Design and Performance Study of Photovoltaic-Thermal (PV/T) Water Based System

Rekabentuk dan Kajian Prestasi Sistem Fotovolta-Terma (PV-T) Berasaskan Air

Wirat Ai Him[1], Mohd Hafidz Ruslan[2] and Zafri Azran Abdul Majid[2]

[1]Department of Physics, Faculty of Science and Technology,
Universiti Pendidikan Sultan Idris, 35900 Tanjung Malim, Perak, Malaysia
[2]School of Applied Physics, Faculty of Science and Technology,
Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia

Abstract

This paper presents a study on the design and performance of a photovoltaic thermal (PV/T) water based system. The objective of the study is to improve the performance of the designed photovoltaic thermal system. Water is used to cool the photovoltaic module by passing it through the thermal solar collector under the bottom surface of the module. Thus, both electrical energy and heat can be generated simultaneously. The system was tested under three simulated solar intensities of 200 W/m^2, 400 W/m^2 and 600 W/m^2. Each intensity was conducted in three modes of condition; a single PV, PV/T with and without water flowing to compare the efficiency and also the maximum power output generation. The results obtained were analyzed in *I-V* and *P-V* curves. From the comparison made between a single PV module and PV/T with water flow, the results showed that the photovoltaic efficiency increased by an average of 0.29%. The maximum power output of photovoltaic at the PV/T with water flow increased by an average of 0.63 W or 5.56%. The average temperature of the bottom surface of the module was reduced by 4.60 ^{o}C. The average fill factor, *FF* of the PV/T calculated was 0.662. The result can be considered as satisfactory since the standard fill factor of a standard photovoltaic module range between 0.7 to 0.85.

Keywords Water based, photovoltaic thermal (PV/T), efficiency

Abstrak

Kertas kerja ini membentangkan kajian ke atas rekabentuk dan prestasi fotovolta terma aliran air (PV/T). Tujuan kajian ini adalah untuk meningkatkan prestasi sistem fotovolta terma yang telah dibina. Air dialirkan di permukaan bawah modul fotovolta melalui pengumpul suria terma untuk menyejukkannya. Dengan itu tenaga elektrik dan tenaga haba dapat dijanakan secara serentak. Sistem ini diuji di bawah lampu simulator pada tiga keamatan iaitu 200 W/m^2, 400 W/m^2 dan 600 W/m^2. Setiap keamatan tersebut diuji pada tiga keadaan berbeza iaitu panel fotovolta kosong, panel fotovolta terma tanpa aliran air dan panel fotovolta terma dengan aliran air bagi membandingkan kecekapan dan penghasilan kuasa output maksimum. Hasil daripada ujikaji diplotkan pada graf lengkung cirian *I–V* dan graf lengkung cirian *P–V*. Kecekapan fotovolta dapat ditingkatkan sebanyak 0.29% secara puratanya untuk perbandingan antara panel fotovolta kosong dan fotovolta terma dengan aliran air. Kuasa output maksimum oleh fotovolta pada panel fotovoltaik terma aliran air dapat ditingkatkan sebanyak 0.63 W atau 5.56% secara puratanya berbanding dengan panel fotovolta kosong. Suhu purata pada permukaan bawah panel fotovolta dapat diturunkan sebanyak 4.60 ^oC. Faktor pengisi, *FF* yang dikira untuk PV/T tersebut ialah 0.662. Prestasi panel fotovolta tersebut berada dalam keadaan memuaskan kerana faktor pengisi piawai fotovolta adalah di antara 0.7 dan 0.85.

Kata kunci Aliran air, fotovolta terma (PV/T), kecekapan

Introduction

Photovoltaic module converts solar radiation to electrical energy. The high intensity of solar radiation increases the module's temperature, and at the same time decreases the efficiency. Normally, the best module's performance claimed by manufacturers is at ambient temperature of 25^oC with irradiation of 1000 W/m^2. This condition is not suitable for the Malaysian climate which has an ambient temperature of more than 30^oC during daytime, and the solar radiation of less than the given value (Othman, Othman, Sopian, Yatim & Dalimin, 1993).

Photovoltaic thermal system or PV/T is a system that combines both solar photovoltaic and thermal units together in a single system that produces heat and electrical energy simultaneously. This is due to the fact that more than 70% of the solar radiation falls on the PV module is converted to thermal energy, and only about 10 - 15% is converted to electricity. In order to improve the efficiency of converting solar energy into useful energy, a PV/T collector has been designed to convert the thermal energy generated to heat water.

Tripanagnostopoulos (2007) has introduced a new type of PV/T collector with dual heat extraction operations, either with water or with air circulation. The system is suitable for building integration, providing hot water or hot air depending on the season and the thermal needs of the building. The modifications made by him included a thin metallic sheet placed in the middle of the air channel, the mounting of fins on the opposite wall to PV rear surface of the air channel, and the placement of the sheet combined with small ribs on the opposite air channel wall for the air heat extraction improvement. The modified dual PV/T collectors were combined with booster diffuse reflectors, achieving a significant increase in system thermal and electrical energy output. Tiwari and Sodha (2006) evaluated the performance of solar PV/T system with an experimental validation. Based on energy balance of each component of the integrated photovoltaic and thermal solar (IPVTS) system, he analyzed and derived an analytical expression for the temperature of PV module and the heated water. The simulations predicted a daily thermal efficiency of 58%.

Vorobiev, Gonzalez, Vorobiew, Bulat (2006) had designed a thermal-photovoltaic solar hybrid system with high temperature stage for efficient solar energy conversion. The system contains a solar concentrator, a photovoltaic solar module, and a heat engine or thermoelectric generator. The calculations made show that the proposed hybrid system has practical and efficient merits. A similar study was carried out by Zakharchenko, et al. (2004). They investigated the performance of different modules in the hybrid PV/T system, in particular, those made of crystalline (c-) Si, a-Si and CuInSe as well as different materials and constructions for the thermal contact between the module and the collector. The study claimed that the designed hybrid collector produced high electrical and thermal efficiency. Chow, He and Ji (2007) investigated building integrated photovoltaic thermal applications. They carried out experimental study on facade-integrated photovoltaic/water-heating system. The system was used to collect pre-heated water for domestic use. The thermal efficiency of the system was found to be 38.9% at zero reduced temperature, and the corresponding electrical conversion efficiency was 8.56%.

The efficiency of the collector in this study can be improved by reducing the temperature of the solar cell. The cooling system was designed to improve the solar cell efficiency. If P_t is PV/T total power gain, P_{pv} is photovoltaic power, P_p is water pump power consumption and P_{hw} is power gain for water heating in the collector, therefore the energy balance of the designed system can be written as,

$$P_t = P_{pv} - P_p + P_{hw} \quad ...(1)$$

Research Methodology

The photovoltaic module used in the study was SHARP NE-80E2EA module with the maximum capability of 80W at intensity of 1000 W/m^2 and surface temperature 25^{o}C. A thermal collector consist of nine parallel hollow square copper tubes with dimension of 23 mm × 14 mm attached to the back of the PV module as shown in Figure. 1. This designed arrangement was to ensure that the maximum heat can be transferred from the PV module to the circulated water. The copper tubes were covered with copper sheet to maximize the heat trapped in the solar collector, and Insulfex foam insulation sheet was used to cover the copper sheet to ensure that the heat losses from the solar collector can be minimized. The system was put into a box made of aluminium sheet as shown in Figure 2.

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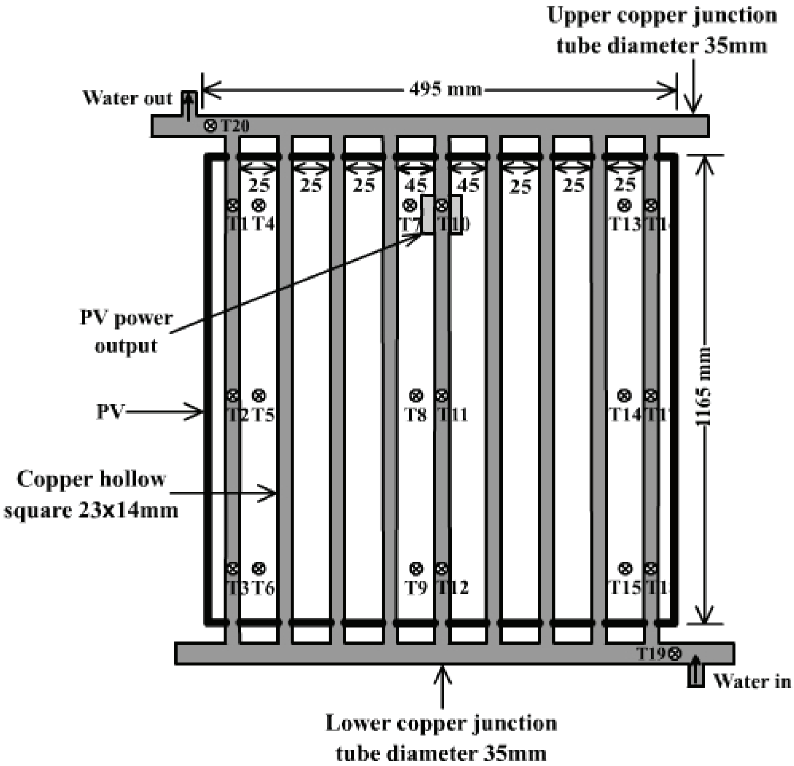

Figure 1 Heat exchanger for the PV/T system made of hollow square copper tube

The experiments were carried out at the Solar Energy Laboratory, Universiti Kebangsaan Malaysia. A solar simulator with 23 halogen lamps, with capability of 500 W each, was used in the experiment as shown in Figure 3 and 4. The simulator was set at solar radiations of 200 W/m^2, 400 W/m^2 and 600 W/m^2 throughout the experiments. Three experiments were carried out using the designed system,

a. To test PV module efficiency without thermal collector.
b. To carry out experiment with the PV/T collector but without the flow of water.
c. To conduct experiment with the PV/T collector with water flow through the system.

The water flow was set at 0.03 litre/s, with the assistance of 6.5 W water pump attached to it.

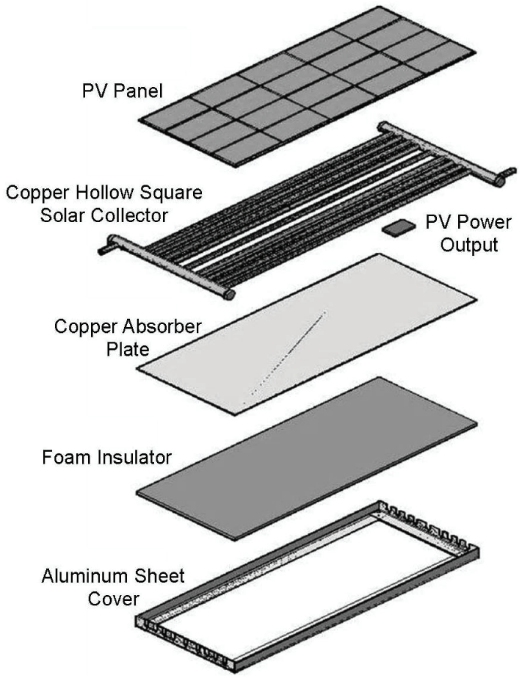

Figure 2 The schematic diagram of the designed PV/T collector

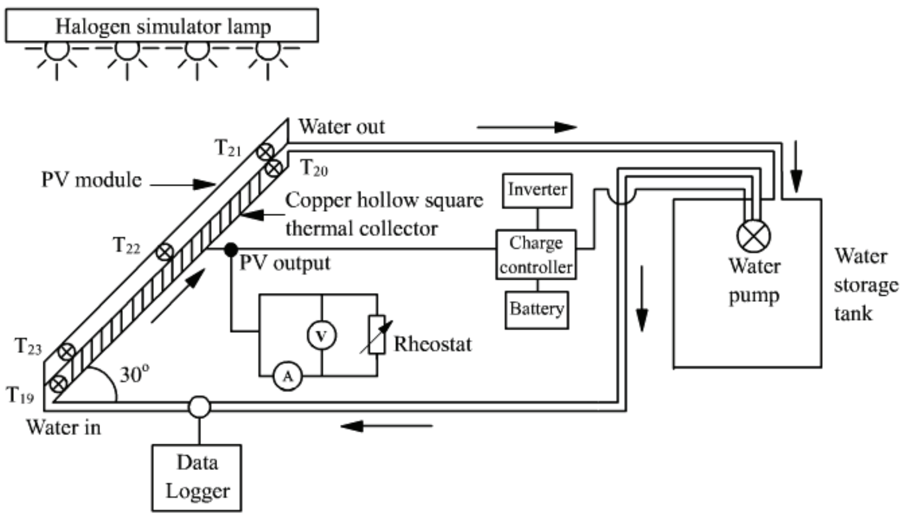

Figure 3 Schematic diagram of PV/T water based system

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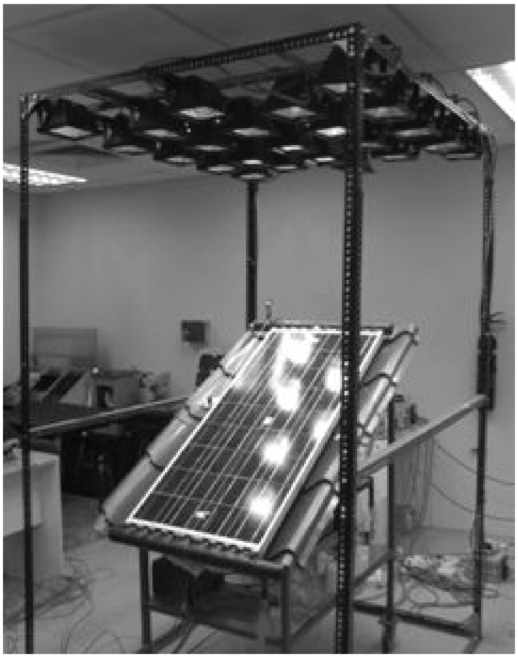

Figure 4 Photovoltaic thermal water based running under simulator lamp

Results and Discussions

Figure 5 shows the effect of solar module temperature on the PV power output for PV/T with flow of water at the highest intensity of 600 W/m^2. In this experiment, the result showed an increment of electricity produced from the PV/T. The temperature of the photovoltaic module decreased from 54.8^{o}C to 50.7^{o}C and the power produced by the photovoltaic modules increased from 18.60 W to 19.44 W. Figure 6 shows the result when there was no flow of water at intensity of 600 W/m^2. This result shows that as the temperature increased the power gain decreased as shown in Figure 6.

Table 1 Comparison of PV/T maximum power output with PV module at three intensities

System Design	Maximum PV Power Output (W) Intensity (W/m^2)		
	200	400	600
PV only	6.02	11.98	18.60
PV/T without water flow	6.11	12.21	18.93
PV/T with water flow	6.43	12.64	19.44

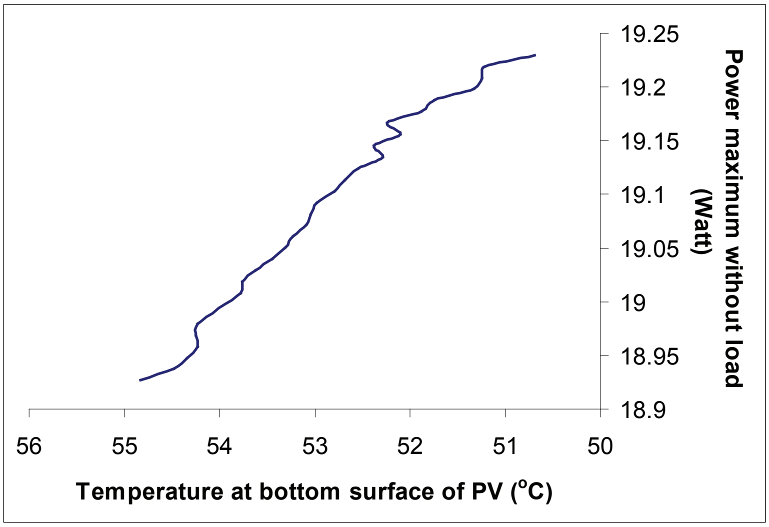

Figure 5 The effect of solar cell temperature to the PV power output for PV/T with water flow

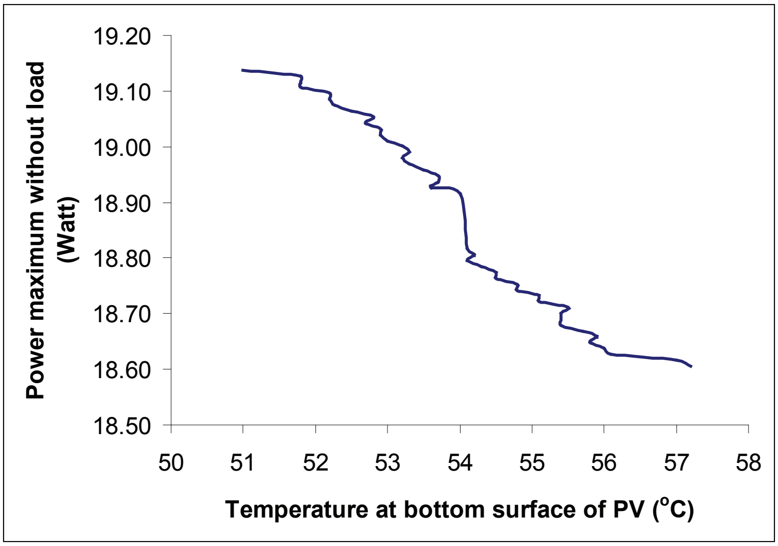

Figure 6 The effect of solar cell temperature to the PV power output for PV/T without water flow

This result showed that the cooling system at the bottom surface of PV influenced the increment of PV power as shown in Figure 5. The cooling system can reduce the temperature of PV when the PV/T have water flow. For the PV/T with water flow, the results obviously showed that the power produced and output voltage produced by the PV were simultaneously increased as shown in Figure 7. The temperature of the solar cell PV module greatly influenced the efficiency of PV. In this study, the cooling system (for solar collector) that was designed at the bottom surface of PV can reduce temperature of the PV module and it increased the PV efficiency.

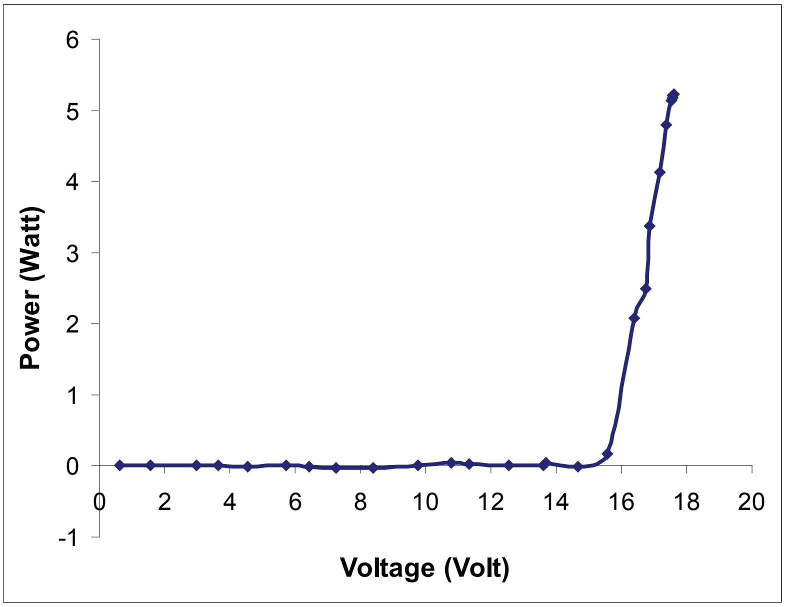

Figure 7 The increment of power and voltage for PV/T with water flow

The *I-V* curves were plotted for the steady state conditions for a normal single PV, PV/T with and without water flow at three intensities. The conspicuous increment of power was at the 200 W/m^2 as shown in Table 1 and Figure 9. It showed that for normal PV module without solar collector, the power maximum recorded was 6.02 W. For PV/T with flow of water, the power maximum increased from 6.11 W to 6.43 W at irradiance 200 W/m^2, this is 6.81% of the increment of efficiency (at this point the photovoltaic temperature decrease from 58.1^{o}C to 53.5^{o}C). For the comparison of a single PV module and the PV/T with flow of water, the generated power increased from 6.02 W to 6.43 W. Both were at the same irradiance of 200 W/m^2. It was shown that, by using the copper hollow square as a solar collector at the bottom surface of PV, it can increase the maximum power output of PV/T by 6.81%.

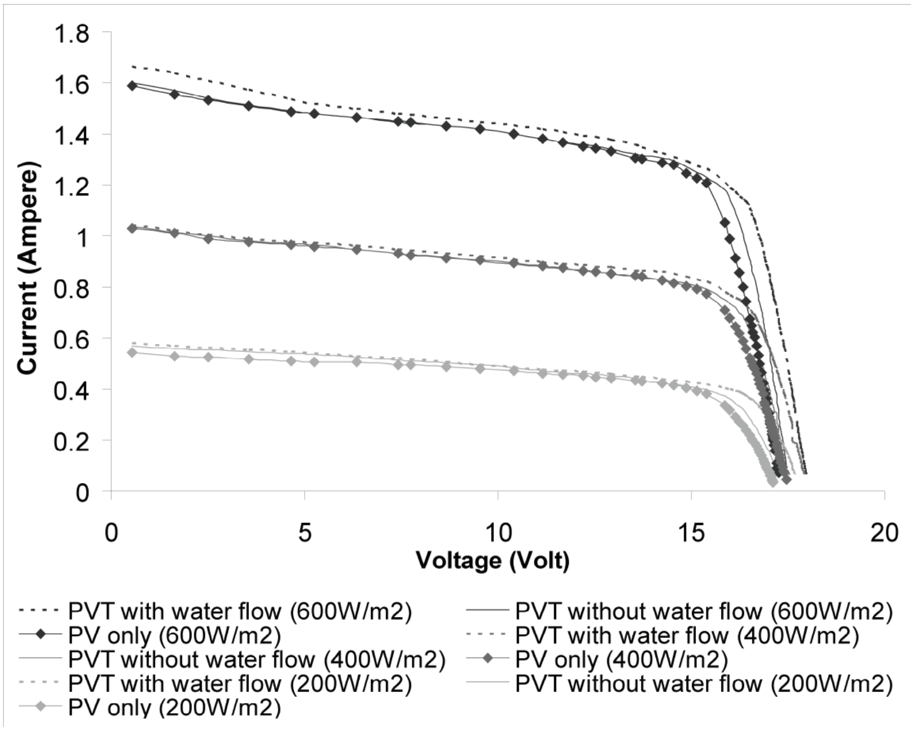

Figure 8 *I-V* curve for PV and PV/T water based at three intensities

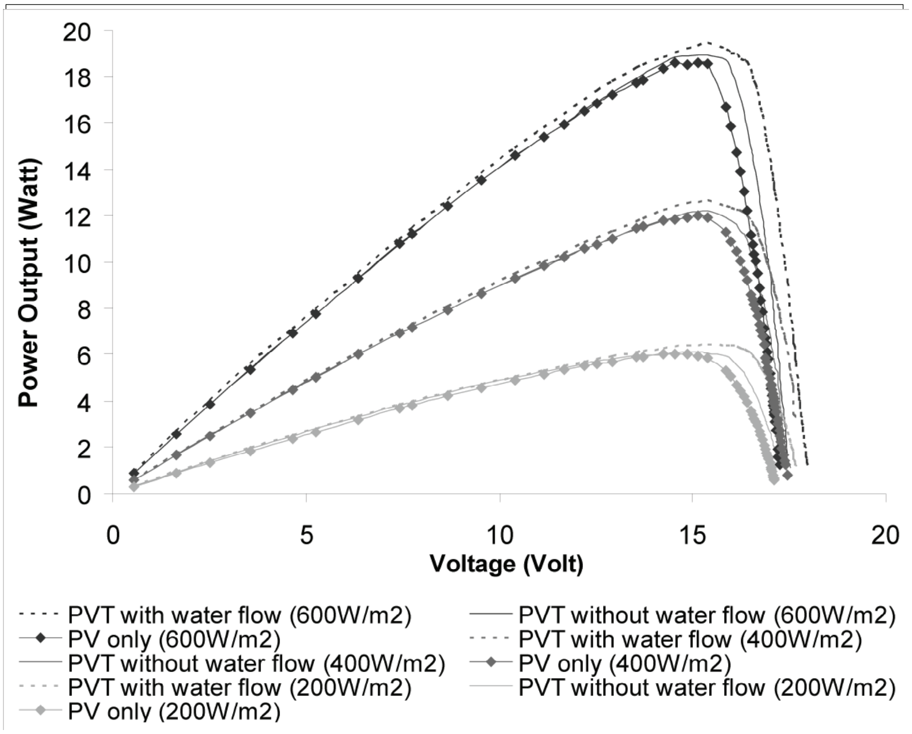

Figure 9 *P-V* curve for PV and PV/T water based at three intensities

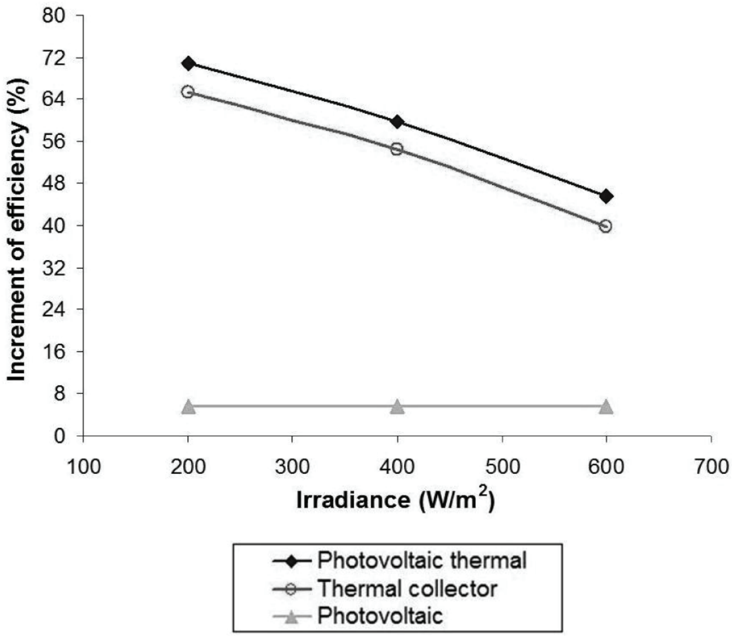

Figure 10 The effect of irradiance due to the increment of efficiency

Figure 10 shows the effect of irradiance due to the percentage of efficiency increment for photovoltaic thermal, thermal collector and photovoltaic module. The percentages of efficiency increment for photovoltaic thermal and thermal collector were gradually decreased due to the increment of irradiance from the 200 W/m^2 to 600 W/m^2. When the irradiance increased, the percentage of efficiency increment decreased. This was caused by the existence of infra red phenomena that probably exists in this experiment resulted from the simulator halogen lamp. The halogen lamp produced more heat rather than produced high intensity of radiation. When the halogen lamp was set at high voltage, the temperature of the photovoltaic surface was greatly increased but surprisingly the intensity of the radiation did not increased.

Conclusion

The results on PV/T water based study showed an average of 0.29% increment of the PV efficiency. For the comparison of normal PV module and PV/T with flow of water both at highest intensity of 600 W/m^2, the power generated from the system were 18.60 W and 19.44 W respectively. In terms of power generated, the PV/T increased by an average of 0.63 W or 5.56% compared to normal PV. In this study, it showed that the solar collector attached at the bottom surface of the PV had increased the efficiency of PV module resulted from the reduction of the solar cell temperature. The temperature of PV will affect the overall efficiency so, to ensure the high performance; the PV must operate at the lowest possible temperature. The water based collector that was designed is very significant as a cooling system for the

PV module because it can reduce the temperature at the bottom surface of PV by 4.60 °C and at the same time it can gain heat from PV for the utilization of solar hot water. Thus, the electricity generated by PV can be increased. This experiment was tested under a solar simulator using halogen lamp which has a disadvantage of excess infrared wavelengths thus, producing more heat than radiation. From the results obtained by the previous researcher using actual solar radiation at 786.6 W/m^2, the photovoltaic module temperature recorded was 65.7 °C. From this result we can conclude that the efficiency of the solar module can be increased for the actual solar radiation, with effective cooling system.

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