Improvement of the PV Module Performance by Cooling Method Through Immersing in a Forced Water Circulation

Sarah Yahya Hattam¹, Mahdi Hatf Kadhum Aboaltabooq², Hazim A. Al-zurfi³
[Engineering Technical Collage of Al-Najaf, Al-Furat Al-Awsat Technical University] ¹² [Al-Najaf Technical Institute, Al-Furat Al-Awsat Technical University, Al-Najaf, Iraq] ³
sara.yahya@student.atu.edu.iq, hatfmahdi@atu.edu.iq, hazim_alzurfi@atu.edu.iq

Abstract. Just 15 to 20 percent of the PV modules solar radiation's turned to electrical energy while the rest's transformed into thermal energy, resulting in a decrease in the efficiency of the electrical energy. Thus, to useful from the each electrical and thermal energy generated by the PV module, a hybrid thermal photovoltaic system is the perfect choice. A hollow rectangular box was used as a water flow channel to absorb heat from the photovoltaic's. Then, this heat extracted from photovoltaic's will be used in secondary applications, which leads to improved performance of photovoltaic modules and increased electrical conversion. The hybrid PV/T system consists of two sides of a rectangular channel made of insulating material, which are built-up on the bottom and top side of the PV panel, where the upper material is glass to transmittance the solar radiation and lower material is insulation foam, with a depth 5 mm of each one and through which water flows along the channel. The front side of the thermal collector contains transparent glass that allows solar radiation to pass through it to reach the PV module. 3D numerical simulation was performed by COMSOL Multiphysics® software, and is validated at different volume flow rates of 1LPM to 5LPM, by Boundary Conditions investigation to keeping the inlet water and ambient temperature at 27°C and solar irradiation at 1000 W/m². Hence, the benefit of this work is to evolve the electricity yield of photovoltaic (PV) module, thus increasing the electrical adequacy, also can be obtained the hot water by the heat absorption from the PV module by use heat exchanger. The results of the simulation had shown that the (PV) / T system produced 14.2% Maximum Electrical Efficiency (ηel), while the Maximum Thermal Efficiency (ηth) was 82%, all the result set at the temperature of ambient and inlet water to the thermal collector channel at 27°C. Where the range of the volumetric rate of water flow ranges between (1-5) LPM and solar radiation between (600-1000) (W/m²)

Key-Words: PV Module, PV/T System, photovoltaic cells, (Electrical, Thermal) Efficiency

1. Introduction

The thermal system (PV / T system) of Photovoltaic produces electricity and heat jointly through the heliacal radiation falling on it [1]. The PV module can tolerate temperature to a certain limit, but PV
module efficiency will decrease when the photovoltaic cells are overheated from the allowable limits [2]. Various former studies have been made to promote the work of a Photovoltaic module by lowering its temperature. To increase electrical efficiency, researchers used air pass to cool photovoltaic’s[3][4]. Meanwhile researchers [5][6] used water flow as a coolant to reduce the heat of the Photovoltaic module.

The (PV/ T) collector generate the electrical energy and hot water simultaneously. Theoretically, Bergene and Lovik (1995) have shown that with a PV/T collector, 60-80% of the total efficiency can be achieved [7].

A new method of PV/ T system can be applied to achieve a higher level of performance as well as reduce the consuming cost. The increasing of conversional efficiency of the PV/T system systems, enable it be used as domestic applications [8].

A total of nine various designs were done by [9] and range from complicated to the easier, so as to research the utmost production of the energy. They all concluded that the design, the channel underneath the transparent Photovoltaic cell, with the PV design on tubes and panels provides better overall efficiency.

Tripanagnostopoulos et al. [10] offered the results of the test regarding their (PV/T) thermo syphon type system and suggested that the polished (PV/T) water-heating system increased thermal efficiency by up to about 30 percent compared to the unglazed systems, but decreased electrical efficiency by about 16 percent.

Due to cell heating, the photovoltaic modules don't produce sufficient electrical energy from the solar rays, according to previous literature. moreover, research into improving the solar cell's efficiency by taking off the excess heat produced in the PV modules by cooling them is still needed.

The influence of pump speed and water mass flow rate on the thermal and electrical efficiency of the PV/T system was investigated in this research, which used immersed forced water cooling to cool the PV module. Thermal images of the photovoltaic cell module surface were taken with a thermal camera and compared to thermal contour images obtained with the Comsol Multiphysics software.

2. Thermal Collector System Analysis

To calculate the efficiency of a PVT system, the (\(\eta_{th}, \eta_{el}\)) thermal and electrical efficiencies respectively can be expressed as follows. Where(thermal efficiency) was measured using the well-known Duffie and Beckman [12]equation, which can be written as:

\[
\eta_{th} = \frac{Q_u}{G_{STC} \cdot A_c} 
\]

Where

\(\eta_{th}\): (Thermal Efficiency), \(A_c\): (Collector Area), \(G_{STC}\): (Solar Irradiance)

\[Q_u = m^* \cdot C_p \cdot (T_{out} - T_{in}) \]

Where \(m^*\): Mass Flow Rate (Kg/s), \(C_p\): Specific Heat for working fluid (J/kg K), and \(T_{i}\) =Fluid Inlet Temperature (°C) and \(T_{o}\) = Fluid Outlet Temperature (°C). Additionally, the (Electrical Efficiency) of the PV/ T system and can be written as: \(\eta_{el} = \eta_{th} [1 - \beta(T_{pm} - T_r)]\)
Where $\eta_{el} = \text{(PV Efficiency)}$ ($\%$), $\eta_r = \text{(Reference PV Efficiency)}$($0.15\%$), $\beta = \text{(Coefficient of Temperature)}$($0.0045^\circ\text{C}^{-1}$), $T_{pm} = \text{(Solar Cells Temperature)}$ ($^\circ\text{C}$), $T_r = \text{Reference Temperature at (STC)}$.

Table 1 shows the analytical properties of the PV/T system.

| Property                                      | Value            |
|-----------------------------------------------|------------------|
| The temperature of surrounding               | $T_a$            |
| Inlet Water Temperature                       | $T_i$            |
| The number of glass covers                   | 1                |
| Emittance of Glass                            | $\varepsilon_g$  |
| Transmittance                                 | $\tau$           |
| A bsorptance                                  | $\alpha$         |
| Slope Angle                                   | $\theta$         |
| Water Thermal Conductivity                    | $k_{\text{water}}$ |
| Water Specific Heat                           | $C_p$            |
| Collector Material                            | $(\text{foam})$  |
| Collector Width                               | $b$              |
| Collector Length                              | $L$              |
| Collector Thickness H                         | 0.025 m          |
| Collector Area                                | $A_C$            |
| Insulation Thermal Conductivity               | $k$              |

Table 1. Analytical Properties of PV/T System

3. Design Configurations of the Absorber Collectors

When the photovoltaic cells are exposed to solar radiation, they produce electricity and at the same time absorb heat which causes their temperature to increase. Meanwhile, the distilled water passing through the thermal collector conduit is heated up due to the contact at the highest and lowest of the photovoltaic's. Thermal absorption collector is equipped with an inlet and outlet for water at opposite ends of the hollow channel. This will ensure that the trapped water is passed into the absorber in a controlled way. All system is a closed cycle with forced circulation, where the distilled cold water entering the upper and lower hollow channel box of the PV/T system is heated at the same time and continuously. In this study, use the double rectangular channel absorber collector design above and under the PV module as shown in Figure 1.

![Figure 1](image1.png) (a) Virtual PV/T Thermal Collector (b) Actual PV/T Thermal Collector

4. Numerical Validation
In any numerical work, the verification is a very important step, to ensure the correct of numerical model proposed in this study, our numerical results were compared with previous literature numerical results. The validation was chosen based on the results of the modeling proposed with Afroza Nahar et al. (2017) [13]. This requires analysis of the results of the CFD validation for average outlet water PV thermal collector temperatures, mesh PV/T system were shown in Figure 2. Figure (3) shows the average temperature of PV/T system water outlet. With a rise in the flow rate, the temperatures dropped noticeably. The accuracy between the CFD validation findings and those of Afroza Nahar et al. (2017) was 3%. It’s worth noting that the current CFD findings are in strong agreement with those of previous studies. The boundary conditions have been effective, and it can be used to predict PV/T system performance.

**Figure 2** Generate finite elements mesh of thermal collector design for the CFD validation results compared with Afroza Nahar et al. (2017) results [13].

**Figure 3** Outlet water temperatures according to variable flow rates for the CFD validation results compared with Afroza Nahar et al. (2017) results [13].

5 Results and Discussion
For this simulation, the COMSOL Multiphysics® program and computational fluids dynamic system (CFD) was used. As a result, steady-state simulation was less expensive to run than the transient simulation, with an error rate of less than 0.2 percent. So it was chosen[14]. The simulations were all run in steady-state mode. The pressure-velocity coupling was achieved with the SIMPLE scheme. For spatial gradient estimation, the least-squared cell-based approach was used, second-order estimation was used for both the momentum and pressure equations. For the continuity, momentum, and energy equations, the residual values were set to $10^{-6}$, $10^{-4}$ and $10^{-4}$, respectively. The greater degree of freedom was used for the flow variables associated with the momentum equations. Furthermore, The following assumptions are recommended to initiate the simulation.

• The inlet and outlet flow water boundary conditions were proposed for the inlet and outlet velocity boundary conditions.
• Thermal boundary conditions of the water inlet was set to a constant temperature.
• The transmitted heat flux via the PV/T system was measured using several factors such as the transmissivity of the glass cover and the electric conversion, which can be written as follows: Heat Flux = $G \tau(1-\eta_e)$.

The surrounding temperature data was obtained from a weather station for 15-minute period and was 27°C. Figures 4,5 shows the relationship of outlet water temperature ($T_o$) and base temperature of PV module ($T_b$) respectively at increased the flow rate from 1 to 5 LPM at 1000 W/m$^2$ of solar radiation. At the constant of solar radiation and increasing the flow rate, the temperature of PV/T system and outlet of water were decreases respectively. Where the highest temperature predicted of PV module base of 37.24°C and 36.277°C for exit temperature of water, all tests at the 1000 W/m$^2$ of solar irradiance.

![Figure 4.](image.png)

**Figure 4.** Represents the outlet water temperature $T_o$ of PV/T system versus a variable volumetric flow rate at 1000 (W/ m$^2$) of solar radiation.
Figure 5. Represents the base temperature $T_b$ of PV/T system versus a variable volumetric flow rate at 1000 (W/ m$^2$) of solar radiation.

At the various inlet flow rates water for the rectangular collector channel, electrical and thermal efficiency of PV module will be vary continuously, as shown in Figures 6, 7 respectively. So, were the result of the PV/T system electrical and thermal efficiency varied between (14.1, 14.27, 14.32, 14.35, and 14.37) % for electrical efficiency and (77.5, 79.9, 80.47, 80.73, and 80.88) % for thermal efficiency at the flow rate of (1-5) LPM and solar radiation 1000 W/m$^2$.

Figure 6 Represents the electrical efficiency $\eta_{el}$ of PV/T system, versus a variable volumetric flow rate at 1000 (W/ m$^2$) of solar radiation.
Figure 7 Represents the thermal efficiency $\eta_{th}$ of PV/T system, versus a variable volumetric flow rate at 1000 (W/ m$^2$) of solar radiation.

6. Conclusion

The current study used a closed system cycle with double pass flow, parallel forced water circulation to cooling the PV module in order to evaluate the $(\eta_{th}, \eta_{el})$ efficiencies caused by a change in the upper and lower surface temperatures of the PV module caused by altering the flow rate of the pumping water. The water was pumped through the thermal collector channel by a DC pump with an 8-watt capacity, circulation the distilled water on both sides of the PV module. Numerical calculations were performed for separated and repeated cases of the thermal collector channel, and then a thermodynamic analysis was performed. The actual thermal image indicates of the thermal behaviour distribution of the PV module surface, (thermal camera) images were compared to virtual contour images derived from the Comsol Multiphysics Program. In the result, $(\eta_{th}, \eta_{el})$ will be increased due to decreasing temperature of the PV module. The electrical and thermal efficiency has been achieved (14.1, 14.37) and (77.5, 80.88) percent for the lowest and highest flow rate of (1, 5) LPM, respectively. Due to the high quality and good contact between the photovoltaic cell surfaces and the distilled water passed through the PV/T system from the top and bottom side, In addition to increasing heat transfer, a PV/T system is recommended to improve the performance of photovoltaic's and increasing the electrical production. Nan fluids can be used on the same research to test the method of heat transfer or dispersion. As a recommendation, nonmaterial's can be used instead of distilled water to absorb heat

References

[1] J. Darkwa, “Hpc 2004 – 3,” October, vol. 1, no. October, 2004.

[2] H. A. Al-Zurfi, H. H. Balla, A. N. Al-Shamani, and A. M. Hayder, “Numerical Study to Enhance the Electrical and Thermal Efficiency of PV/T System,” IOP Conf. Ser. Mater. Sci. Eng., vol. 928, no. 2, 2020, doi: 10.1088/1757-899X/928/2/022136.
[3] N. Aste, G. Chiesa, and F. Verri, “Design, development and performance monitoring of a photovoltaic-thermal (PVT) air collector,” *Renew. Energy*, vol. 33, no. 5, pp. 914–927, 2008, doi: https://doi.org/10.1016/j.renene.2007.06.022.

[4] J. K. Tonui and Y. Tripanagnostopoulos, “Improved PV/T solar collectors with heat extraction by forced or natural air circulation,” *Renew. Energy*, vol. 32, no. 4, pp. 623–637, 2007, doi: https://doi.org/10.1016/j.renene.2006.03.006.

[5] S. Dubey and G. N. Tiwari, “Thermal modeling of a combined system of photovoltaic thermal (PV/T) solar water heater,” *Sol. Energy*, vol. 82, no. 7, pp. 602–612, 2008, doi: https://doi.org/10.1016/j.solener.2008.02.005.

[6] T. T. Chow, W. He, J. Ji, and A. L. S. Chan, “Performance evaluation of photovoltaic–thermosyphon system for subtropical climate application,” *Sol. Energy*, vol. 81, no. 1, pp. 123–130, 2007, doi: https://doi.org/10.1016/j.solener.2006.05.005.

[7] M. Chaabane, W. Charfi, H. Mhiri, and P. Bournot, “Performance evaluation of solar photovoltaic systems,” *Int. J. Green Energy*, vol. 16, no. 14, pp. 1295–1303, 2019, doi: 10.1080/15435075.2019.1671405.

[8] S. A. Kalogirou and Y. Tripanagnostopoulos, “Hybrid PV/T solar systems for domestic hot water and electricity production,” *Energy Convers. Manag.*, vol. 47, no. 18–19, pp. 3368–3382, 2006.

[9] H. A. Zondag, D. W. De Vries, W. G. J. Van Helden, R. J. C. Van Zolingen, and A. A. Van Steenhoven, “The yield of different combined PV-thermal collector designs,” *Sol. energy*, vol. 74, no. 3, pp. 253–269, 2003.

[10] Y. Tripanagnostopoulos, T. H. Nousia, M. Souliotis, and P. Yianoulis, “Hybrid photovoltaic/thermal solar systems,” *Sol. energy*, vol. 72, no. 3, pp. 217–234, 2002.

[11] A. Tiwari and M. S. Sodha, “Performance evaluation of solar PV/T system: An experimental validation,” *Sol. Energy*, vol. 80, no. 7, pp. 751–759, 2006, doi: 10.1016/j.solener.2005.07.006.

[12] J. A. Duffie and W. A. Beckman, *Solar engineering of thermal processes*. John Wiley & Sons, 2013.

[13] A. Nahar, M. Hasanuzzaman, and N. A. Rahim, “Numerical and experimental investigation on the performance of a photovoltaic thermal collector with parallel plate flow channel under different operating conditions in Malaysia,” *Sol. Energy*, vol. 144, pp. 517–528, 2017, doi: 10.1016/j.solener.2017.01.041.

[14] N. Aste, C. Del Pero, and F. Leonforte, “Thermal–electrical optimization of the configuration a liquid PVT collector,” *Energy Procedia*, vol. 30, pp. 1–7, 2012.