Original Article

Synergistic experimental investigation of the nano-ceramic cover sheet on the PV module performance

Mohamed H. Mohamed[1,2]

Received: 6 August 2022 / Accepted: 9 August 2022
Published online: 15 September 2022

Abstract
Due to the accumulation of the heat on surface of the photovoltaic collector as well as the module's components, the efficiency of photovoltaic (PV) module is influenced by the increase of temperature in particular at high load (high voltage). Therefore, the efficiency and the current output decrease dramatically, and the full performance of the module tends to be zero in these conditions. In the present work, an experimental comparison between a controlled active water-cooling system and nano-ceramic cover sheet system is performed to get the best performance in high load. Water-cooling system is designed to minimize this effect of the high temperature and dust on the photovoltaic module. In addition, the nano-ceramic cover sheet is installed on the module to reduce the infrared permeability. Furthermore, Experiments were performed on the plain module without active cooling or nano-ceramic cover. After the experimental comparison, the results indicated that the controlled active water-cooling system is extremely improve the performance on the contrary the nano-ceramic cover sheet system which reduces the performance.

Keywords Solar energy · Photovoltaic · Active water-cooling · Nano-ceramic · High load

1 Introduction

Renewable energy is the energy that man can get from natural sources as wind and solar and waves …. etc. It is known as "clean energy" or "green power" and the energy that can be constantly replenished. There are various benefits for using the renewable energy, it introduces substantial benefits for climate, health, and economy. Renewable energy decreases the emissions generated from the combustion of the fossil fuels; therefore, it reduces the global warming and increases the impacts on the health and environment. In addition, renewable energy supports a lot of jobs, as manufacturing, projects development, constructions and turbines installation, maintenance operations, transportations and logistics, financial, legal, and consulting services. Furthermore, renewable energy is provided affordable electricity across the country right now and can help stabilize energy prices in the future. On other hand, the main disadvantage of using renewable energy is it can't generate the huge quantities of electricity as large as electricity produced fossil fuel generators. In addition, one of the disadvantages of renewable energy sources is the reliability of supply. Renewable energy often relies on the weather for its source of power.

Solar energy is the main source of the renewable energy, and the main components of the solar beam spectrum is light and heat. The main two technologies to extract solar energy are photovoltaic systems and concentrated solar power. In this work, author is focusing on the photovoltaic system and its performance. Photovoltaic

✉ Mohamed H. Mohamed, mhmohamed@uqu.edu.sa; moh75202@yahoo.de | [1]Mechanical Engineering Department, College of Engineering and Islamic Architecture, Umm Al-Qura University, P.O. 5555, Mecca, Kingdom of Saudi Arabia. [2]Mechanical Power Engineering Department, Faculty of Engineering, Mattaria, Helwan University, Cairo, Egypt.

system converts sunlight into electricity using solar cells. photovoltaic technologies actually were invented in the last 160 years ago but the acceleration in the manufacturing and commercialization is since only three decades. Photovoltaic modules are manufactured from semiconductors that allow sunlight to be converted directly into electricity. The main drawback of the photovoltaic systems (PV) is its low efficiency.

Many computational and experimental studies concerning to improve the efficiency of the PV module with different methodologies. In the next lines, a summary of the main attempts to improve the PV performance. Ali [1] introduced a review of the main activities performed in last 5 years. This review included some techniques to improve the efficiency of PV system such as cooling techniques with phase-change materials and nanofluids. In Refs. [2, 3] the drawback of the efficiency of the PV systems was discussed, and the authors concluded that the efficiency of the module within range 12–18% and the rest of the absorbed solar energy is converted into heat which warm up the module.

Several parameters influence the electricity conversion efficiency of PV modules such as solar irradiance, ambient temperature, dust and humidity, all these parameters have been studied in several publications as Refs. [4–6]. Simon and Meyer [7] studied the effect of the temperature on the performance of the PV cells and they indicated that by increasing the temperature, the module efficiency decreased due to the increasing in carrier concentrations at the p–n junction. In the same way, some publication [8–10] indicated that a deep reduction in the fill factor and open circuit voltage due to increase of the module temperature and by the sequence the notable reduction in the module efficiency. King and Eckert [11] investigated the effect of the temperature on the module efficiency and they stated that with every 1 °C increasing in PV-module temperature, the module efficiency will decrease within range 0.2–0.5%. Furthermore, many authors studied the effect of the increasing of the module temperature, and they concluded that reduction within range by 0.3–0.65%/K [12–14].

It is clear now that the temperature is playing a deep rule in the output performance of the PV module. Therefore, in the next lines, the research efforts in the thermal systems which were introduced to solve this overheating problem are summarized. All the researcher realized that the cooling of the module during the operation is the magical solution to improve the efficiency and the hole output performance of the module. As mentioned before, a large amount of the incidence solar energy on the module is not converted into electricity. In sequence, this loss energy contributes to overheat the module and reduce the output electricity and efficiency. Several fluid media were used to absorb this waste heat to reduce the total temperature of the module such as air, water, phase-change materials (PCMs), nanofluids [15, 16]. Actually, the phase change method introduced a good result to reduce the temperature of the PV module. Many researchers concluded that the phase change method is an attractive solution to absorb the waste heat in the PV module as in Refs. [17–19]. By the same sequence, the nanofluids is used to recover this waste heat because it recently achieved an acceptable trend in the heat transfer due to the higher thermal conductivity than the base fluid. Therefore, some researcher used the nanofluids in the cooling of the PV module to reduce the temperature [20–22]. An experimental passive cooling system utilizing the phase change method was performed in Ref. [23]. Nature convection is the base of the heat transfer to absorb the waste heat in the module. Additionally, in the same work the authors used also the nanofluids to improve the heat transfer. The results revealed the cooling system with the composed oil as PCM has a great capacity to increase the module efficiency. In sequence, a significant efficiency improvement of 21.19% were achieved. However, by using the nanofluid (adding Boehmite nano powder to the composite oil), the results indicated an enhancement in the efficiency was achieved by 44.74%. A numerical investigation was introduced on a horizontal single-ended evacuated tube [24] to study the fluid flow and heat transfer within the tube. The results showed that the secondary flow had a significant influence on the natural circulation flow rate and the temperature distribution within the tube. Gkouskos and Tsoutsos [25] deduced the effectiveness of phase change method in cooling of PV module in Greece. Phase change method when integrated with PV module, keeping the module temperature close to 25 °C which is the standard of PV. Japs et al. [26] concluded the influence of using phase change method for PV modules cooling with comparison to conventional PV modules. The temperature reduced by 7 °C with PCM and showed lower fluctuation in temperature, giving more uniformity. In Ref. [27], the authors studied the concentrating photovoltaic CPV system with aid of an equipment with cheap optics. A deep accumulation of the heat due to the solar concentration on the module. As a result, the module temperature rises and leads to a deterioration in both the lifetime and the efficiency. The authors studied effect of the cooling water rates within range 0.01 kg/s to 0.04 kg/s. Surface temperature is recoded around 72.5 °C and after cooling by water the temperature was reduced to 47.2 °C, 45.5 °C, 41.8 °C and 39.3 °C with flow rates of 0.01 kg/s, 0.02 kg/s, 0.03 kg/s and 0.04 kg/s, respectively. Additionally, there were 18.6%, 20.9%, 23.5% and 28.3% increase in the electricity output of the module compared to the uncooled module under the effect of water flow rates of 0.01 kg/s, 0.02 kg/s, 0.03 kg/s and 0.04 kg/s, respectively. The influence of the mass flow rate of the cooling water was studied by Pang et al. [28]. The cooling water mass flow rate was within range (0.005–0.25 kg/s); the module tilt angles was in range (15°–40°) to obtain an optimal condition for the PV module. The results indicated an expected output that the surface temperature of PV module decreases with the increasing water mass flow rate, while the output power increases. Additionally, the results dedicated that the electrical energy increment and thermal efficiency of the PV module are 11% and 57%, respectively. Munzer et al. [29] studied the nanofluids with base of water as coolant for the PV module experimentally. The authors used (TiO_2) nanofluid in water-polyethylene glycol mixture and (Al_2O_3) nanofluid in water-cetyltrimethylammonium bromide mixture. The results revealed that higher concentration ratio of nanofluid introduced a better cooling influence of the PV modules in most experiment with different volume flow rates. Furthermore, electrical performance (power and efficiency) presented that TiO_2 nanofluid gave better performance for several ranges of volume flow rates and concentration ratios compared with water cooling and without cooling. A theoretical analysis was performed using EES (Engineering Equation Solver) software by Bahaidarah et al. [30]. They studied the full performance of the module under the effect of the cooling. The authors concluded that the active cooling of the water reduced the temperature by 20% and this leads to increase the module efficiency by 9%.

The heat transfer was improved by using cylindrical pin fin by Rajput and Yang [31]. This system is called passive methodology to reduce the temperature of the PV module and it depended on the wind to absorb the waste heat on the module. The authors in that paper tested the module indoor experimentally by halogen light of intensity 1378.4 W m^{-2}. They stated the temperature of the module was reduced from 81.7 to 58.4 °C. The cooling water was utilized also in Ref. [32] using a DC pump to make a spry on the surface of the module to reduce the surface temperature. The experimental work was performed under the effect of the halogen lamp bulbs with different solar intensities (413, 620, 821 and 1016 W/m^2). The results represented that water cooling enhanced the efficiency due the reducing the of the module temperature. An economic study has been studied in Ref. [33] to get the payback period by using the cooling water within 10-h daily operating time (7:00–17:00). The authors concluded that 23.76×10^3 kWh_e of the annual grid electrical energy was saved and the payback period of the unit was 7.87 years. Kabeel et al. [34] studied three different cases for water cooling (air forced cooling technology, water cooling technology and forced-air and water-cooling technologies). The results concluded that the using water cooling methodology represented an optimal method that can be used for the PV modules.

2 New design and novelty of work

Nevertheless, all the previous researches and attempts improved the performance of the PV and a lot of these researches succeeded in this target. However, these researches indicated that the water cooling is the best way for the improving and enhancement of the PV performance. In addition, the active cooling is better that the passive cooling due the passive cooling depends on the wind velocity and environmental conditions. The author

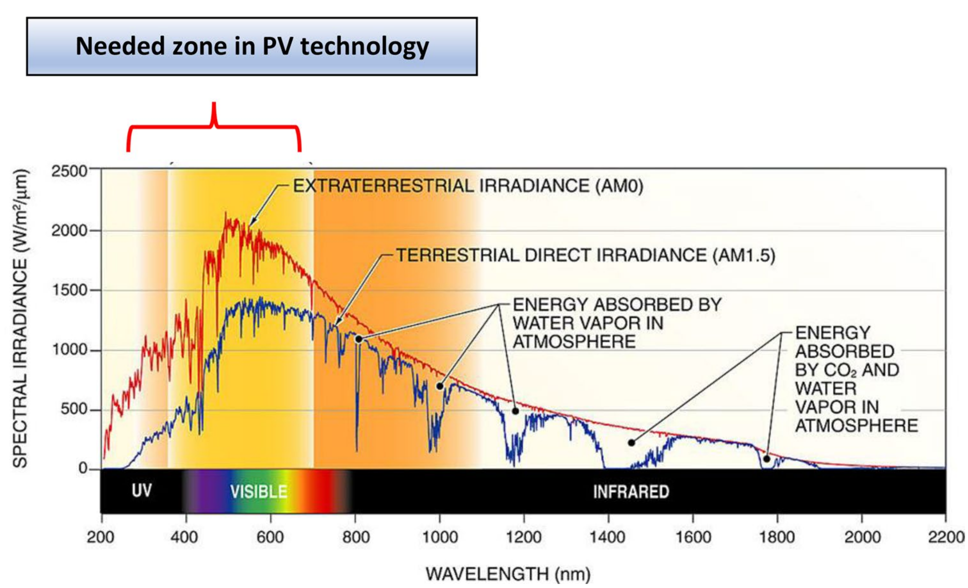


Fig. 1 Electromagnetic spectrum of the solar radiation with different wave lengths

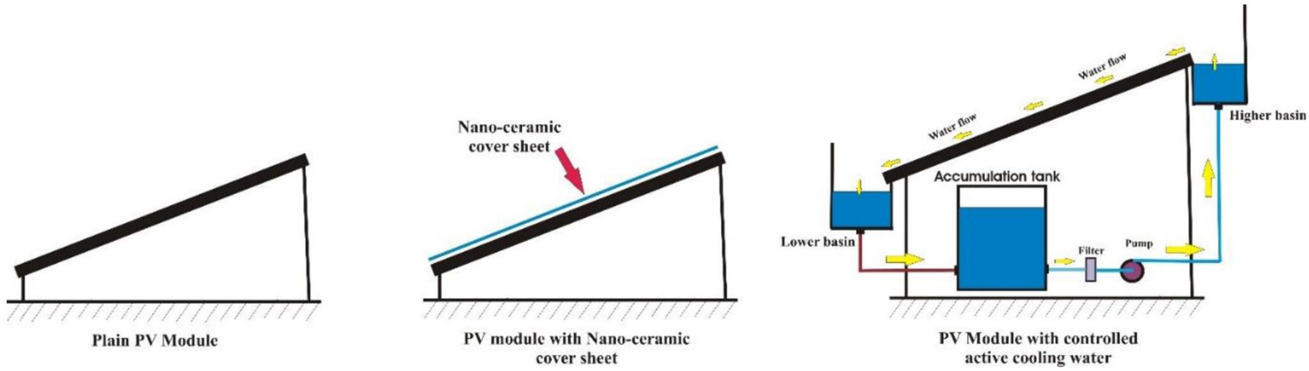


Fig. 2 The tested three systems in the present work

noted that there is no any published paper dealing the solar electromagnetic spectrum separation (Fig. 1). Therefore, in the first target in this work, the author introduces a new idea to separate the sunlight (visible light) and infrared by using nano-ceramic cover sheet to reflect the infrared and absorb the visible light which needed for the PV module. The infrared radiation of the solar beam causes the warmup of the PV surface and increases the overall temperature of the module which reduces the performance of the PV module.

The second target of this work is focusing to improve the active water-cooling system to be a controlled active water-cooling system. The author uses in this part an electronic circuit to control the operation time of the pump to reduce the consuming electricity of the pump and accordingly, increases the overall the efficiency of the system and reduces the total daily Expenses. Finally, in this work the author compares between the two new ideas (Nano-ceramic cover sheet and controlled active water cooling) with the plain PV module (Fig. 2) to select the best design from the performance point of view.

3 Methodology

PV system is commonly used in all over the world, the solar irradiation absence in cloudy days is the major problem is to be faced in some countries, unlike the middle east countries, the solar irradiation is available in most of the year. High continuous solar irradiation on the PV modules causes the module surface temperature to increase, which leads to high drop in the power output of the solar PV panels in the middle east countries. The main idea of the present work is to find a way to reduce the temperature during the work to improve the overall performance of the PV module. The author attempts in this way to introduce two methodologies to reduce the temperature of the PV module. The two methods are as follows:

- Nano-ceramic cover sheet.
- Controlled active water cooling.

The output results also will be compared with the plain module to obtain the gain or the loss in the PV performance.

3.1 Nano-ceramic cover sheet

Nanoparticle technologies were discovered in the early 1980s. It is formed using a process called sol–gel which mixes nanoparticles within a solution and gel to form the nanoparticle. Nano-ceramic is a type of nanoparticle that is composed of ceramics. This technology is considered as the largest technological advance in insulation. Nano-ceramic sheet or film is not dark, shiny or reflective. The spectrally selective coatings on Nano-Ceramic films filter out 65–99% of the infrared heat normally transmitted through insulated double pane glass. In the hot zone

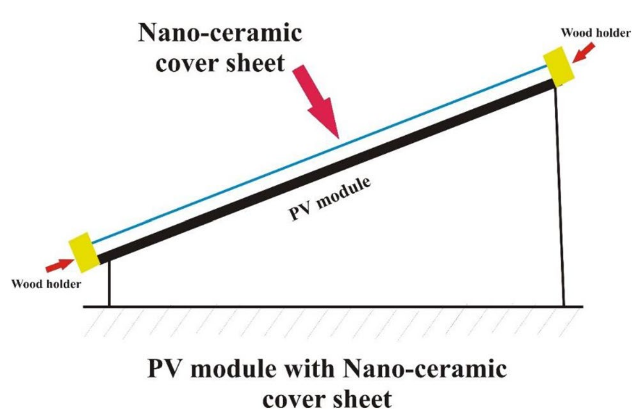
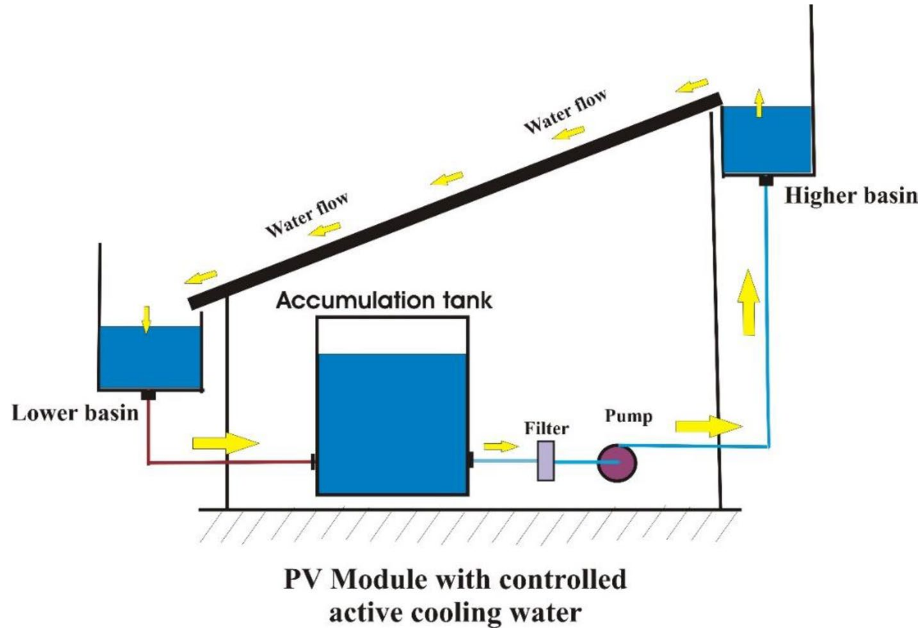


Fig. 3 Schematic drawing for the tested PV module with nano-ceramic cover sheet

Fig. 4 Schematic drawing for the tested PV module with controlled active water cooling



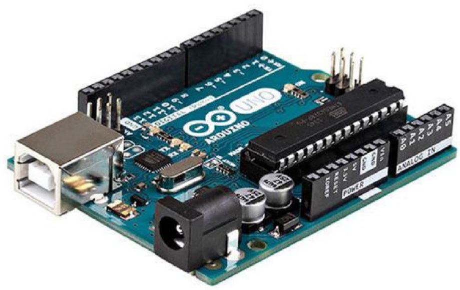
such as golf zone, this technology of Nano-ceramic isolation is now used in isolating the vehicle glass to keep the vehicle interior under low temperature. Therefore, the author idea depends on the using a cover sheet from this Nano-ceramic to insulate the PV module by reflecting the infrared to prevent the warmup of the PV module and keep the surface temperature near the ambient temperature during the operation time (see Fig. 3). The separation of the solar spectrum is the main idea; reflect the infrared and permeation to visible light.

A 6 mm glass covered with Nano-ceramic cover sheet is utilized to insulate the module and separate the thermal spectrum from the visible light spectrum. The module is inclined on holder at a tilt angle of 21.5° which is the angle of latitude of the study city, Makah, KSA. The nano-ceramic sheet was established on a thin sheet of glass and had been put at 3 cm distance over the PV.

3.2 Controlled active water-cooling

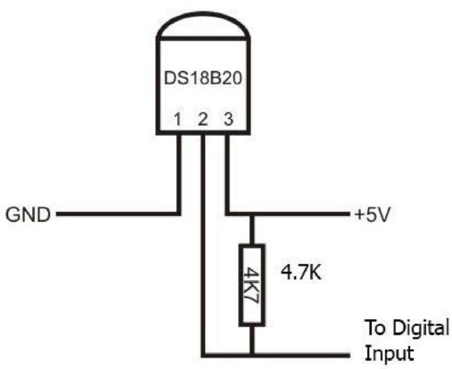
As known the specific heat of the water is high enough and considered as a coolant to flow over the surface of the PV module. In the present work, a closed water cycle is installed to work as cooling system. Additionally, a controller is added to control the time of the pump operation, this means in this system, the pump in normally off.

Fig. 5 Water flows over the PV module



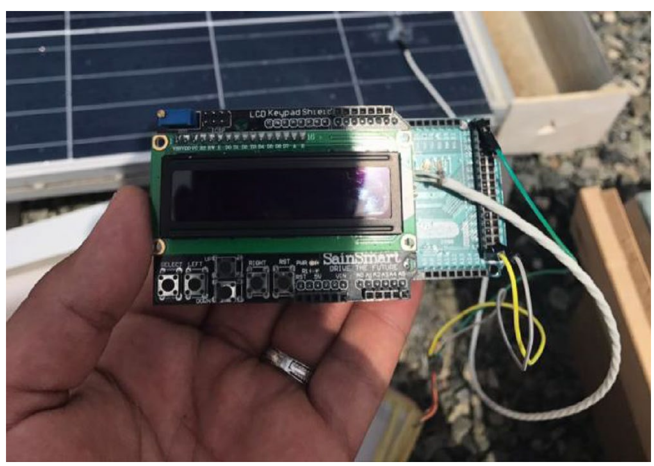
Arduino Uno

Waterproof DS18B20 Digital temperature sensor



Sensor automation details

Sensor placed over the PV



Arduino connected to the screen and sensor

Fig. 6 Automatic control system details used to control the pump operation

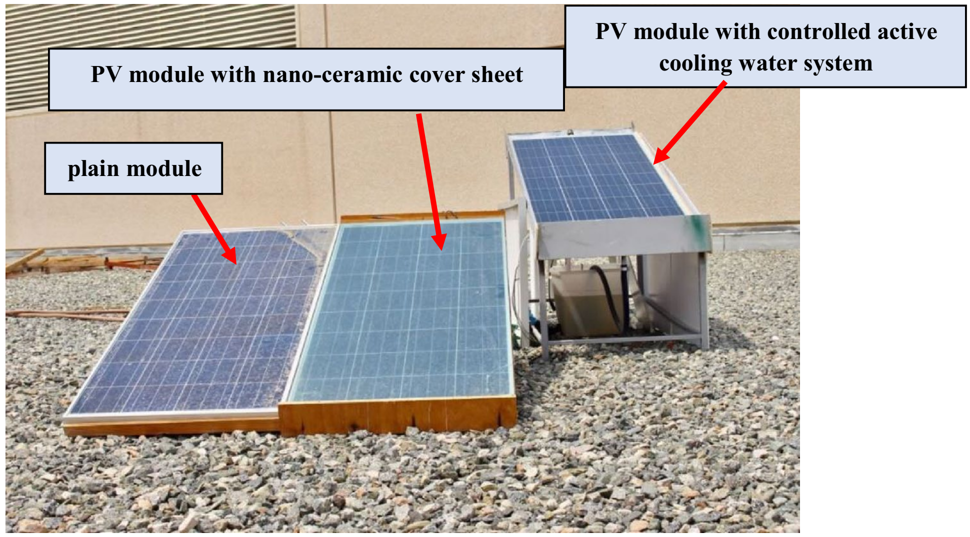


Fig. 7 Present work modules (i) plain module; (ii) PV module with controlled active cooling water system; and (iii) PV module with nano-ceramic cover sheet

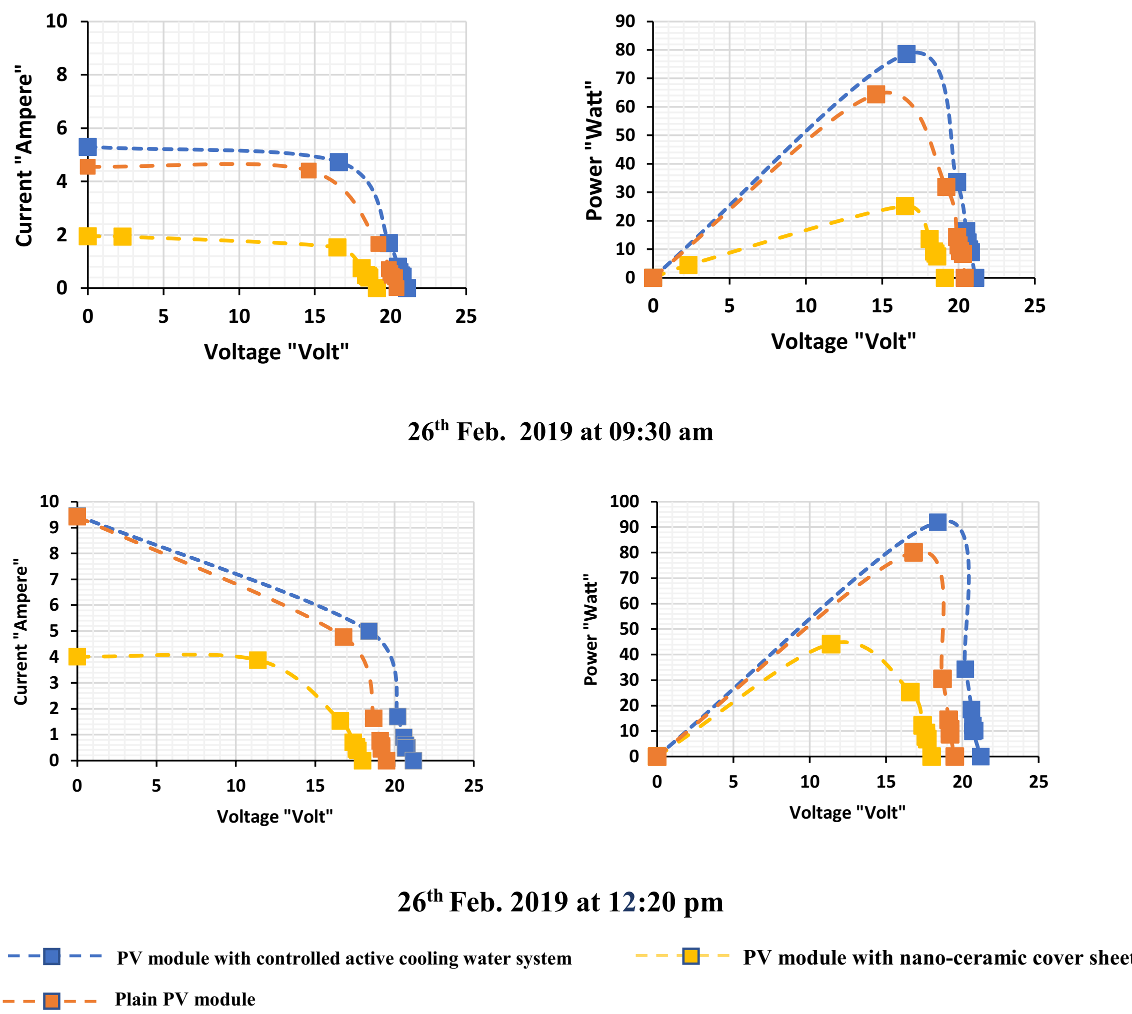


Fig. 8 Full performance for the three systems (26th Feb. 2019 at 09:30 am and 26th Feb. 2019 at 12:20 pm)

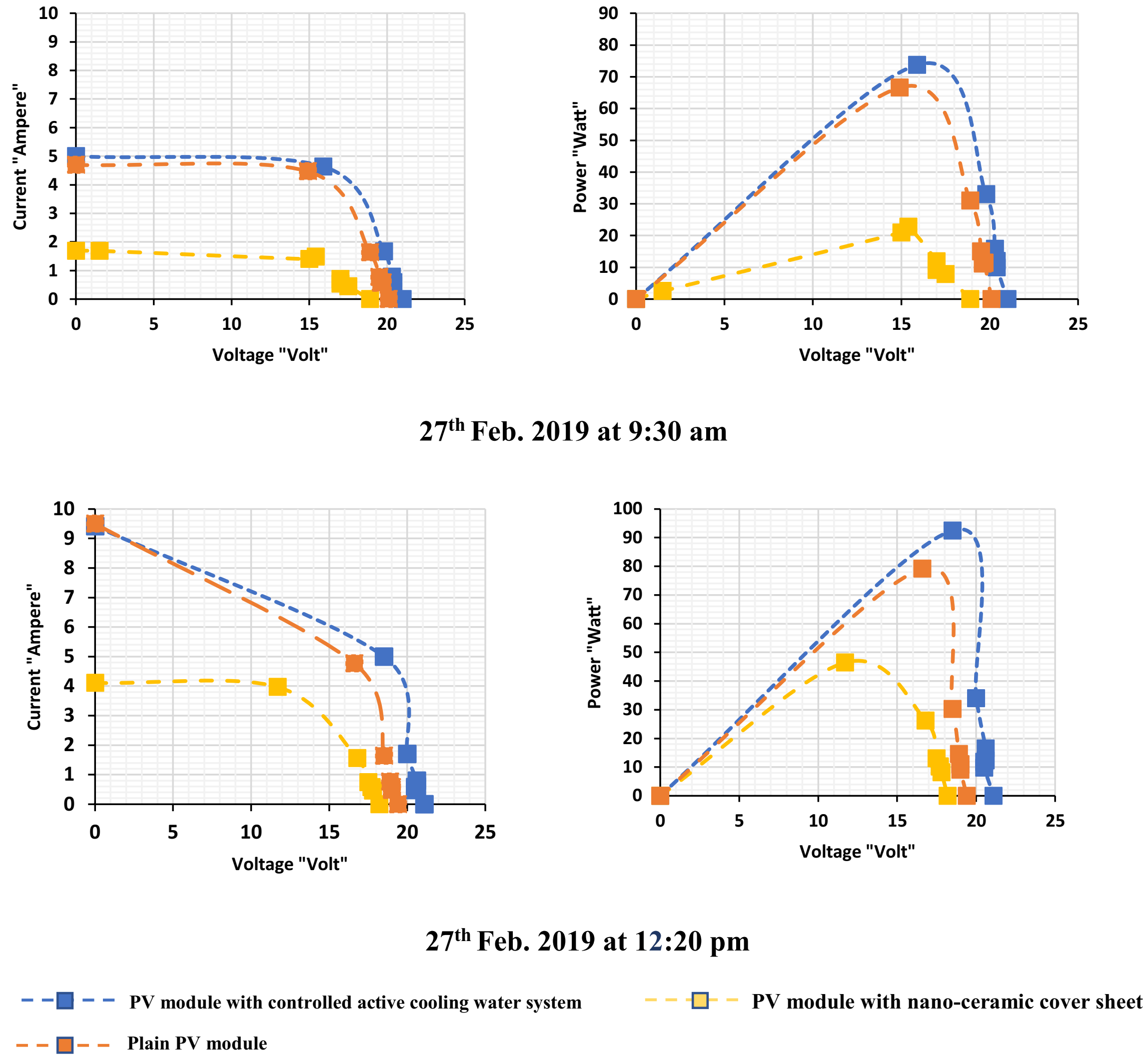


Fig. 9 Full performance for the three systems (27th Feb. 2019 at 9:30 am and at 12:20 pm)

The pump operates under the effect of the electrical circuit with a temperature sensor. The system of the cooling water includes higher basin, lower basin, accumulation tank, filter and pump as shown in Fig. 4. Figure 4 presents the water cycle during the operation time of the pump. If the pump starts to work, the higher basin will be filled, water overflows from the PV module edge and flows under gravity over the PV module surface (as shown in Fig. 5). The lower basin collects the water after the module then also under gravity the water will be collected in the accumulation tank. The water is pumped through a DC pump and automated according to the temperature reading, the water flows over the module with flow rate of 1 L/s. Another benefit for using the cooling water over the module is cleaning the dust from the surface especially in the dusty zones as in the middle east.

Automatic control systems are used to control machines and devices without direct human participation, its widely used in industrial. Therefore, the author decides to use the automatic control system to control the operation time of the pump in the water-cooling system. The desired automatic control system controls the pump and switch it on and off according to the surface temperature of the PV module. This will keep the surface temperature of the PV under a desired temperature. The control system is set to control the pump operation after the surface temperature of the PV is equal or greater than 45 °C and shutdowns when the temperature goes lower than 40°. These temperatures can be adjusted by the users according to the season and ambient temperature of the zone. To measure the surface temperature and to give the order to the pump to start pumping, a waterproof sensor is connected to controller that will

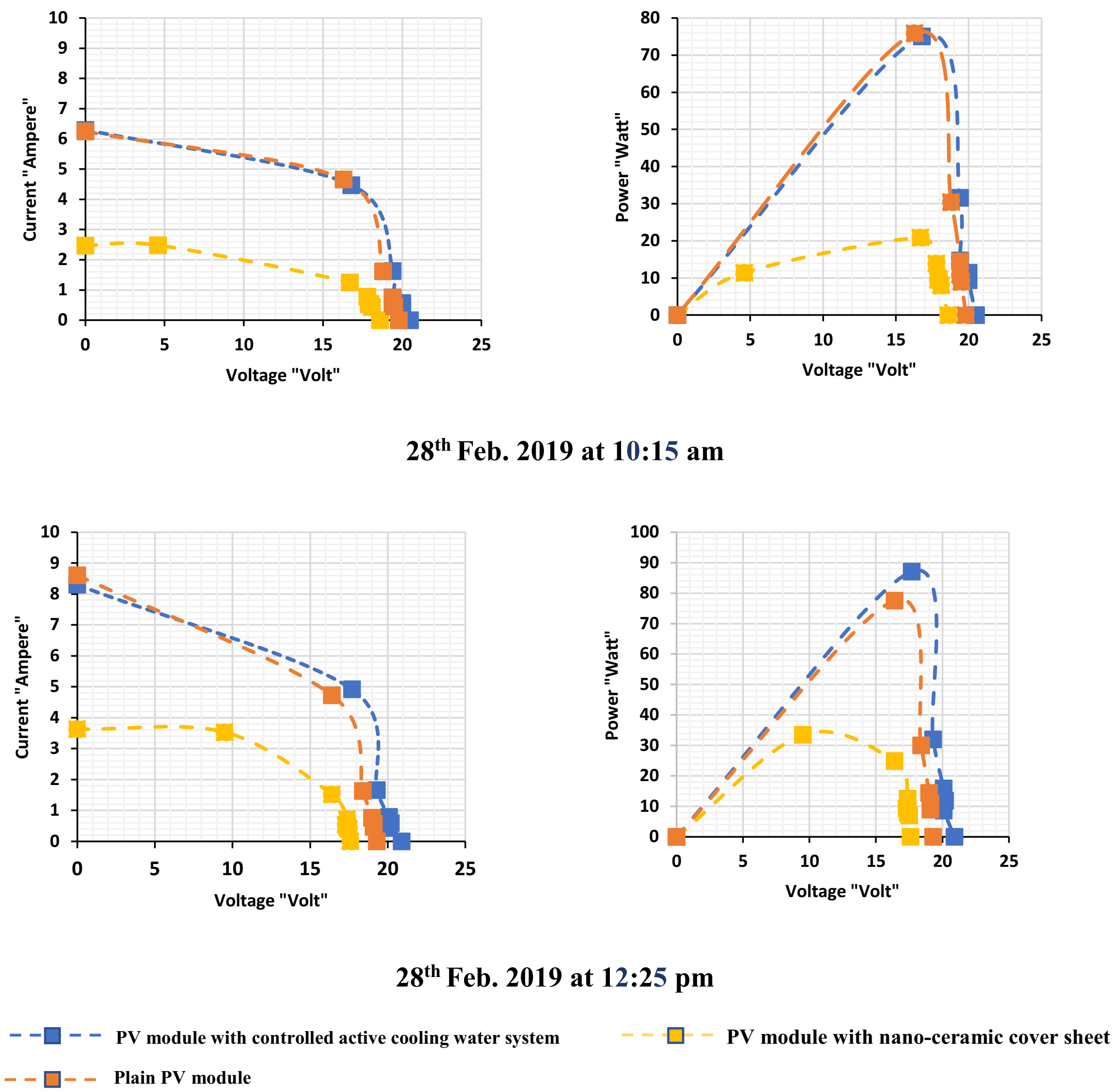


Fig. 10 Full performance for the three systems (28th Feb. 2019 at 10:15 am and at 12:25 pm)

read the surface temperature of PV and depending on that temperature the controller will decide if the pump should work or not. Arduino Uno is a microcontroller board (Fig. 6). It has 14 digital input/output pins, USB connection and power jack. It can work by USB cable connected to the computer or AC, DC adapter. The controller can be programmed using an Arduino Uno software. DS18B20 sensor is a digital temperature sensor, it has three wires—orange connects to 3–5 V, white connects to ground and blue is for data. DS18B20 technical specifications are usable temperature range within – 55 to 125 °C (– 67°F to + 257°F), ± 0.5 °C accuracy from – 10 °C to + 85 °C and usable with 3.0 V to 5.5 V power/data and the current, voltage and power are measured by a multimeter with accuracy of ± 0.03%.

3.3 Measurement comparison

The comparative experimental study is introduced in this work between three PV modules. The measurements are carried out at the same time for the module type but with different improvement techniques as shown in Fig. 7. As mentioned before, the three techniques are (i) plain module; (ii) PV module with controlled active cooling-water system; and (iii) PV module with nano-ceramic cover sheet. The output put measurement results are recorded in the

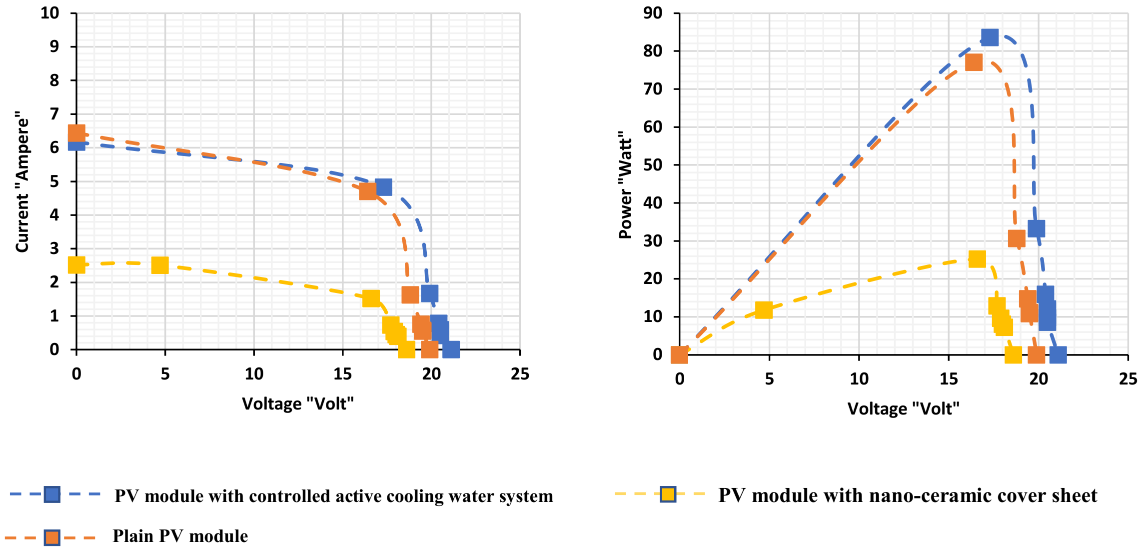


Fig. 11 Full performance for the three systems (1st Mar. 2019 at 10:15 am)

same time for the three systems to get a successful and impartial comparison. The measurements are carried out for several times within the solar day to cover the output performance of the three systems under different weather conditions and different solar irradiations. In addition, the measurements are taken at different days in February, March, April and May. Variable resistance is used as an output load on the three systems. It is applied on the three modules using the same resistance to the three modules at the same time. In sequence, voltage and current readings for each load is recorded. All the experimental measurements were carried out on the roof of the College of Engineering and Islamic Architecture—Umm Al-Qura university; Makkah; Kingdom of Saudi Arabia.

4 Results and discussions

As mentioned before, this experimental work introduces a primary idea to separate the solar irradiation beam spectrum into two main zones; infrared and visible light. The target is to absorb the visible light and reflect the infrared to avoid the warmup of the PV module. Therefore, the author attempts to achieve this target by installing a nano-ceramic cover sheet above the PV module. In addition, another system is tested to improve the overall performance of the PV module; the controlled active water-cooling is performed as a modification to the normal module. In sequence, the author compares between these two systems and the plain PV module to decide which system is better from the performance point of view. The first set of measurements are executed with the period from 26th February to the 14th of March 2019; the measurements are performed during the solar day from the sunrise to the sunset. Figure 8 shows the full performance of the three tested systems under the same weather conditions. It is clear that the controlled active water-cooling is the best system. Additionally, the same trend is noted for both times during morning and noon of the 26th Feb. The main note in the results that the nano-ceramic cover sheet reduces the output peak power from the module by 45.4% with the comparison to the plain module at noon. However, the peak power output is increased by 15.1% by the controlled active water-cooling with comparing with the plain module at noon. In the high load zone (high voltage), the system of the water cooling is the best also; it reaches to 21 voltes, however, the nano-ceramic cover sheet module is 19.1 volte.

In 27th of Feb. (Fig. 9), it was some clouds in the morning (at 09:30 am) which affects the results, and this is clear, if a comparison is performed between the results of the morning in 26th and 27th of Feb. It is noted that the peak power is reduced by 6.1% due to these clouds. However, at the noon, there is no clouds, therefore, the results of the two days (noon) is equal approximately. As the results, it is noted that the performance also of the controlled active water-cooling system is better than the plain module and nano-ceramic cover sheet system. The water-cooling system improved the peak power by 8.8% in the morning and 17.7% in the mid-day (noon), this means that the cooling water system is more effective at noon due to the

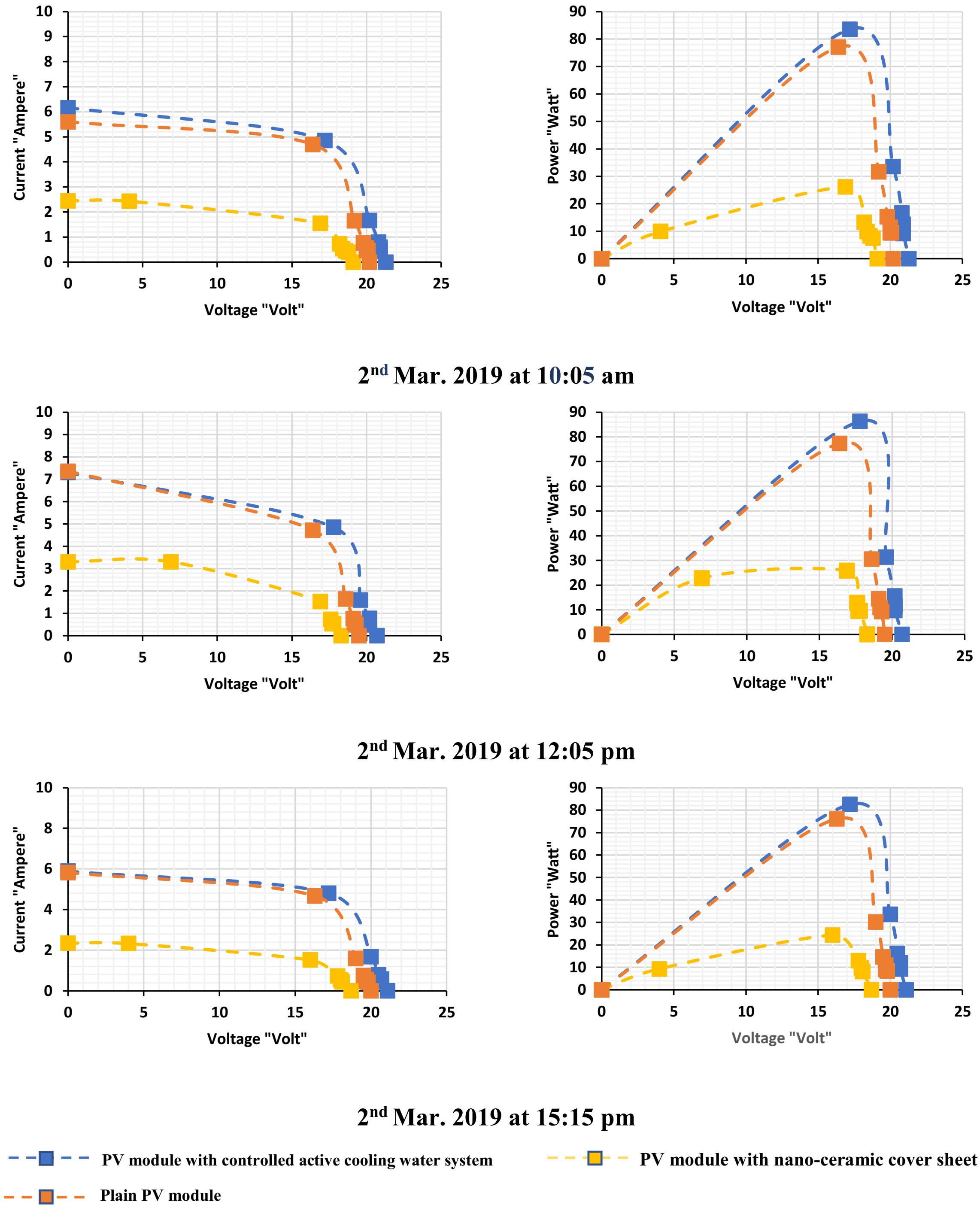


Fig. 12 Full performance for the three systems (2nd Mar. 2019 at 10:05 am, at 12:05 pm and at 15:15 pm)

accumulation of the heat on the PV module and water cooling remove this heat to reduce the temperature.

It is observed in 28th of Feb. morning some heavy clouds, therefore, it is clear that there was no deep effect for the cooling system as shown in Fig. 10. Unlike in the noon in the same day, there was no clouds and the influence of the water cooling is very effective in the improving the full performance of the module. The results reveal that the cooling system increases the peak power by 12.26% at the noon with comparison to the plain module. In addition, the nano-ceramic cover sheet system is failed to improve the performance during the cloudy and clear

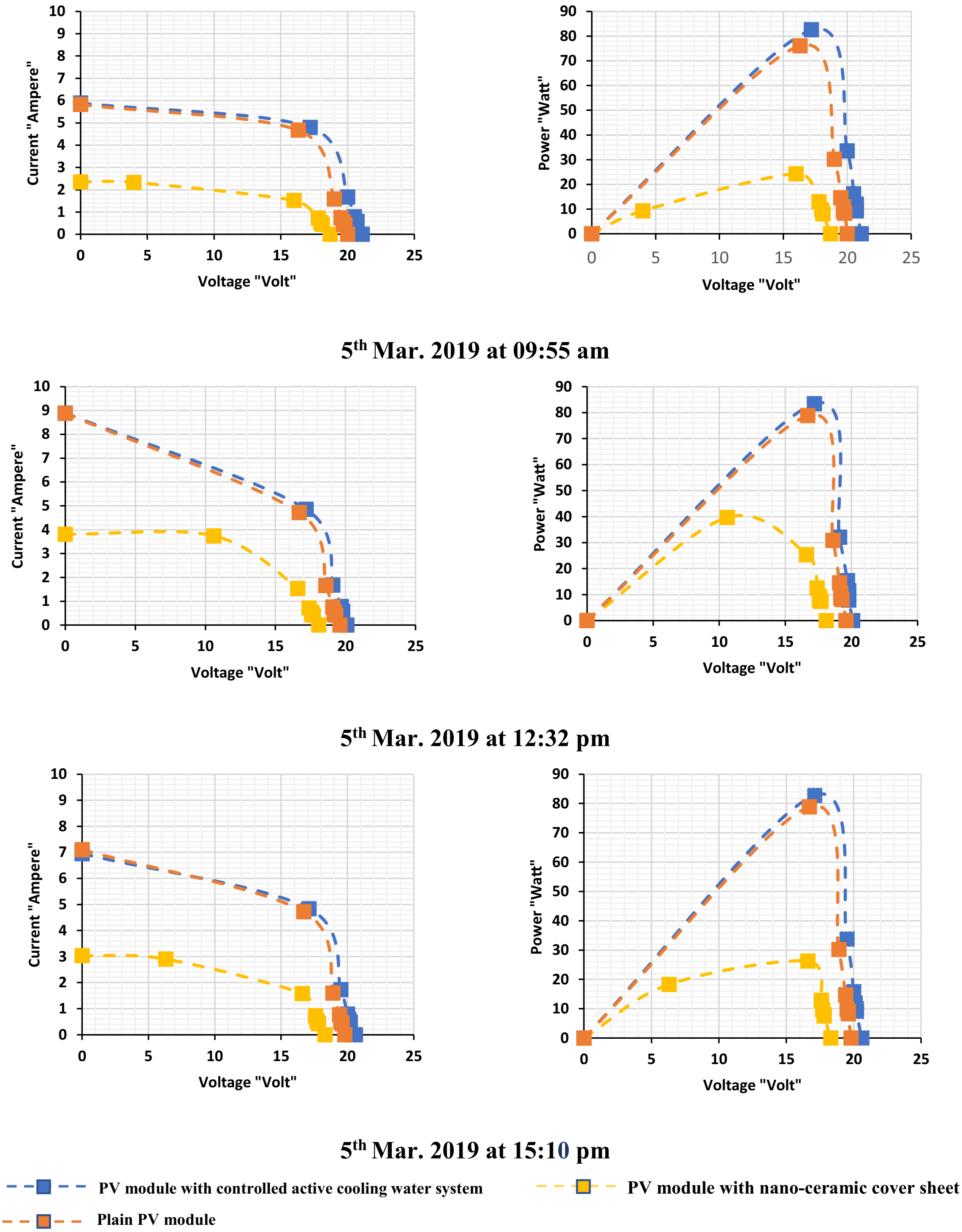


Fig. 13 Full performance for the three systems (5th Mar. 2019 at 09:55 am, at 12:32 pm and at 15:10 pm)

times, this means that the permeability of the used sheet is very bad and this the main problem in this sheet and if the we replace this sheet with another sheet with high permeability, it will improve the performance.

By the sequence, in the 1st of Mar. on morning, the measurements have been carried out and compared with the day before (28th of Feb. cloudy morning). It is noted that the pure sky morning (1st Mar.) (as shown in Fig. 11)

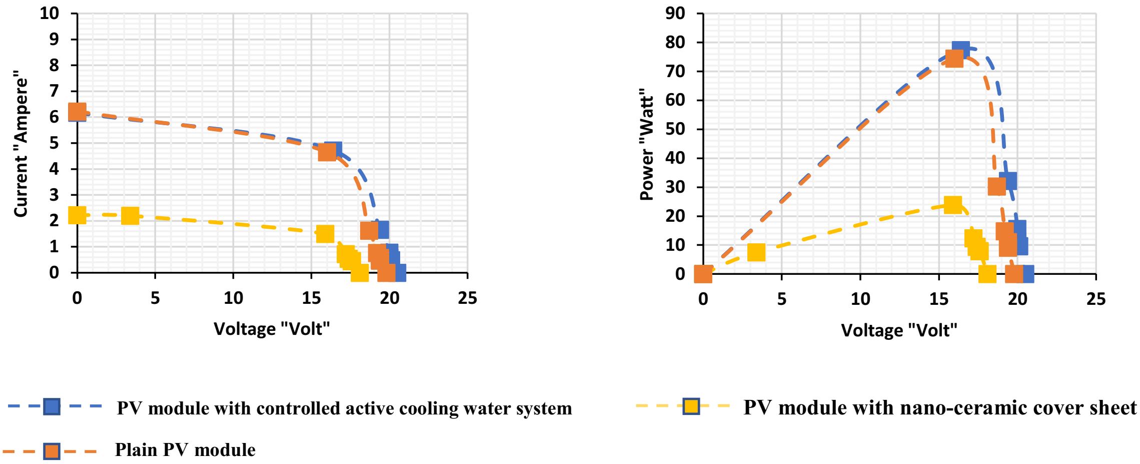


Fig. 14 Full performance for the three systems (8th Mar. 2019 at 15:10 pm)

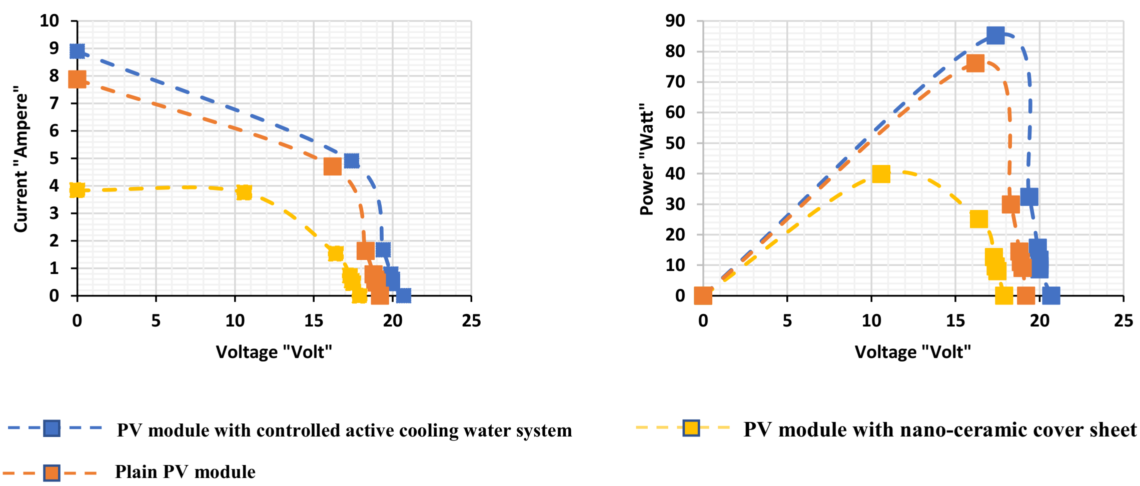


Fig. 15 Full performance for the three systems (14th Mar. 2019 at 15:10 pm)

introduces higher performance than the cloudy morning (28th of Feb.) by using the water-cooling system; this is due to the reduction of the surface temperature of the module. The measurements faltered after eleven in the morning on the first of March, due to the winds laden with dust and it was difficult to be present at the location of the measurements.

On the 2nd of March, the measurements have been continued to check the full performance of the three systems. The results indicate the controlled active cooling-water is the best with comparison to the plain module and nano-ceramic cover system as shown in Fig. 12. The measurements have been repeated three time that day at 10:05 am, at 12:05 pm and at 15:15 pm. The peak power is improved by the water cooling system by 9.1% in the morning and by 10.6% at noon as well as by 9.2% at the evening before the sunset. It is noted that the performance is approximately identical in both the morning and evening as expected due to weakness of the solar irradiation. Similarly, the measurements have been repeated in the 5th of March and the same output performance results have been obtained as shown in Fig. 13.

In the evening of days 5th, 8th, and 14th of March, a comparison of the performance of the three systems are appeared in Figs. 13, 14, and 15. The results reveal that the same trend of the improvement of the cooling water system and drawback of the nano-ceramic cover sheet system with comparison to the plain PV module. It is noted the performance of the 8th of March day less than 5th and 14th March due to the some clouds in that day which affect the solar irradiance. The peak power of the controlled active water-cooling system is better than

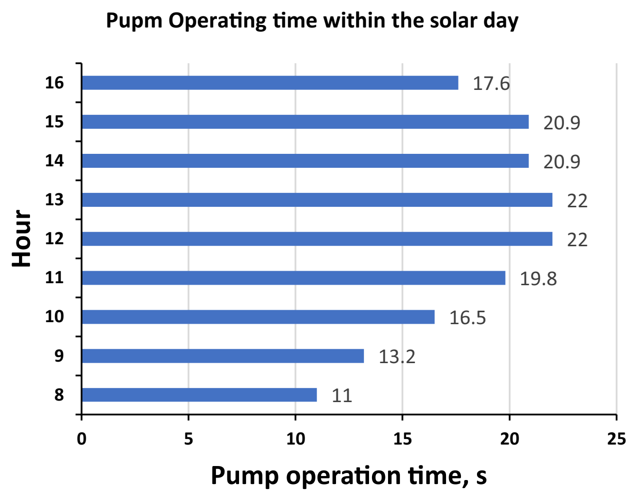


Fig. 16 Pump operation time during the solar day (from the sunrise to sunset)

the plain module by 5.1%, 4.02%, and 11.8% at 5th, 8th, and 14th of March, respectively.

The main conclusion of the results is that the controlled active water-cooling is best system from the performance point of view. Therefore, it is important to check how many times will the pump operate during the solar day. In this part, the author introduces a small study for the duration of the pump operation on 27th of April to get the operation time within the solar day. The average operation time of pump is measured hourly as shown Fig. 16. It is noted that the duration time of the pump operation is low in the morning and evening as expected due to low solar intensity in that hour of day. However, the operation time of the pump increases at the mid-day hours due the accumulation of the heat which rises the surface temperature. The average operation time was in the morning up to 13.56 s (from 8 am: 11 am o'clock), at mid-day up to 21.18 s (from 11 am: 14 pm o'clock), and at evening it was up to 19.25 s (from 14 pm: 16 pm o'clock). In addition, the author observes and counts the number of times of the pump operation within one week (last week of April). It is found that the pump operates one time per hour in the morning (from 8 am: 11 am o'clock), five times per hour in mid-day (from 11 am: 14 pm o'clock) and two times per hour at the evening (from 14 pm: 16 pm o'clock).

Finally, the performance is measured in a dusty day (7th of May) to obtain the full performance of the three systems under the effect of the dusty atmosphere. By the same methodology in the measurements, the three systems performance is measured under this difficult dusty condition. It is found that the controlled active water-cooling system is very effective because the water prevents the accumulation of the dust on the PV module surface as shown in Fig. 17. The peak power is improved by utilizing the water-cooling system by 45.7% with comparing to the plain PV module. Moreover, in the high load (high voltage) zone, it is found that the maximum voltage 20.4 volte for the water-cooling system, however, it was 18.2 for the plain PV module. This is emphasis the capability of the controlled active water-cooling system in the improving the performance of the PV module even in the dusty condition.

5 Conclusions

In this work, the author is focusing on the photovoltaic system and its performance to improve the main drawback of the PV module at the high temperature. The warmup of the PV module surface is due to the accumulation of the heat during the solar day especially in the hot locations

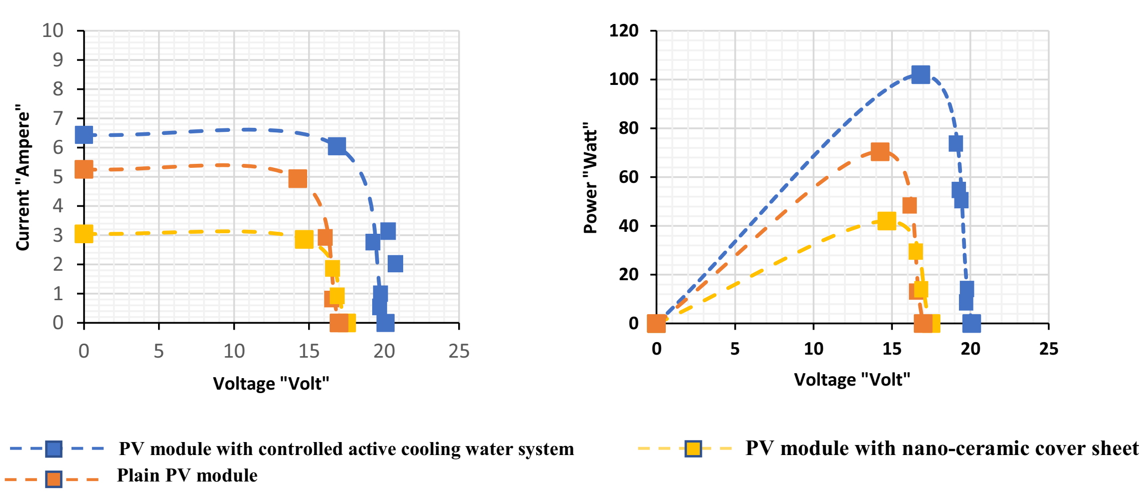


Fig. 17 Full performance for the three systems (7th May. 2019 at 12:10 pm)

such as middle east. In the present work, three systems are tested experimentally under the weather conditions of Makkah, KSA. Nano-ceramic cover sheet system, controlled active water-cooling system, and plain PV module are tested in this study to obtain the best system from the performance point of view. The nano-ceramic cover sheet is a new idea in this technology; it aims to separate the solar spectrum to reflect the infrared and absorb only the visible light from the solar spectrum. Furthermore, the author introduces a modification on the regular cooling systems; a controller is added to the system to control the operation time of the pump. The results of the intensive comparison of the three systems can be summarized in the following points:

- The nano-ceramic cover sheet system is failed to improve the power output of the PV module during the cloudy and clear times due to the type of the nano-ceramic material and its bad permeability. Therefore, High permeability nano-ceramic cover sheet is needed to absorb the visible light.
- The controlled active water-cooling system is the best system to improve the PV module performance under several weather conditions.
- On 27th of Feb., the water-cooling system improved the peak power by 8.8% in the morning and 17.7% in the mid-day (noon), this means that the cooling water system is more effective at noon due to the accumulation of the heat on the PV module and water cooling remove this heat to reduce the temperature.
- During the full day measurements (2nd of March), the peak power is improved by the water-cooling system by 9.1% in the morning and by 10.6% at noon as well as by 9.2% at the evening.
- The operation time of the pump increases at the mid-day hours due the accumulation of the heat which rises the surface temperature; however, it is less in morning and evening. In addition, number of the operation times of the pump in the mid-day is higher than the morning and evening.
- The controlled active cooling-water system is very efficient under the dusty weather conditions, it improves the peak power by 45.7% with comparison to the plain PV module.

Acknowledgements The author would like to thank the Deanship of Scientific Research at Umm Al-Qura University for supporting his work by Grant Code: 22UQU4361231DSR05.

Author contributions MHM: conceptualization, experimental work, data curation, writing—reviewing and editing.

Funding No Fund.

Availability of data and materials The datasets generated during and analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of interest The author declares that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

1. Muhammad Ali H (2020) Recent advancements in PV cooling and efficiency enhancement integrating phase change materials-based systems—a comprehensive review. Sol Energy 197:163–198
2. S. Kurtz (2012) Opportunities and challenges for development of a mature concentrating photovoltaic power industry opportunities and challenges for development of a mature concentrating photovoltaic power industry. Natl Renew Energy Lab 35
3. Agrawal B, Tiwari GN (2010) Optimizing the energy and exergy of building integrated photovoltaic thermal (BIPVT) systems under cold climatic conditions. Appl Energy 87:417–426. https://doi.org/10.1016/j.apenergy.2009.06.011
4. Katsumata N, Nakada Y, Minemoto T, Takakura H (2011) Estimation of irradiance and outdoor performance of photovoltaic modules by meteorological data. Sol Energy Mater Sol Cells 95:199–202. https://doi.org/10.1016/j.solmat.2010.01.019
5. Ali HM, Zafar MA, Bashir MA, Nasir MA, Ali M, Siddiqui AM (2017) Effect of dust deposition on the performance of photovoltaic modules in city of taxila, Pakistan. Therm Sci 21:915–923. https://doi.org/10.2298/TSCI140515046A
6. Chatterjee S, Tamizhmani G (2012) BAPV arrays: side-by-side comparison with and without fan cooling. In: Conf. Rec. IEEE Photovolt. Spec. Conf., pp 537–542. https://doi.org/10.1109/PVSC.2012.6317672
7. Simon M, Meyer EL (2010) Detection and analysis of hot-spot formation in solar cells. Sol Energy Mater Sol Cells 94:106–113. https://doi.org/10.1016/j.solmat.2009.09.016
8. Ali HM, Mahmood M, Bashir MA, Ali M, Siddiqui AM (2016) Outdoor testing of photovoltaic modules during summer in Taxila Pakistan. Therm Sci 20:165–173. https://doi.org/10.2298/TSCI131216025A
9. Bashir MA, Ali HM, Khalil S, Ali M, Siddiqui AM (2014) Comparison of performance measurements of photovoltaic modules during winter months in Taxila, Pakistan. Int J Photoenergy 2014:1–8

10. Amin N, Lung CW, Sopian K (2009) A practical field study of various solar cells on their performance in Malaysia. Renew Energy 34:1939–1946. https://doi.org/10.1016/j.renene.2008.12.005
11. King DL, Eckert PE (1996) Characterizing (Rating) the performance of large photovoltaic arrays for all operating conditions. pp 1385–1388. https://doi.org/10.1109/PVSC.1996.564391
12. del Cueto JA (2002) Comparison of energy production and performance from flat-plate photovoltaic module technologies deployed at fixed tilt. In: Conf. Rec. Twenty-Ninth IEEE Photovolt. Spec. Conf., vol 2002, pp 1523–1526. https://doi.org/10.1109/PVSC.2002.1190901
13. Sandberg M (1999) Cooling of building integrated photovoltaics by ventilation air. In: First Int. One Day Forum. Nat. Hybrid Vent., pp 1–10
14. Krauter S, Araújo RG, Schroer S, Hanitsch R, Salhi MJ, Triebel C et al (1999) Combined photovoltaic and solar thermal systems for facade integration and building insulation. Sol Energy 67:239–248. https://doi.org/10.1016/S0038-092X(00)00071-2
15. Xu J, Wang RZ, Li Y (2014) A review of available technologies for seasonal thermal energy storage. Sol Energy 103:610–638. https://doi.org/10.1016/j.solener.2013.06.006
16. Alva G, Lin Y, Fang G (2018) An overview of thermal energy storage systems. Energy 144:341–378. https://doi.org/10.1016/j.energy.2017.12.037
17. Lin Y, Jia Y, Alva G, Fang G (2018) Review on thermal conductivity enhancement, thermal properties and applications of phase change materials in thermal energy storage. Renew Sustain Energy Rev 82:2730–2742. https://doi.org/10.1016/j.rser.2017.10.002
18. Souayfane F, Fardoun F, Biwole PH (2016) Phase change materials (PCM) for cooling applications in buildings: a review. Energy Build 129:396–431. https://doi.org/10.1016/j.enbuild.2016.04.006
19. Kant K, Shukla A, Sharma A (2017) Advancement in phase change materials for thermal energy storage applications. Sol Energy Mater Sol Cells 172:82–92. https://doi.org/10.1016/j.solmat.2017.07.023
20. Mota MDS, Regitano LCA (2012) World's largest Science, Technology & Medicine Open Access book publisher c. RFID Technol Secur Vulnerabilities, Countermeas, pp 75–100. https://doi.org/10.5772/711
21. Elsheikh AH, Sharshir SW, Mostafa ME, Essa FA, Ahmed Ali MK (2018) Applications of nanofluids in solar energy: a review of recent advances. Renew Sustain Energy Rev 82:3483–3502. https://doi.org/10.1016/j.rser.2017.10.108
22. Devendiran DK, Amirtham VA (2016) A review on preparation, characterization, properties and applications of nanofluids. Renew Sustain Energy Rev 60:21–40. https://doi.org/10.1016/j.rser.2016.01.055
23. Abdollahi N, Rahimi M (2020) Potential of water natural circulation coupled with nano-enhanced PCM for PV module cooling. Renew Energy 147(Part 1):302–309
24. Li J, Li X, Wanga Y, Jiyuan T (2020) A theoretical model of natural circulation flow and heat transfer within horizontal evacuated tube considering the secondary flow. Renew Energy 147(Part 1):630–638
25. Gkouskos Z, Tsoutsos T (2012). Integrating phase change material to photovoltaics in a Mediterranean region. Photovolt Sol Energy
26. Japs E, Sonnenrein G, Steube J, Vrabec J, Kenig E, Krauter S (2013) Technical investigation of a photovoltaic module with integrated improved phase change material. In: 28th Eur. Photovolt. Sol. Energy Conf. Exhib., pp 500–502. https://doi.org/10.4229/28thEUPVSEC2013-1CV.2.19
27. Elminshawy NAS, El-Ghandour M, Elhenawy Y, Bassyouni M, El-Damhogi DG, Addas MF (2019) Experimental investigation of a V-trough PV concentrator integrated with aburied water heat exchanger cooling system. Sol Energy 193:706–714
28. Pang W, Cui Y, Zhang Q, Yu H, Zhang L, Yan H (2019) Experimental effect of high massflow rate and volume cooling onperformance of a water-type PV/T collector. Sol Energy 188:1360–1368
29. Ebaid MSY, Ghrair AM, Al-Busoul M (2018) Experimental investigation of cooling photovoltaic (PV) panels using (TiO2) nanofluid in water-polyethylene glycol mixture and (Al2O3) nanofluid in water-cetyltrimethylammonium bromide mixture. Energy Convers Manage 155:324–343
30. Bahaidarah H, Subhan A, Gandhidasan P, Rehman S (2013) Performance evaluation of a PV (photovoltaic) module by back surface water cooling for hot climatic conditions. Energy 59:445–453
31. Rajput UJ, Yang J (2018) Comparison of heat sink and water type PV/T collector for polycrystalline photovoltaic panel cooling. Renew Energy 116(Part A):479–491
32. Irwan YM, Leow WZ, Irwanto M, Fareq M, Amelia AR, Gomesh N, Safwati I (2015) Indoor test performance of PV panel through water cooling method. Energy Procedia 79:604–611
33. Kong R, Deethayat T, Asanakham A, Kiatsiriroat T (2020) Performance and economic evaluation of a photovoltaic/thermal (PV/T)-cascade heat pump for combined cooling, heat and power in tropical climate area. J Energy Storage 30:101507
34. Kabeel AE, Abdelgaied M, Sathyamurthy R (2019) A comprehensive investigation of the optimization cooling technique for improving the performance of PV module with reflectors under Egyptian conditions. Sol Energy 186:257–263