Experimental investigation of thermal & electrical performance of PV module using wick biomaterials

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Received: May 17, 2021; Accepted: October 22, 2021

A photovoltaic module (PV) absorbs a considerable amount of solar irradiance that is converted into electricity, and the major part of solar energy produces heat, and consequently, causes thermal degradation of the PV. Therefore, cooling of the PV module is an essential integral part of a system to decrease the effect of high temperature to obtain the PV panel's high electrical performance. Hence, passive cooling was investigated with cotton and jute wick biomaterial with different water streams in the present work. It was observed that the thermal performance of the PV system with jute and husk for two streams of water (0.02 Kg/s and 0.05 Kg/s) increases by 15-18%. The increase in short circuit current with jute wick material is higher than with husk wick material. Average output power rises by 8-10% with both biomaterials and correspondingly, the electrical efficiency also increases by 9.0-9.8%. We experimentally found that a water stream of 0.05 Kg/s controlled thermal performance and improved proficiency.

Keywords: Jute, husk, thermal, electrical, photovoltaic module.

INTRODUCTION

With an increase in population and living standard power requirement also increases, and the geographical place restricts the supply of conventional sources. The problem in the north India border region is that it is necessary to produce the energy locally. The PV system is the most suitable alternative system for water pumps in agriculture fields, street lighting, and residential area. Installation and operational module of the PV system are quite simple, but its electrical efficiency drops in the months May-June due to high temperature in the Northern region of India. Published literature reveals that the PV module's temperature can be minimized by a cooling system arrangement with the PV module. He *et al.* [1] designed an experimental study on PV modules under natural water circulation and observed that the PV module's energy-saving efficiency was much higher than that of the individual PV plate and the conventional solar collector. Chandrasekar *et al.* [2] investigated the PV module's thermal and electrical performance with a cooling system using cotton wick with water, Al_2O_3/water nanofluid, and CuO/water nanofluid. Teo *et al.* [3] designed, fabricated, and experimentally investigated a hybrid photovoltaic/ thermal (PV/T) solar system. The experimental results showed that the temperature dropped significantly and boosted solar cells' efficiency by 12 % - 14 %. Rahman *et al.* [4] observed the effects of various operational constraints (irradiation intensity, cooling fluid mass flow rate, humidity and dust) on PV module performance. They observed that the module temperature dropped to 22.4 °C, improved the output power by 8.04 W and increased the electrical efficiency by 1.23% using water cooling on the PV module. Hasanuzzaman *et al.* [5] reviewed the literature works rendered to attain enhanced efficiency through cooling systems. The passive cooling arrangement is found to accomplish a reduction in PV module temperature by 6–20 °C with a step up in electrical efficiency up to 15.5% maximum. Elnozahy *et al.* [6] investigated the performance of the PV module after cooling and surface cleaning and observed that cooled and surface-cleaned module has an efficiency of 11.7% against 9% for the module without cooling and cleaning. Rostami *et al*. [7] investigated the use of high-frequency ultrasound for improved cooling of a PV module. Results showed that cooling by atomized nanofluid was more efficient than cooling by atomized pure water. Idoko *et al.* [8] applied the water-cooling technique on the PV module's surface with an aluminum heat sink. The experiment recorded an increase in power by 20.96 watts, and an increase in efficiency by around 3%. Elminshawy *et al.* [9] experimentally investigated passing pre-cooled ambient air over the back panel surface and observed an upgrading in the PV module output power and electrical efficiency to around 18.90 % and 22.98 %, respectively. Winston *et al.* [10] studied the uplift in performance, efficiency, and developed an economical cooling system using air-conditioners. The results showed that the PV module, being cooled, showed 7.2 % higher electrical efficiency.

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Bashir *et al.* [11] analyzed a water-cooled photovoltaic/thermal system to enhance efficiency by absorbing the heat. They concluded that temperature drop, and electrical efficiency of c-Si, p-Si were higher by 13 % and 6.2 %, respectively. Li *et al.* [12] focussed on the conversion efficiency techniques of heat transfer in PV modules and proposed passive cooling methods, and integrated energy-saving efficiency gains the power generation and the shading performance. Abdollahi *et al.* [13] introduced a PV module with a hybrid cooling system and used nano-based composed oil to achieve higher efficiency. Rosa-Clot *et al.* [14] suggested a cooling system to improve the PV module's efficiency and observed that the impact of cooling on the lifetime of the PV gives positive results due to the reduction of the thermal shocks. Elbreki *et al.* [15] combined the planar reflector and back-plate extended surface with a module to optimize its efficiency. A parametric study concluded that the lapping fins have a superior performance in reducing PV module temperature. Younas *et al.* [16] used a simple cooling system and achieved a 1.61 % increase in the PV module's overall efficiency. The performance ratio increased as high as 12.85 %. Tiwari *et al.* [17] designed, fabricated, and investigated the cooling system experimentally and observed improved electrical performance.

Literature review reveals that a lot of research progress has been made in advance of a cooling system for the PV module. The research literature deals with the cooling of the PV module using different cooling systems, namely natural, hybrid, air conditioning, nanomaterial, and composite cooling systems. Hence, the present work's objective is to develop a simple passive cooling system with biomaterials that are available even in a remote area of India. The cooling of the PV system with husk and jute wick structures in the presence of a different stream of water is presented.

EXPERIMENTAL

Methodology and setup

The photographic view of the experimental PV module is shown in Fig. 1. This experimental setup was operated from 9:00 am to 4:30 pm in May 2019 on the roof of the Mechanical Engineering Department of Beant College of Engineering & Technology, Gurdaspur, located on 32.0613°N 75.4411°E position. The PV module's performance was observed on the first day for the PV module with jute wick structure and the subsequent days with husk wick structures on 30 min intervals against the reference PV module. The average of the ambient temperatures measured during these days was considered as the ambient temperature for comparing the results. The experimental setup consists of two solar panels of 100 watts each, a digital multimeter for measuring the open-circuit voltage (V_{OC}) and short-circuit current (I_{SC}) of the solar panel. A six-channel temperature indicator is placed in each solar panel at the appropriate location to measure the temperature accurately. Power meter is used to measure the intensity of solar irradiance falling on the solar panel in experimental observation. A tray made up of a galvanized iron sheet of dimensions 800 mm×450 mm×40 mm supports the different wicked materials behind one of the solar systems. A constant head device (CHD) was placed below the water tank to maintain the stream of water (0.02 and 0.05 Kg/s).

Fig. 1. Photograph of the experimental PV module

Reduction of data

The output power (P) of the PV module is a product of voltage (V) and current (I) data and electrical efficiency and fill factor are given by the following equations:

$$\eta_E = \frac{V * I_{sc} * f(f)}{I * A_c} \quad \text{(i)}$$

$$f(f) = \frac{P}{V * I_{sc}} \quad \text{(ii)}$$

Electrical efficiency (η_E) and fill factor (*f*) are functions of current (I), voltage (V), area of solar cell (A_C), and incident solar irradiance (I_{SC}). Thermal proficiency (η_T) of the PV module is dependent upon mass flow rate (m), specific heat (C_p), inlet and outlet temperature (T_i & T_o), global solar irradiance (G_{SC}), and area of the thermal accumulator.

$$\eta_T = \frac{m * c_p * (T_o - T_i)}{G_{sc} * A} \quad \text{(iii)}$$

The calculations indicated that the mathematical errors involved in the estimations of η_E and η_T are at a minimum level (±0.20%).

RESULTS AND DISCUSSION

Calibration of thermocouple

Accurate measurement of temperature throughout the experiment is an utmost requirement. With this objective, five thermocouples were placed on the backside of both PV modules. It was observed that the variation of temperature between thermometer and thermocouple at different points is less than 0.42 % during morning and afternoon time of measurement in the month of May. The five average temperatures of thermocouple and thermometer measured on the back surfaces of the PV module are plotted in Fig. 2. Thus, it was confirmed that the average temperatures of the thermometer and thermocouple are approximately the same, hence, the K type thermocouple tested in this experiment was used in the present work.

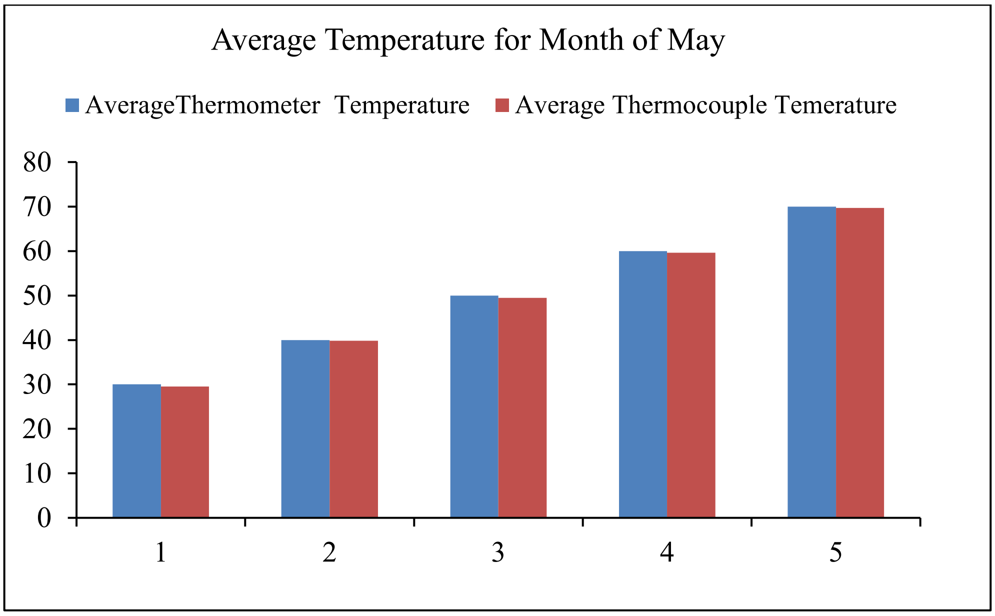

Fig. 2. Calibration of average temperature of thermocouple with reference to thermometer

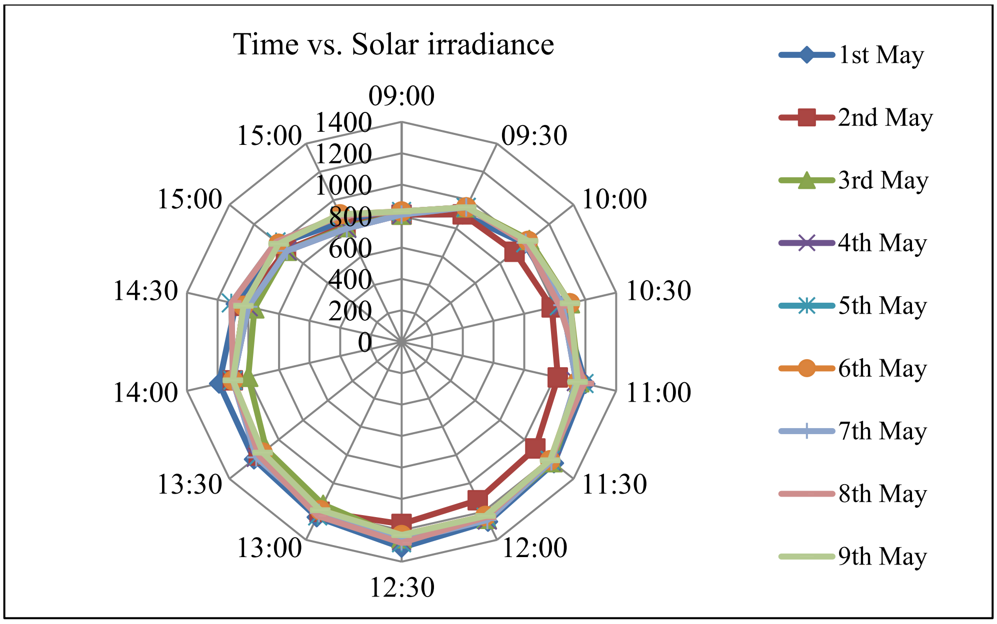

Fig. 3. Solar radiation measurement with respect to time using a solar power meter at equatorial location 32.0613°N 75.4411°E

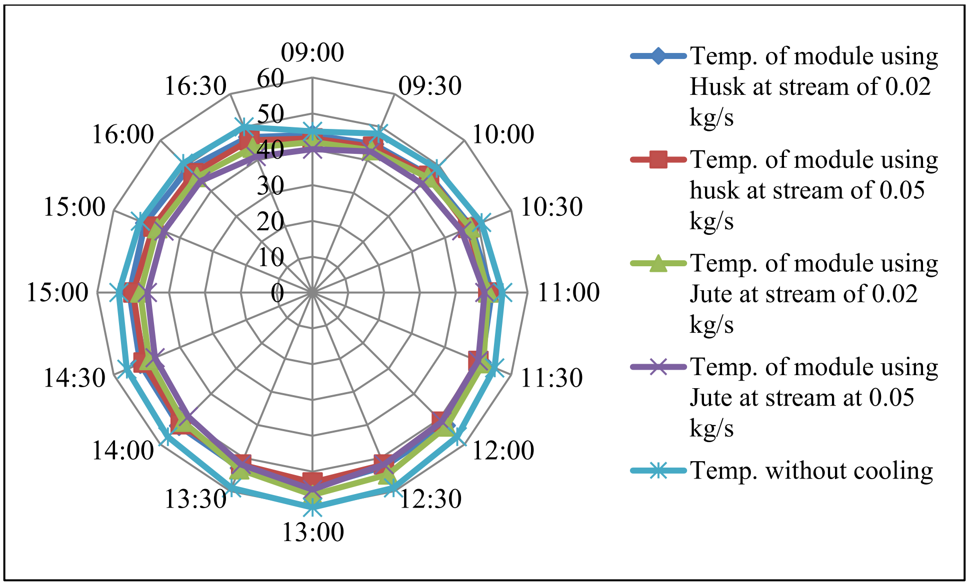

Fig. 4. Variation of temperature in PV module with time and under different operating conditions

The hourly solar radiation data measured using an ambient weather solar power meter/ pyranometer for nine consecutive days of experimentation from May 1st to 9th 2019, are presented in Fig. 3. It is observed that the rising and falling solar irradiation values during the day are due to a change in sun location with time. Fig. 3 reveals that the radiation intensity on the experimentation setup was parallel. It is observed that due to the location of the experimental setup, maximum solar power (1310, 1240 W/m^2) prevailed at around 12.30-1.30 pm, and minimum solar irradiance (810, 850 W/m^2) was detected at 9.00 am and 3.00 pm, respectively. May 1st - 9th solar intensity data were used for the present analysis for the PV module's electrical and thermal performance employing jute/water and husk/water biomaterial.

Thermal characteristics

Thermal performance assessment was executed through the hourly temperature data of the PV module under different operating conditions, as shown in Fig. 4. The hourly variation of temperature under the five operating conditions is continuous. The maximum temperature of the PV reference modules is around 59-60 °C from 12.30 to 1.30 pm. The temperature profiles of the PV module are approximately equal for different cases of experiments, i.e., different biomaterial, stream of water, and without cooling. The reliability of the PV module under different operating conditions was authenticated. It is observed that the temperature of the reference PV module is top during the day with a maximum of 60 °C, and the temperature of the module is reduced to 52.6 °C, 52 °C, 55 °C, 52 °C at the same time when cooling with husk and jute wick is provided in combination with two different water streams (0.02 and 0.05 Kg/s), respectively. Combination of jute and husk biomaterial with a water stream of 0.02 Kg/s reduces the temperature by 8.33 % and 12.33 %, respectively, toward the reference module. On the other hand, when the water stream increased from 0.02 to 0.05 Kg/s, jute and husk wick material corresponded to a reduction of about 13 % and 16 % in module temperature compared to the module temperature obtained without cooling. On comparing the cooling performance of the wick biomaterial, it is clear that the highest level of cooling performance is achieved in husk wick structures with both streams of water. A higher water stream favours the thermal cooling with both wick biomaterials. Overall, the moist condition of the biomaterial with water at the backside of the module was maintained with CHD to decline the module temperature. Fig. 4 shows that the radar curve representing the variation of module temperature throughout the day using biomaterial wick in combination with two water streams is a cyclic structure.

Electrical characteristics

Fig. 5 depicts the variation of output power (W) of the module with time under different working conditions. Experimental investigation shows that the cooling system offers the maximum output power. The maximum output power of 80, 80.5 W was obtained using husk and jute material without water at time 12.30 pm. Minimum output power without cooling with both biomaterials observed was 48 and 45 W for husk and jute, respectively, around 4.30 pm, at the same time of observation for the module of husk wick structures with a water stream of 0.02 and 0.05 Kg/s increased output power by 8.2 % and 9.5 % corresponding to the case without cooling. The output power for jute wick material was higher than that of the husk supported module with both streams of water.

Current-voltage characteristic curve (Fig. 6) demonstrates the PV module with different arrangements of cooling and without cooling. Simpson numerical integration technique was used to calculate the area under the curve to evaluate the cooling performance. It was found that the area under the curve for the module without cooling with biomaterial is smaller than the maximum area under the curve observed with biomaterial with a water stream of 0.05 Kg/s. Both biomaterials with a water stream of 0.05 Kg/s cover an area under the curve higher by 5-8 % compared to the stream of 0.02 Kg/s. Fig. 6 also indicates that maximum cooling is achieved with wick biomaterials in combination with water.

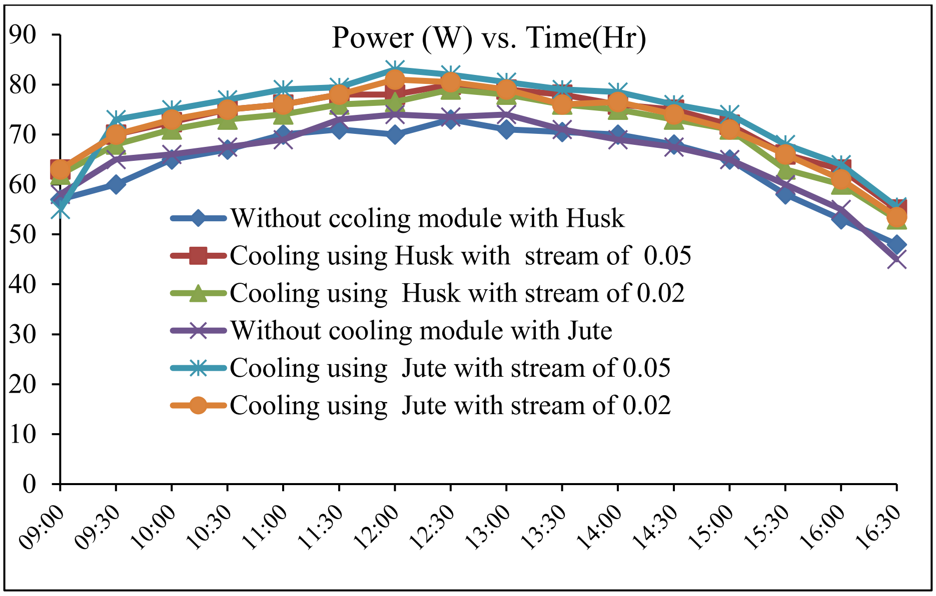

Fig. 5. Variation of output power in PV module with time under different operating conditions of cooling

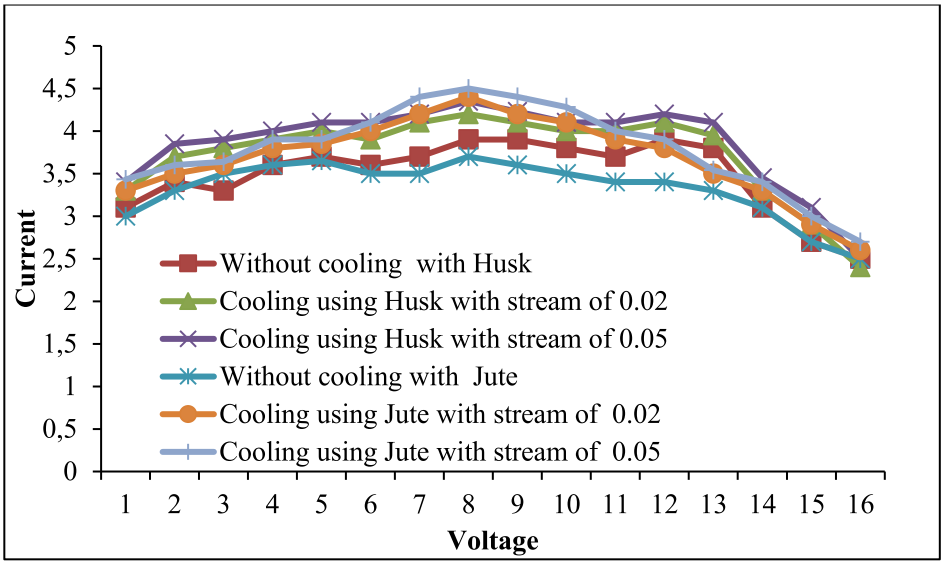

Fig. 6. Current-voltage characteristic curve of the PV module under different operating conditions

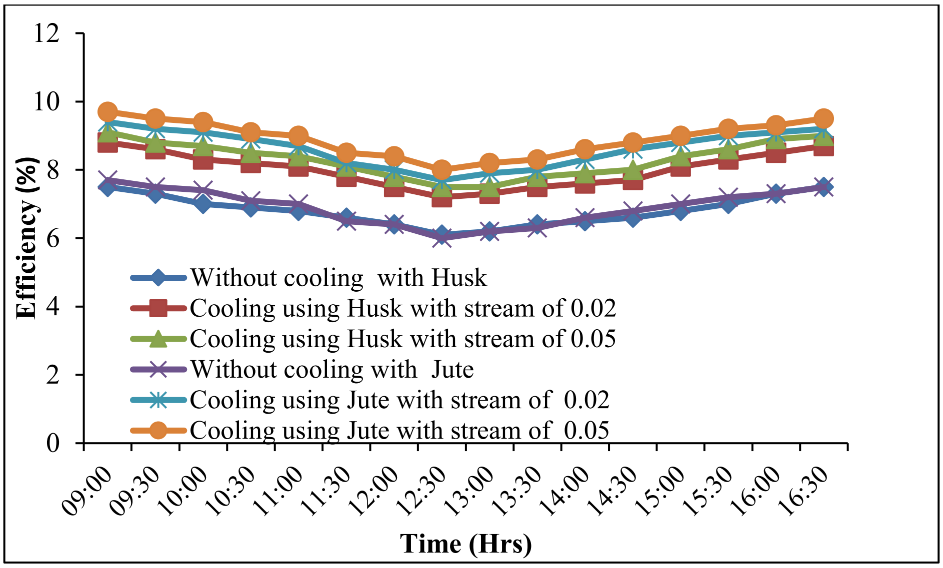

Fig. 7. Electrical efficiency of the PV module with respect to time under different operating conditions

Results supported that maximum output power is achieved when the PV module is cooled with wick biomaterial in combination with the different water streams. From equation (iii), the fill factor was evaluated using open-circuit voltage (V_{oc}), incident solar irradiance (I_{SC}) corresponding to maximum Pm. The maximum fill factor value obtained was 0.82 in jute biomaterial with a cooling stream of 0.05 Kg/s. As regards the fill factor, it was observed that jute biomaterial with cooling of 0.02 Kg/s has the same value (around 0.78) as husk with a stream of 0.05 Kg/s.

Fig. 7 depicts the variation of electrical efficiency of the PV module with time under different operating conditions. From the previous output of results, it is clear that the higher electrical efficiency of the PV module is a result of the cooling arrangement. Maximum efficiency of 9.4% to 9.7 % was obtained using jute wick biomaterial in combination with a water stream of 0.02 or 0.05 Kg/s. The PV module efficiency was about 8.1 % and 9.1 % when using husk biomaterial, with a water stream of 0.02 and 0.05 Kg/s respectively. Without cooling with the biomaterial, electrical efficiency remained 7.5 % (husk) and 7.7 % (jute). As the temperature of the PV module increases, uniform movement of electrons takes place, and the electrical impedance reduces the efficiency of the module. Hence, the experimental results point out that the PV module temperature has a substantial effect on the PV system's output power and efficiency. PV module temperature and efficiency are correlated parameters, as deduced from Figs. 5 and 7. The module without cooling arrangement has high temperature and low efficiency between 6-7.3 %. The efficiency ranges from 9.1 % to 7.5 % with husk and water stream of 0.05 Kg/s in the temperature range of 45–60 °C. Wicked jute biomaterial with a water stream of 0.05 Kg/s has a higher efficiency of 9.5 to 8.0 % at the same temperature, but the temperature coefficient ranges from -0.3 to 0.27 $^{o}C^{-1}$. The present investigation's temperature coefficient value shows a better result with cooling and an overall improvement compared to the conventional system.

CONCLUSIONS

Passive cooling was performed in a PV experimental setup with wicked biomaterial under constant water stream. Based on work conducted, it was observed that the temperature of the PV module without cooling reached to 60 °C, while with cooling, the corresponding temperature was reduced by 20 % with jute biomaterial. Jute biomaterial with a water stream of 0.05 Kg/s displayed better performance as compared to husk biomaterial. Maximum output power was achieved for both biomaterials around 80 W with the higher stream of water. The electrical efficiency improved by 7.0 to 9.0 %, for husk and jute wicked biomaterial, respectively. It was also found that the thermal degradation of PV modules is reduced with a cooling system suitable for optimizing output power and life cycle.

REFERENCES

1. W. He, Y. Zhang, J. Ji, *Applied Thermal Engineering*, **31**(16), 3369 (2011).
2. M. Chandrasekar, S. Suresh, T. Senthilkumar, *Energy Conversion and Management*, **71**, 43 (2013).
3. H. G. Teo, P. S. Lee, M. N. A. Hawlader, *Applied Energy*, **90**(1), 309 (2012).

4. M. M. Rahman, M. Hasanuzzaman, N. A. Rahim, *Energy Conversion and Management*, **103**, 348 (2015).
5. M. Hasanuzzaman, A. B. M. A. Malek, M. M. Islam, A. K. Pandey, N. A. Rahim, *Solar Energy*, **137**, 25 (2016).
6. A. Elnozahy, A. K. A. Rahman, A. H. H. Ali, M. Abdel-Salam, S. Ookawara, *Energy and Buildings*, **88**, 100 (2015).
7. Z. Rostami, M., Rahimi, N. Azimi, *Energy Conversion and Management*, **160**, 141 (2018).
8. L. Idoko, O. Anaya-Lara, A. McDonald, *Energy Reports*, **4**, 357 (2018).
9. N. A. Elminshawy, A. M. I. Mohamed, K. Morad, Y. Elhenawy, A. A. Alrobaian, *Applied Thermal Engineering*, **148**, 1 (2019).
10. D. P. Winston, P. Pounraj, A. M. Manokar, R. Sathyamurthy, A. E. Kabeel, *Desalination*, **435**, 140 (2018).
11. M. A. Bashir, H. M. Ali, K. P. Amber, M. W. Bashir, H. Ali, S. Imran, M. S. Kamran, *Thermal Science*, **22**(6) Part A, 2401 (2018).
12. H. Li, J. Zhao, M. Li, S. Deng, Q. An, F. Wang, *Solar Energy*, **181**, 70 (2019).
13. N. Abdollahi, M. Rahimi, *Renewable Energy*, **147**, 302 (2020).
14. M. Rosa-Clot, G. M. Tina, in: Floating PV Plants, Academic Press, 2020, p. 67.
15. A. M. Elbreki, K. Sopian, A., Fazlizan, A. Ibrahim, *Case Studies in Thermal Engineering*, 100607 (2020).
16. M. F. Younas, M. Abubaker, H. M. Ali, M. A. Nawaz, M. Hassan, M. J. Awan, K. A. Sultan, *VW Applied Sciences*, **2**(1), 52 (2020).
17. A. K. Tiwari, R. Kumar, R. R. Pande, S. K. Sharma, V. R. Kalamkar, in: Advances in Energy Research, Vol. 1, Springer, Singapore, 2020, p. 159.