

ENERGY & EXERGY ANALYSIS OF A PV PANEL WITH PASSIVE COOLING MECHANISM

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Abstract

A photovoltaic (PV) array is greatly responsive to changes in temperature; contrarily, reduction in temperature is the major factor that subsidize to an raise in the electrical efficiency and output power of a PV system. To optimize the production of energy by PV panels and reduce their temperature, a photovoltaic (PV) cooling system is basically used. Nonetheless, more insolation is generally associated with higher temperatures, which is ambiguous for photovoltaic (PV) panels because they rely on that irradiance to create power. These extreme temperature rises have a devastating effect on how skillfully photovoltaic (PV) panels transforms energy. A solar photovoltaic (PV) system can opearate more accurately with an adequate cooling system on its surface. In this paper, a passive cooling model for the PV panel has been developed which cools down the PV panel by employing dry grass and water at the back surface. A correlation has been made with a non-cooled panel. Two PV panels are simultaneously tested. Electrical output properties of both the PV panels have been recorded and energy and exergy analysis for the system has been presented to have a more detailed understanding of the cooling effect on PV panel performance. The cooled panel has an increase in efficiency by 47%. Along with the electrical efficiency, the thermal efficiency has also been presented in this paper for performance evaluation in the form of overall efficiency.

Keywords: PV Panel, Energy, Exergy, Efficiency, Operating Temperature

Introduction

Electricity and heat may be generated from the sun, making as the most versatile nonconventional power sources. The conversion efficiency of solar panels, and thus their output power, is very sensitive to the operating temperature of the panels. Rahman et al. (Ashish Raj *et al.*, 2016), who studied the effects of several conditions on the power and efficiency

produced by photovoltaic panels, found that the efficiency with which sunlight was converted into electricity decreased by 0.06% for every 1 degree Celsius the panel was exposed to. (Sampurna Panda *et al.*, 2022) conducted a literature review and found that the output power of a solar module increases in a linear fashion with an increase in operating

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temperature. Crystalline silicon solar cells lose 0.66 percent of their power output for every degree above freezing, according to studies by (Mingke *et al.*, 2020; Panda *et al.*, 2022) looked into a number of cooling methods, including water back cooling, water front cooling, and air cooling, and found that water back cooling offered the most benefit. (Praveen Kumar *et al.*, 2021) investigated the effects of mounting an air-cooled heatsink to the back of a solar panel and found that the panel's output power increased by 6.97 to 7.55%. Sprinkling of water over the back and front of a PV panel reduced its temperature from 52°C to an average of 24°C, and boosted the output energy of module by 5.9%, according to research by (Hadipour, 2021). For their part, (Deepak *et al.*, 2022) created and examined the impact of water cooling the panel's front side, and their experiments showed an increase of roughly 15% in system output was attained. Using an air blower and ducts on the back of a solar panel, (Panda *et al.*, 2020) created an active cooling system, and experimental findings showed a 12-14% improve in the efficiency of the solar module. In order to reduce the module's temperature and boost its output power, (Elbreki *et al.*, 2021) developed an active back water cooling system. By placing a micro channels heatsink with varying water flow rates on the rear of the solar panel, (Gupta *et al.*, 2020) were able to increase the panel's output power by 14%. Kordzadeh (panda *et al.*, 2022) established a thin water layer circulation on the back, and the findings showed a considerable increase in output power and surface temperature. Evaporative cooling was studied by (Ghadikolaei *et al.* 2021), who found that by soaking the back half of the module with water supplied from a vessel under the influence of gravity, solar panels' efficiency may be increased by 14%.

This paper investigates a back surface PV cooling technique along with its energy and exergy analysis. A productivity comparison of the cooling panel has been established with the non-cooled panel.

Methodology

An experimental set up has been established on a shade free roof top. Two cases have prepared and tested; one with no cooling is considered as reference (non-cooled PV panel). Second case is with dry grass and water as cooling system (cooled PV panel). Dry grass has the ability to retain a significant amount of water. When air flows through these mats, it becomes cooled down and subsequently reaches the panel, providing

a refreshing sensation and reducing the temperature of the panel. They are cheap and economical. Both cases have been tested on a shade free rooftop at Gwalior, Madhya Pradesh. In the cooling type panel, dry grass has been spread on the frame which holds the PV panel. Water from pipes installed into the grass keeps this grass moist. It has determined that gravity could be used to start a water circulation. The water supply has kept in a tank. Pipes carry cold water from a storage container to the base of a photovoltaic (PV) module, where the pressure differential causes the water to rise uniformly. The cooling system is now free to deal with the elevated surface temperature at the back. Utilizing the thermo siphon phenomenon, heat is transmitted from the back surface of the hot PV module to the water and grass that have entered the water cooling jacket from the tank. Figure 1 represents the schematic diagram of back cooled PV panel.

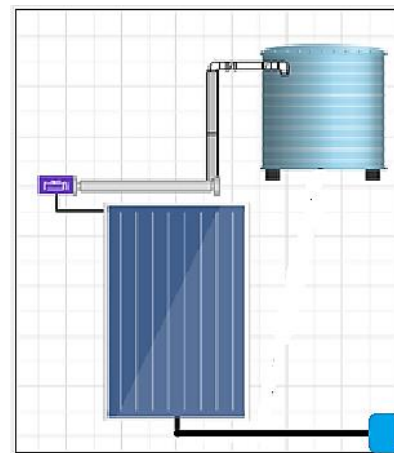


Figure 1. Schematic diagram of the back cooled panel

In the experimental configuration, water does not flow back into the tank since it necessitates an external energy source to pump the water back. Further more, the outflow water can also increase the temperature of the water in the tank. The water that has been discharged is being gathered in a smaller reservoir and afterwards utilized for domestic needs, such as cleaning automobiles and irrigating plants.

Figures 2 to 4 depict the back view of back cooled panel, the front view of cooling structure and the experimental set up used for the analysis respectively.



Figure 2. Back view of the cooled panel



Figure 3. Front view of the cooling structure



Figure 4. Experimental set up

Figure 5 displays the measuring instruments used the experimental analysis of the PV Panel.



Figure 5. Measuring instruments used

After collecting the data, the calculated parameters have been calculated by using the following equations,

The PVT collectors output is measured in combined efficiency measures. Thermal efficiency and electrical efficiency are the cornerstones. Besides serving as a measure of overall efficiency, total efficiency is defined as the addition of thermal output and electric output (Panda *et al.*, 2022).

$$\text{Photo Electric efficiency, } \eta_e = \frac{I_m V_m}{G A} \quad (1)$$

$$\text{Thermal Efficiency, } \eta_{th} = \frac{m c_p (T_f - T_i)}{G A} \quad (2)$$

The mass flow rate (m), the specific water heat (c_p ; 4200 J/kg), the global solar radiation at the collector's surface (G), the initial water temperature (T_i), and the final water temperature (T_f) in the storage tank are all inputs in the following equation (Sarafraz *et al.*, 2019).

$$\text{Overall efficiency, } \eta_0 = \eta_{th} + \eta_e \quad (3)$$

The thermal efficiency is denoted by η_{th} and the electrical efficiency by η_e . The energy-saving effectiveness of electricity is often regarded as a premium kind of energy gain, and is hence called:

$$\text{Energy saving efficiency, } \eta_f = \eta_e / \eta_{power} + \eta_{th} \quad (4)$$

Where η_{power} is the power conversion efficiency.

Results and Discussions

The experimental set up has been studied from 7 am to 5:30 pm to analyze energy and exergy of the cooled PV panel and also a comparison has been established between the cooled and non-cooled panel.

The PV panels have been exposed to solar irradiation of 1047 w/m^2 and the variation in irradiation can be understood from Figure 6.

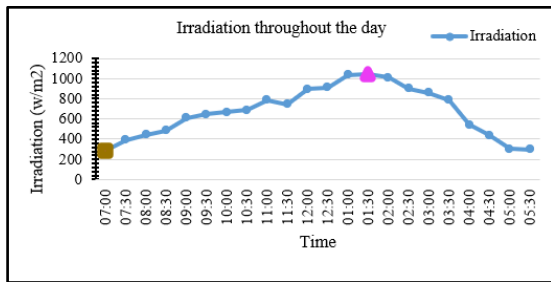


Figure 6. Irradiation throughout the day

Mass flow rate

During the hours of 1:00 and 2:00 on a sunny day, the output power of a PV panel was measured while water was permitted to flow over its back surface at four distinct mass flow rates. The flow rate for future studies has been determined with thermal efficiency and electrical efficiency in mind. In order to achieve optimal overall efficiency, a mass flow rate of 3 LPM is required.

Figure 7 depicts the overall efficiency values for all the different water flow rates. It helps in deciding the water flow rate and also to evaluate the impact of water flow or cooling on efficiency of the module. The lowest efficiency has been recorded for the mass flow rate of 2.5LPM and the highest is for 3LPM.

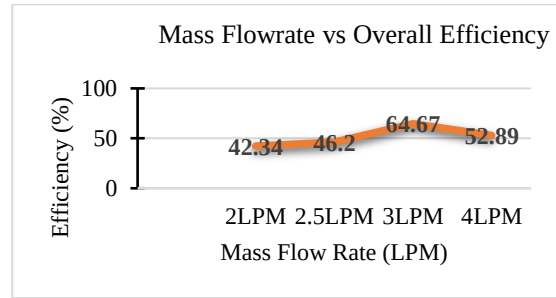


Figure 7. Overall Efficiency for different water flow rates

Temperature and Output electrical Parameters

Figure 8 represents the difference between back surface temperatures for the cooled and non-cooled PV modules. The minimum temperature difference recorded is 2°C and the maximum is 12°C . These difference in temperature between cooled and non-cooled panel is the reason behind the higher efficiency of the cooled PV module (Panda *et al.*, 2020).

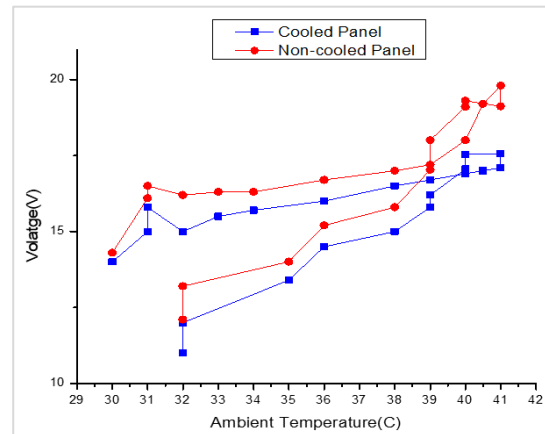


Figure 8. Back temperatures for cooled & non-cooled panel

Due to decreased operating temperature of the cooled PV panel, this panel has performed better in providing output electrical parameters which is displayed in Figure 9.

For the cooled system, the voltage ranges between 13.5V to 11.2V throughout the day attaining a peak of 20.2V. Whereas the non-cooled panel reached to 17.6V. Figure 10 shows the heat absorbing ability of the cooling system.

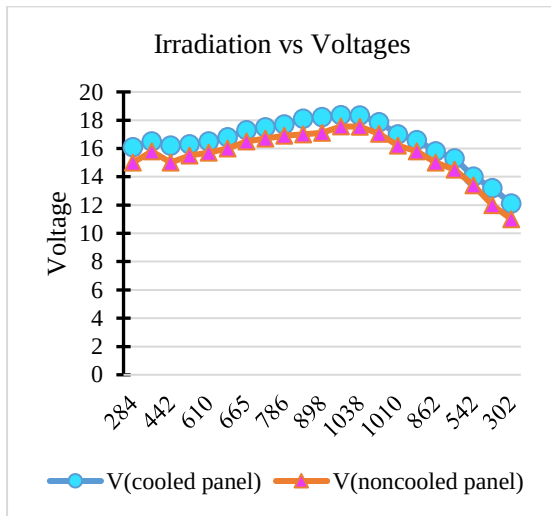


Figure 9. Voltages for cooled& non-cooled panel w.r.t irradiation

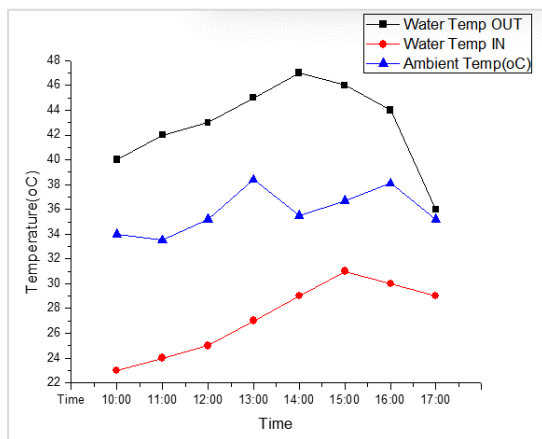


Figure 10. Input and output temperature of the cooled panel

Exergy and Energy Quality Variation for Different Mass Flow Rates

A system's exergy is its potential to convert low-quality energy into useful forms of energy. In other words, Exergy is defined as the volume of work (entropy free energy) a system can perform when it is brought into thermodynamic equilibrium with its condition. Solar PV exergy efficiency can be estimated by dividing exergy output by total exergy input. The cooled panel's exergy efficiency varies between 2% and 13% based on the mass flow rate as shown in Figure 11. Maximum exergy efficiency for a mass flow rate of 2.5LPM has been calculated to be 13.10%. The amount of energy that can be saved while maintaining the maximum

possible efficiency is presented in the Figure 11. Maximum energy saving efficiency for the average mass flow rate of 2.5 LPM is 66.58%. While minimum energy efficiency is 52.68% as displayed in Figure 12. The difference between the energy efficiency of the lowest and greatest water flow rates, 2LPM and 4LPM, is 2.78%.

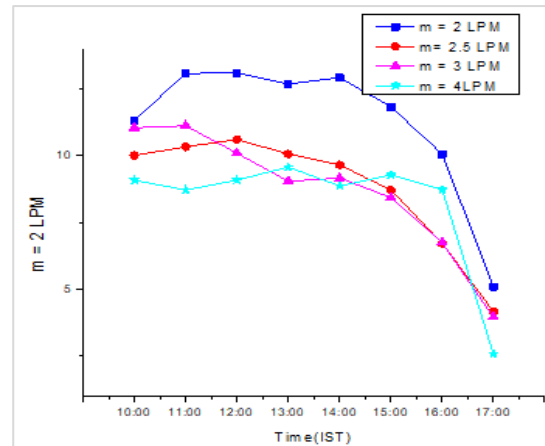


Figure 11. Exergyefficiency Variation for different PV/T Mass Flow Rate

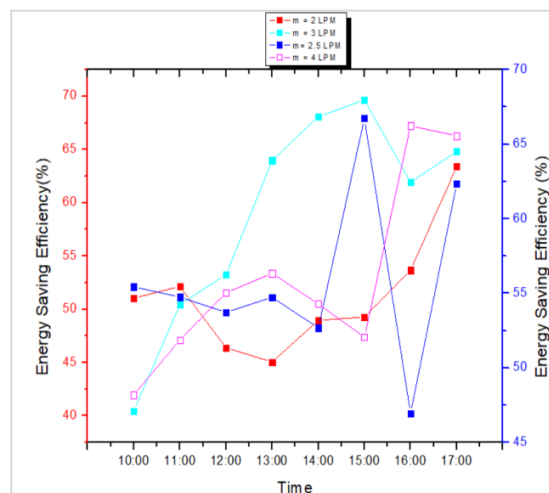


Figure 10. Energy-Saving efficiency for different PV/T Mass Flow Rates

The energy efficiency value varies from 51.05% to 63.39% for mass flow rate of 2 LPM. However for the double the value of mass flow rate, the energyefficiency value varies from 48.18% to 65.55%.

Back-contact (IBC) cells are currently the most efficient panels, reaching up to 23.8% efficiency. This is attributed to the high purity N-type silicon substrate and the absence of losses caused by busbar shadowing. Nevertheless, solar panels created employing the most recent N-Type TOPcon and advanced heterojunction (HJT) cells have successfully attained efficiency levels over 22%. Tandem Perovskite cells with ultra-high efficiency are currently being researched and are anticipated to achieve commercial viability within the next two years. The proposed cooled PV panel has shown an efficiency of 19.28%.

Conclusion

As the proposed PV panel has a cooling mechanism attached, its operating temperature remained lower when compared to other non-cooled panels. When the operating temperature of the PV panel goes beyond the MAT, the efficiency of the panel starts decreasing.

The temperature of the PV modules has a prominent impact on the performance of the system. With a cooled Photovoltaic system, solar panels no longer lose energy to heat. This paper represents a hybrid solar PV/T collector methodology to improve output power in a small footprint. As shown in experiments, the electrical efficiency of the PV panel has been much increased, thanks to the use of cooling techniques. The results proved that the PV/T system delivers more energy and temperature than PV alone.

The following findings are derived from the experiments:

- 1) Experiments have been carried out outside in the environmental condition at mass flow rates that range from 2 LPM to 4 LPM and at a number of different initial water temperatures. The mass flow rate of 2.5 LPM has been found efficient for an ideal cooling panel.
- 2) At a mass flow rate of 2.5 LPM, the average PV/T output ranges between 47% and 77%. When measuring the total mass flow rate of 2 LPM, the greatest attainable average PV/T output is 67.16 %.

References

- Ashish Raj, Gupta Manoj and Panda Sampurna (2016). Design simulation and performance assessment of yield and loss forecasting for 100 KWp grid connected solar PV system, 528-533.
- Sampurna Panda, Manoj Gupta, Babita Panda, Chitralekha Jena, Lipika Nanda, Arjyadhara Pradhan and C.S. Malvi (2022). A review on advanced cooling techniques for photovoltaic panel. *Materials Today: Proceedings*, 62(12):6,799-6,803. <https://doi.org/10.1016/j.matpr.2022.04.925>.
- Mingke Hu, Bin Zhao, XianzeAo, Xiao Ren, Jingyu Cao, Qiliang Wang, Yuehong Su, and Gang Pei (2020). Performance assessment of a trifunctional system integrating solar PV, solar thermal, and radiative sky cooling. *Applied Energy*, 260(2020):114167.
- Praveen Kumar, Seepana, Ephraim Bonah Agyekum, Vladimir IvanovichVelkin, Salam J. Yaqoob and Tomiwa Sunday Adebayo (2021). Thermal management of solar photovoltaic module to enhance output performance: An experimental passive cooling approach using discontinuous aluminum heat sink. *Int. J. Renew. Energy Res.*, 11(2021):1,700-1,712.
- Hadipour, Amirhosein, Mehran Rajabi Zargarabadi, and SamanRashidi (2021). An efficient pulsed-spray water cooling system for photovoltaic panels: Experimental study and cost analysis. *Renewable Energy*, 164(2021):867-875.
- Deepak, Sampurna Panda, and CS Malvi. (2022). Developments in Solar PV Cells, PV Panels, and PVT Systems. in *Solar Thermal Systems: Its Analysis and applications*, 2022:258-286.
- Gupta Manoj, Sampurna Panda and CS Malvi. (2020). Experimentally Diagnosing the Effect of Colour and Shade on PV Panel in Gwalior Region. *Test Engineering and Management*, 426-429.
- Elbreki, A.M., A.F. Muftah, K. Sopian, H. Jarimi, A. Fazlizan, and A. Ibrahim (2021) Experimental and economic analysis of passive cooling PV module using fins and planar reflector. *Case Studies in Thermal Engineering*, 23(2021):100801.
- Ghadikolaei, Saeed SiahChehreh (2021). Solar photovoltaic cells performance improvement by cooling technology: An overall review. *International Journal of Hydrogen Energy*, 46(18):10,939-10,972.
- Panda S., R.K. Dhaka, B. Panda, A. Pradhan, C. Jena and L. Nanda (2022). A review on application of Machine Learning in Solar Energy & Photovoltaic Generation Prediction, 2022 International Conference on Electronics and Renewable Systems (ICEARS), 1,180-1,184. Doi: <https://doi.org/10.1109/ICEARS53579.2022.9752404>.
- Sarafraz M.M., Safaei M.R., Leon A.S., Tlili I., Alkanhal T.A., Tian Z., Goodarzi M., Arjomandi M. (2019). Experimental Investigation on Thermal Performance of a PV/T-PCM (Photovoltaic/Thermal) System Cooling with a PCM and Nanofluid. *Energies*. 2019, 12(13):2,572. Doi: <https://doi.org/10.3390/en12132572>.