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Development of Electrical Power Output Simulation for Photovoltaic Cell

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Abstract: The objective of this study presents how to increase the electrical efficiency and power output of Photovoltaic (PV) panel by using Phase Change Material (PCM) to cool the back surface of PV as a passive way. These are dependent on its back temperature when the back cell temperature increases its electrical efficiency decreases. The current research is based on experimental study the effect of using paraffin wax as a PCM on thermal behavior and electrical performance of a PV panel by compared the performance of PV/PCM to that of conventional PV. A simulation of both PV panels in MATLAB Software was performed to calculate the I-V and P-V characteristic to evaluate the MPP. The final results showed that for 4 h of testing the efficiency of PV/PCM panel range from 19.66-12.72% and from 18.84-12.24% for conventional PV. Also, the maximum enhancement Electrical Efficiency Percentage (EEP) is 6.89%.

Key words: Photovoltaics (PV), Phase Change Material (PCM), efficiency, back cell temperature, maximum, panel

INTRODUCTION

The requirement on fossil fuels for power generation is one of the most discussed problems in the previous few decades. These discussions associated with the great demand on energy in the future. By 2035, the world energy consumption is projected to increase by approximately 49% from year 2007. Also to the environmental effects behind fossil fuel burning. Therefore, the countries should be careful in using energy sources and they must hardly reduce the fossil fuels share as possible and try substitute it with other clean, environmentally friendly and renewable energy resources such as solar energy, hydropower, wind energy and others. Duran *et al.* (2008) showed that the using solar energy is an efficient way in producing electrical and thermal energy, greenhouse gases emission reduction (clean energy), reducing the importing rates of fossil fuels in addition to the industrial and economic development most attention of alternative energies is solar energy. There are two types of technology that employed solar energy, namely solar thermal and solar cell. A solar cell (PV cell) converts the sunlight into the electrical energy by photovoltaic effect. Energy from PV modules offers several advantages such as requirement of little maintenance and no environmental pollution. Lately, PV arrays are used in many applications, for example, battery charges, solar powered water pumping systems, grid-connected PV systems, satellite power systems and solar hybrid vehicles.

High operating temperatures induce a loss of efficiency in solar photovoltaic and thermal panels. Elevated operating temperature reduce the solar to electrical conversion efficiency of photovoltaic devices. Phase Change Material (PCM) can absorb a large amount of energy over a limited temperature range during phase change. PCM are of interest for use in applications as diverse as thermal energy storage and the thermal management of systems as well as for active and passive cooling of electronic devices. A number of researchers have investigated the behavior of this process experimentally. Maiti *et al.* (2011) carried out to take advantage of the enhanced solar insolation in V-trough while limiting the temperature of the Photovoltaic (PV) module at nearby the maximum 65°C observed for conventional usage without any concentration. Paraffin wax of 56-58°C melting range was selected as a Phase Change Material (PCM) and integrated at the rear of the module to absorb the excess heat. The problem of the low thermal conductivity of the wax was solved with the help of packed metal turnings wherein the wax resided. Two sets of experiments were achieved indoor and outdoor. Employing a 0.06 m thick bed of the PCM medium, the module temperature in the indoor experiment could be kept at 65-68°C for 3 h whereas in its absence the temperature rose beyond 90°C within 15 min. In outdoor studies, the module temperature in V-trough could be reduced from 78-62°C with the PCM assembly and operation could be constant throughout the day. Using the V-trough PV-PCM system, the output power over the day could be improved 1.55 times with self-regulation

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of temperature. The molten wax formed during operation re-solidified during the evening and night and could be recycled. Park *et al.* (2014) examined the performance improvement of a vertical PV module with the application of a Phase Change Material (PCM) in a device known as a PV/PCM module was examined in an experiment. The PCM could avoid the PV module from overheating by absorbing a considerable amount of heat during the phase change. A simulation was also carried out to analyze the annual electric energy generation with changes in the installation direction of the PV/PCM module and the melting temperatures and depths of the PCM. Through an investigation of the results, the optimal melting temperatures and thicknesses of the PCM according to the installation directions were presented. When the amount of vertical solar radiation was high and when the outdoor air temperature was moderate, the electric power output of the PV module was increased by at most 3% using the PCM. However, during the Winter, the effect of the PCM was decreased. The best melting temperature was determined to be 298 K in all installation directions. The optimal PCM thickness varied slightly depending on the installation direction of the PV/PCM module. The amount of electric power generation was increased by 1.0-1.5% compared to that of the conventional PV module. Khanna *et al.* (2017) extracted the heat by attaching a box comprising a Phase Change Material (PCM) behind the PV panel. Due to the large latent heat of PCM, it can absorb heat without a rise in temperature. It will lower down the PV temperature and will increase its efficiency. The available numerical studies analyzed the vertical PV/PCM systems. However, PV panels are generally tilted according to the latitude of the place. The effects of melting-temperature of PCM, tilt-angle, wind-velocity, wind-direction and ambient-temperature on the rate of heat extraction by PCM, melting process of PCM and temperature of the PV/PCM system are also studied. The results show that as tilt-angle increases from 0-90°, the PV temperature in (PV/PCM system) decreases from 43.4-34.5°C which leads to increase in PV efficiency from 18.1-19%. The comparison of PV/PCM with only PV is also carried out and it is found that PV temperature can be reduced by 19°C by using PCM and efficiency can be improved from 17.1-19%. Villalva *et al.* (2009) showed that PV module has a non-linear voltage-current (V-I) characteristic which can be modeled using current sources, diodes and resistors. Single-diode and double-diode models are windely used to simulate PV characteristics. The single-diode model emulates the PV characteristics fairly and accurately. The manufacturer provides information about the electrical characteristics of PV by specifying certain points in its V-I characteristics which are called remarkable points.

In the current research, it uses paraffin wax with melting temperature 42°C as a PCM in order to improve the energy output and electrical efficiency of the PV cell. This study compared the performance of PV/PCM module to that of a conventional PV module under real outdoor climatic conditions in an effort to determine whether a PV module with a PCM shows improved performance. Theoretical work for simulation the I-V and P-V to produce MPP was performed.

MATERIALS AND METHODS

Experimental setup: The rig designed by using two a polycrystalline silicon PV cells module type (FRS-50 W) with dimensions 64 cm long, 54 cm width and 4 cm thickness. Bagher *et al.* (2015) detailed the PV layers as illustrates in Fig. 1. One of them is used the PCM, known as a PV/PCM module. The PCM was attached on the back side of the PV module and enclosed with acrylic glass. The detailed electrical properties of the PV cellare shown in Table 1. The thermophysical properties of PCM which is used in experimental study are listed in Table 2. The melting temperatures, latent heats of melting and heat capacities are measured by Differential Scanning Calorimetric (DSC) technique. The temperature of backside for two cells were measured by temperature recorder device model (BTM-4205D) with 12-channels of thermocouples sensor type K with SD card and auto data

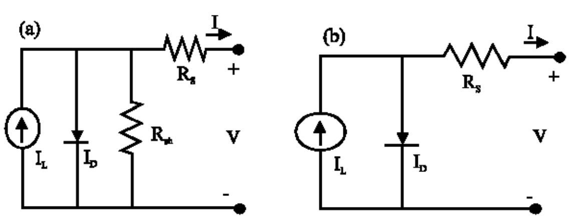

Fig. 1: PV-cell equivalent-circuit models: a) Single-diode model and b) Simplified-PV-equivalent circuit

Table 1: Photovoltaic electrical properties

Variables	Values
Peak Power (P_{max})	50 (W)
Peak Voltage (V_{mp})	18 (V)
Peak current (I_{mp})	2.8 (A)
Short circuit current (I_{sc})	3.17 (A)
Open circuit Voltage (V_{oc})	22 (V)

Table 2: Thermos-physical properties of paraffin (Nizetic *et al.*, 2018)

Property	Paraffin 42
Melting temperature (°C)	41.76 measured
Latent heat (kJ/kg)	140 measured
Specific heat of solid (kJ/kg-°C)	2.21
Specific heat of liquid (kJ/kg-°C)	2.95
Thermal conductivity of solid (W/m-°C)	0.2
Density of solid (kg/m^3)	760
Density of liquid (kg/m^3)	818

logger working. These readings were calibrated with digital calibration device type (Prova Model 123) and produced a polynomial equation to correct the temperature readings. Solar power meter data logger device was used to measure the intensity of solar radiation which incident of the two cells. Solar module analyzer device was used to measure and plot the output of voltage and current of PV. It calculates the maximum electrical output power upon the maximum voltage and current. Hot wire anemometer device model (YK-2005AH) was used to measure wind speed around the two cells. It has thermistor thermometer to read the ambient temperature.

They holed by metal frames and installed in the outdoor of laboratory building of Mechanihecal Engineering Department at University of Babylon, Iraq. These are installed at coordinates of site 23° 2329.3 North, 44, 24 00.5 East. Japs *et al.* (2016) recomended about the position of PV cell, it should be mounted with 30 for inclination with horizontal and a azimuth angle of 0°. The experimental works are conducted in Babylon, Iraq for 7 days from 12th-19th March 2018. These two PV cells with measurement devices are combined the experimental rig of this current research. A photograph and schematic diagram of the rig are illustrated in Fig. 2 and 3, respectively.

Simulation model: A method of modeling and simulation Photovoltaic (PV) module that implemented in design computer program in MATLAB Software. It is necessary to define a circuit-based simulation model for a PV cell in order to allow the interaction with a power converter. Characteristics of PV cells that are affected by irradiation and temperature are modeled by a circuit model. In the simulation model used a simplified PV cell with single-diode a current source is parallel with it. It is necessary to Model PV for the design and simulation of Maximum Power Point Tracking (MPPT) for PV system applications. A single-diode model of PV has four components: photo-current source, diode parallel to source, series of resistor R_s and shunt resistor R_{sh}. The shunt resistance Rsh is large, so, it usually can be neglected. Then, four-parameter models can be simplified equivalent-circuit model of this study as shown in Fig. 4.

Krismadinata *et al.* (2013) detailed how to calculate the load current I in PV cell depending upon the value of out voltage, solar irradiance and many parameters in order to obtain the I-V relationship to get the electrical power output of PV equivlent circuit. They presented in Eq. 1 as:

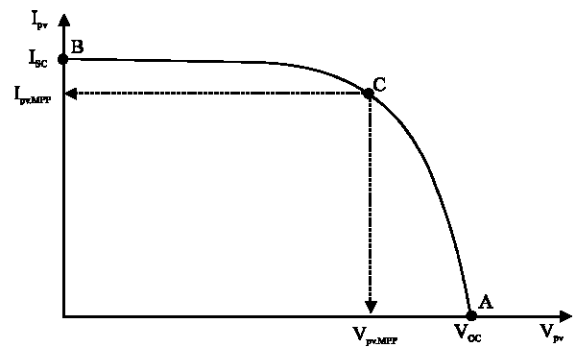

Fig. 2: PV-cell operating point on I-V curve

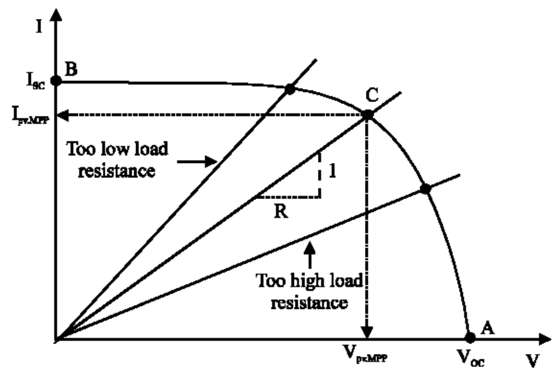

Fig. 3: Intersection of I-V characteristic and the load characteristic curve

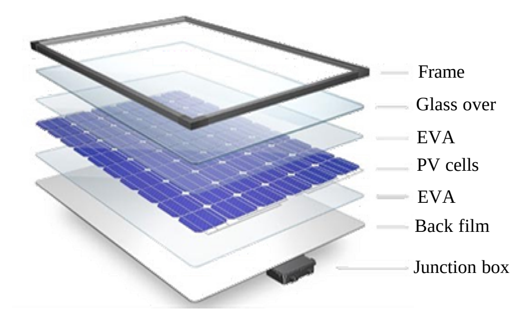

Fig. 4: Polycrystalline silicon photovoltaic layers (Bagher *et al.*, 2015)

$$I = I_L - I_D = I_L - I_o\left[\exp\left(\frac{V+IR_s}{a} - 1\right)\right] \quad (1)$$

where, the V is the voltage which was measured through experment research with time. The load current was depended upon many parameters. Four parameters (I_L, I_0, R_S and) must be determined to obtain the I-V relationship. The four parameters are functions of temperature and solar irradiance. Ulleberg (1998) showed that light current I_L can be calculated as:

$$I_L = \frac{G}{G_{ref}}\left[I_{L,\,ref} + \mu_{I,sc}(T_c - T_{c,ref})\right] \quad (2)$$

Townsend (1989) reported the equation for calculation the another factor in Eq. 1 which is tha saturation current I_0 as:

$$I_o = I_{o,\,ref}\left(\frac{T_{c,\,ref}+273}{T_c+273}\right)\exp\left[\frac{e_{gap}N_s}{q_e a_{ref}}\left(1-\frac{T_{c,ref}+273}{T_c+273}\right)\right] \quad (3)$$

$I_{o,\,ref}$ is saturation current (A) at reference conditions can calculated as:

$$I_{o,\,ref} = I_{L,\,ref}\exp\left(-\frac{V_{oc,\,ref}}{a_{ref}}\right) \quad (4)$$

where, $V_{oc,\,ref}$ is the reference-condition open-circuit Voltage (V) of the PV module its value is manufacturer-provided. Townsend (1989) pointed how to esitmate the a_{ref} as:

$$a_{ref} = \frac{2V_{mp,\,ref} - V_{oc,\,ref}}{\frac{I_{sc,\,ref}}{I_{sc,\,ref}-I_{mp,\,ref}}+\ln\left(1-\frac{I_{mp,\,ref}}{I_{sc,\,ref}}\right)} \quad (5)$$

Wang (2006) explain how to calculate the another two parameters in Eq. 1 which are a_{ref} and the series resistance a is a function of temperature, expressed as:

$$a = \frac{T_c+273}{T_{c,ref}+273}a_{ref} \quad (6)$$

Then, the series Resistance R_s is estimated by Eq. 7 as:

$$R_s = \frac{a_{ref}\ln\left(1-\frac{I_{mp,\,ref}}{I_{sc,\,ref}}\right)+V_{oc,\,ref}-V_{mp,\,ref}}{I_{mp,\,ref}} \quad (7)$$

Figure 5 shows the I-V operating characteristics of a solar cell and gives suitable power rating. Its characteristics are determinable by multiplying the voltage of cell by the current of the cell. Three important operating points are open-circuit voltage, shortcircuit current and Maximum Power Point (MPP).

Voltage at operating-point-A in Fig. 5 is the open-circuit voltage. The operating point of a PV array under constant irradiance and cell temperature is the intersection point of the I-V characteristics and the load characteristics (Fig. 6). A straight line with gradient $M = 1/R = I_{loqd}/V_{lood}$ represents the load characteristic. The systems operating point moves along the I-V characteristic curve from B to A as load resistance increases from zero to infinity. The Maximum Power Point (MPP) is at C where the area (equivalent to output power) under the I-V characteristic curve is maximum. Tan (2004) demostrated that for too-high load resistances, the operating points go into the CA region. For too-low load resistances, the operating points go into the CB region. MPP can thus, be obtained by matching load resistance to PV array.

Simulation of I-V and P-V curves characteristic to evaluate the Maximum Power Point (MPP) for various irradiances and back cell temperature under the weather boundary conditions by design a computer program in MATLAB Software to. The block digram of the theoretical model is illustrated in Fig. 7.

The solar module analyzer can calculate maximum Voltage (V_{max}) and maximum current (I_{max}) the maximum power can calculate as:

(a) (b)

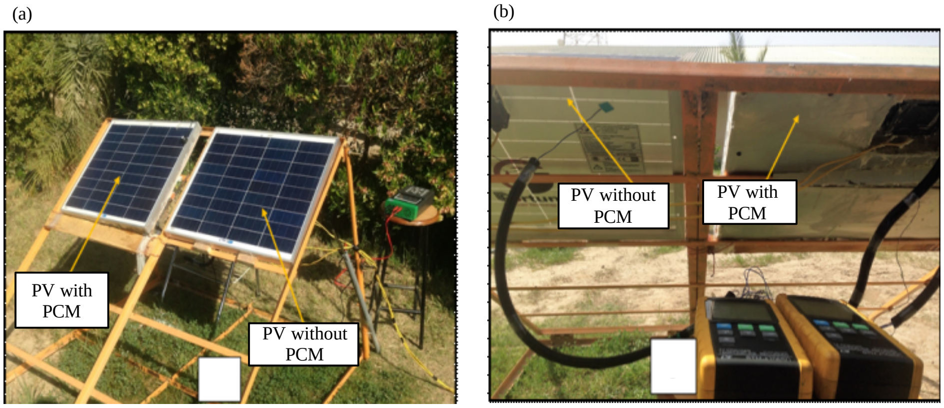

Fig. 5: Photograph of experimental rig: a) Front view and b) Back view

$$P_{max} = V_m * I_m \quad (8)$$

Skoplaki and Palyvos (2009) show how to calulate the electric efficiency (η) of the PV panel as:

$$\eta = \frac{P_m}{G\ A} \quad (9)$$

In present analysis, it assumed that the electrical efficiency calculated from above equation as a reference efficiency. Evans (1981) showed the generation efficiency of PV a cell is inversely proportional to its operation temperature. This is called the PV cell efficiency which is presented as:

$$\eta = \eta_{ref}\left[1-\beta(T_c - T_{ref})\right] \quad (10)$$

where, η_{ref} is the reference efficiency was calculated from Eq. 5 at every ten minutes with value of solar irradiation at reference temperature (ambient temperature at this time). The value of β is dependent on the material of PV cell and it is 0.0045C-1 for crystalline silicon. Hachem *et al*. (2017) defined the Power Enhancement Percentage (PEP) as follows:

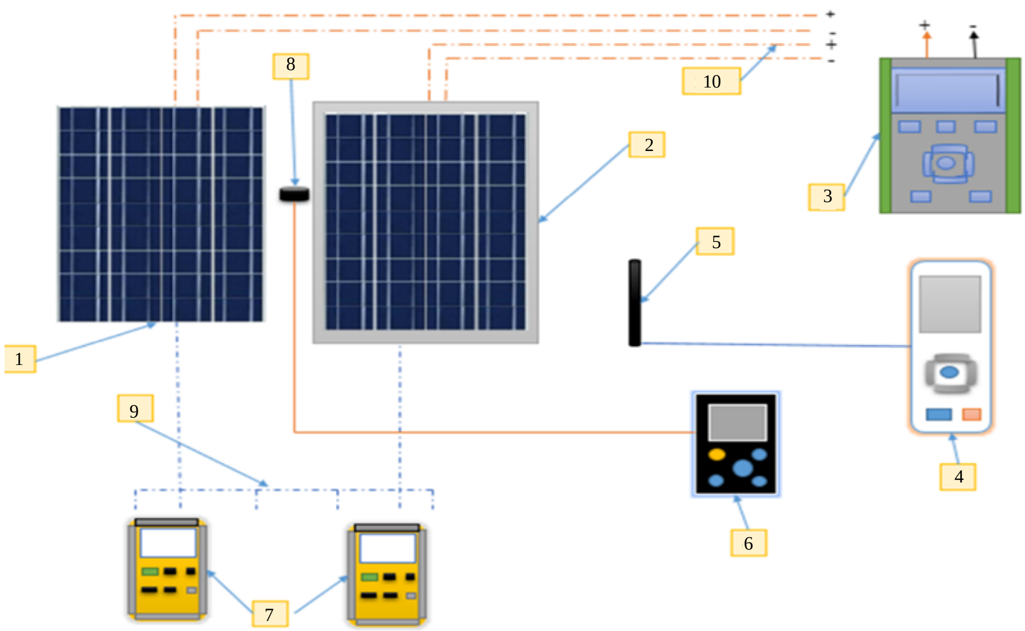

Fig. 6: Schematic diagram of the rig test: 1) PV; 2) PV with PCM; 3) Solar module analyzer; 4) Hotwire anemometer; 5) Wind speed senser; 6) Solar power meter; 7) Temperature recorder; 8) The lens of the power meter; 9) Thermocouple wire and 10) Electrical wire

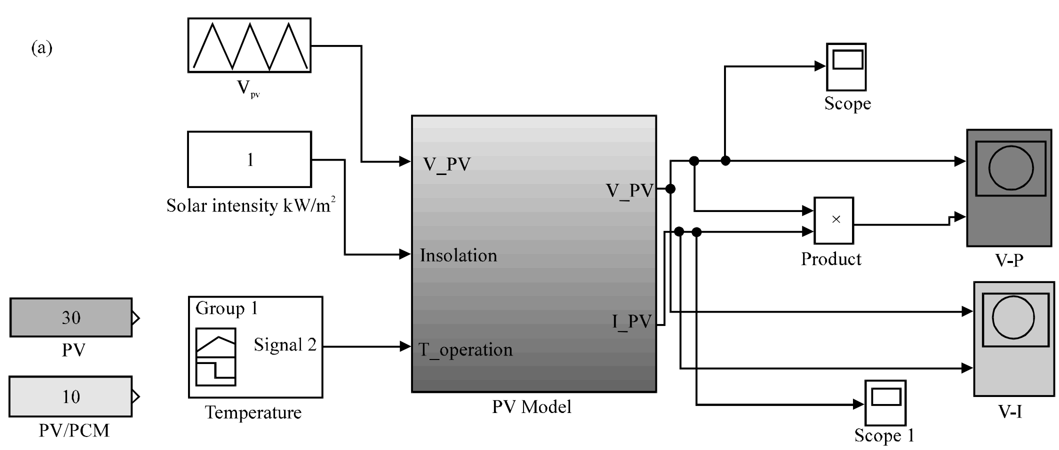

Fig. 7: Continue

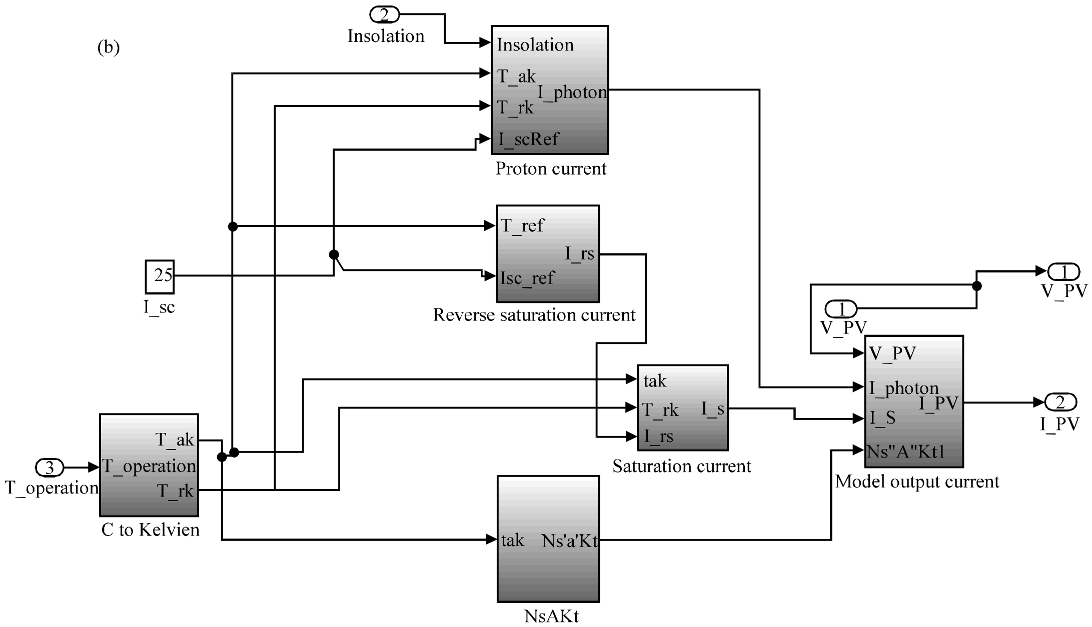

Fig. 7: Block diagram for PV Model: a) Input and output variable to PV Model and b) PV simulated equation

$$PEP = \frac{P_{PV/PCM} - P_{PV}}{P_{PV}} \times 100\% \quad (11)$$

In addition, Enhancement in Electrical efficiency (EEP) is illustrated as:

$$EEP = \frac{\eta_{PV/PCM} - \eta_{PV}}{\eta_{PV}} \times 100\% \quad (12)$$

RESULTS AND DISCUSSION

Figure 8 shows the relation between the output electrical power and output of voltage at time 10:10 am. That means after 40 min of testing the two PV cells. It has be shown the power of PV cells is function of voltage. The power state at short circuit condition which is the power equal to zero. Then, the power increases with increasing the voltage until reaches peak point on the relation response called a Maximum Power Point (MPP). In this time, it points 38.143 W of PV and 39.334 W of PV/PCM at value of voltage 15.697 and 16.255 V, respectively. Then, the power drops sharply to the zero after maximum point. It has be seen the PV/PCM gives a higher value of MPP than the PV cell. It has be seen the PV/PCM gives a higher value of maximum electrical power output than PV cell with lower reading value of current and higher voltage than PV cell. This test of reading does at same value of solar irradiation which is 728 W/m^2 and same boundary conditions of ambient temperature and wind velocity. This due to the temperature of back cell of PV/PCM is less than the back cell temperature of PV. This difference value between each other's is 6.43°C and the difference of maximum electrical power output between each other's is 1.191 W. While Fig. 9 and 10 represents the same response of electrical power output and voltage output for two cells at time 12:50 pm. The value of MPP are 45.887 W of PV/PCM and 42.887 W of PV cell with value of power intensity is 961 W/m^2. The boundary conditions of ambient temperature 35.1°C and wind velocity is 0.7 m/sec. It should be mentioned that the MPP

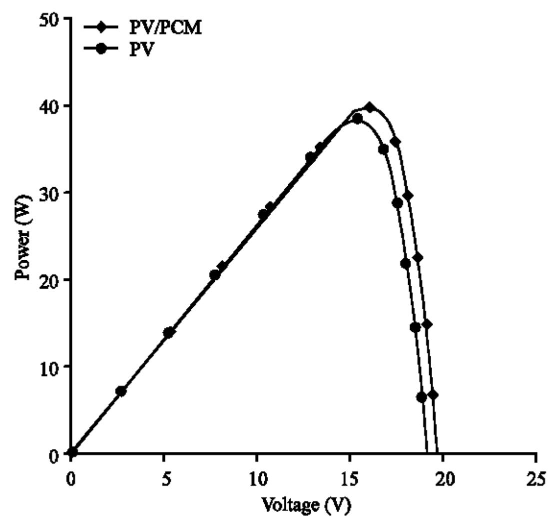

Fig. 8: Power with voltage curve at 10:10 am for PV with PCM and PV without PCM

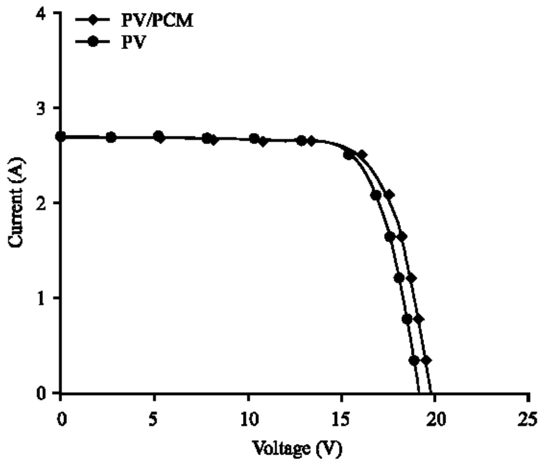

Fig. 9: Current with voltage curve at 10:10 am for PV with PCM and PV without PCM

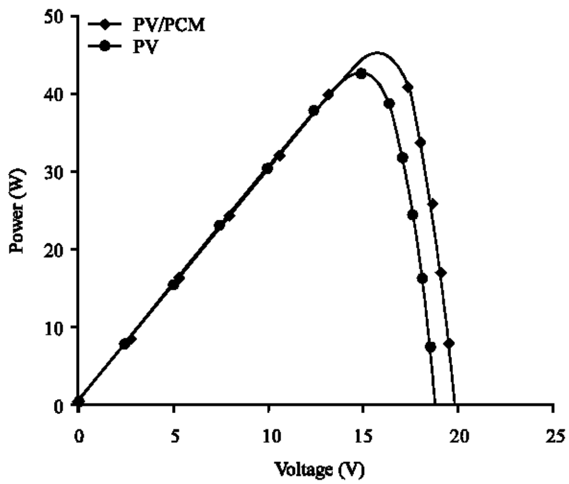

Fig. 10: Power with voltage curve at 12:50 am for PV with PCM and PV without PCM

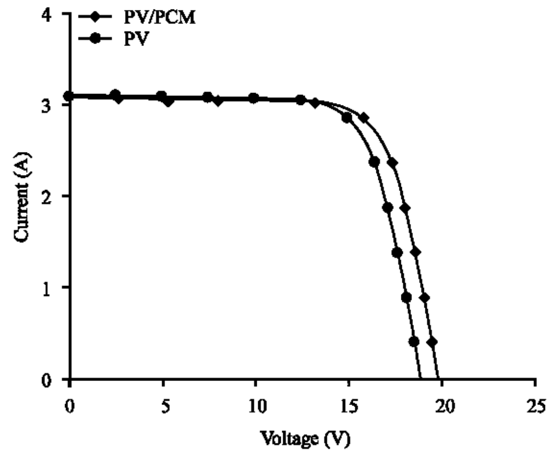

Fig. 11: Current with voltage curve at 12:50 pm for PV with PCM and PV without PCM

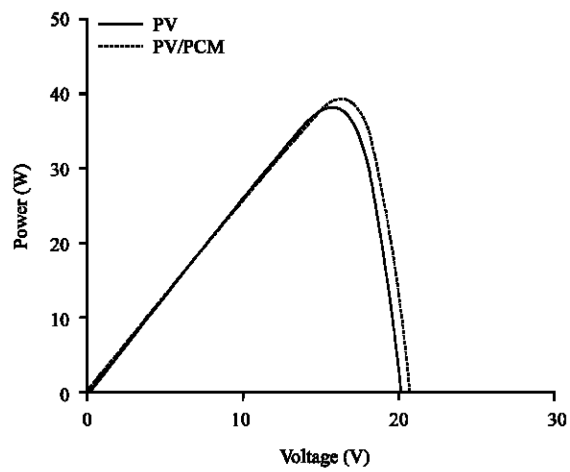

Fig. 12: Theoretical result of current with voltage curve at 10:10 am for PV with PCM and PV without PCM

increases with increasing the power intensity of falling radiation but it is not true through experimntal research. Then, the actual reason of increasing the MPP output of solar cells is the back temperature value of PV cell.

Figure 9-11 demonstrate the relationship between the current and voltage at two levels time for two cells which are used. These cells have a non-linear voltage-current characteristic. The response function clears that the voltage output at MPP increases when the current decreasing. The PV/PCM has high voltage than the PV cell for two intervals time. It shows that the I-V characteristic increases with increases with increasing the electrical power output at MPP depending upon the increase of the power intensity of radiation and the back cell temperature. Maximum electrical power for PV/PCM records at time 12:50 pm than other interval time at 10:10 am with value of Voltage 15.35 V and current 2.951 A while the PV cell records lower electrical power which is 42.887 W with value of Voltage 14.887 V and current 2.964 A. These results agree with the experimental result of Tan (2013).

Figures 12-14 show the power curve with voltage at times 10:10 am and 12.50 pm, respectively. These results were extracted theorectically using MATLAB program. In Fig. 12 indicates maximum point of electrical power for PV/PCM cell is 39.334 W and for PV is 38.143 W values of Voltage are 16.255 V for PV/PCM and 15.697 V for PV. These values were estimated at value of power intensity is 728 W/ m^2 and at back cell temperature of PV/PCM is 38.52 and 44.95°C for PV. While Fig. 14

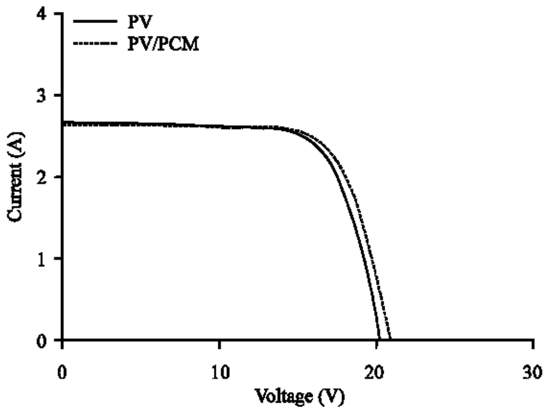

Fig. 13: Theoretical result of current with voltage curve at 10:10 am for PV with PCM and PV without PCM

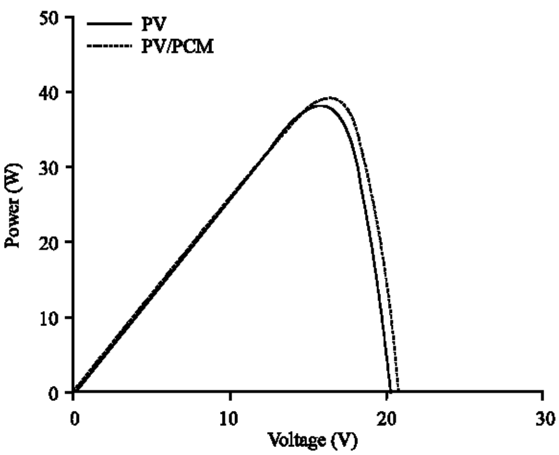

Fig. 14: Theoretical result of power with voltage curve at 12:50 pm for PV with PCM and PV without PCM

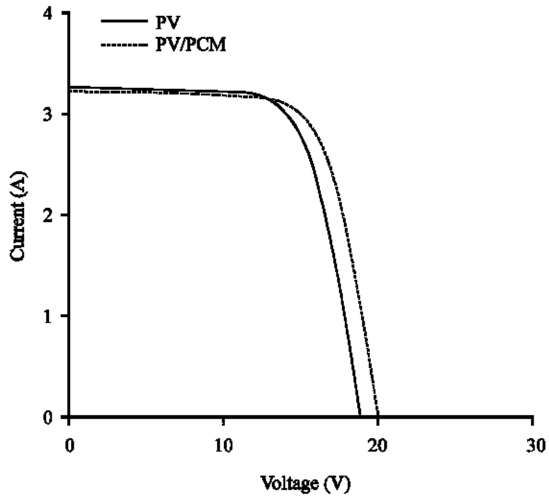

Fig. 15: Theoretical result of current with voltage curve at 12:50 pm for PV with PCM and PV without PCM

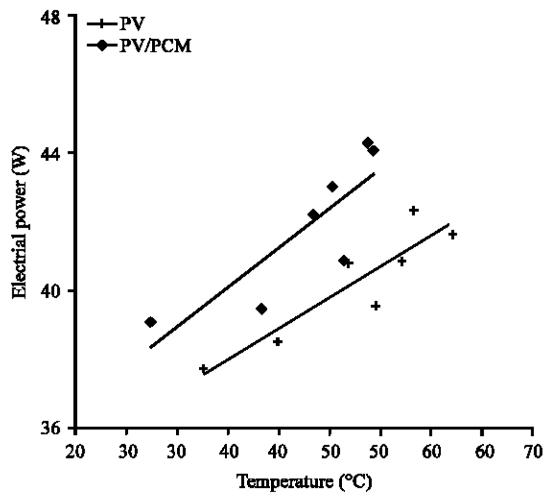

Fig. 16: Temperature effect on photovoltaic electrical power for PV and PV/PCM

represents the same theoretical relation at time 12:50 pm at value of solar irradiation is 961 W/m^2. Is clculates maximum power value which is 45.306 W for PV/PCM cell and 42.887 W for PV at back cell temperature of PV/PCM less than of PV under the same boundary conditions.

Figure 13 and 15 depicts the theoretical results of current with voltage realation for two PV cells at two intervals time. Figure 13 points maxinum vale of current 2.429 A for PV and 2.41 A for PV/PCM. While these values were estimated at time 12:50 pm as 2.984 A for PV and 2.95 for PV/PCM. From the figure it has seen higher current value was calculated for PV than the PV/PCM cell. This is due the back cell temperature of PV cell is higher than the PV/PCM cell which they observed for the same value of solar irradiation.

Figure 16 perceives the electrical power for PV and PV/PCM variation with back cell temperature. PROVA 200 A measures the maximum power output of solar module while it tracks the largest point on power voltage curve. A scatter plot between maximum power and the module temperature, linear regression fitting implemented to find the linear equation and the slope represents the TemperatureCoefficient(TCO) of maximum power. PV cell showed a increasing of 0.14222 W for each degree centigrade while 0.1463 W/°C for PV/PCM cell. This is due to the solar irradition increases the temperature of back cell of PV higher than the back cell temperature of PV/PCM. This result agrees with the experimental result of Hachem *et al.* (2017).

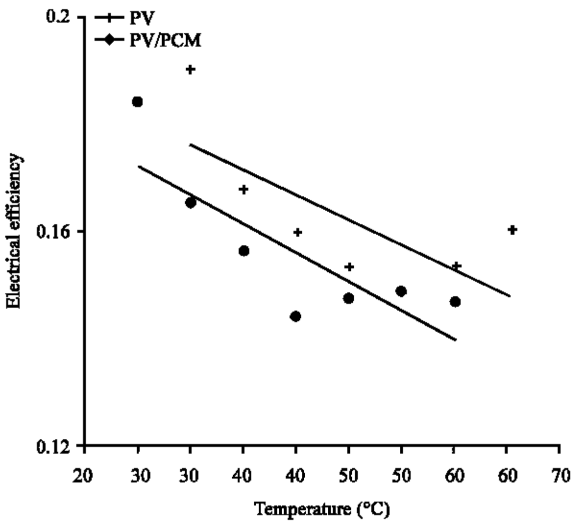

Fig. 17: Back cell temperature relation with electrical efficiency of PV and PV/PCM cell

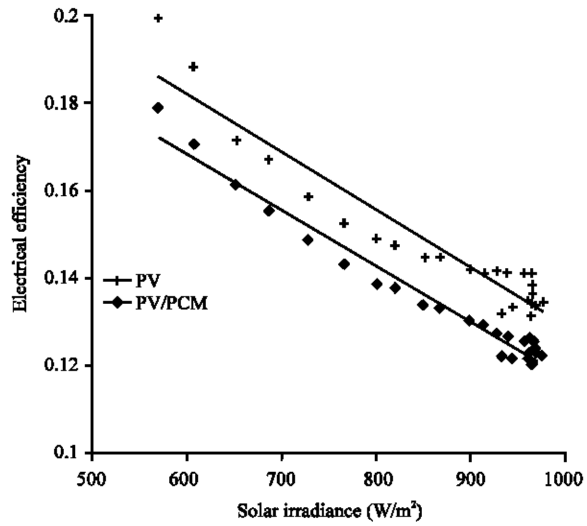

Fig. 18: Solar irradiance effect on electrical efficiency of PV and PV/PCM

Figure 17 shows the impact of PV cell in the temperature at back side of cell. The graphics shows that electrical efficiency of PV cell with and without PCM ranged from 18.84-12.24% while for PV cell with PCM the efficiency ranged from 19.66-12.72%. It notices that the PV/PCM electrical efficiency is higher than PV efficiency. It shows at same temperature at 45°C that efficiency is 12.2% for PV and 13.62% for PV/PCM cell. This is due to the PV/PCM cell reaches back cell temperature 45°C at value of solar intensity 898 W/m^2 while PV cell reaches temperature 45°C at solar intensity 728°C. This is due to the phase change material absorb the heat from the backside of PV cell. This result agree with the experimental result of Thaib *et al*. (2018).

Figure 18 induces the variation of PV and PV/PCM cell electrical efficiency with solar irradiance, the electrical efficiency is decreased with increasing solar radiation. It was noticed that an increase of 0.013% for PV/PCM and 0.012% for PV every 100 W/m^2 increase in irradiation level. This result is consistent with experimental results of Rahman *et al*. (2015).

Figure 19 moderates the average incident solar irradiation to the PV cells surface and ambient temperature during experimental period. The experiments perform in selected days of March 2018. The solar irradiation measurement values dependent on PV cells direction and the incident angle with horizontal. It observes that solar radiation reach maximum value is 974 W/m^2 at 12:30 pm and the ambient temperature maximum value is 35.7°C at 12:50 pm. These results are consistent with experimental results of Sardarabadi *et al*. (2017).

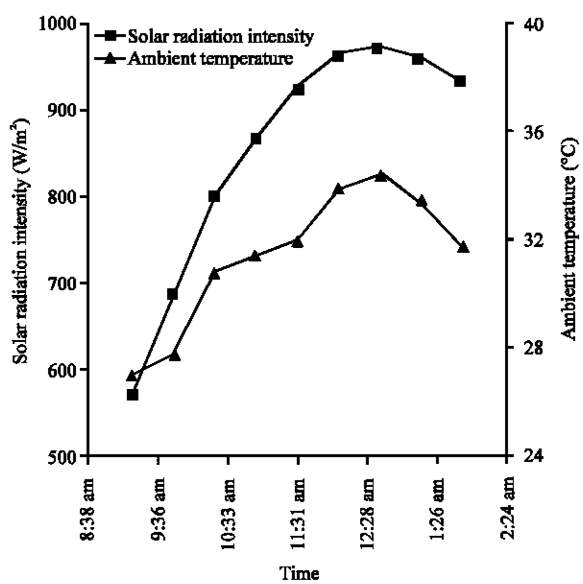

Fig. 19: Variation of solar radiation intensity and ambient temperature at 13 March, 2018

Figure 20 observes the back cell temperature for PV cell and PV/PCM cell varation during experimental time. It demonstrates that the temperature of two cells increases with time. The PV/PCM cell records lower values of temperature than the PV cell due to using phase change material. This reduction in temperature is due to the using paraffin as a phase change material which is absorbed the rejected heat from the back of PV/PCM cell. These results are consistent with experimental results which obtained by Sharma *et al*. (2016)

Table 3: Results calculation of parameters output for PV and PV/PCM

	Ambient conditions			PV			PV/PCM		
Time	G (W/m²)	T_a (°C)	Wind velocity (m/sec)	T_{bc} (°C)	I_m (A)	V_m (V)	T_{bc} (°C)	I_m (A)	V_m (V)
9:30	570	27.4	3.4	37.67	2.272	16.342	27.4	2.260	17.194
10:10	728	30.4	1.3	44.95	2.430	15.697	38.52	2.420	16.255
10:50	851	30.1	0.5	51.90	2.719	15.069	43.6	2.711	15.759
11:30	927	30.6	0.8	57.20	2.813	14.611	45.32	2.801	15.626
12:10	962	35.7	0.2	62.07	2.968	14.164	49.46	2.952	15.269
12:50	961	35.1	0.7	58.40	2.964	14.469	48.8	2.951	15.351
13:30	932	36.7	1.4	54.62	2.663	14.817	46.5	2.656	15.482

Table 4: Electrical power output and efficiency of conventional PV and PV/PCM panel

	Solar irradiation	Electrical power (W)			Electrical efficiency (%)			
Time	(W/m²)	PV	PV/PCM	Difference in power	PV	PV/PCM	Difference in efficiency (r)	Efficiency enhancement (%)
9:30	570	37.120	38.856	1.735	18.844	19.662	0.818	4.342985
10:10	728	38.143	39.334	1.191	15.160	15.584	0.424	2.795783
10:50	851	40.976	42.722	1.746	13.932	14.480	0.548	3.931207
11:30	927	41.098	43.774	2.676	12.828	13.620	0.792	6.173087
12:10	962	42.035	45.078	3.043	12.643	13.516	0.872	6.899011
12:50	961	42.887	45.308	2.421	12.913	13.599	0.685	5.308704
1:30	932	39.453	41.115	1.662	12.249	12.724	0.475	3.881438

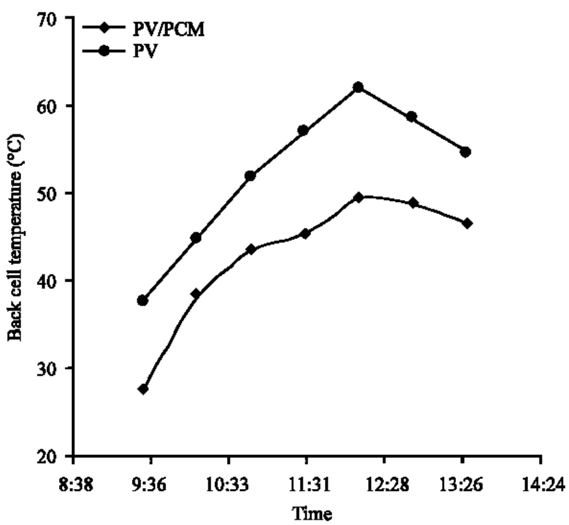

Fig. 20: Average back cell temperature for PV cell and PV/PCM cell variation during experimental time

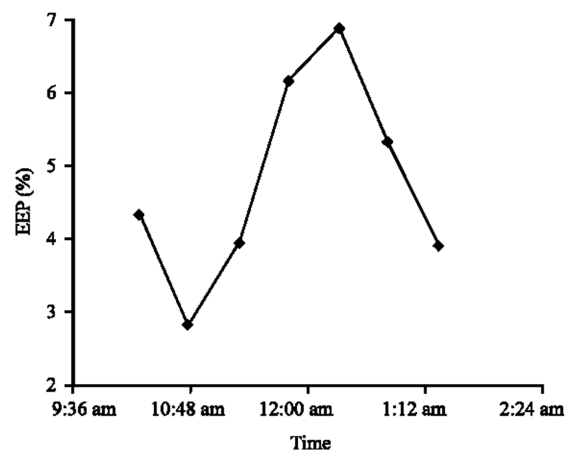

Fig. 21: Variation of the efficiency enhancement percentages as function of time

Figure 21 imposes the variation of Efficiency Enhancement Percentages (EEP) as a function of time. It can be shown that the efficiency enhancement of PV panel increases with time until reach maximum enhancement percentages of efficiency is 8.899% at time of 12:10 pm and boundary conditions 62.07 and 49.46°C back cell temperature for PV and PV/PCM, respectively, solar intensity is 962 W/m², wind velocity 0.2 m/sec and ambient temperature is 35.7°C.

Table 3 represents many data readings for experimental paramters for produced voltage, current, due to the back cell temperature with time of PV and PV/PCM panel. The values of power output voltage and current are not llinear characteristic with time and with solar irradiation. The output value of voltage and current at Maximum Power Point (MPP) for two cells clears that the voltage increases when decreasing of current. The PV/PCM panel shows higher values of voltage and lower current values at MPP than conventional PV with back cell temperature of PV panel. This is due to the values of back cell temperature of PV/PCM are lower than PV cell under given weather conditions and various values of solar irradiation.

Table 4 gives more discription about the values of electrical power and generation efficiency of PV and PV/PCM panel. The electrical efficiency of PV/PCM panel was more than PV panel. Increasing of electrical production of the PV/PCM panel ranges from 3.8-6.8% during 4 h of testing. Even the electrical power output of PV/PCM panel gives more values than conventional PV panel. The mean reason of these results dependent upon the values of back temperature of two cells. This temperature is proportonal inversily with efficiency and it is a function of electrical output power. It increases with increasing the back cell temperature.

CONCLUSION

Main conclusions extracted for this research are: improvement the electrical efficiency and performance of PV panel by using paraffin wax as a PCM are cooled its back temperature as a passive way.

According to the simulation when using the PCM, the electrical efficiency and the generation electrical output power of PV panel increased compared to conventional PV module. It was found the back cell temperature proportional inversely with electrical efficiency.

Design model in MATLAB Software for simulation the I-V and P-V characteristics to calculate the MPP is given more reliable results when compared with experimental measurements.

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