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PERFORMANCE ENHANCEMENT OF A PV PUMPING SYSTEM IN A DESERTIC REGION – PART 1

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ABSTRACT

Among the many applications of photovoltaic energy, water pumping systems stand out as a clean, reliable alternative suited to the needs of remote areas. This type of system essentially relies on the direct use of electricity generated by solar panels to power a pump, thus ensuring autonomous, economical, and environmentally friendly operation.

In the MENA region, climatic conditions are generally harsh, and ambient temperatures are generally high. This greatly influences the performance of PV systems due to the negative effect of temperature on the efficiency of solar modules, despite these regions being characterized by considerable sunshine. To address this problem, various solutions have been presented in the literature, such as air or water cooling, whether active or passive. However, some are not admissible in real-world applications.

This article aims to present an effective and innovative methodology devoted for PV pumping systems. A fraction of the pumped water is diverted to the PV generator for cooling and then reinjected back into the irrigation water flow. This improves the system's efficiency without any additional energy loss required to pump the cooling water. A theoretical simulation is performed, and an experimental platform is built to validate the results.

Keywords: Solar Energy, Photovoltaic Pumping, PV Panels, Active Water Cooling, Efficiency.

INTRODUCTION

Nowadays, there is growing interest for renewable and environment-friendly energy sources such as solar energy, on which some kind of sustainable growth may be based (Long et al., 2023; Birbal and Azamathulla, 2024). Solar energy is indeed a renewable source of energy, the use of which avoids most of the negative repercussions due to the use of fossil fuels. For North Africa and Middle East countries (MENA), the most promising issue is solar photovoltaic systems, in which energy is produced as a direct result of the conversion of the energy of the solar ray, using the so-called photovoltaic effect (Hammad et al., 2018, Al-Kouz et al., 2019) (Memiche at al., 2020).

In MENA region, climatic conditions are generally harsh, and ambient temperatures are generally high. This greatly influences the performance of PV systems due to the negative effect of temperature on the efficiency of solar modules, despite these regions being characterized by considerable sunshine. To address this problem, several cooling methods to reduce the negative effects of rising solar cell temperatures are reported in literature, various solutions have been presented and discussed, even so many of them are practically non-viable. The two most widely used cooling methods today are air cooling and water cooling (Grubišić et al., 2016, Pushpendu et al., 2020, Zubeer et al., 2017).

This paper presents an effective and innovative methodology for PV pumping systems. Because of water scarcity in desertic regions and initial installation cost of PV pumping systems, it is necessary to fully optimize the use of the pumped water and also maximize energy yields of the solar field using adequate configuration and appropriate control strategies to track the maximum power point (MPPT), as investigated in early optimization studies of photovoltaic pumping systems (Moussi et al., 2003; Betka and Moussi, 2003). In this context, a cooling system has been proposed for possible system setup of agricultural applications and concerns hot regions where the use of some techniques would be wasteful of precious water resources. The proposed scheme suggests deviating a portion of the pumped water to the PV source for cooling and then reinjected back into the irrigation water stream (Fig. 1). This procedure improves system efficiency without any additional energy losses required to pump the cooling water and saves the amount of water that would otherwise be wasted after using it in the spray cooling process for example.

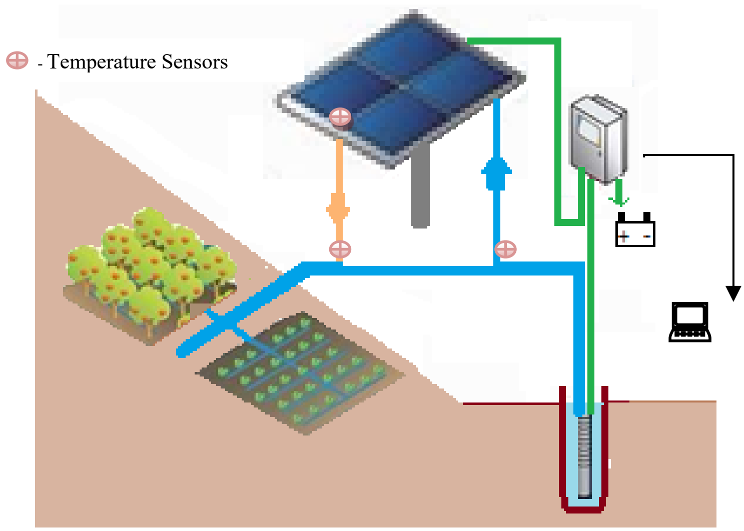

Figure 1: General illustration of a PV pumping system

PV MODULES COOLING TECHNIQUES

Literature reported several cooling methods to reduce the negative effects of rising photovoltaic cell temperatures. The two most widely used are air cooling and water cooling. Both techniques rely on contact between the surface of the solar module and the cooler, allowing for heat exchange between them, a principle widely used in thermal energy engineering applications such as geothermal air/ground heat exchangers (Belloufi et al., 2016)."

Passive Cooling

For air cooling, we distinguish: Natural cooling, which uses natural convection to cool the solar panels. Perforated aluminium heat sinks are attached to the back of the photovoltaic (PV) panels to optimize heat transfer between the panels and the surrounding air. The results showed a significant reduction in operating temperature and an improvement in the electrical efficiency of the panels (Mittelman et al., 2009, Firoozzadeh et al., 2019)

Regarding passive water cooling, one of the methods cited in the literature is immersion cooling in water. It has shown an efficiency improvement of 17.8% after immersion to a depth of 1 cm. The disadvantage lies in the impact of immersion on the longevity of the solar modules (Mehrotra et al., 2014).

On the other hand, the most widely used methods at large scale are the FPV stations where the PV modules float on the water surface. A study conducted by Ocean Sun AS showed a power efficiency increase of 5 to 7% between a system cooled by natural air and one in direct contact with a floating membrane on the water surface (Kjeldstad at al., 2021).

Active Cooling (Forced Cooling)

It has been shown that the use of forced air can improve energy efficiency by up to 18.67% (Mittelman et al., 2009). Regarding active water cooling, several techniques are distinguished; each differing in the way the water is used. These include:

- Front-mounted spray cooling of photovoltaic panels: In this case, energy efficiency is increased by up to 15% in extreme weather conditions. Although water-intensive, this method remains a cost-effective and efficient solution for floating solar systems (Moharram et al., 2013).

- Front-to-back spray cooling of photovoltaic panels: This method simultaneously cools both sides of the panel by applying a water spray. Experimental results show a maximum increase in electrical energy production of 16.3%. In addition, the panel temperature was reduced from 54°C to 24°C. This technique also exhibits a self-cleaning effect on the panel surface, which helps improve their long-term efficiency (Nižetić et al., 2016).

- - Constant water flow on the surface of the solar panel: results showed a significant improvement in the efficiency of the PV module of up to 15% compared to the module without cooling.
- - Constant water flow on the back surface of the PV: Unlike the previous procedure, in this case the water flow is applied to the back of the solar module. It was reported in literature that a front water film cooling increased the energy production by 22%, while the back cooling improved the production by 29.8%. While the combination of the two cooling methods increased the energy production by 35% compared to the module without cooling.

METHODOLOGY AND PRACTICAL IMPLEMENTATION

PV module Cooling procedure

The following describes the implementation of a cooling system to improve solar module performance. Active back-end water cooling has been shown to be the most effective solution, compared to air cooling or passive water cooling. Indeed, this method allows for better heat dissipation, which significantly contributes to improving the efficiency of photovoltaic modules. Consequently, this technique is adopted by implementing a cooling system based on direct contact between water and the back of the photovoltaic module to ensure optimal heat exchange. In this experiment, and to better study the effect of heat transfer on module efficiency, the back surface of the module was divided into four zones, each with its own cooling circuit (Fig. 2). These zones can be connected in series, parallel, or in a mixed connection. This arrangement will subsequently allow for varying the configuration of the solar module's thermal model. These experiments were carried out at Biskra University (Algeria). This city has an agricultural character and is characterized by a hot climate in most months of the year.

The principle involves diverting some of the pumped water to the back of the solar panel, where it absorbs heat, before reintegrating it back into the irrigation circuit. This process allows for rational use of water without any waste.

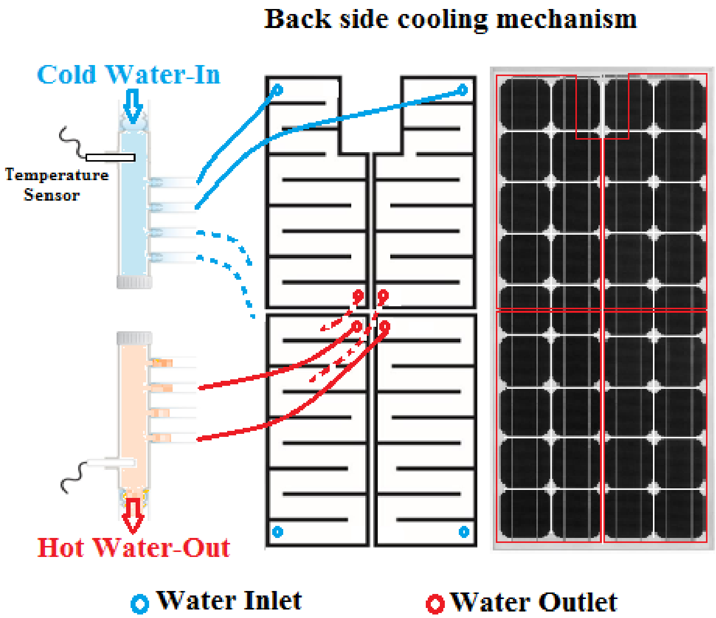

Figure 2: The designed active cooling system

Experimental Rig

In the experimental setup, a comprehensive measurement and control system was implemented to monitor and evaluate the performance of solar module. The system incorporates a power stage to optimize the power output of the PV panels to their Maximum (MPPT) and a set of sensors and electronic components to measure key environmental and electrical parameters. An 85Wp mono-crystalline solar module is used. It is mounted on a mobile frame that allows either sun tracking or tilt angle adjustment. For the preliminary tests, a 22W, 800L/H Brushless DC type pump is used for pumping (and cooling) and a set of sensors were used, Table 1.

Table 1: List of sensors used in the experiment

Parameter	Sensor specifications
Celle and ambient temperature	LM35
water temperature	DS18B20
optimal current	ACS712
Optimal voltage	B25
Solar radiation	PYR 20

For maximum power tracking, an MPPT Charge Controller SR-MT2410 was used to optimize and match between the solar array and the battery and Load pump (Fig. 3).

For continuous data monitoring, an Arduino board is used as an intermediary for data collection and send them synchronously to the main PC where they are stored in a ready to use Excel data.

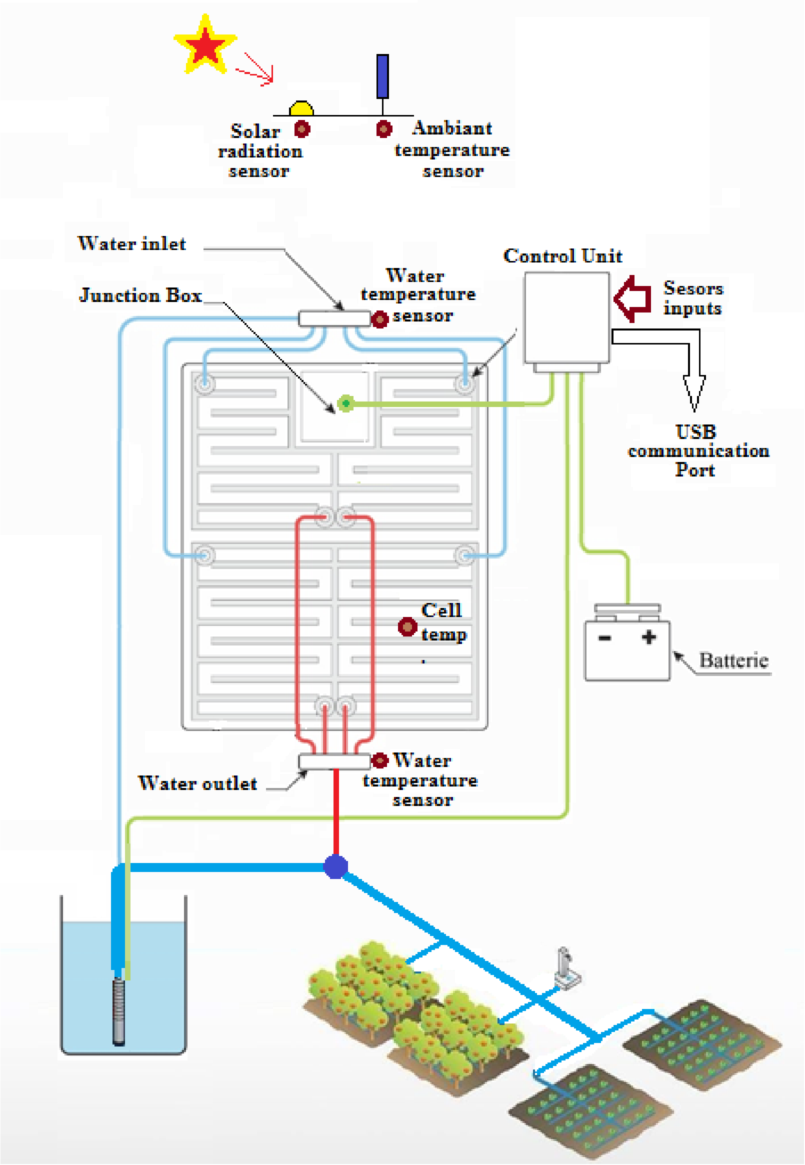

Figure 3: The experimental setup of cooling system

SIMULATION AND EXPERIMENTAL TESTS

Results from both practical and simulation-based work are presented. The solar module under tests is simulated using its characteristic parameters given by the manufacturer. PVSyst software was used in this context to simulate the behaviour of the PV module under various working conditions, mainly at different temperatures and variable solar insolation.

Since PV module performances are directly influenced by sunlight; output current, voltage and subsequent power are shown in Fig. 4 for different levels of solar radiations at STC conditions. However, in real weather conditions, many parameters influence the ideal module operation, especially rising ambient temperature along the day, solar radiations heating effect, wind and humidity effects …etc. Fig. 5 illustrates clearly solar radiation heating effect. The cell temperature rises extensively with rising solar radiation (at constant ambient temperature, 25 C°) which reduces significantly the power yield of the PV module as shown on the P-V characteristics compared to results shown in Fig. 4.

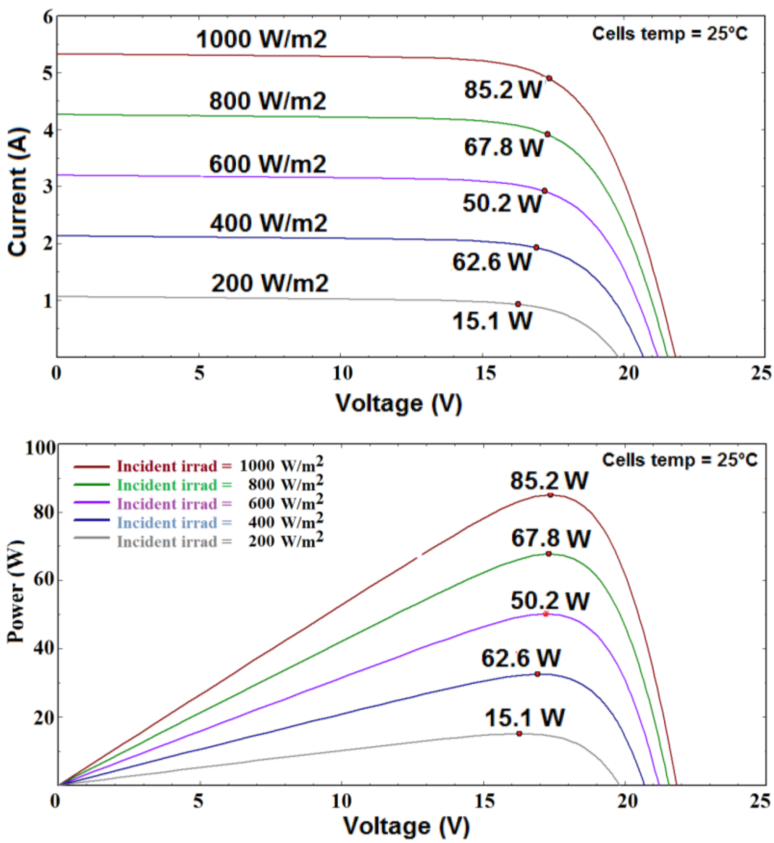

Figure 4: Simulation results of the ALPV 85 solar panel, without heating effect of solar radiation

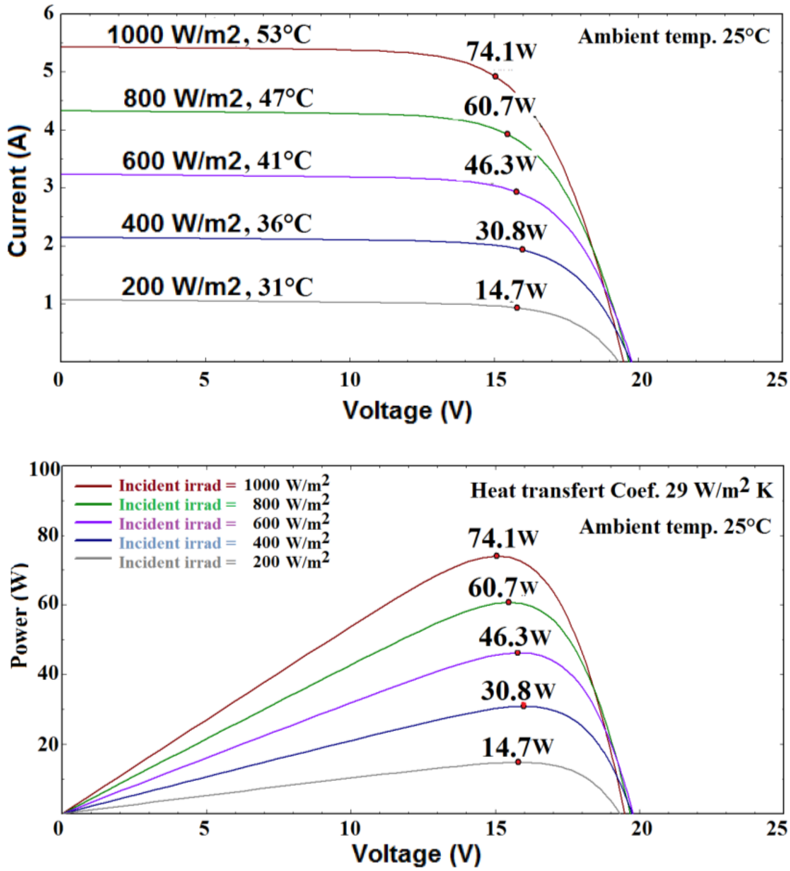

Figure 5: Simulation results of the ALPV 85 solar panel, with heating effect of solar radiation

The effect of rising cell temperature on module efficiency is clearly seen on Fig. 6 obtained by simulation. The module efficiency is given for different solar radiation and increasing solar cell temperature caused mainly by the heating effect of solar radiation in addition to a fixed value of ambient temperature.

This heating effect was investigated practically on the test rig previously described. It is known that Solar cell temperature is affected by a combination of environmental and material factors mainly ambient temperature, solar irradiance, wind speed, material properties and its mounting structure; in addition, humidity, dust accumulation, and even the size and design of the solar cell itself play a role.

Fig. 7 illustrates how cell temperature increases as solar radiation increases. While ambient temperature varies from 25 °C in the morning and reaches its maximum of about to 32 °C in the noon, cell temperature approached 60°C at its maximum at noon and then decreases gradually as solar radiation decreases. This high temperature increase will surely reduce solar module efficiency according to the theoretical curves illustrated previously and depicted in Fig. 6.

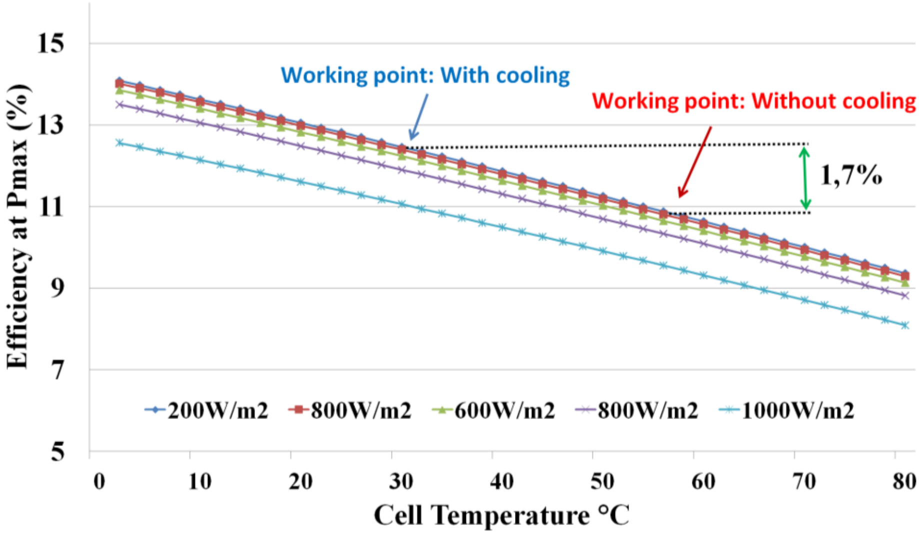

Figure 6: Simulated results of module efficiency versus cell temperature

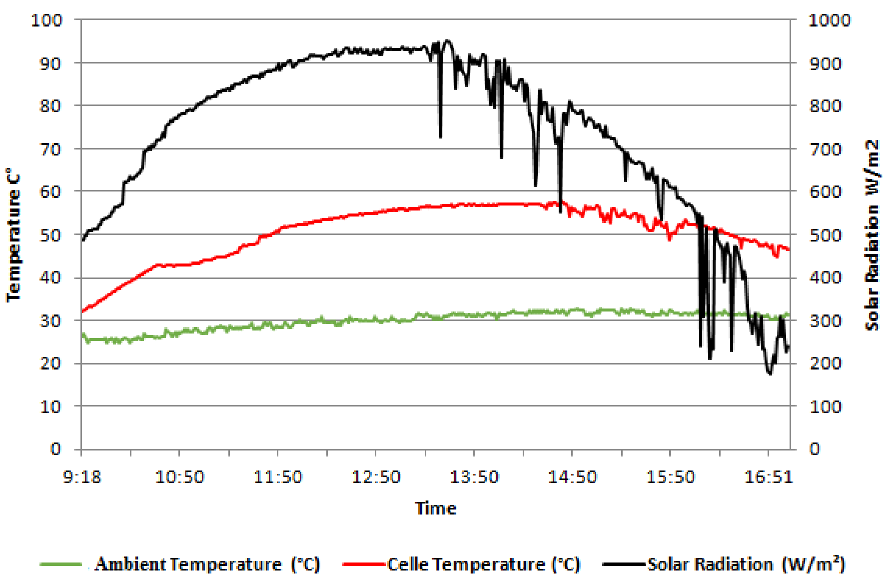

Figure 7: Instantaneous global solar radiation, ambient temperature and cell temperature without cooling

To investigate the cooling effect of the proposed procedure, pumped water is injected in the back of the solar module and collected afterword to be reinjected to the main pipe, Fig. 3. The recorded results for a time period at midday are depicted in Fig. 8. Ambient temperature, initial cooling water temperature at the in-let and the subsequent transmitted water at the outlet are all recorded continuously. As can be seen, the water temperature rises from 28°C to approximately 32 °C absorbing hence heat from the solar panel and cooling subsequently the solar cells to about 33.5°C. Solar cell temperature using the cooling process is compared to the one if the solar panel if not cooled. It is clearly seen that in the normal working conditions, the cell temperature might reach 57°C at 13H while the ambient temperature is only about 29°C. The excessive heat is due to the heating effect of the solar radiations in addition to the ambient temperature effect.

To monitor the daily solar panel thermal behaviour during a sunny day, data were collected for a full day and are illustrated in Fig. 9. It is shown that the negative effect of the solar radiation heating manifest heavily if the module is not cooled. If cooling is adopted, the cell temperature almost aligns with ambient temperature. The difference will depend on the heat transfer between the module materials and the cooling water. Of course, this will depend on the thermal parameters of the materials and the flow rate of the cooling water in the module, which will be determinant.

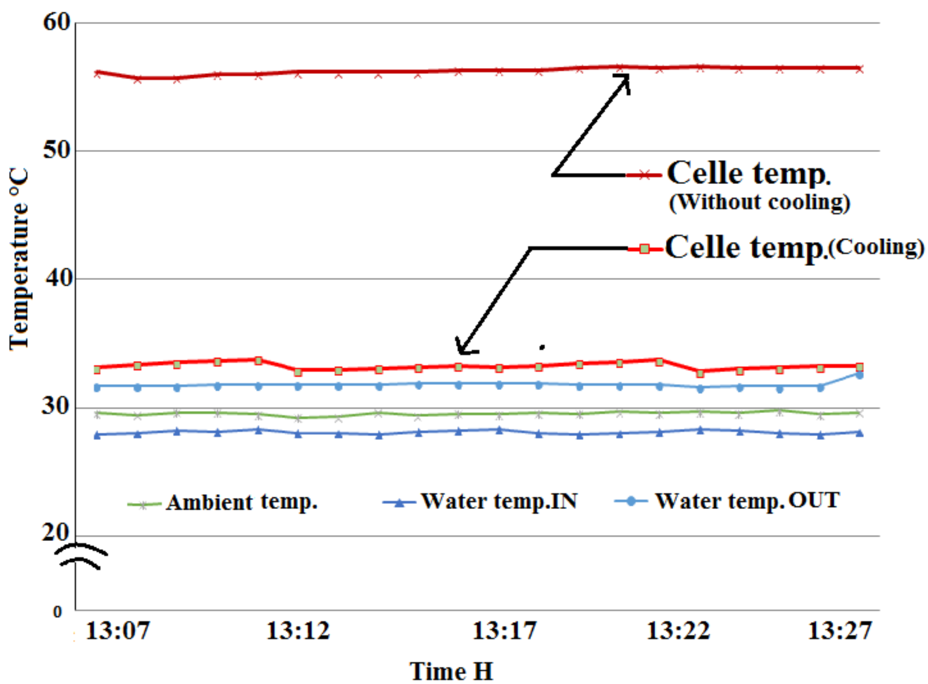

Figure 8: Comparisons on solar panel temperature between cooling and without cooling

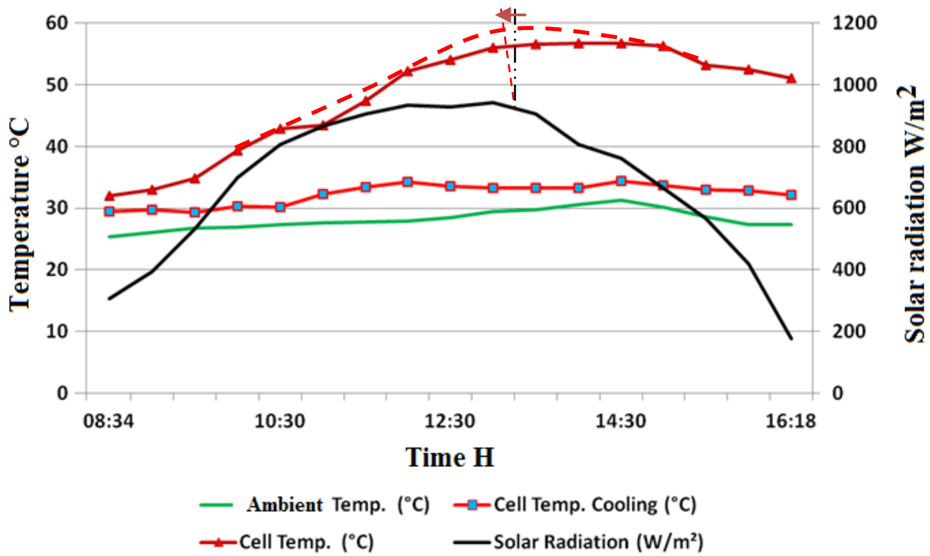

Figure 9: Instantaneous global solar radiation, ambient temperature and cell temperature with and without cooling

In addition, the bell shape of the solar radiation variations is reflected by the solar panel temperature waveform shape (without cooling) with a slight tilt to the left due to the effect of the ambient temperature (dashed line). This was examined throw an approximate mathematical interpolation of the 3 curves, for the day under consideration Fig. 10. Equations 1,2 and 3 reflect the mathematical model of the three parameters:

Ambient temperature (*linearised*)

$$y_1 = 0.0398x + 24.363 \tag{1}$$

Solar radiation

$$y_2 = -0.0111x^2 + 4.5423x + 462.82 \tag{2}$$

and

Cell temperature

$$y_3 = -0.0003x^2 + 0.1804x + 31.275 \tag{3}$$

It is clearly seen that:

$$\text{Cell temperature waveform} = \begin{cases} \text{solar radiation waveform (scaled)} + \\ \text{ambiant temperature waveform (liearised)} \end{cases}$$

This will help future data prediction of module temperature regarding climatic conditions which will assist overall cooling system dimensioning.

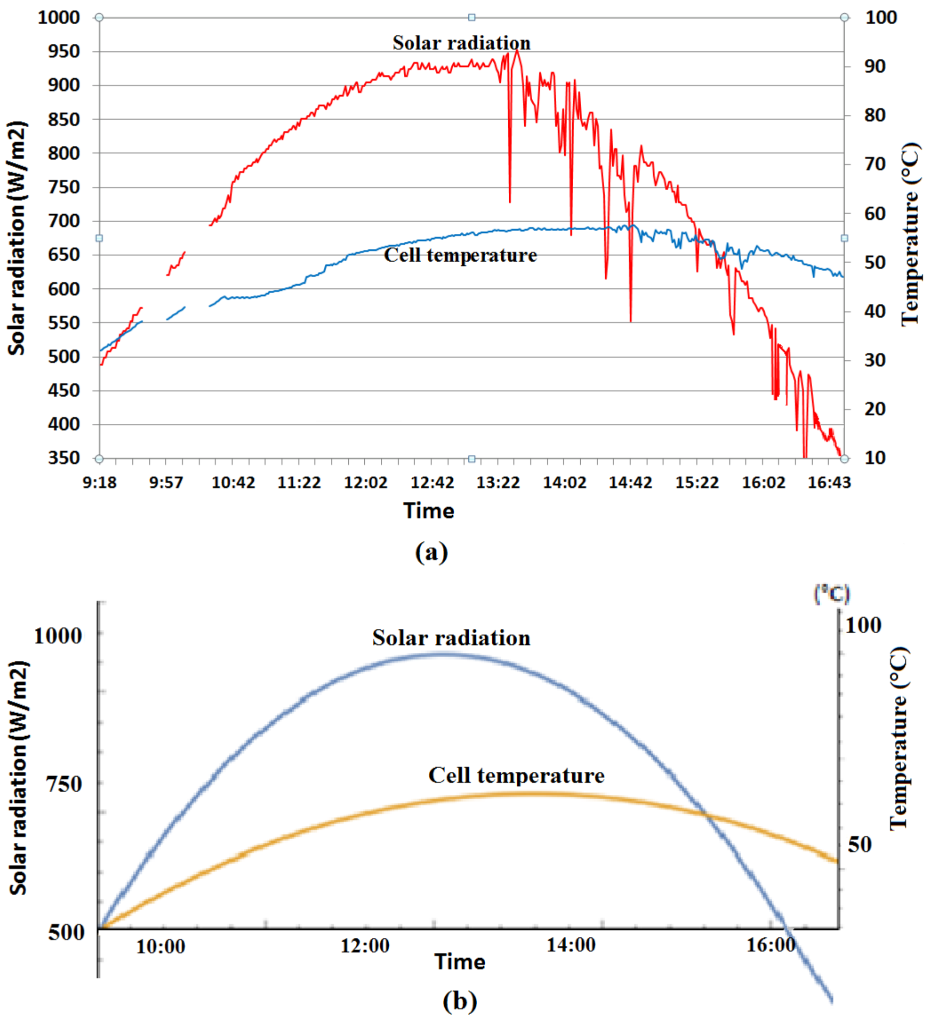

Figure 10: Actual and interpolated results for solar radiation and Cell temperature without cooling; (a) Experimental results; (b) Mathematical interpolation.

Fig. 11 illustrates the daily harvested power along two consecutive days where the climatic conditions were similar (Solar radiation and temperature profiles). It is clearly seen that the power generated under cooling conditions is much higher the one collected in normal conditions (without cooling) with a remarkable increase of 15-20% approximately. This power increase will increase the daily flow rate and hence the overall pumped water quantity. The average power increase is about 20% which might lead to

10% average increase in pump flow rate. This part of the study will be considered in part two f this work (Wu et al., 2022; Moubarak et al., 2017).

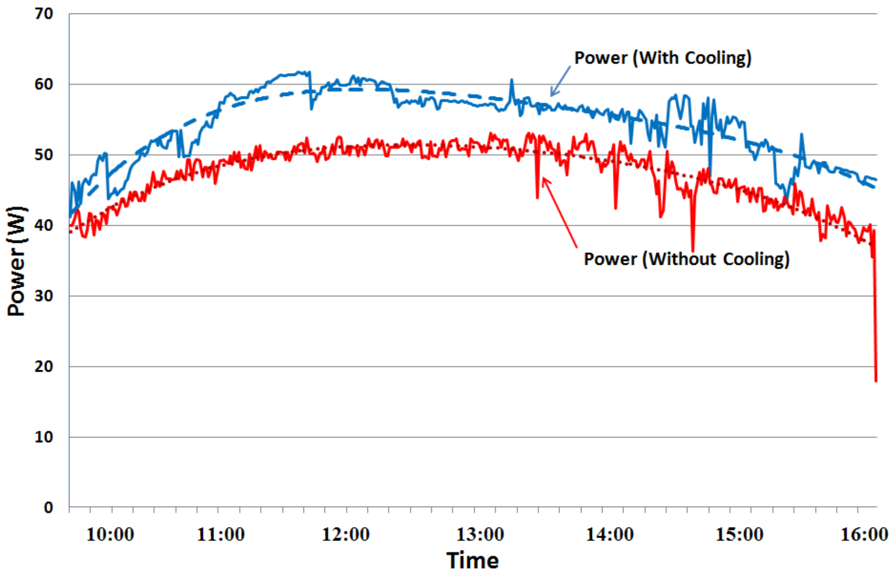

Figure 11: Instantaneous output power with non-cooling and Continuous cooling

CONCLUSION

A cooling system has been proposed for possible system setup of agriculture irrigation system application to cool down the solar panel. The distinguishing result among the solar panels with and without cooling, using an integrated serpentine cooling system at the back of the module is given in Figure 4 revealing the fact about cell temperature and Intensity of radiations. Comparison between temperatures of solar panels with and without cooling made obvious that temperature with water cooling reduces significantly solar module temperature if an appropriate flow rate is observed. For the present test, solar module temperature is reduced by 23°C in a desertic region as shown in figure5, increasing therefore the PV conversion efficiency by 1.7% approximately. This will increase the harvested solar energy consequently and reduce the cost payback time thereafter. This would be investigated in future work as well as a quantitative investigation about water use for cooling and what is the optimal proportion to adopt.

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