Photovoltaic Module Electrical Efficiency Enhancement Using Nano Fluids and Nano-Paraffin

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Abstract. Today, photovoltaic modules have become accepted by the public and scientists in the production of clean electricity and as a possible alternative to electricity produced from fossil fuels. These modules suffer from a deterioration in their electrical efficiency as a result of their high temperature. Several researchers have proposed the use of high-efficiency hybrid photovoltaic (PV/T) systems that can cool PV modules and also produce hot water. Improving the PV modules’ electrical efficiency increases the investment attraction and commercialization of this technology. The possibility of restoring the electrical efficiency of the photovoltaic panel that was lost due to its high temperature was investigated in this study. A PV/T system designed to operate with a paraffin-filled thermal tank attached to the PV module was used. Inside the paraffin is a heat exchanger that circulates inside a nanofluid. This design is adopted to cool down the PV module temperature. The study was carried out in the climatic conditions of the month of May in the city of Baghdad - Iraq. The proposed PV/T system’s electrical efficiency was compared with similar systems from the literature. The proposed system has achieved an obvious enhancement as its electrical efficiency was 13.7%.

Keywords: PV/T; nanofluids; Electrical efficiency; Combined efficiency, Nano-PCM

1- Introduction
Because of the successive wars and the economic blockade imposed on Iraq for more than four decades, the electricity production system deteriorated and the number of cut-off hours increased. This caused the Iraqi citizen to depend on diesel generators, which cause high air pollution and noise [1]. Currently, serious consideration is being given to deploying several electricity production plants using photovoltaic modules [2]. This trend is to reduce the large pollution rate resulting from fossil fuels combustion to generate of electricity as well as its use in various modes of transportation [3]. Photovoltaic modules tend to face a deterioration in electrical efficiency when the cell temperature increases, due to the fact that the big portion from the received irradiance is converted into heat and the lesser part of it into electricity [4]. Therefore, the optimal use of photovoltaic modules in countries with high radiation intensity (G) and high ambient temperatures (T) such as Iraq depends mainly on reducing the temperature of PV modules to reach optimal performance of this technology. PV modules can be cooled using various cooling methods such as air [5], water [6], nanofluids [7], PCMs [8], and nano-PCM.
cooling [9]. Several researchers have proposed systems called PV/T, which is a system that combines a photovoltaic module and a thermal collector. The heat collector absorbs the excess heat in the PV module and excretes it using a working fluid [10].

In the literature, there are many designs suggested by researchers to cool the photovoltaic panel and improve its performance. Ref. [11] Numerically and experimentally used a solar concentrator to improve the performance of the PV/T system. While Ref. [12] employed water circulation to cool the solar collector to improve the electrical efficiency of the proposed PV/T system. Both studies reported a clear improvement in the electrical efficiency of the proposed systems compared to the standalone PV module. Ref. [13] suggested adding nanoparticles to water to form a nanofluid coolant for the purpose of improving heat transfer from the PV module to the thermal collector. The researchers studied the effect of the proposed fluid numerically on the thermal and electrical properties of the system. Many studies investigated the addition of different nanoparticles that have metallic and non-metallic sources to form efficient cooling fluids [14-16]. Also, many studies focused on the type of base fluid and its effect on heat transfer in nanofluids [17-19]. Water can be considered the best of these basic fluids because of its thermal properties [20].

On the other hand, Ref. [21] found that adding PCM to PV/T system in a thermal collector resulted in an improvement in the system’s thermal and electrical efficiencies. PCM is considered a suitable material for heat storage as it has the property of storing large amounts of heat in the form of latent heat. These materials have been used to store heat in many solar applications such as solar water heaters [22], concentrated solar plants [23], and solar stills [24]. This property allows these materials to absorb large amounts of heat when their phase changes from solid to liquid, and then release this heat when their phase changes from liquid to solid. The study of Ref. [21] was numerical using TRNSYS and the results were confirmed experimentally. The results showed a significant reduction in the PV panel’s surface temperature because of the addition of PCM. The disadvantage of using PCM in PV/T systems is the low thermal conductivity of these materials [25]. To increase the efficiency of any solar system, many researchers suggested adding highly conductive nanoparticles to PCM to reduce the effect of low thermal conductivity of these materials [26-28].

In this practical study, the use PV/T systems in the harsh environmental conditions of Iraq for cooling photovoltaic modules is investigated. The proposed design PV/T system used a tank attached to the photovoltaic panel from the back and filled with paraffin, which is used to absorb the excess heat of the photovoltaic panel and reduce its temperature fluctuation. A heat exchanger was dipped inside this wax. A nanofluid with high thermal conductivity was circulated inside the exchanger, which absorbs heat from the paraffin and excretes it outside. This study focuses on enhancing the PV/T system’s electrical efficiency, which is degraded by high G and T.

2- Methodology

The studied system was set up in the “Energy and Renewable Energies Technology Center at the University of Technology, Baghdad, Iraq”. Experiments were conducted from 7 am to 7 pm and included measurement of G, T, PV module surface temperature and the nanofluid flow rate. In practical experiments, a 120 Wp polycrystalline PV module was used. The open circuit voltage of this module is 21.5V and the short circuit current is 7.63A. The nano-PCM tank is designed and manufactured from galvanized steel. Inside PCM basin there are conductive copper tubes, which nanofluid passes through. The materials used are characterized by good durability, acceptable cost and can be easily welded together. Nano-silicon carbide (SiC) nanoparticles were used in this study added to water to form a nanofluid. Cubic nano-SiC used were manufactured by US Research Nanomaterials, Inc. It has purity of 99.99% and a Grayish white color. These nanoparticles have grain size of 45-65 nm and has a thermal conductivity between 380-497 W/m. K. This type of nanoparticle was selected for its availability in the local markets at a moderate cost and for its high thermal conductivity. Paraffin wax (Iraqi made by Al-Doura refinery in Baghdad-Iraq) was used in the study, which is considered an organic PCM. The used paraffin has a melting point of 43°C, which can be considered acceptable for the studied application. Also, it is characterized by high Latent heat of fusion (190 kJ/kg), as well as high specific heat in both cases solid and liquid (2.1 kJ/kg °C). However, it has very low thermal conductivity that does not exceed 0.21 W/m °C. Using paraffin as a PCM was because it is available in Iraqi markets (as it is being
produced in Iraqi refineries) at a cheap cost (1 US $/kg). Paraffins have the ability to store large amount of thermal energy, and its melting and solidification points are suitable for the studied application. Figure 1 illustrates the methodology used in this study.

A self-standing PV module was also used to compare its productivity to the PCM system. The studied system has a water pump and a fluid tank to be able to take advantage of the thermal energy absorbed from the PV/T system. Glass wool was used to insulate the paraffin tank to prevent heat from escaping out of the container and forcing it to transfer to the nanofluid. To improve PV panel’s heat transfer from the paraffin tank, the area between them was coated with silicone oil. This oil prevents the formation of air gaps that hinder heat transfer.

Nano-paraffin was prepared by adding 2% of Nano-SiC to the melted paraffin and mixing them using an ultrasonic mixer. Figure 2 shows the change of color of paraffin from brown to a gray color close to nano-SiC. For mixing, an ultrasonic mixer type “TELSONIC ULTRASONICS CT-I2” was used. The paraffin-nano-SiC mixture was shaken for 60 minutes to ensure a wider diffusion and dispersion of nanoparticles through the paraffin. The thermophysical properties of the product such as viscosity, density, stability, and thermal conductivity were examined. The results showed that the density and viscosity did not increase significantly, while the thermal conductivity increased by 56% while the stability of the system was good.
“KD2 Pro” Analyzer was used to measure the thermal conductivity of nano-paraffin and nanofluid. The “DII-300L” densitometry and Brookfield (Model: “LVDV-III ultra-programmed”) viscometer were used to measure the density and viscosity of the mixture, respectively. The method described by Ref. [7] was used to prepare the nanofluid by mixing distilled water with nano-SiC. The interested reader can refer to the reference to get more details. The stability of the product (the nanofluid) was also studied and it was found to be stable for more than four months using an examination method that was used by the same reference. This period is considered good and acceptable for handling and using the nanofluid.

Several devices were used in the experiment’s measurements. A solar radiation (G) sensor was used to measure and record solar energy in W/m² (it has an uncertainty of ±1.012). Several K-type thermocouples distributed in various locations (in the nanofluid inlet tube, the exit nanofluid tube, on the surface of the PV panel, and inside the nano-paraffin container). These thermocouples have an uncertainty of ±0.9. Ammeters and voltmeters were used to check the electrical performance of the PV module and it has an uncertainty of ±0.39 and ±0.6, respectively. Polysulphone-flow meter was used to measure nanofluid flow with an uncertainty of ±0.62.

This practical study aims to measure the PV/T electrical system performance because of the impact of G, and T on proposed system efficiency.

3- Results and Discussion

The first practical experiments were carried out to determine the optimum flow rate of the circulated nanofluid, which results in the best cooling effect for the photovoltaic panel of the PV/T system. The system was run for several days using nano-paraffin and nanofluid to achieve this optimum flow rate. Figure 3 shows a decrease in the temperature of the photovoltaic panel when the flow rate of the nanofluid was increased from 0.083 kg/sec to 0.175 kg/sec. This result is expected, as the heat transferred from the medium to the nanofluid increases with the increase in the flow rate. Vibration generation was observed in the studied PV/T system when at the flow rate approached 0.175 kg/sec. Therefore, the flow rate of 0.15 kg/sec was selected as the optimum, which gives the best cooling effect without causing vibrations in the system. All of the following practical experiments were carried out using this flow rate.

The practical measurements shown in Figure 4 indicate that there is a difference in the electrical power generated between the standalone polycrystalline PV and the studied PV/T system. The temperatures of the PV/T system were about a 25% lower than that of standalone PV. The generated power of the PV panel of the PV/T system increased by 80% from 11 am to 3 pm (the period of peak solar radiation) due to the reduction in its temperature. The results confirm the existence of a significant difference in the output power up to 41.9 W in favor of the studied PV/T system. Figure 4 also shows the intensity of solar radiation during the measurement period. The measurements show a high intensity of solar radiation, although the experiments were carried out at the end of spring in the city of Baghdad. These results confirm the suitability of Iraqi weathers for generating electricity by PV module in Iraq as Ref. [3] claimed. There is a proportional relationship between the intensity of the received solar radiation and the electrical energy generated.
Figure 3. The nanofluid flow rates cooling effect on the temperature of the PV panel in the studied PV/T system

The measurements show that the maximum achieved power was around 1:25 pm (119.5 W). The figure indicates that the ambient temperature didn’t exceed 40°C during the tests. However, the difference between the PV temperature and $T$ couldn’t reduce the panel temperature. The wind was between 0.1 to 0.3 m/s throughout the tests, which could not enable fast heat transfer. Conversely, the presence of paraffin attached to the PV panel caused a significant portion of the excess heat to be drawn off while damping its oscillation. This damping causes PV panel life increase and reduces the harmful thermal stresses. The persistence of heat in paraffin means that it reaches a stage where its temperature is equal to that of the PV panel. However, this condition did not occur due to efficient cooling by the nanofluid.

Figure 4. Electrical yield variation of the tested systems.

Figure 5 manifests clear increments in the current generated by the photovoltaic module with an increase of $G$ and $T$. The same applies to the voltage (Fig. 6), which was increased with irradiance escalated, but at a lower rate. Increasing the solar radiation intensity causes a rise in the temperature of the PV module, but the current is proportional to this $T$. On the contrary, the voltage of the PV module decreases with an increase in its temperature, as Figure 6 concluded. It is inferred from Figure 7 that it is important to
keep the voltage of the PV module high through its cooling. Figure 7 reveals the current and power produced relationship when the solar radiation intensity was changed. The current at 1000 W/m² is close to its value under standard test conditions. This confirms the conclusion from the figure 4, which is that the current is directly proportional to the intensity of solar radiation.

![Figure 5. PV/T system’s I-V curve at different solar radiation intensities](image)

![Figure 6. PV/T system’s P-V curves at variable solar radiation intensities](image)

![Figure 7. PV/T system’s P-I curves at variable solar radiation intensities](image)
Summarizing the results of the cooling process of a PV panel in the proposed PV/T system compared to conventional PV module, the following differences were achieved:
- The highest measured panel temperature for PV was 68.3 °C while for PV/T was 39.52 °C.
- The maximum achieved PV electrical efficiency was 7.11% while for PV/T was 13.7%.
- The maximum achieved electrical power for PV was 77.6 W while for PV/T was 119.5 W.

These results reveal that the cooled PV module has a lower temperature of about 28.78°C than the stand-alone one (which has not been cooled). Also, the maximum power generated by the considered PV/T design reached 41.9 Wp more than the stand-alone PV module power.

3.1. Comparison with literature

Figure 8 compares the PV and PV/T efficiencies reported in the literature. Certainly, such comparison process may not be fair to some of these studies, as each of them was conducted in different climatic conditions from the other, as it was done with different designs and using water as a cooling fluid or nanofluids, with or without PCM, and using different PCMs types. Therefore, the difference in electrical efficiencies is not due to the cooling of the PV modules only, but rather due to other variables related to the weather, system design and the cooling method used. This comparison may be unfair, but it certainly can indicate that the PV/T system cooled using nano-paraffin and nanofluid gave higher electrical efficiency as a result of better cooling compared to other systems shown in the figure.

Figure 8. Electrical efficiency of the studied system compared to different PV/PVT systems in the literature

4. Conclusion

Photovoltaic modules are affected by solar radiation, as their electrical efficiency draw back when its temperature escalates to high levels. This high temperature results from the conversion of big part of the irradiance into thermal energy that heats the PV panel’s body. Iraq is characterized by it is located close to the sun belt with high radiation intensity most of the days of the year, which makes it suitable for applications of PV. However, these modules need cooling because of relatively high temperature. In the present study, a tank attached to the PV module was used from the back filled with nano-paraffin and inside it a heat exchanger was dipped through which the nanofluid circulates. This new system caused a clear improvement in the PV/T system electrical efficiency, as sufficient PV cooling resulted in an improvement in the open circuit voltage and thus improved electrical efficiency. The measurements showed an obvious increment in the electric power generated by the proposed PV/T system compared conventional PV module. Hot water was provided by the PV/T system in addition to electricity, while the PV module can only provide electricity. The study results confirmed the capabilities of the proposed...
system to work efficiently in the conditions of the Iraqi continental climate.

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