Numerical Study to Enhance The Electrical And Thermal Efficiency Of PV/T System.

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Abstract
At increases the PV module temperature, electrical efficiency of a photovoltaic cells will be decreases. Due to facing the PV module to the solar irradiance to generate electricity, heating the PV cells is inevitable. A thermal channel collector can be used to absorbed heat from a PV cells, this heat absorbed from the cells can be using for other application, therefore increasing the electrical and conversion efficiency. The thermal collector system consists of a rectangular channel made from insulating materials (form) and on it the round water guides, is mounted to the backside of PV panel, through which water flow. In this modeling and numerical study, to solve this problem, was adding a cooling system to the PV panel. In the result, the benefit from this work to cooling the solar cells and increase the electrical efficiency, also to obtain heat gain in the form of hot water. Shown the simulation results, the absorber of thermal collector channel generates the maximum electrical efficiency of 14.6674% with maximum thermal efficiency of 82.532% at ambient of temperature set between 27°C to 32°C, set the temperature of inlet water at 27°C, water flow rate range (1-5) Liter/minute by increasing ratio of (1Liter/minute) and solar radiation between 300 to 1000 (W/m²) by increasing ratio of 100 (W/m²). Because high effectiveness and perfect the contact surfaces between the PV module and the thermal collector channel underneath, the recommended of (PV/T) system to enhance heat transfer.

Key-Words: - PV/T system, Thermal collector channel, (Thermal, electrical) efficiency, water guides.

1 Introduction
Today, energy is the main key to the economy and growth of countries. However, the majority of the energies comes from the fossil-fuels, which pollute the environment through greenhouse gas emissions. In addition, the fossil-fuels are considered to be non-renewable energy [1-4]. Therefore, the researchers went on to explore renewable and environmentally friendly energy as alternatives to fossil fuels polluting of environment. Solar panel manufacturing technologies have achieved a rate 20% of electrical efficiency and thus increasing this energy will result in raise the system temperature. Photovoltaic panels withstand temperature to a certain level, but when the panels are overheated from the permissible limits, the electrical efficiency of PV will decrease [5]. Several studies have confirmed that it is possible to increase the PV module efficiency by reducing the photovoltaic cells temperature. To improve electrical efficiency, researchers [6,7] they was the air used as a working fluid to cool the photovoltaic panels. while researchers [8,9] used water as a working fluid to cool it.

Researcher [10] and [11] they presented a various study of concept combined thermal PV assembly techniques. They presented and evaluated nine different designs to investigate the maximum return, ranging from complex to simple. They concluded that the channel thermal collector as design transparent and placed under PV, The PV/T system was designed with a thin metal plate containing tubes to give the best overall efficiency.

A theoretical study perform of a flat-plate, to assessed as a model of solar collector, integrated with solar cells [12]. They found the system combination of both Producing about 60-80% of efficiency by developing the multi of Algorithms to understand and prediction quantity of thermal efficiency and electrical energy of the PVT system.

They developed study of the photovoltaic thermal system using solar photovoltaic polycrystalline module, connected with thermal collector plate [13]. The flat plate collector directly contacted with the photovoltaic module by using the thermal grease, to improve the coefficient of heat transfer and thermal conductivity. Placed the layers from insulating material under the PV/T panel and attached by frame.
Thermal collector made from polycarbonate material and designed as the corrugated plate. Where the water flows in the corrugation channel at the plate structure. For hybrid PV/T system, the study was presented, which used the water as the cooling working fluid with natural circulation of convection, the model of thermal collector like the flat-box to absorber heat design [14]. With daily contributing of the thermal efficiency approximately 40%, The system showed a combined efficiency of 50%.

2 PVT Collector Analysis

To assess the effectiveness of the PV/T systems, the following could be expressed in terms of thermal and electric efficiencies. Where consisted of the electrical and thermal efficiency ($\eta_{el}$, $\eta_{th}$) respectively. The thermal efficiency was calculated by [15] and it can be written with the following equation:

$$\eta_{th} = \frac{Q_u}{G_{STC} \times A_c}$$

(1)

Where $\eta_{th}$: thermal efficiency, $A_c$: area of collector, $G_{STC}$: solar radiation at the standard test conditions, $Q_u$: useful heat gain and given as the follow:

$$Q_u = m^* C_p^* (T_{out} - T_{in})$$

(2)

Where $m^*$ = mass flow rate (Kg/s), $C_p$ = specific of heat for working fluid (J/kg K), and $T_i$ = fluid inlet temperature (K) and $T_o$ = fluid outlet temperature (K).

By H.C Hotel [16], They was relation between the thermal losses and absorber solar radiation, where is identified by the below equation:

$$Q_u = A_c \times F_R \times S (T_i - T_a)$$

(3)

Where $A_c$ = area of collector (m$^2$), $F_R$ = flow rate factor, $S$ = absorbed of solar energy (W/m$^2$), $U_L$ = overall heat loss coefficient of collector (W/m$^2$ K), $T_i$ = inlet temperature of fluid (K), $T_a$ = ambient temperature (K),

Can also from the equation (2), the $S$ is determined as:

$$S = (\pi \alpha)_{pp} G_T$$

(4)

The factor of flow rate ($F_R$) can be obtained as:
\[ FR = \frac{m^* \times C_p}{A_c \times U_L} \left[ 1 - \exp \left( \frac{A_c \times U_L \times F'}{m^* \times C_p} \right) \right] \]  \hspace{1cm} (5)

Corrected efficiency of fin (F’) is neglected, can be taken equal (one) as no fin.

The Overall efficiency (\(\eta_{\text{overall}}\)), used to assess the overall performance of the system and indicates the total efficiencies, where the written as the follows:

\[ \eta_{\text{overall}} = \eta_{\text{th}} + \eta_{\text{pv}} \]  \hspace{1cm} (6)

Depending upon the photovoltaic panel temperature, obtained the electrical efficiency (\(\eta_{\text{el}}\)) as follows [17].

\[ \eta_{\text{el}} = \eta_r \left[ 1 - \beta (T_{\text{pm}} - T_r) \right] \]  \hspace{1cm} (7)

Where \(\eta_{\text{el}}\) = (electrical efficiency), \(\eta_r = 0.15\%\) (reference efficiency of PV panel), \(\beta = rC \times 0.0045rC^{-1}\) (temperature coefficient), \(T_{\text{pm}}\) = solar cells temperature (C), \(T_r\) = the reference temperature at (STC). The presented of analytic characteristics of PV/T collector are in Table 1.

Table 1 characteristics of the PV/T channel thermal collector

| Parameter                              | Value | Units |
|----------------------------------------|-------|-------|
| Ambient temperature                    | Ta    | 300 K |
| Inlet fluid temperature                | Ti    | 300 K |
| Numbers of glass cover                 | N     | 1     |
| Glass Emittance                        | \(\varepsilon_g\) | 0.88 |
| Transmittance                          | \(\tau\) | 0.88 |
| Absorptance                            | \(\alpha\) | 0.95 |
| Tilt (slop)                            | \(\gamma\) | 0    |
| Fluid thermal conductivity             | \(k_{\text{fluid}}\) | 0.613 |
| Fluid Specific heat                    | \(C_p\) | 4180 J/kg. K |
| Channel material                       | -     | (foam)|
| Channel width                          | \(b\) | 0.5 m |
| Channel length                         | \(L\) | 0.8 m |
| Collector channel area                 | \(A_C\) | 0.4 m² |
| Conductivity for (back insulation)     | \(k_b\) | 0.045 W/mK |
| Thickness for (back insulation)        | \(L_b\) | 0.025 m |
| Insulation conductivity                | \(k_e\) | 0.045 W/mK |
| Thickness for (Edge insulation)        | \(L_e\) | 0.025 m |
3 System Descriptions

Photovoltaic thermal system consists of four main parts are (pump, thermal collector channel, condenser, and fluid storage tank). Thermal collector channel is the main part of the PV/T system, shown in Figure 1. It consists of 66 round water guides with 10mm diameter and the height 3mm, divided and distributed equally as the matrix form, to guide the water flow to the base of photovoltaic cells and absorb the heat accumulation through the thermal collector channel. The thermal collector channel made from thermal insulation martials (solid foam), drilling and fabricating by CNC machine and placed directly below the PV panel at the same area, they well controlled to prevent water leakage, through allows good contact between them obtained the best process absorption to heat and good accuracy of data reader. Thermal collector channel, contain of water inlet and outlet at the two terminal of the PV/T system, this will ensure the water flow trapped in the absorber thermal channel only. Can be considered the (PV/T) system as a closed loop, where the fresh and cooler water enters the absorb channel to bleeding the rising of temperature from the base of PV panel and cooled it continuously.
4 Results and Discussion

The simulation results indicated that there is perfect heat absorption from the PV panel base, with taking into account the pressure drop for the thermal collector channel as well as the energy consumption of the water pump. Therefore, this work modeling simulation, used and based on the following assumptions:

1- Stationary solution.
2- 3D CFD simulation.
3- The pressure drop in the PV/T system will be neglect.
4- Fully insulated water channel from outside.
5- Constant heat flux.
6- Heat transfer with fluid.
7- Laminar flow and fully developed.
8- Constant heat flux.
9- Inlet water temperature is equal to the ambient air temperature.
The ambient of temperature data were collected from the local weather station was 27 °C for 30 minutes. Figure 2 showing the relation of outlet water temperature with increase of the solar irradiance. In figures (3,4) the X-axis shows the solar radiation at 1000 (W/m²) and volume flow rate (1,2,3,4 and5) Liter/minute respectively, Y-axis shows the outlet and base temperature respectively. At the solar radiation intensity constant with volume flow rate increase, the temperature of photovoltaic cells decrease and outlet temperature water also decreasing. A maximum temperature predicted of PV cells base of 38 °C and 37.018 °C for outlet water temperature at the 1000 w/m² of solar radiation. By different the pumping flow rate of water to PV/T system, thermal and electrical efficiency of PV cells will vary continuously, as shown in Figure 5 and Figure 6 respectively. In the resulted, the PV/T electrical and thermal efficiency varied (14.122, 14.293, 14.351, 14.38, and 14.397) %, (79.1, 81.58, 82.117, 82.3768, and 82.532) % respectively at the flow rate of (1, 2, 3, 4 and 5) Liter/minute and solar radiation 1000 (W/m²).

Figure 2. The effect of cooling processes on water outlet temperature, at increase in the solar radiation.
Figure 3. Effect the cooling processes on water outlet temperature, when the solar radiation of 1000(W/m²).

Figure 4. Effect the cooling processes on the base temperature of (PV) panel, when the solar radiation of 1000(W/m²).
Figure 5. Shows the various value of electrical efficiency with increase in the process of cooling effect, when the solar radiation of 1000 (W/m²).

Figure 6. Shows the increase of thermal efficiency with increase in the volume flow rate of water, when the solar radiation of 1000(W/m²).
5 Conclusions

In this study, applied the forced water circulation by closed system cycle to cool the PV thermal system, to know the effect on the (thermal, electrical) efficiency, through the change in PV panel surface temperature by change in pumping water flow rate. The water has been circulated by the pump 8 Watt capacity DC, through the thermal collector channel where they placed on the back side of the PV panel. To increase and enhance heat transfer and provide more of efficient cooling, it has been placed the water guides inside the thermal collector channel. Numerical computations have been carried out for frequent sparse cases situations of the water channel, and then analysis thermodynamic have been performed. image of thermal camera Indicate to the surface thermal behavior distribution for PV panel, have been obtained, and compared with contour images obtained from Comsol Multi-physics Program. In the result, (thermal, electrical) efficiency was increased by decreasing the base temperature of PV panel. At minimum and maximum volume flow rate of (1,5) Liter/minute, they was electrical and thermal efficiency can archive (14.271,14.595) and (79.1,82.532) % respectively. Because high effectiveness and perfect the contact surfaces between the PV module and the thermal collector channel underneath, the recommended of (PV/T) system to enhance heat transfer.

References

[1] F. Ahmed, A. Q. Al Amin, M. Hasanuzzaman, and R. Saidur, “Alternative energy resources in Bangladesh and future prospect,” Renew. Sustain. Energy Rev., vol. 25, no. September, pp. 698–707, 2013, doi: 10.1016/j.rser.2013.05.008.

[2] H. Fayaza, N. A. Rahimb, R. Saidura, K. H. S. H. Niazc, and M. S. Hossaina, “Solar Energy Policy : Malaysia VS Developed Countries J ) Renewable Portfolio Standard ( RPS ) The formation Incentives T ) Feed-in tariffs ( FIT ) 3 ) Production tax credit Target,” no. November 2003, pp. 374–378, 2011, [Online]. Available: https://core.ac.uk/download/pdf/11440024.pdf.

[3] A. Qazi, H. Fayaz, A. Wadi, R. G. Raj, N. A. Rahim, and W. A. Khan, “The artificial neural network for solar radiation prediction and designing solar systems: A systematic literature review,” J. Clean. Prod., vol. 104, no. May
2017, pp. 1–12, 2015, doi: 10.1016/j.jclepro.2015.04.041.

[4] H. Fayaz, N. A. Rahim, R. Saidur, and M. Hasanuzzaman, “Techno-economic Analysis of Evacuated Tube Solar Water Heater using F-chart Method,” IOP Conf. Ser. Mater. Sci. Eng., vol. 358, no. 1, 2018, doi: 10.1088/1757-899X/358/1/012016.

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

[6] 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.

[7] 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.

[8] 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.

[9] 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.

[10] L. W. Florschuetz, “Extension of the Hottel-Whillier model to the analysis of combined photovoltaic/thermal flat plate collectors,” Sol. Energy, vol. 22, no. 4, pp. 361–366, 1979, doi: https://doi.org/10.1016/0038-092X(79)90190-7.

[11] H. A. Zondag, “Flat-plate PV-Thermal collectors and systems: A review,” Renew. Sustain. Energy Rev., vol. 12, no. 4, pp. 891–959, 2008, doi: https://doi.org/10.1016/j.rser.2005.12.012.

[12] T. Bergene and O. M. Løvvik, “Model calculations on a flat-plate solar heat collector with integrated solar cells,” Sol. Energy, vol. 55, no. 6, pp. 453–462, 1995, doi: https://doi.org/10.1016/0038-092X(95)00072-Y.

[13] B. J. Huang, T. H. Lin, W. C. Hung, and F. S. Sun, “Performance evaluation of solar photovoltaic/thermal systems,” Sol. energy, vol. 70, no. 5, pp. 443–448, 2001.
[14] W. He, T.-T. Chow, J. Ji, J. Lu, G. Pei, and L. Chan, “Hybrid photovoltaic and thermal solar-collector designed for natural circulation of water,” Appl. Energy, vol. 83, no. 3, pp. 199–210, 2006, doi: https://doi.org/10.1016/j.apenergy.2005.02.007.

[15] W. A. D. Beckman, “Solar engineering of thermal processes,” 2010.

[16] H. Hottel and A. Whillier, “Evaluation of flat-plate solar collector performance,” in Trans. Conf. Use of Solar Energy();, 1955, vol. 3.

[17] A. Tiwari and M. S. Sodha, “Performance evaluation of hybrid PV/thermal water/air heating system: A parametric study,” Renew. Energy, vol. 31, no. 15, pp. 2460–2474, 2006, doi: https://doi.org/10.1016/j.renene.2005.12.002.

[18] H.H. Balla"Enhancement of Heat Transfer in Six-Start Spirally Corrugated Tubes"Case Studies in Thermal Engineering Vol. 9, Pp. 79-89, 2017.

[19] H.H. Balla, S. Abdullah, Wan MohdFaizal, R. Zulkifli and K. Sopian "Numerical Study of the Enhancement of Heat Transfer for Hybrid CuO-Cu Nanofluids Flowing in a Circular Pipe" J. Oleo Sci. Vol.62, no.7, pp.533-539, 2013.