Experimental Investigation of Enhancing the Energy Conversion Efficiency of Solar PV Cell by Water Cooling Mechanism

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Abstract: Solar photovoltaic cells produce electricity by receiving solar radiation. The output power of photovoltaic cells (PV) is mainly influenced by the significant increase in cell temperature during the absorption of radiation. The solar cooling system has been considered and investigated experimentally in this research paper. A passive cooling system was designed and fabricated for efficiently cool the PV module, with inlet/outlet manifold considered for uniform flow of water at the rear side of the PV module. The experimentation was performed with and without the cooling system. In this paper, a linear trend has been established between the electrical efficiency and the temperature of the photovoltaic cells. Without a cooling system, the average cell temperature reaches to 60°C, and the solar panel efficiency reduced to 8 to 16%. However, when the panel was operated under the passive water system, the temperature of the PV cell was reduced to 47°C, resulting in a 10% -21% improve in the solar PV cell efficiency. Both systems, without cooling and with cooling systems are validated experimentally.

1. Introduction
While the world faces the problem of energy scarcity, global warming and the deterioration of energy and the environment, there is a need for alternative energy for the production of energy other than fossil energy, water, and wind. The fossil fuel will run out over the next few decades, hydroelectric plants depend on annual rainfall and wind energy also depends on climate change. Solar energy is one of the alternative sources of energy. Solar energy is a very inexhaustible source of energy. The power of the sun intercepted by the earth is about 1.8 × 1011 MW, which is higher than the current consumption rate on Earth of all commercial energy sources. Therefore, solar energy could regularly supply all the current and future energy needs of the world. This makes it one of the least promising sources of energy [1-4]. A solar cell is a device that directly converts the energy of sunlight into electricity through the photovoltaic process. In 2009, a thin-film cell was installed between two layers of glass. A typical photovoltaic module has an ideal conversion efficiency of the order of 15%. The remaining energy is converted into heat and this heat increases the operating temperature of the photovoltaic system which affects the electricity production of photovoltaic modules, which can also lead to a structural deterioration of the PV modules and reduce their lifetime. The output power of the photovoltaic module decreases due to the increase in temperature if the heat is not removed [5]. The solar cell temperature usually reaches 80 °C or more when the solar cell is a silicon series solar cell. The various publications reveal that cell temperature has a significant effect on its efficiency. The temperature increase of 1K corresponds to the reduction of the electronic conversion efficiency of 0.2% -0.5%. Photovoltaic module to prevent the lowering of electrical efficiency [1-4]. Performance
of a solar-photovoltaic (PV) plant maximum power, tolerance, maximum voltage, maximum current, open circuit current, maximum system voltage, but it is also negatively influenced by various obstacles such as ambient temperature, relative humidity, dust storms and air suspension, shading, global solar radiation, spectrum, and irradiation angle. Dubey et al. [5] reported the effectiveness of the different configurations of the PV / T air collector: it was indicated as the case of maximum efficiency among the four cases considered by the author. The average annual efficiency varies between 10.41% and 9.75% for the cases considered. In order to improve the heat transfer of the photovoltaic module, we will be able to reduce the efficiency of the photovoltaic module: Prasad and Saini [6] artificially increase the roughness of the absorber plate and the channel wall. However, the greater roughness of the wall and absorber occurred with a pressure drop penalty and, therefore, required more pumping power. Han and Park [7] and Gupta et al. [8] shows that different types of ribs in the air can provide better heat extraction performance, but are also accompanied by a significant increase in friction losses. Garg and Datta [5] have suggested several practical changes to improve heat transfer in the air duct. Garg et al. [6] presented in a study on a hybrid PV / T air system, in which the system included a flat plate collector mounted with an expandable photovoltaic module. A study to optimize the geometry of the absorber for solar air collectors has been studied by Pottler [11]. Naphon [12] conducted a study on the performance and generation of the entropy of the double-pass solar air heater with longitudinal fins. This study shows that the thermal efficiency of the photovoltaic module increases as the flow increases.

2. Effect of Temperature on PV Cell

Suhas et al. [1] presented a journal on dynamic and stability analysis of delaminated rectangular composite panels. This investigation deals with the study of static, vibration and the dynamic stability of delaminated composite plates by using finite element method. The influence of various geometrical parameters like delamination size, aspect ratio, number of layers etc. have been analyzed numerically. One of the main disadvantages of the photovoltaic module (PV) was the surfaces overheating due to the excessive solar intensity and high environmental temperatures. Overheating decrease the efficiency of the panels dramatically [16]. The ideal P–V characteristics of a solar panel for a temperature variation between 0°C and 75°C are shown in Fig. 1, which is adapted by Rodrigues et al. [17]. The P–V characteristic is the relation between the electrical power output, P, of the solar PV module and the output voltage, V, while the solar radiation, E, and cell temperature, Tm, are kept constant. If any of those two factors, namely Tm and E, are varied then all characteristics have also change. The maximum power output from the solar cells decreases as the solar panel temperature rise, as can be seen in Fig.1

![Figure: 1. P-V Characteristics for the Temperature Variation Between 0 and 75°C (2)](image-url)
3. Experimentation and Methodology
The experiment was investigated according to the meteorological conditions of Belgaum (latitude of 15.8497° N; longitude of 74.4977°E) in India from 09.00 a.m. in the morning to 5.00 p.m. in the evening. Water is used as a coolant in the investigation, voltage (Voc), current (Isc), solar radiation (G) and power output of solar PV system were measured every one hour for both normal solar PV and water cooled solar PV systems. The passive water-cooled solar PV system was fabricated using 110W monocrystalline silicon and amorphous (Thin) silicon solar panel. The area of the panel was 0.8905 m². The maximum output voltage and current are respectively 17V, 6.5A and with a maximum power output of 110W. One of the panels is used to set up water cooling system. The cooling water was supplied uniformly on the back surface of PV panel for homogeneous cooling of the panel as shown in Fig.2.

Figure: 2. Experimental Setup

4. Results and Discussion
In order to find out the energy conversion efficiency of the solar panel, the following parameters were measured, such as the output power in terms of voltmeter and ammeter reading, the panel surface temperature and real-time solar radiation intensity (W/m²). In addition that ambiance temperature, the inlet and outlet temperature of water flow and water flow rate were measured and tabulated.

The photoelectric conversion efficiency is calculated as:

\[ n_e = \frac{V \times I}{A_s \times G} \times 100 \] ........................... (1)

Where, v- Voltage in volts
I-Current in Amps
A_s-surface area = 0.8905 m²
G- Solar intensity in w/m²

\[ Q_{\text{gained by cooling water}} = Q_{\text{dissipated from PV panels}} \]
\[ m_w \times c_w \times \Delta T_w = m_g \times c_g \times \Delta T_g \]

\[ t = \frac{m_g \times c_g \times \Delta T_g}{m_w \times \Delta T_w} \] ........................... (2)

Since the solar cells are manufactured from silicon which is almost glass and covered by glass, therefore, the glass physical properties are taken to be the physical properties of the PV panels. Where
$M_w$ is the mass flow rate of water, $m_g$ is the mass of glass, $c_w$ is the specific heat capacity of water, $c_g$ is the heat capacity of glass, $\Delta T_w$ is the water temperature rise, $\Delta T_g$ is the glass temperature change due to water cooling, and $t$ is the time taken to cool the solar PV panel to a moderate temperature.

4.1. Without Cooling System

The experimental results with respect to time are tabulated. Readings of temperature, voltage and current output from the solar panel without cooling are tabulated.

Table: 1 Experimental Reading of without cooling system

| Time (hrs) | Module Temp(°C) | Voltage (V) | Current (A) | Solar Intensity (W/m²) | Electrical Efficiency (%) |
|-----------|-----------------|-------------|-------------|-----------------------|--------------------------|
|           | Day1 | Day 2 | Day1 | Day 2 | Day1 | Day 2 | Day1 | Day 2 |
| 9         | 44.2 | 51    | 19.48 | 19.07 | 3.68 | 3.50 | 458 | 16.35594 |
| 10        | 50.1 | 52.2  | 19.36 | 19.05 | 5.30 | 4.61 | 768 | 12.83385 |
| 11        | 57.7 | 57.4  | 18.36 | 18.95 | 5.92 | 6.03 | 809 | 15.85259 |
| 12        | 61.5 | 58    | 18.77 | 18.91 | 6.44 | 5.64 | 1129| 10.60227 |
| 13        | 54.3 | 51.2  | 19.10 | 19.35 | 5.71 | 5.40 | 1249| 9.38933 |
| 14        | 50.3 | 47.1  | 19.35 | 19.54 | 5.21 | 4.43 | 1194| 8.13662 |
| 15        | 40.7 | 44.1  | 19.70 | 19.38 | 3.35 | 2.67 | 1059| 5.483923 |
| 16        | 39.9 | 40    | 19.4  | 19.35 | 2.27 | 2.13 | 809 | 5.717871 |
| 17        | 39.3 | 37.5  | 19.2  | 19.02 | 1.61 | 1.12 | 556 | 4.300075 |
| 18        | 37.4 | 33.2  | 18.01 | 18.44 | 0.92 | 0.54 | 538 | 2.077278 |

4.2. With Passive Cooling System

The experimental results it was found that the output of the photovoltaic module is a function of temperature. The power output from the panel decreases with the increase in panel surface temperature and hence to optimize the power generation, the photovoltaic module is provided with the passive cooling system. The working fluid used is water, as its heat absorption capability is high. Readings of temperature, voltage and current output from a solar panel with cooling are recorded.

Table: 2. Experimental Reading of Passive Cooling System

| Time Hrs. | Voltage (°C) | Current (I) | Surface temp.(°C) | Water inlet temp. (°C) | Water outlet temp. (°C) | Solar intensity (W/m²) | Electrical efficiency (%) |
|-----------|-------------|-------------|------------------|------------------------|------------------------|------------------------|--------------------------|
| 9         | 20.7        | 4.33        | 36.2             | 29                     | 29.9                   | 459                    | 21.91633 |
| 10        | 20.4        | 5.2         | 39.8             | 29                     | 31                     | 761                    | 15.64484 |
| 11        | 20.1        | 6.55        | 47.5             | 29                     | 40.4                   | 812                    | 18.19716 |
| 12        | 19.6        | 6.77        | 50               | 29                     | 53.2                   | 1142                   | 13.0407 |
| 13        | 19.8        | 6.53        | 45.7             | 29                     | 40.1                   | 1265                   | 11.47123 |
| 14        | 20.1        | 5.17        | 39.6             | 29                     | 38.7                   | 1196                   | 9.751641 |
| 15        | 19.7        | 4.64        | 38.5             | 29                     | 36.3                   | 1072                   | 9.569995 |
| 16        | 19.9        | 3.4         | 37.3             | 29                     | 34.5                   | 801                    | 9.480293 |
| 17        | 19.2        | 1.73        | 34.6             | 29                     | 31.8                   | 548                    | 6.802821 |

Figure 3 represents the comparison between peak output voltage module by providing a cooling system and without providing a cooling system. From the plot, it is clear that the output voltage is greater for a system with cooling system compared to that of the system without a cooling system, as the working fluid continuously extract heat from the panel surface thereby maintains the lower value of temperature compared to that of the system without the cooling system.
Figure 3. Shows Voltage v/s Time

Figure 4 represents the comparison between peak current output of the module with the cooling system and without a cooling system. It is found from the graph that the current output is also higher for a system with cooling system compared to a system without a cooling system. The maximum current was found to be 13 amps and 6.5 amps for a system with and without a cooling system.

Figure 4. Shows Current v/s Time

Figure 5 shows a variation of module surface temperature with and without a cooling system. It is clearly observed that the temperature of the module is less compared to that of the module without a cooling system at all time intervals. The peak temperature of the surface of the module with cooling system was found to be 50°C compared to that of 63.2 °C for a system without the active cooling system.
Module efficiency determines the effectiveness of the system. With the water cooling arrangement, the efficiency is calculated to be 21% whereas the efficiency without cooling is 16%. A difference of 5% is observed which makes the system more effective.

5. Conclusion

The objective of this research is to cool the PV panel using the smallest amount coolant and power. A passive cooling system has been designed and fabricated based on the flow rate of water. A cooling rate model has been developed to determine how long it will take to cool the PV panels by water to its operating temperature. Photovoltaic module with water cooling system generates both electrical energy and thermal energy. This Study shows that the influence of cooling system on the performance of PV panels. It can be concluded from the results of this study that:

1. The experimental results show the improvement in conversion efficiency of PV module by using a cooling system.
2. The maximum temperature attained by the PV module without a cooling system is 63.2°C by cooling system the peak temperature brought down to 50°C.
3. The temperature of water at the outlet is 53.2°C, hence it can be used to fulfill domestic hot water requirement.
4. The system can be used to generate power as well as to produce hot water. (Thermal energy).
5. The experimental results are a clear indication of variation of efficiency with panel surface temperature.
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