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COOLING PHOTOVOLTAIC CELLS USING PHASE CHANGE MATERIALS – EXPERIMENTS AND ECONOMICAL STUDY

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ABSTRACT

This work concerns an experimental study of the effect of Phase Change Materials PCM on the thermal behavior and electrical performance of a Photovoltaic PV panel. To proceed, an appropriate experimental setup is devised and two prototypes constructed and tested. Prototype 1 corresponds to a reference case and consists of a stand, a PV panel, and an electrical circuit with a given load. Prototype 2 corresponds to an enhanced case of prototype 1 with in addition a container at the rear face of the PV panel that holds PCM. It was shown that the use of PCM can increase the electrical efficiency of PV panels by an average of 5%.

الملخص العربي

هذا العمل بخصوص دراسة عملية لتأثير المواد متغيرة الطور PCM على السلوك الحرارى والأداء الكهربى للخلايا الشمسية. لأداء ذلك، صنع جهاز معملى مناسب وأنشأ واختبر نموذجين. النموذج الأول مناظر للحالة المرجعية ويتكون من حامل والخلية الشمسية والدائرة الكهربية بالحمل المعطى. أما النموذج الثانى مناظر للحالة المحسنة أو المتطورة للنموذج الأول وذلك باضافة وعاء يحتوى على المادة نتغيرة الطورPCM تحت السطح السفلى للخلية الشمسية. وقد وجد أن استخدام المواد متغيرة الطور PCM يمكن أن تزيد الكفاءة الكهربائية للخلية الشمسية زيادة متوسطة بمقدار 5%.

Keywords: PV Cell, PCM, Cooling, Efficiency, Experimental Setup.

I. INTRODUCTION

Solar energy concepts are mainly implemented in water heating solar systems (flat collectors) and electricity production solar systems (concentrating solar energy systems) and photovoltaic panels. Photovoltaic cells (PV) are used to convert sunlight energy into electricity by taking the advantage of radiant photons. The efficiency of a PV panel, defined as the ratio of the delivered electrical power to the incident sun irradiation rate, is highly dependent on temperature [1]. For 1 °C increase in the temperature of a crystalline-silicon PV panel, the relative efficiency decrease can be of 0.45 % [2]. At this point, finding ways for decreasing the temperature of a PV panel will increase the panel efficiency.

In the literature, there are several passive and active techniques for removing heat. The most commonly used passive techniques are: (1) techniques relying on the buoyancy driven air flow in a duct [3] or in an opening or air channel in building applications [4] and (2) techniques cooling the photovoltaic panel by a container of Phase Change Material PCM [5]. Active cooling techniques are based on water or air flow on the front [6] or back [7] of the PV surface.

Water cooling may be unsuitable due to the weight of water required [6]. The presence of water is scarce in some locations where the sun irradiation is susceptible to be significant, such as deserts. Moreover, the use of air or water in the active cooling techniques induces additional maintenance issues and operating costs. At this point,

the use of phase change material PCM stands nowadays as the most reliable tool to cool and regulate the temperature of PV panels and then to increase their electrical efficiencies.

Phase Change Materials PCMs are latent heat storage materials. They are basically used for thermal energy storage and control because of their heat absorption and release during the phase change material operation [8]. The use of PCM in cooling PV panels is widely investigated numerically and experimentally [9-11]. Passing through the existent art in cooling PV cells by PCM [12-14], the different methods of using PCM in cooling PV help to improve the performance of PV although there is still more to be explored and improved. In this context, this work concerns an experimental study of the effect of using PCM on the thermal behavior and electrical performance of a PV panel.

II. MATERIALS AND METHODS

In order to test the effect of using PCM on the performance and efficiency of the photovoltaic panel, two prototypes are constructed. Figure 1 shows a schematic of the prototypes.

As shown in the figure, Prototype 1 corresponds to a reference case and consists of a stand, a PV panel, and an electrical circuit with a given load. Prototype 2 corresponds to an enhanced case of prototype 1 with in addition a container at the rear face of the PV panel that holds PCM.

The PCM is used at the mushy state. This state corresponds to the process where the heat absorption occurs. Petroleum jelly PCM with a melting point of 37 °C is used in prototype 2 as pure PCM. This will absorb the excess of heat from the panel leading to more electric flow.

Petroleum jelly is added to the container as mentioned. Aluminum flat plate of length 48.6 cm and width 46.2 cm is placed at the end of the container's rear and fixed with bullets. To prevent leakage of petroleum jelly, any vacuum spacing in the container is filled with RTV grey silicon.

Thermocouples are placed at many locations in the different prototypes. They are placed at the top and rear surfaces of the PV panel in prototype 1. In prototype 2, thermocouples are placed at the top and rear surfaces of the panel, middle of PCM, and at the back aluminum plate (Figure 2).

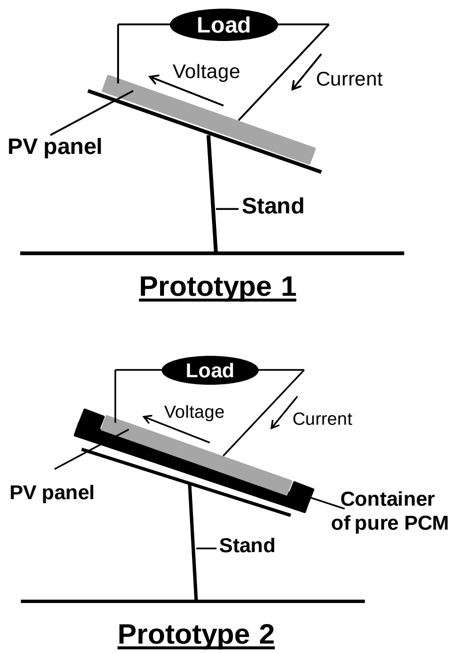

Figure (1): Schematic of the different prototypes constructed

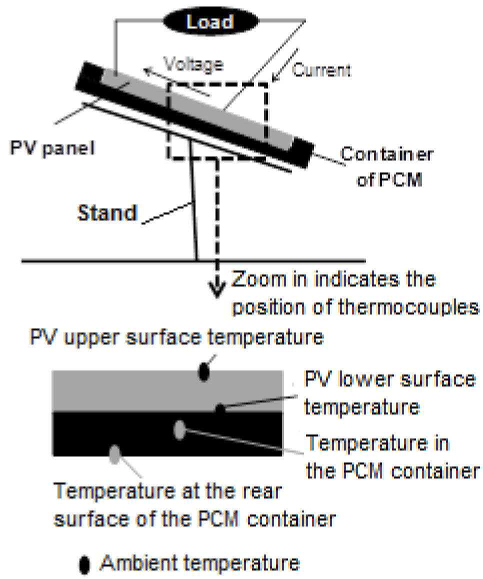

Figure (2): Schematic diagram showing the different locations of the thermocouples

Experiments are planned to show the output voltage and current variation as a function of change in PV panel temperature. In the experiments, Prototypes 1 and 2 are facing the sun at the same time and location and different parameters are recorded;

During testing, the photovoltaic panel, the PCM, angle of the panel, and experiment time are held constant and wind speed, temperatures, output current and voltage are recorded every 10 minutes for three continuous hours.

To measure the output voltage and current, three loads are connected in series with the panel and parallel to each other (Figure 3). An ammeter is connected in series with the panel; also a voltmeter is connected in parallel with the loads.

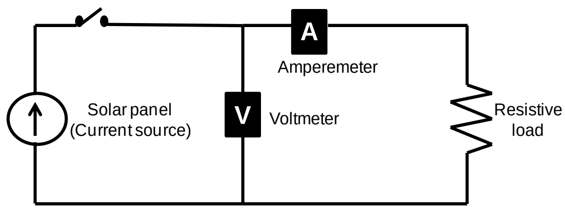

Figure (3): Measuring electric circuit

The output power in Watts is calculated as follows:

$$P_{out} = V.I \qquad (1)$$

Where V is the voltage in volts and I is the current in Amperes.

The intensity of solar irradiation I is measured at many locations and many times and an average value is calculated and used in the calculation of different pertinent parameters.

The efficiency of the PV panel can then be calculated from the following relation:

$$\eta = \frac{P_{out}}{IA} \qquad (2)$$

Where A is the area of the PV panel equal to 0.257 m^2.

III. RESULTS AND ANALYSIS

Figure 4 shows the temporal variation of the PV panel temperature (average of the top and rear surfaces temperatures) and ambient temperature for prototypes 1 and 2.

From Figure 4, it is clear that the temperature of the panel with PCM is lower than that without PCM. As illustrated, the average temperature of the PV increases from 42.8 to 66.3 °C with an average of 59 °C when the PV panel is without PCM and from 36.2 to 65.6 °C with an average of 56.3 °C when the PV panel is cooled by pure PCM at its rear surface. These numbers imply that the PCM use can decrease the temperature of the PV panel up to 6.6 °C and with an average of 2.7 °C.

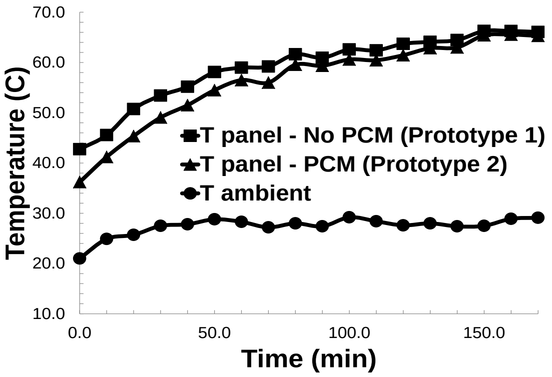

Figure (4): Temporal variation of ambient and PV panel temperatures in prototypes 1 and 2

Figure 5 shows the variation of the PV electrical output power and efficiency in function of time for the reference case and enhanced case using PCM.

From Figure 5-a, it can be shown that power generated by both the PV panels "without PCM" and "with PCM" cases decrease with respect to time. This is attributed to the temperature increase with the time. Moreover, the power generated by the PV panel with pure PCM at its rear face is higher than that of the standard reference case.

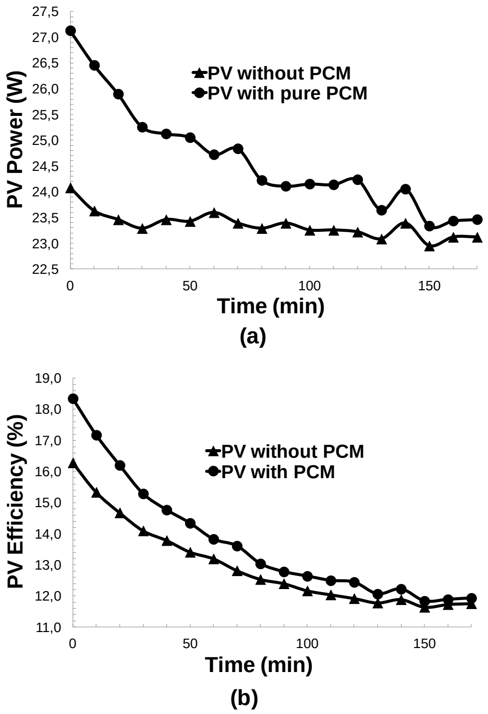

Figure (5): Variation of the PV electrical output power and efficiency in function of time for the reference case and enhanced case using pure PCM

As illustration for the 170 minutes of measurement, the power generated by the PV in prototype 1 decreases from 24.1 to 23.0 W and that generated by the PV in prototype 2 decreases from 27.1 to 23.3 W. Similar behaviors are approximately obtained for the efficiency of the PV panel (Figure 5-b). As illustration for the 170 minutes of measurement, the efficiency of the PV panel in prototype 1 decreases from 16.3 to 11.6 % and from 18.4 to 11.8 % in prototype 2.

The power enhancement percentage is defined as follows:

$$PEP = 100 * \frac{P(\text{Prototype2}) - P(\text{Prototype1})}{P(\text{Prototype1})} \qquad (3)$$

Where $P(\text{Prototype2})$ is the PV panel power obtained in case of prototype 2 and $P(\text{Prototype1})$ is the PV panel power obtained in the reference case of prototype 1.
The efficiency enhancement percentage is defined as follows:

$$EEP = 100 * \frac{\eta(\text{Prototype2}) - \eta(\text{Prototype1})}{\eta(\text{Prototype1})} \qquad (4)$$

Where $\eta(\text{Prototype2})$ is the PV panel efficiency obtained in case of prototype 2 and $\eta(\text{Prototype1})$ is the PV panel efficiency obtained in the reference case of prototype 1.

Figure 6 shows the variation of the power and efficiency enhancement percentages in function of time of measurement.

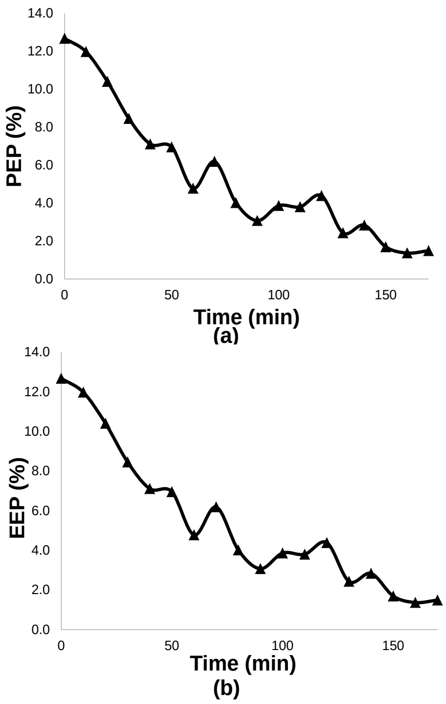

Figure (6): Variation of (a) power and (b) efficiency enhancement percentages in function of time of measurement for prototype 2

As illustration for the 170 minutes of measurement, the power enhancement percentage PEP corresponding to pure PCM varies from 12.7 to 1.4 % with an average of 5.4 %. Concerning the efficiency enhancement percentage EEP, same order of magnitude is obtained.

The area of the used PV panel is 0.257 m^2. This panel gives 22.11 Watts average power without making changes on it, while 23.3 Watts power was obtained when PCM was used. Consider now a field of panels of 1 km^2. Let N be the number of panels that can be placed on 1000 m^2, then:

$$N = \frac{10^6}{0.257} = 3891 \, panels \tag{18}$$

The cost incurred by the installation of PCM to cool the rear surface of the PV panel corresponds to three costs: cost of the container material, cost of manufacturing the container, and cost of the PCM itself.
Each panel needs 4.12 kg of PCM, and then the total amount of PCM needed for 3891 panels is 16.04 tons. The total cost for 1 ton of PCM is 1,350 $ when purchased in tones of the materials. Then, the total cost of PCM to be installed is 21 654 $.

The amount of aluminum used in each container is 2.6 kg costing 1.2 $/kg when purchased in tones of the materials. Then, the total amount of aluminum required is 10.12 tons and the total cost of aluminum used in the containers will be 12 144 $.

The cost of manufacturing one container is 1 $ when done for tones quantities. Then, the total cost of manufacturing the containers is 3891 $.

Finally, the total cost incurred in installing the PCM containers is 37 689 $.

Now, considering the field working for 12 hours/day, the energy saving per day will be 1.2 W/panel/day * 3891 panels * 12 hours = 56 kWh/day. Then with a 0.15 $/kWh cost in Lebanon, the money saving per day will be 8.4 $/day.

Finally, the installation of PCM containers to cool the rear surface of a PV panel will provide money saving of 252.2 $ per month and will have a payback period of:

$$\begin{aligned} Payback\ Period &= \frac{37689\$}{8.4\$/day} \\ &= 4487\ days = 12.3\ years \end{aligned} \tag{19}$$

IV. CONCLUSION

The present work introduces an experimental study of the effect of using PCM on the thermal behavior and electrical performance of a PV panel.

It is found that the use of PCM can decrease the temperature of PV panels by up to 6.5 °C with an average of 2.7 °C and then increase the electrical efficiency by an average of 5 %. The total cost for installing the PCM containers required for 3891 solar panels is $37,689. The payback period, according to this study, is about 12.3 years.

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