing cells temperature. Based on this results the aim of the investigation is to study the effects of a simple air and water cooling systems on the electrical efficiency of a PV module by a duct located on the back of PV panel without exceeding the frame dimension and thus allowing the installation even in the existing one. An energy comparison of the best presented PV panel – cooling system solutions are shown afterwards.

2. Methodology

The PV panel used in this research consists of the following layers from the top to the bottom:

Tempered prismatic glass with low Fe content with anti-reflective coating, Ethylene – Vinyl – Acetate EVA