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Yearly performance of a hybrid PV operating with nanofluid

Evangelos Bellos[*], Christos Tzivanidis

Thermal Department, School of Mechanical Engineering, National Technical University of Athens, Zografou, Heroon Polytechniou 9, 15780, Athens, Greece

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A B S T R A C T

The objective of this study is to estimate the yearly thermal and electrical enhancement of a hybrid PV operating with nanofluids. The examined nanofluid is Cu/water and it is compared with water as working fluid for various operating conditions. An integrated solar thermal system with a hybrid PV and a storage tank is examined for twelve typical days in order its yearly performance to be determined. Different storage tank volumes are investigated because of the storage capacity influence on the thermal and the exergetic performance of the system. According to the final results, the storage tank of 150 L is found to be the most suitable solution for the hybrid PV of 2 m^2 collecting area, using exergetic criteria. For this case, the yearly thermal performance enhancement is about 4.35%, while the electrical and exergetic enhancements are 1.49% and 3.19% respectively. Moreover, it is found that the yearly enhancement is higher in the cases with greater storage tanks. The study is performed with a developed thermal model in EES (Engineering Equation Solver) which is validated with experimental literature results. The climate data has been taken from the literature for Athens, Greece.

1. Introduction

Renewable energy sources utilization is one of the most promising ways for achieving the energy sustainability in our society [1–3]. Solar energy is able to be converted either to useful heat either to electricity, the fact that makes it a flexible energy source [4,5]. Solar collectors are the devices which able the suitable conversion of solar energy to useful outputs. They are separated mainly to solar thermal collectors and to photovoltaic panels [6]. The solar thermal collectors are devices like heat exchangers which capture the incident solar energy and they convert it into useful heat. On the other hand, the photovoltaic panels capture the incident solar energy and they convert it into electricity. The last years, the hybrid photovoltaics (PV) gain more and more attention because these devices are simultaneously thermal collectors and photovoltaics [7,8]. More specifically, these devices capture the incident solar energy and the convert it both to useful heat and to electricity.

The hybrid PV or thermal PV (PVT) are ideal devices for utilization in the building sector because the produced useful heat is usually in low-temperature levels (~50 °C) and it can be used for domestic hot water or for space heating proposes [9,10]. They can be coupled with heat pumps in order to give the demanded heat input and the demanded electricity input. Moreover, the buildings have great electrical needs and the produced electricity can be utilized directly in them. Many techniques have been applied the last years in order to increase the performance of the hybrid PV. The most usual are the use of concentrators (CPC –PVT) [11–14] and the use of nanofluids as working fluids in them [15–18]. Nanofluids are created by dispersing metallic nanoparticles, as Cu, CuO, Al_2O_3, SiO_2, TiO_2 and Fe inside a base fluid which is usually water or thermal oil. The basic idea is to increase the fluid thermal conductivity and with this way to enhance the heat transfer conditions inside the flow.

The use of nanofluids is one technique which increases the thermal output of the collector with simultaneous effective cooling of the PV cells. Khanjari et al. [19] examined the use of Ag ($\varphi = 10\%$) nanoparticle in water and finally proved 3.9% electrical enhancement and 12.43% thermal enhancement. On the other hand, the lower enhancement was found with Al_2O_3 ($\varphi = 10\%$) in the same study with 1.83% electrical and 4.54% thermal enhancement. Ghadiri et al. [20] examined the use of Fe_3O_4 ($\varphi = 3\%$) in water and finally they found 4.93% electrical improvement and 46.29% thermal improvement. Xu and Kleinstreuer [21] investigated the use of Al_2O_3 nanoparticle in water ($\varphi = 5\%$) and they proved 9.72% electrical enhancement and no thermal enhancement. The same authors [22] proved that lower concentration ($\varphi = 4\%$) of Al_2O_3 leads only to 1.45% electrical enhancement without thermal enhancement. Al-Shamani et al. [23] examined three different nanoparticles

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[*] Corresponding author.
E-mail address: bellose@central.ntua.gr (E. Bellos).

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with 1% concentration. They proved that SiC leads to 42.97% electrical enhancement and 13.16% thermal enhancement, while SiO_2 and TiO_2 to lower improvements. Rejeb et al. [24] performed an interesting study about the utilization of Al_2O_3 and Cu ($\varphi = 0.4\%$) in hybrid PV. They finally proved that Cu leads to higher electrical and thermal improvements (0.77% and 79.97% respectively) compared to Al_2O_3 with 0.15% and 8.88% respectively. Moreover, it is essential to state that Ag and Cu have been proved to be the most effective nanoparticles compared to the other usual, according to the studies [25,26]. Another interesting study proved that higher amounts of nanoparticles lead to greater thermal and exergetic enhancements [27]. Khanjari et al. [28] proved that the use of Al_2O_3 nanoparticles inside water leads always to higher thermal performance in a hybrid PV. More specifically, they examined various solar irradiation levels and fluid inlet temperature levels in order to perform a multilateral study.

As it is obvious from the previous literature studies, the use of nanofluids enhances both the electrical and the thermal performance of hybrid PV. The majority of the literature studies are focused on determining the performance of the system with nanofluids and not the daily yield of an integrated hybrid PV with a storage tank operating with nanofluid. This study aims to estimate the yearly performance enhancement by the utilization of nanoparticles inside the base fluid (water). Cu is the examined nanoparticle and this selection is based on the above literature review which indicates it as one of the most suitable nanoparticles. A typical hybrid PV is examined for the weather conditions of Athens (Greece) for twelve different typical days, one for every month. A thermal model is developed in EES (Engineering Equation Solver) and it is validated with an experimental literature study. Moreover, it is essential to state that the methodology of ISO 9459-2 [29] is followed by the definition of the daily thermal performance of the integrated system. Furthermore, it is essential to state that different storage tank volumes are examined in order to determine the most suitable choice for the examined system.

2. Materials and methods

This section is devoted to the description of the followed methodology. The examined model is described with many details and the basic mathematical modeling is given. Moreover, the properties of the working fluids and the weather data are also given with details.

2.1. The examined system

The examined collector is a hybrid PV collector which is depicted in Fig. 1. More specifically, one intermediate strip of this collector is given in this figure. There is glass cover, PV cell, absorber plate, working fluid tube and insulation. Liquid working fluids are investigated in this study and there are totally 10 risers in the collector (N = 10). Table 1 summarizes all the data about the collector dimensions and the other useful parameters [30,31]. The hybrid PV is examined also with a storage tank and Fig. 2 depicts this configuration.

2.2. Mathematical modeling

2.2.1. Basic equation for the collector performance definition

The available solar irradiation in the collector level (Q_s) is calculated as the product of the collecting area (A_c) and the incident solar irradiation (G_T):

$$Q_s = A_c \cdot G_T, \tag{1}$$

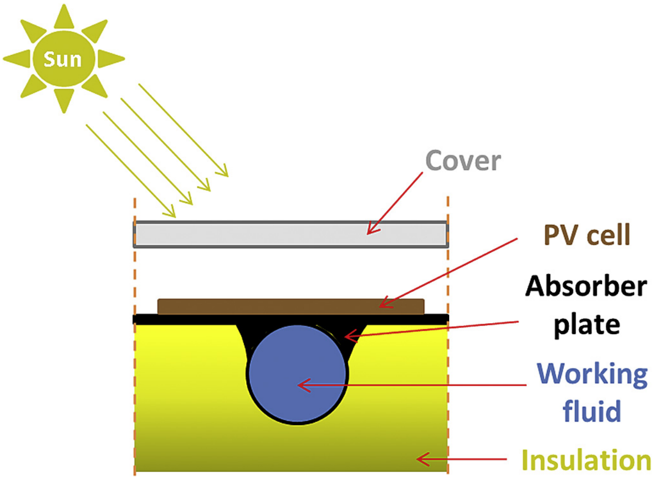

Fig. 1. The examined strip of the hybrid PV.

Table 1
Basic parameters of the examined hybrid PV [30,31].

Parameter	Value
Collector aperture (A_c)	2 m^2
Collector length (L)	1.916 m
Number of water tubes (N)	10 tubes
Inner tube diameter (d_{in})	$7.72 \cdot 10^{-3}$ m
Outer tube diameter (d_{out})	$9.52 \cdot 10^{-3}$ m
Cover transmittance (τ)	0.83
Plate absorbance (α)	0.95
Cover emittance (ε_c)	0.88
Plate emittance (ε_p)	0.93
Reference efficiency of PV (η_{ref})	0.173
Packing factor (PF)	0.804
Reference temperature (T_{ref})	298 K
Temperature coefficient (b)	0.00405 K^{-1}
Insulation layer thickness (L_{ins})	0.03 m
Plate – Cover distance (δ_{pc})	0.03 m
Collector slope (β_{col})	45°
Insulation thermal conductivity (k_{ins})	0.034 W/mK
Density of Cu (ρ_{np})	8933 kg/m^3
Specific heat capacity of Cu (cp_{np})	396 J/kg/K
Thermal conductivity of Cu (k_{np})	332 W/mK

The useful heat production (Q_u) is calculated by the energy balance on the fluid volume using the mass flow rate (m_c), the specific heat capacity (c_p), as well as the inlet (T_{in}) and the outlet (T_{out}) temperatures.

$$Q_u = m_c \cdot c_p \cdot (T_{out} - T_{in}), \tag{2}$$

The thermal efficiency (η_{th}) of the collector is the ratio of the useful heat (Q_u) to the available solar irradiation on the collector level (Q_s):

$$\eta_{th} = \frac{Q_u}{Q_s}, \tag{3}$$

The electricity production (P_{el}) can be calculated as the product of the collecting area (A_c), the packing factor (PF) and the PV cell efficiency (η_{PV}) [28]:

$$P_{el} = A_c \cdot PF \cdot \eta_{PV}, \tag{4}$$

The electrical efficiency of the PV cell (η_{PV}) is a function of the cell temperature (T_{cell}), the reference temperature coefficient (b) and the reference efficiency (η_{ref}), as it is presented below [28,30]: