Hybrid pv/t system performance based on the electrical and thermal efficiency in Iraq

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Abstract Nowadays, solar energy is one of the important clean energies through converting the light sun into electricity by photovoltaic solar cells which is a semi-conducting material. Solar radiation is one of the most important factors in determining the amount of produced energy through absorbing it by the solar cells. On the other hand, heat is one of the sources of energy loss if it rises more than the prescribed limit, thus reducing the amount of electrical energy generated and reducing production efficiency. Therefore, this paper focuses on designing, testing and comparison the photovoltaic panel system (PVS) with and without Active cooling process via water in Baghdad environments. The active cooling system (ACS) was placed behind the solar cell in order to absorb the generated heat that is isolated from the environment. The testing of both models was conducted in April 2021 in Baghdad. As a result, PVS with cooling performed well compared with uncooled, where uncooled model at highest panel temperature produced about 8 % from operation efficiency. While, the ACS worked on increasing the system performance up to 16.5% by decreasing the panel temperature. The efficiency conversion has recorded to be 50% and 52% at two mass flow rates. Water flow rate increased the heat transfer through cover glass which led increasing the efficiency. Finally, ACS for PVS can improve the efficiency by about 12% as an average value. At high temperature environment, cooling system should be employed to get better PVS performance and reducing the payback period.

Introduction

In the world, PVS is considering one of the renewable energy resources that uses to convert the sunlight into the electricity. The main resource for PVS is the solar radiation which increases the electrical output power and PVS efficiency when its increase. The main problem faces the power in PVS is the temperature that decaes the power about .0.2 to 0.5% when the temperature rises each 1k in addition the panel temperature due to conversion process. Therefore, reducing the temperature is an important issue nowadays by cooling or recycling the heat to prevent the heat loss. Many applications have used the generated heat (Photovoltaic/thermal (PV/T)) by transferring it into hot air or water such as industrial preheating. PV/T system can be classified into two categories; forced and natural convection based on the flow dynamic. an integrated photovoltaic and thermal solar system (IPVTS) has been improved by Hung et al. [1]. The system included on the storage tank, PV/T collector and pump in addition to controller. The Average and overall PV/T thermal efficiency arrived to 0.38 and 0.5 per day respectively. Recently, energy resources became an important...
demand. Based on the Energy Information Administration for U.S.A, they expected increasing in solar energy utilization up to 1.4 trillion Kw. h during 2015 to 2040 [2]. Based on the previous works, solar energy superior on other renewable energies like water power and wind energies [3-5]. PV and thermal solar energy still the main utilizing. One of the main advantages of PV/T is to produce the electricity as well as the heat by a solar collector compared with using of PV only [6-7]. Many papers used flat plate PV/T since 1978 in order to enhance the PV/T efficiency [8-14]. Study the performance of electrical and thermal efficiency has been done by Heng Zhang et al. [15] on the flat-plate PV/T and low-concentrating flat plate PV/T systems. The outcomes proved that the low-concentrating flat plate PV/T enhanced the electrical power about 3 times compared with flat plate PV/T, while the thermal power enhanced about 1.9 to 2 times. Modeling the PV/T collector in order mimic the system was conducted by Oussama Reje et al [16]. The main indication was increasing of heat conduction coefficient and packing factor which led to improve the electrical efficiency. On the other hand, heat conduction coefficient and packing factor reduced when the solar radiation and inlet water temperature increased. R. Hosseini et al [17] studied a combination between PV and heat systems experimentally, and the work revealed that proposed system performed well compared with traditional system. Pratish Rawat [18] evaluated the PV/T system by analyzing the PV/T system performance at different mass flow rate of cooling fluid. Finally, risen the temperature of water tank was an important result by Chao-Yang Huanga [19] when used a hybrid PV/T system experimentally. Current work focuses on the PV system with cooling technique experimentally by flowing the water through thin film on the top PV surface as well as using the produced hot water from the system.

**Experimental setup**

Two PV systems were used in this work one is a traditional PV (as a reference) and the other was PV/T system with colling technique via flowing the water in thin film on the top surface without front glass. Maximum output voltage for each system was 23 V, while the maximum output current was 2.61 A, and Maximum output power was 60 W. the area between two panels was 0.44 m² as shown in Figure 1. To apply the thin film, a tube with a slit has employed and installed along panel which provided by a water through pump with power of 0.25 hp. Where, a circulation water enters the tube and then leaves the slit. The exist water collected at the lower end of the panel. The advantages of the finned tube are gaining the heat from the panel (as heat exchanger) and getting the constant water temperature (low) by dissipating it to the environment. Then, the water enters again to the system to repeat the process with 1 lit/min as a flow rate as shown in Figure 2.
8.7 Ω of optimized ohmic load has used to get the maximum power output, and multimeter (omega) has used to measure the current (1 mA of accuracy) and voltage (1 mV of accuracy). The position of panels was in the south direction with inclination angle of 45°. Solar meter type Kimo SL100 also employed to measure the irradiance, and inclined exactly with PV system. Patch thermocouples type k have used to measure the PV temperature at the front and back surfaces of PV, but the difference between temperature readings in the front and back surfaces for the same panel were 1.5 OC for the front surface. Another thermocouples type k used to measure the water temperature before running and after existing. In 2019, the measurement period was done during 14 days on September based on Baghdad environment (latitude 33.34° and longitude 44.1°), and recorded each 10 mins.

The energy analysis on the photovoltaic cell

In order to calculate the net energy that absorbed by the cell, Equation 1 has employed as:

\[ E_c = p \alpha_c \tau_g G(t) \]  

Where, \( \alpha_c \) is the cell absorptive to sunlight (\( \alpha_c = 0.926 \times 0.8 + 0.073 \times 0.2 = 0.7554 \)), \( G(t) \) refers to the solar irradiation incident on the glass cover, \( p \) is the packing factor of cell which is a ratio of solar cell area to the blank absorber area, \( \tau_g \) was equal to 0.95 and refers the fraction transmitted through the front and low iron glasses. The length of absorption being less than typical cell thickness (260μm at wavelength less than1.1μm. Then, the process of absorption will be accomplished before reaching the radiation to the rear surface.
\[ E_T = (1 - p)\alpha_T \tau G(t) \]  

(2)

Where \( \alpha_T \) is referring to the Tedlar absorptive, and \( E_T \) is referring to the solar energy rate which absorbed by Tedlar (Backsheet) after transferring from EVA.

All collector components undergoes to the laws of Energy conservation as follows:

\[
(1 - \eta_e \alpha_e) p \alpha_e \tau G(t) + \tau_g \alpha_T G(t)(1 - p) = E_{loss} + q_c
\]

(3)

\( E_{loss} \) is referring to the losses in energy to the environment from the front glass through the free and forced radiation and convection.

\[
E_{loss} = h_g [T_g - T_a(t)] + \varepsilon_g \sigma T_g^4 - \alpha_g \sigma [T_a(t) - 6]^4
\]

(4)

Where, \( T_g \) is the temperature of glass, \( T_a \) is the temperature of ambient, \( \varepsilon_g \) is the glass emittance, \( \alpha_g \) is the glass absorptivity. \( T_a \) is supposed to be -6°C to represent the temperature of sky. According to the forced and free convection, the heat losses transfer from top glass cover to the surrounding after exposing the solar collector to the ambient. Wind was representing the forced convection, while the air near the collector surface represents the free convection which leads to produce the natural buoyancy after heating it. Thus, \( h_g \) is referring to the coefficient of convective heat transfer coefficient from glass to the environment. The empirical correlation by Stultz and Wen has been conducted as,

\[
h_g = 1.247 \left( [T_g - T_a(t)] \cos \theta \right)^{3/2} + 2.658V
\]

(5)

Where, \( h_g \) is referring to the surface convection coefficient, \( \theta \) is referring to the horizontal inclination of the module, and \( V \) is referring to the speed of wind. The water energy balance which flows in the pipe an be written as;

\[
\frac{m c_p}{dx} dT_{fluid} dx = q_c
\]

Where, in cooling pipes, \( q_c \) is the transferred heat to the fluid flow.

**Electrical efficiency Evaluation for the photovoltaic cell**

Equation below used to calculate the electrical efficiency of cell (\( \eta_e \)), and the parameters is functioned of the cell temperature.

\[
\eta_e = \eta_o \left[ 1 - \beta (T_c - T_o) \right]
\]

(6)

Equation 7 used to calculate the nominal electrical efficiency (\( \eta_o \)) under standard condition

\[
\eta_o = \frac{V_{mp} I_{mp}}{GA}
\]

where \( A \) is the PV module area, \( G \) is the irradiation based on the standard condition.
which equal to 1000W/m$^2$, $V_{mp}$ and $I_{mp}$ are the voltage and current of PV at maximum power point respectively. $T_o$ is the standard condition temperature which equal to 25°C, $T_c$ is the temperature of cell, and $\beta$ is the silicon cell temperature coefficient which equal to 0.0045°C$^{-1}$.

Article I.

Efficiency of Electrical Power

Definition of the power efficiency is a ratio of the output to the input powers. Where, $\eta = 100\% \times \frac{P_{out}}{P_{in}}$

$P_{in}$ is referring to the consumption of input power in watts (W), while $P_{out}$ is referring to the actual output power in watts (W).

Results and Discussions

all results that will be analyzed and discussed in this work was collected form 25th on May 2021 in Baghdad / Iraq environment in spite of the experimental works were tested during April to the end of May after measuring the highest irradiance. The first result was the irradiance variation during 9 hours which received by the panels surfaces as shown in in Figure. 3.

Based on Figure 4, the results appeared that the relationship between solar irradiance and cell temperature was proportional. Moreover, when the solar irradiance increases 100 W/m$^2$, temperatures of PV and PV/T panels increase about 5.4 °C and 1.2 °C respectively. Also, it observed that the highest temperatures of PV and PV/T were 65 °C and 32 °C at time 13:00 respectively which was the same time for highest irradiance value. It can be seen the PV/T performance compared with PV panel. Although the PV cell temperature increased with solar irradiance increasing, but the PV/T cell temperature variation remained between of 20-30 °C.

Figure. 3. irradiance Variation during 9 hrs.
For PV/T, the temperature difference variation was between the inlet and outlet water temperature ($T_{fi} - T_{fo}$). Two values of mass flow rate have been tested for PV/T in order to study the system performance which are 0.05 kg/s and 0.08 kg/s as shown in Figure 5. The difference temperatures increased with increasing of solar irradiance for both mass flow rates, and the range difference temperatures between 0.05 kg/s and 0.08 kg/s as mass flow rates were 0.62 °C and 0.45 °C respectively, therefore, the when the mass flow rate increased, the temperature difference decreased and solar irradiance increased. Table 1 shows the formula at different mass flow rates.

| Mass flow rate | Formula         |
|---------------|-----------------|
| 0.05          | $t = 0.67 - 5.32 \Delta T / I_\eta$ |
| 0.08          | $t = 0.86 - 6.22 \Delta T / I_\eta$ |

the results also included the relationship between electrical efficiency and temperatures for both PV and PV/T as shown in Figure 6. The results appeared that the PV/T electrical performance was better than PV about yields 19.22% at 1000 W/m² solar radiation, where the temperature ranged for PV/T between 30 °C and 45 °C, and 50°C and 66 °C for PV module. PV/T electrical efficiency was 14.6% while 12.5% for PV module.
Figure 6. PV and PV/T electrical efficiency at 1000 W/m² solar radiation

Figure 7. PV and PV/T Electricity rate that generated during 9 hrs.

PV/T generated 1135 W.h as an electricity rate during 9 hrs., and 1030 Wh was for PV in the same conditions. On the other hand, Total electricity efficiencies that generated for PV/T was 14.2%, while 13.5% recorded for PV module as shown in Figure 7. The total solar radiation has been recorded and reached up to 8390 Wh/m² day. The total energy that produced per day for PV/T module were 12% compared with PV module. Theoretical calculation was compatible with the experimental results and noticed a similar behavior especially for the solar radiation amount. But there is some difference due to the losses in connections, losses in cable and losses in measurement devices.

Conclusion
This work investigated the effect of the ACS for PV module compared with PV module without cooling system. Thin film was inserted on the top surface of PV and fed by water. The temperature recorded
for PV module and electrical efficiency to be 63 °C and 9% respectively. While, the biggest electrical efficiency after using ACS was 14.6% experimentally. Therefore, ACS played a big role to increase the electrical efficiency compared to the uncooled system. The better flow rate that led to generate a better electrical efficiency was 0.05 kg/s. Also, the biggest PV/T thermal performance was 52% on 25th May 2021. PV/T generated of 1135W.h as a electricity rates during 9 hrs., and 1030 Wh was for PV in the same conditions. On the other hand, Total electricity efficiencies that generated for PV/T was 14.2%, while 13.5% recorded for PV module. The total solar radiation has been recorded and reached up to 8390Wh/m²/day. The total energy that produced per day for PV/T module were 12% compared with PV module. It can conclude that the high temperature working on reduce the PV life and leads to the material damage. Moreover, the temperature was a biggest influence of electrical production compared with the other environment factors. Since the PV/T systems also deliver heat, the environmental impact per unit energy delivered should be less than for regular PV systems.

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