



Research Article

Analysis of immersion depth in cooling a photovoltaic module by water immersion: An experimental study

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ABSTRACT

Photovoltaic systems are one of the important methods used to obtain electricity from solar energy. Photovoltaic module temperature and the angle of incidence of solar radiation are the most important factors affecting the electrical energy obtained from the photovoltaic module. There are many experimental and numerical studies in the literature on increasing electricity production by cooling photovoltaic modules. Cooling with air, liquid, phase change materials, thermoelectric effect, and immersion in water are the commonly used cooling methods. In this study, the cooling of the photovoltaic module by the water immersion method was experimentally investigated. In addition to the results of the related studies in the literature, analyzes were made for different immersion depths and the most appropriate immersion depth was tried to be determined. Three scenarios, 5 cm, 20 cm, and 30 cm immersion depth were investigated in the immersion of the PV module in liquid. As a result of immersion of the PV module in water, the PV module temperature decreased, and the voltage output increased for all parameter values. The highest voltage increase was obtained for 5 cm immersion depth (7.85%). Although PV module temperatures decreased with increasing immersion depth, the voltage output decreased after 5 cm immersion depth.

1. Introduction

Increasing global warming with the use of fossil fuels has made it necessary to use renewable energy sources more efficiently. Renewable energy sources can be classified as solar energy, wind energy, hydraulic energy, biomass energy, geothermal energy, and hydrogen energy. Among these renewable energy sources, solar energy has a very important place with the huge amount of energy it emits (3.85 million exaJoule) [1].

Photovoltaic modules are widely used devices to benefit from solar energy. In photovoltaic modules, some of the solar energy is directly converted into electrical energy, and because of this electricity production, the temperature of the module increases. One of the most critical factors affecting the electrical efficiency of the photovoltaic module is the module temperature. As a result of the increase in the module temperature, the electrical efficiency decreases, and accordingly, the electricity production also decreases [2]. In the literature, there are many studies on increasing electricity production by lowering the temperature of the photovoltaic module.

studies on increasing electricity production by lowering the temperature of the photovoltaic module. The cooling methods applied to reduce the temperature of the photovoltaic module can be examined in two main categories as active and passive methods. In active methods, energy is consumed by devices such as pumps and fans for cooling, while in passive methods, natural coolant sources that do not require energy are used. In Fig. 1, active and passive methods used for cooling photovoltaic systems are given

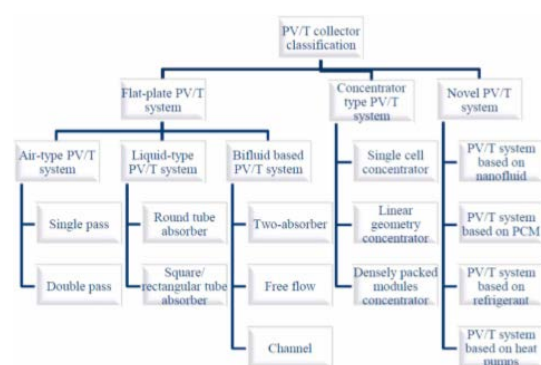


Fig. 1. Cooling methods of photovoltaic thermal systems

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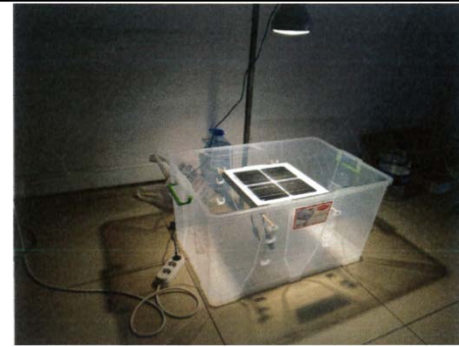


Yazdanifard et al. and Chow et al. used air cooling to improve photovoltaic system performance. In addition, they developed a theoretical model for the air-cooled photovoltaic thermal (PV/T) system and validated it with the experimental study results [4,5]. Herrando et al. analyzed a liquid-cooled PV/T system. The hot water obtained from the waste heat of the PV module was used for heating a house [6]. Zondag et al. compared the electrical and thermal performances of different liquid-cooled PV/T system designs [7]. The integrated operation of heat pumps, which have a higher coefficient of performance (COP) than electric heaters, with PV modules increases the electrical efficiency of the PV module while increasing the COP value of the heat pump [8-10]. Another method discussed in the literature for the cooling of PV modules is the combination of the PV module and the thermoelectric cooler (TEC) [11-13]. Phase change materials (PCM) used in high-density energy storage are also one of the passive cooling methods used in cooling PV modules [14,15]. PCMs melt at a low temperature and can cool the PV module longer because its temperature remains constant during melting. The use of nanofluids as a refrigerant in the cooling of PV modules is another common method discussed in the literature in recent years. In these studies, different types of nanofluids were tested and the electrical and thermal performance of the PV/T system was investigated [16-18]. The nanoscale solid particles in the nanofluid increased the heat transfer and provided better cooling. There are studies that include cooling a PV module by immersion in liquid and examining its electrical performance. In these studies, analyzes were carried out considering different PV/T system configurations and different liquids in which the PV module was immersed [19-21]. Apart from the methods mentioned above, there are also different PV module cooling methods. References [3], [22], and [23] can be viewed for details of these methods.

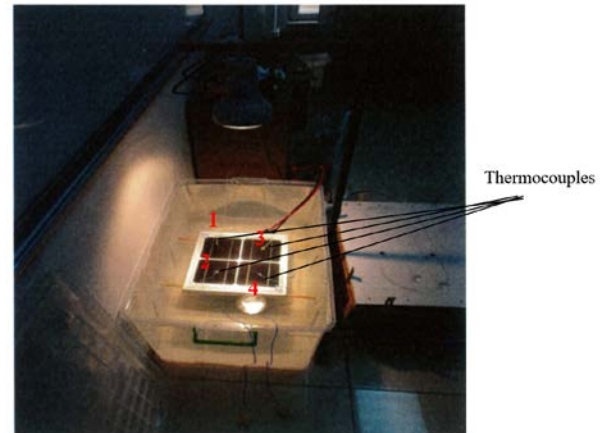
In this study, it was aimed to cool the PV module by liquid immersion method. In addition to the studies related to this method in the literature, in this study, the effect of the immersion depth of the PV module on the electricity production of the PV module was investigated experimentally. For this purpose, an M-Si type PV module was immersed in water in a plastic reservoir at different depths and the output voltages of the PV module at different depths were measured. Thus, the most suitable immersion depth was tried to be determined.

2. Experimental Study

In the experiment, a plastic container with a volume of 120 liters, a lamp with 800 W/m^2 radiation, and a $40 \times 40 \text{ cm}$ M-Si PV module were used. Water was used as a fluid in the plastic reservoir. Fig. 2 shows PV modules in dry and immersed environments. To keep the PV module at different depths, protrusions were created in the plastic chamber and the PV module was placed on wooden blocks. Four K-type thermocouples were used to measure the temperatures on the PV module. A multimeter was also used to measure the voltage obtained from the PV module. Three scenarios, 5 cm, 20 cm, and 30 cm immersion depth were included in the immersion of the PV module in liquid.



a)



b)

Figure 2. Experimental set-up a) without cooling, b) PV module submerged in water

First, the data obtained from the PV module in the case of no cooling were recorded. Afterward, the PV module was immersed in water, and temperature and voltage values were obtained for three different depths, and the experimental study was terminated. Temperature and voltage measurements were made at one-hour intervals for three hours. Uncertainties due to the devices used in temperature and voltage measurements in the experimental study are 1% and 0.5%, respectively.

3. Results and Discussion

PV module temperature and output voltage values measured at 1-hour intervals were given in Fig. 3. Temperature values are arranged according to the thermocouple numbers given in Fig. 2. As can be seen from Fig. 3a, in the absence of cooling, the module temperatures increased approximately 2 times compared to the situation with cooling. In the uncooled condition, the PV module temperatures varied between $40\text{--}45^\circ\text{C}$, while in the case of immersing the PV module in water, the module temperatures varied between $20\text{--}24^\circ\text{C}$. This decrease in PV module temperatures resulted in an increase of 2.84% to 7.85% of the voltage output obtained from the module cooled at different depths.

As a result of the increase in the depth of immersion in the water, the temperature of the PV module decreased (Fig 3b, 3c, and 3d). However, despite the temperature decrease, it was observed that the obtained voltage decreased from 2.27 V to 2.17 V when the depth was increased from 5 cm to 30 cm. This situation occurred because of more refraction of light as the depth increases and its arrival on the PV module at different angles. The measurement results revealed that besides the module temperature, the angle of incidence of solar radiation was also very important for PV module performance. The highest voltage output was obtained by cooling the PV module in 5 cm water depth (Fig. 3b).

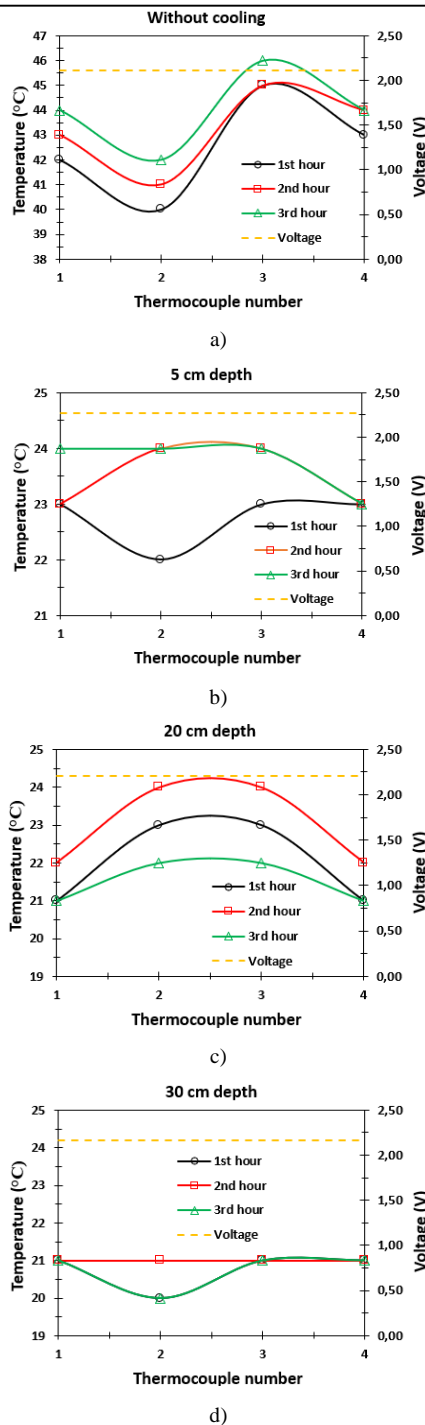


Fig. 3. Temperature and voltage values depending on time and depth a) without cooling, b) 5 cm deep cooling, c) 20 cm deep cooling, d) 30 cm deep cooling

4. Conclusions

In this study, the cooling of a PV module by the water immersion method was experimentally investigated. The PV module was immersed in water at different depths and the obtained results were compared with the results in the case without cooling.

As a result of immersion of the PV module in water, the PV module temperature decreased, and the voltage output increased for all parameter values. The highest voltage increase was obtained for 5 cm immersion depth (7.85%). Although PV module temperatures decreased with increasing immersion depth, the voltage output decreased after 5 cm immersion depth. Thus, after a certain level of depth increase, it has been determined that the radiation coming to the PV module

decreases due to the refraction of the light. Therefore, in future studies, the most suitable operating conditions can be determined by using optimization algorithms for the immersion depth of the PV module.

Declaration of conflicting interests

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