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Research paper

Performance evaluation of a solar photovoltaic system

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A B S T R A C T

The solar energy conversion into electricity is a very promising technique, knowing that the source is free, clean and abundant in several countries. However, the effect of the solar cells temperature on the photovoltaic panel performance and lifespan remains one of the major disadvantages of this technology. In this work, we present an experimental study of a particular photovoltaic panel. It is self-cooled due to its open design which facilitates natural ventilation helping to improve its performance mainly in hot hours of the day and to avoid dust accumulation on its surface. This solar system is tested for two soil natures, white and gray, and for two inclination angles, 0° and 30°. Results show that the photovoltaic panel performs better when it is inclined and placed on a white soil. A 3D CFD model describing the performance of this solar system is then developed and a good agreement between the numerical results and experimental data is found. Similarly, this CFD model was used to compare the thermal performance of this solar system to that of the flat PV system and to show that its lower temperature allows better electrical production.

1. Introduction

The increasing political and environmental problems related to the fossil fuel are the main drawbacks of this energy source exploitation. A way to overcome these difficulties and to satisfy the growing electricity demand around the world is the use of photovoltaic systems which allow converting solar energy into electricity from sunlight. This clean technology inspired many researchers who studied the performance of different systems aiming to maximize the PV production with the least cost modifications. Ramadhan and Nasseb (2011) presented an economic study of the viability of the PV solar energy implementation in the state of Kuwait. Other technical and economical analyses of concentrating solar thermal systems, non tracked and tracked photovoltaic systems were performed by Quasching (2004) for different sites in Africa and Europe while Grasso et al. (2012) evaluated the economical competitiveness of a stationary low concentration PV system and discussed the different parameters influencing its optical power ratio. Other research and experimental studies have focused on the comparison of concentrating and non-concentrating photovoltaic systems (Mallick et al., 2006, 2007; Matsushima et al., 2003), fixed and different tracking systems (Koussa et al., 2011; Gomez-Gila et al., 2012; Kelly and Gibson, 2009) and concentrator based in stationary linear Fresnel lenses and secondary CPC systems (Chemisana et al., 2009). Similarly, the effect of some parameters affecting the PV systems performance like the angle of inclination (Wilson and Paul, 2011; Gajbert et al., 2007), the heat transfer mode (Kumar et al., 2012) and the Thomson effect (Ari and Kribus, 2011) was numerically discussed using different simulation tools in order to find the optimum values of these parameters and to evaluate the optimum configuration of these solar systems. Skoplaki and Palyvos (2009) were interested to another parameter which is the operating temperature of solar cells and modules, they presented different correlations concerning its effect on the electrical performance of photovoltaic installations. Other papers (Razykov et al., 2011; Parida et al., 2011; El Chaar et al., 2011; Si et al., 2017) were focused on the progress made in the different photovoltaic technologies, and particularly on the effect of the solar cells materials. In other experimental investigations (Wu et al., 2012; Ryu et al., 2006), different configurations of solar photovoltaic concentrating systems using Fresnel lenses were proposed and tested under different operating parameters such as the solar radiation intensity, the ambient air temperature and the natural and forced convection. Another new technology, in which PV cells of high flux levels were used for different designs of solar cell concentrators, was proposed by Feuermann and Gordon (2001). These authors proposed a new approach for concentrating

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Nomenclature

A_c	Collector area (m^2)
G	Solar irradiance ($W\ m^{-2}$)
I	Current (A)
P	Power (W)
T	Temperature (K)
U	Voltage (V)
V	Velocity ($m\ s^{-1}$)
η	Efficiency

Subscripts

a	Ambient
el	Electrical
max	Maximum
mp	Optimum operating
oc	Open-circuit
sc	Short-circuit
w	Wind

PV systems that can easily attain the maximum flux level commensurate with solar cell technology. Chaabane et al. (2013) are among the authors who are interested in the exploitation of solar energy in Tunisia using photovoltaic systems. They proposed an experimental study in which they discussed the effect of the cooling system that they designed on the global performance of their photovoltaic device.

In this paper, we present an experimental study of a particular photovoltaic panel. The open design of this solar system, which allows solar cells cooling by natural ventilation, is its main characteristic. Measurements are taken for two different soil natures and inclination angles. Computational fluid dynamics (CFD) are also used to model the performance of this photovoltaic system and to compare it to that of a Flat one.

2. Experimental study

2.1. Experimental setup

In this study, the tested PV panel consists of 40 cylindrical solar cells made of CIGS (Fig. 1). Due to cylindrical shape of the tube and its concentrating effect, the PV panel is collecting light over 360° and thus operating with direct, diffuse and reflected solar radiation. This experimental investigation has been conducted under a Tunisian Saharan climate, in the city of Tozeur. The experiments were undertaken during three consecutive spring days, 19, 20 and 21 April. These tests correspond respectively to an horizontal panel for a white soil, an horizontal panel for a gray soil and a sloped panel for a gray soil. All the measurements were continuously monitored each 1/2 hour, from 7 am to 6 pm.

The characteristics and dimensions of the photovoltaic panel used in this experimental study are specified in Table 1:

Table 1
Photovoltaic panel characteristics.

Parameter	Value
Maximum power at STC (P max)	200 W
Optimum operating voltage (U mp)	78.3 V
Optimum operating current (I mp)	2.55 A
Short-circuit current (I sc)	2.78 A
Open circuit voltage (U oc)	99.7 V
Electrical efficiency	10.18%
Dimensions of PV panel	1820∗1080∗50 mm
Temperature coefficient of power	−0.38%/K
Temperature coefficient of voltage	−0.289 V/K

2.2. Analyzed parameters and measuring instruments

For this PV system electrical performance evaluation, the current I and voltage U were continuously measured. The meteorological parameters defined by the ambient temperature Ta, the wind speed Vw and the incoming solar irradiance G were also experimentally determined using specific data acquisition devices. The characteristics of the measuring equipments used in this experimental study are listed in Table 2.

2.3. Experimental results

The ambient temperature, incident solar irradiance and wind velocity were experimentally measured and respectively presented in Figs. 2 and 3. During these three days, the climatic conditions were characterized by clear sky conditions. The solar radiation intensity and therefore the ambient air temperature were slightly higher for the gray soil test days, they achieved respectively 861 $W\ m^{-2}$ and 30.5 °C. Concerning the wind velocity, its maximal value has not exceed 5 m/s, so the climate corresponding to our experiments was stable and without sand storms which can cause disturbances during measurements.

The current I and the voltage U delivered by the PV panel were measured, the electrical power generated by these PV systems, which is defined as their product, was calculated and its temporal evolution is presented in Fig. 4. The analysis of this figure shows that the electrical power increases during the day up to noon, then decreases with the solar radiation intensity decrease. It is also noted that the produced electrical power is higher for the inclined PV paned due to the difference in the incoming solar radiation relatively to the horizontal panel. Concerning the effect of the soil nature, it can be seen that the highest production corresponds to the white soil (181 W), and this is due to its reflected part of the solar radiation which is negligible in the case of the gray soil.

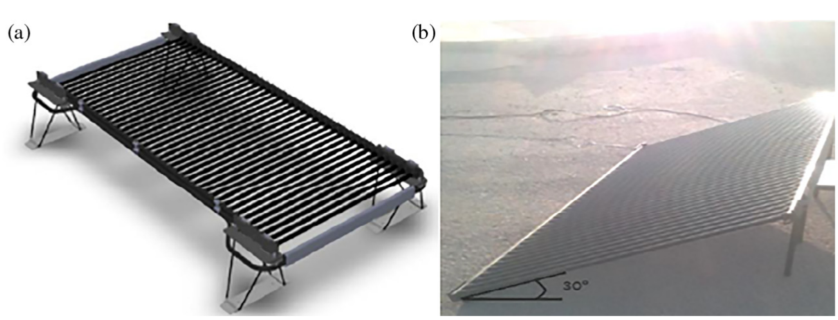

Fig. 1. Photographic picture of the horizontal (a) and titled (b) PV panel.