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Photovoltaic Cooling Using Phase Change Material

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Abstract

In this work an experimental work was conducted to improve the performance of photovoltaic panels (PV) by cooling them using phase change materials (PCM). A photovoltaic system made up of two identical PV panels were installed side by side, PCM was integrated on the back side of one of these photovoltaic panels, while the other one was kept as a standard one for comparison purposes. A micro converter with all necessary accessories to conduct the work were also used. The generated currents and voltages, temperatures of the ambient and the PV panels and the incident solar irradiance were recorded on hourly basis for twenty-eight days using a data acquisition system. The stored data was analyzed and it was found that the cooled PV panel using PCM had performed 2.6% better than the standard panel.

Keywords: *Photovoltaic Panels (PV), Phase Change Materials (PCM), Photovoltaic Cooling*

1. Introduction

Worldwide energy has become the main concern for nations, especially with unpredictable fossil fuel prices, political driven energy market, global warming, environmental aspects, and the future availability of fossil fuel versus demand. This has driven researchers to study the possibility to compensate part of the energy which is generated by fossil fuel with alternative and sustainable resources. Among such sources, solar energy was found to be a very promising source of energy.

Solar energy is converted into electricity using Photovoltaic cells (PV) with maximum efficiency at around 15-20 %, depending on the type of solar cells. Almost 80% of the solar radiation reaching the (PV) will be reflected or transformed into heat energy. This leads to an increase in the cells temperature, and consequently a drop in the PV efficiency. So a reliable heat dissipation system is needed to cool the cells effectively in order to enhance the efficiency of the cells.

Tonui and Tripanagnostopoulos (2007a) [1] studied the use of a suspended thin flat metallic sheet at the middle or fins at the back wall of an air duct as heat transfer augmentations in an air-cooled photovoltaic/thermal (PV/T) solar collector to improve its overall performance. The steady-state thermal efficiencies of the modified systems are compared with those of typical PV/T air system. Daily temperature profiles of the outlet air, the PV rear surface and channel back wall are presented confirming the contribution of the modifications in increasing system electrical and thermal outputs and found that photovoltaic (PV) panels suffer efficiency drop as their operating temperature increases especially under high insolation levels.

Tonui and Tripanagnostopoulos (2007 b) [2] studied the performance of two low cost heat extraction improvement modifications in the channel of a PV/T air system to achieve higher thermal output and PV cooling so as to keep the electrical efficiency at acceptable level. The validated model was then used to study the effect of the channel depth, channel length and mass flow rate on electrical and thermal efficiency. PV cooling and pressure drop for both improved and typical PV/T air systems and their results were compared. Both experimental and theoretical results showed that the suggested modifications improved the performance of the PV/T air system and the excess temperatures on installed photovoltaic (PV) modules lead to efficiency loss and PV cooling protected them from this undesirable efficiency drop.

Odeh and Behnia (2009) [3] carried out a long-term performance modeling of a proposed solar-water pumping system, which consists of a PV module cooled by water, a submersible water pump, and a water storage tank. Cooling of the PV panel is achieved by introducing water trickling configuration on the upper surface of the panel. The experimental results indicated that an increase of about 15% in system output is achieved at peak radiation conditions. Long-term performance of the system is estimated by integrating test results in a commercial transient simulation package using site radiation and ambient temperature data. The simulation results of the system's annual performance indicated that an increase of 5% in delivered energy from the PV module can be achieved during dry and warm seasons.

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Huang (2011) [4] has modified a numerical simulation model for single PCM application to predict the thermal performance of the multi-PCMs in a triangular cell system. Having conducted a series of numerical simulations tests in static state and realistic conditions, he discussed the thermal regulation of the PV/PCM system with a different range of phase transient temperature PCMs .

Teo et al (2012) [5] have designed, fabricated and experimentally investigated a hybrid photovoltaic/thermal (PV/T) solar system to actively cool the PV cells, a parallel array of ducts with inlet/outlet manifold designed for uniform airflow distribution was attached to the back of the PV panel. Experiments were performed with and without active cooling. A linear trend between the efficiency and temperature was found. Without active cooling, the temperature of the module was high and solar cells can only achieve an efficiency of 8–9%. However, when the module was operated under active cooling condition, the temperature dropped significantly leading to an increase in efficiency of solar cells to between 12% and 14%.

Zhao and Tan (2014) [6] have investigated the theoretical performance characteristics of PV modules using an adapted analytical model.A prototype thermoelectric system integrated with PCM heat storage unit for space cooling is used for this study. It was found that using PCM heat storage unit leads to a saving of 35.3% in electrical energy.

Hasan et al (2014) [7] studied the effect of using PCM to cool PV panels in two different countries, Ireland and Pakistan by integrating PCM into PV panels to absorb excess heat. Electrical and thermal energy efficiency analysis of PV-PCM systems was conducted to evaluate their effectiveness and found that in Ireland the financial benefit of both PV-PCM systems is less than the cost incurred to mass produce such systems confirming that such systems are not cost effective in Ireland. However, the cost of the PV-PCM systems is almost half of the benefit in Pakistan which shows that such systems are cost effective in such climates, and thus encourages the possibility of future research to improve performance to make them more effective.

Tan and Zhao (2015)[8] have proposed a numerical model for space cooling purpose using a thermoelectric cooling system integrated with phase change material (PCM). The analysis conducted was under two modes (1) dissipating the generated heat directly to outdoor air through the air-water heat exchanger, and (2) releasing heat to the shell-and-tube PCM heat storage unit. The model was validated using experimental work, which showed the average system cooling COP is increased by 56% (from 0.5 to 0.78) due to PCM integration.

The performance of a PV/T module that employs a Micro-encapsulated Phase Change Material slurry as the working fluid was presented by Qui et.al (2015)[9]. It was found that the established model, based on the Hottel–Whillier assumption, was able to predict the energy performance of the MPCM slurry based PV/T system at a very good accuracy, with 0.3–0.4% difference compared to a validated model. Furthermore, and under the turbulent flow condition, an increase in the concentration of the slurry leads to an improvement in the performance of the module, which is due to the drop in temperature. Also, it was found that the net efficiency of the PV/T module reached the peak level at the concentration ratio of 5%.

For Jordan which is located in the Sun Belt area, solar energy is considered one of the best renewable energy resources to be used in heating water or generating electricity; with the fact that the average daily solar irradiation in Jordan is between 5 to 7 kWh/m^2 and the total annual irradiation is between 1600 to 2300 kWh/m2. This proves to provide strong potential for energy generation in a sustainable way (EPIA, 2013) [10].

The main objective of this was to investigate the effect of cooling PV panels using phase change materials. To achieve this, a system was built using two identical panels of 250 Watt peak each. Both systems are installed at a tilt angle of 26 and facing south, one of the PV panels was a base unit and used for comparison purposes, while the second one was cooled by a PCM. The two panels were installed side by side and instantaneous measurements. The system is equipped with all necessary instruments to collect the performance data for each panel separately.

2. Experimental setup

As shown in figure 1, the experimental main components used in this work are:

1. Two Poly-Crystalline PV panels.

Each panel has 250Wp as nominal power and consists of 60 poly crystalline cells with 3.2mm low iron glass as a cover and aluminum anodized frame for protection.

2. Two micro inverters

These inverters enable individual panel control when flexibility and modularity is required which also can reduce shading and mismatching effect. Micro inverters are also equipped with a Maximum Power Point Tracker (MPPT) algorithm that maximizes energy and flexibility with an efficiency of 96.5 %, hot dip galvanized steel structure for fixing PV panels

3. Monitoring system and data acquisition system including weather station and the following devices

a) Radiation sensor (Photoelectric).
b) Two Temperature Sensors (RTD).
c) Ambient Temperature sensor.
d) Two current clamps.

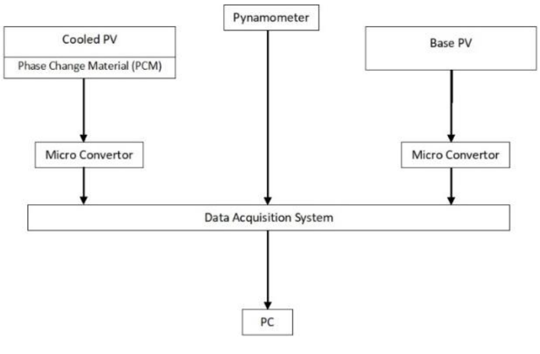

Figure 1. Experimental setup

PCM was chosen to have a melting point close to the V panels STC temperature condition; a product number 51-27 was used from PHASE CHANGE energy solutions. Table 1 shows the chosen PCM properties.

Table 1. PCM properties.

Parameter	Units	Value
Melting point	°C	27
Freeze point	°C	20
Latent heat storage capacity	J/g	200
Latent heat storage capacity	kWh/m²	0.161
PCM Weight per m²	kg	2.7

3. Experimental procedure

The two mounting systems were installed to face south at 26° tilt angel, the PV panels were installed on top of the mounting system and fixed using bolts and nuts. One PV module was covered from the back side with aluminum sheet, so it can accommodate the PCM while the other was used a base panel. The PCM was loaded manually to fill up the space between the aluminum sheet and the backside of the module, 8.33 Kg of PCM was enough to fill up the empty space between the sheet and the module which is equivalent to 3.03 m^2.

The Modules were connected to the micro inverters, which were connected to the data acquisition system. Also connected to the DAS, the pyranometer, which was used to measure the hourly incident solar radiation intensity and the temperatures sensors used to measure the ambient and the panel temperatures. The parameters that affect the performance of each panel were collected and analyzed to implement s the objectives of the experiment.

4. Results and Discussion

The ambient temperature, cooled module temperature, standard module temperature, irradiance and both PV panels performance expressed in terms of accumulative energy produced were recorded and stored through data acquisition system into a PC on a daily basis.

The accumulated daily energy production during the working period between 24th Oct 2014 and 18th Nov 2014 is presented in figure2. It may be noticed from this figure that there is a difference in the accumulative performance of the cooled panel and the base panel with a difference value of 2.6% based on the period during which work was conducted. The cooled panel generated 27.7 kWh, while the base one generated 26.9 kWh.

Figure 3 shows the daily energy generated by each panel and figure 4 shows the average daily temperature for each panels. As indicated in this figure the ambient maximum and minimum temperatures were recorded on 26th of October and 16th of November respectively. Consequently, only these days will be considered in this section.

Figure 4 shows the hourly generation from 6 am to 6 pm on 26th of Oct., which shows the highest ambient temperature and the highest average temperature for the panels cooled by PCM. While figure 5 shows the accumulative energy by each panel during this day.

From the figures above it can be noticed that the energy gap between the PCM cooled panel and the standard panel is 1.78% only, which is lower than the average energy gap for the whole experiment, with the value 2.6%.

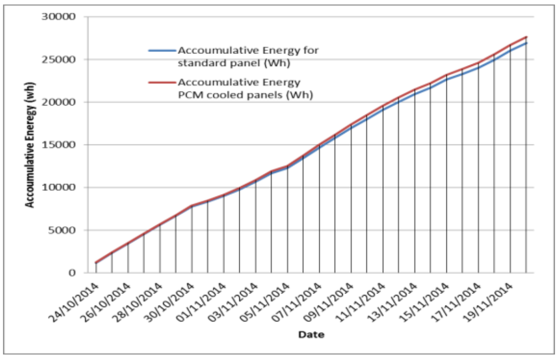

Figure 2. Accumulative energy generated for PCM cooled and standard PV panels.

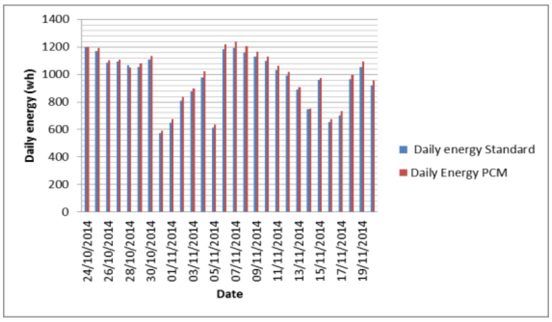

Figure 3. Daily energy generated for PCM cooled and standard PV panels.

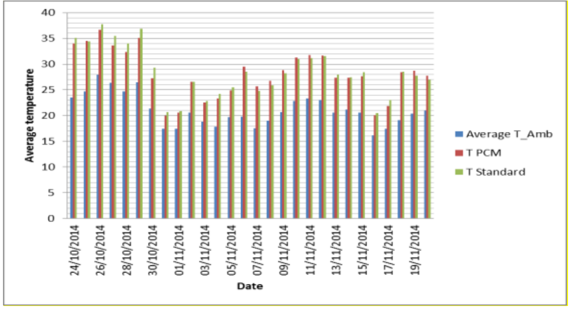

Figure 4. Daily average temperature for ambient, PCM cooled and standard panels

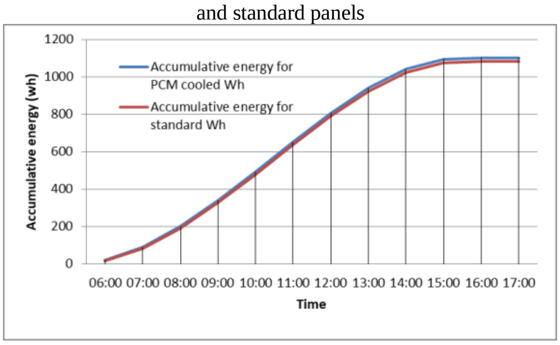

Figure 5. Accumulated energy generation on 26th Oct

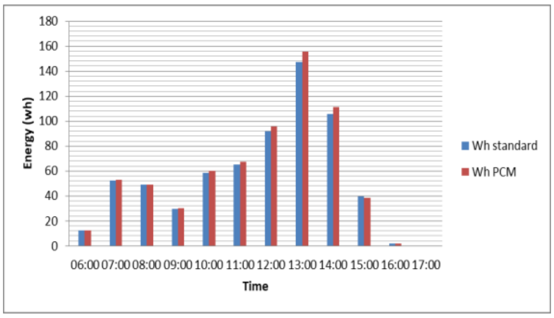

Figure 6. Hourly energy generation on 16th Nov

Figure 6, shows the hourly generation from 6 am to 6 pm on 16th of Nov., as indicated in this figure, the lowest average ambient temp and the lowest average temperature for the standard panel. Figure 7, shows the accumulative energy by each panel.

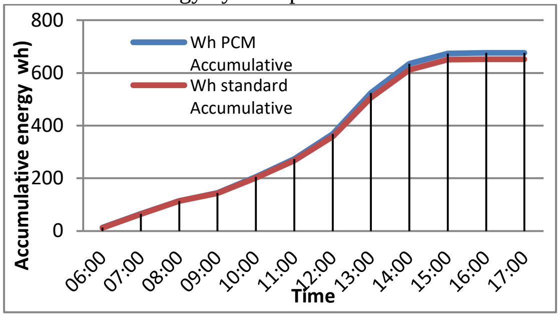

Figure 7. Accumulative energy generation on 16th of Nov

From these figures above it may be noticed that the energy gap between the PCM cooled panel and the standard panel is 3.6%, which is higher than the average energy gap for the whole experiment which was 2.6%.

From the above discussion, and based on the selected samples, on the extreme data collected and on the period of the experiment and location it may be concluded that as the temperature increases the energy gap between the cooled and the standard module will be less than the average energy gap for the total experiment. This means that lower performance than the average performance for the PCM cooled panels. While during the day with the lowest radiation and the day with the lowest average temperature the cooled PV by PCM showed a better performance than the average performance. This may be attributed to the capacity of storing energy in the PCM

On the other hand, on the lowest average temperature day (16th Nov., 2014), it was found that the maximum energy that can be absorbed within the PCM from the total energy delivered to the surface of the panel is 11.3% which will reflect positively on the performance of PCM cooled panel by absorbing a higher percentage of energy preventing it to increase the temperature of the PV panel.

Furthermore, it was observed that the PCM cooled panel showed lower performance compared with the standard panel when temperature and radiation dropped at the end of each day, which leads to the fact that the PCM is approaching the freezing temperature point and causing it to be a heat source and hence the PCM cooled panel temperature will be higher than the standard panel causing a drop in performance.

5. Conclusions

In this work, the effect of cooling PV panels using phase change materials was investigated by using a system. To achieve this, a system was designed and constructed, this consistd of two identical panels of 250 Watt peak each and installed at a tilt angle of 26 and facing south, one of the PV panels is installed normally (without being cooled) and the other one is covered from the back side with PCM.

From this work, it may be concluded that the PCM cooled panel performed better that the standard panel, the stored data was analyzed and the main findings were that the cooled PV panel using PCM had performed 2.6% better than the standard panel.

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