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ARAŞTIRMA MAKALESİ / RESEARCH ARTICLE

PHASE CHANGE MATERIAL (PCM) EFFECT ON PHOTOVOLTAIC PERFORMANCE OF SOLAR PANELS

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Abstract

Photovoltaic (PV) cells energy production limitation leads to make its important to operate those panels in the best operating conditions. In addition, sunlight is lower and cell temperature is higher, all of which are variables that adversely affect power generation. The potential reduction of cell temperature by one of the alternative thermal control techniques, phase change material (PCM) installation is discussed in this article. Three types of PCM (RT15, RT35, and SP25E2) are used together in the proposed system to overcome wide temperature range, in such method to reduce the PV panel temperature. The proposed scheme is simulated using MATLAB. Simulation results shows that the effect of high temperature PCM is the overall effect. If the temperature is smaller than the PCM melting point, the use of PCM is disadvantage. This disadvantage is that the temperature of the panel increases more than the ambient temperature.

Keywords: Sunlight, Cell temperature, Phase change materials, Photovoltaic.

GÜNEŞ PANELLERİNİN FOTOVOLTAİK PERFORMANSI ÜZERİNDE FAZ DEĞİŞİM MALZEMESİ (PCM) ETKİSİ

Özet

Fotovoltaik hücrelerin enerji üretiminin sınırlı olması, bu cihazların en iyi çalışma koşullarında çalıştırılmasının önemli olduğunu gösterir. Ayrıca, güneş ışığının daha düşük olması ve hücre sıcaklığının daha yüksek olması, bunların tümü güç üretimini olumsuz yönde etkileyen değişkenlerdir. Bu makalede, alternatif ısıl kontrol tekniklerinden biri olan faz değişim malzemesi kurulumu ile hücre sıcaklığının azaltılması tartışılmaktadır. Fotovoltaik panel sıcaklığını düşürmek için böyle bir yöntemde geniş sıcaklık aralığının üstesinden gelmek için önerilen sistemde üç tip faz değişim malzemesi (RT15, RT35 ve SP25E2) birlikte kullanılır. Önerilen şema MATLAB kullanılarak simüle edilmiştir. Simülasyon sonuçları, yüksek sıcaklıklı PCM'nin etkisinin genel etki olduğunu göstermektedir. Sıcaklık PCM erime sıcaklığından daha düşük olduğunda PCM'nin kullanılması bir dezavantaj oluşturur. Bu dezavantaj, panelin sıcaklığının ortam sıcaklığından daha fazla artmasıdır.

Anahtar Kelimeler: Güneş ışığı, Hücre sıcaklığı, Faz değişim malzemeleri, Fotovoltaik

1. INTRODUCTION

The huge increase in the global energy demand has made it extremely important to utilize renewable clean energy sources. Photovoltaic-(PV) cells are one of the most favorable renewable power technologies. Photovoltaic modules have virtually endless sources of energy, do not generate any kind of emissions or waste and provide remarkably long life because of the lack of moving components (some producers guarantee an absolute guarantee of more than 30 years). As the solar energy (PV) system costs decline, energy supply from PV system nowadays comparable with conventional electricity. A variety of studies and innovative intelligent energy systems have recently been introduced to connect the PV electricity supply to city networks and to this efficient photovoltaic method (Nada, El-Nagar, and Hussein, 2018).

Photovoltaic solar cell manufacturer evaluate their panels on the basis of maximum power, i.e. energy that meets standard test requirements commonly accepted (Tcell.temperature = 25°C, irradiation G = 1 kW/m2, air mass AM = 1.5 kg). Conditions rarely happen outside a regulated environment like the laboratory (Kladisios and Steggou-Sagia, 2016). In most cases, the temperature is slightly lower and module temperature higher, which harms electricity generation. Solar cells also can reach a maximum temperature of 20-30 ° C in above air. One of the ways to minimize the solar cell temperature and thus increase the energy produced is the use of phase changes materials (PCM). Among the factors directly associated with efficiency is the work temperature of the panel. Temperature changes normally contribute to a decrease in the power production of the solar cell. Therefore, in order to avoid the high temperature of the PV system, a cooling system should be mounted on the PV modules, to make solar photovoltaic system more efficient (Indartono et al. 2015). Phase Change Material (PCM), due to its latent heat power, may be used for heat storage. At their melting temperature, PCM may absorb large quantities of heat as latent heat. This PCM keeps the temperature on the surface as low as possible when placing the PCM into the mitigation and mounted on the lower surface of the PV panel. Paraffin, coconut oil, palm oil and gel album are few instances of this PCM (Kim et al. 2017). As a consequence, the temperature of the panel stays stable throughout this transformation time as PCM is inserted into PV module because of the heat absorption ability. Over the past years, a variety of work was done on the subject, and many of these are focused on a highly complex digital framework like CFD (Piratheepan and Anderson, 2017).

2. TEMPERATURE EFFECT ON PHOTOVOLTAIC PANEL PERFORMANCE

Solar cell array temperature is the surface temperature of the panel. During the night the ambient temperature is equal to PV panel's temperature, but in maximum light, the panel's temperature increases just to exceed 30°C (Brihmat and Mekhtoub, 2014).

Photovoltaic panels are based on three factors for energy conversion efficiency. Solar energy intensity and the chemicals that make up solar cells and temperature. Therefore, study on discovering unprecedented solar cell materials and preserving on low operating temperatures are of great importance to improve transmission performance. Solar radiation is as a natural source of energy that cannot be controlled by humans (Biwole, Eclache, and Kuznik, 2011). The activity of solar cells is based on the semiconductor ability to transform sunlight (photons) into energy by utilizing the photovoltaic effect (T. Ma et al. 2014). In the opposite, only part of the absorbed solar energy becomes electric power and the remainder is drained away by heat radiation or heat sinks. The photovoltaic effect is produced only by photons with energies higher than the gap difference. Those under this energy point are discharged as heat and all too much photon active energy is often discharged as a heat (Sandberg, 1999). Spectral photovoltaic splitting technology, which can transform more solar spectrum into electric power, can prevent overheating generation, while only a concentrated PV system is capable of that (Segal, Epstein, and Yogev, 2004). Figure 1 shows the influence of temperature on the PV panel operation.

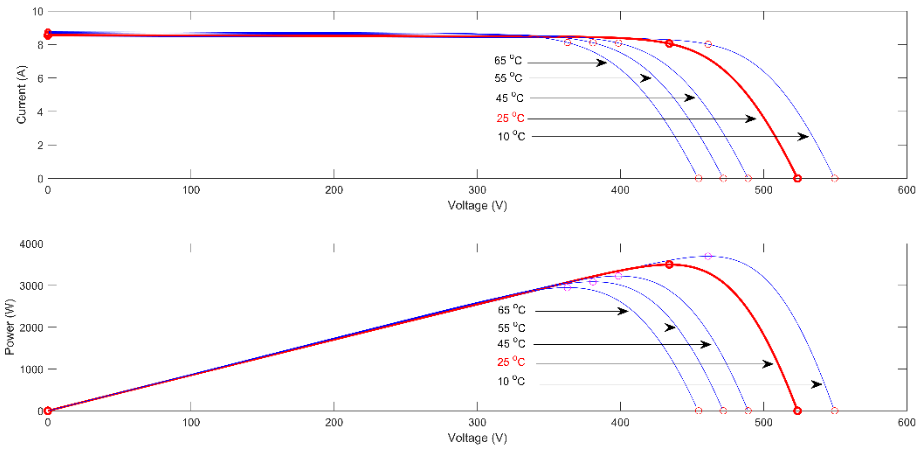

Figure 1. Influence of temperature on PV panel performance

As seen in Figure 1 the panel voltage is more influenced by the temperature than by the panel current influence. The maximum power point (MPP) is also influenced by changes in temperature. High temperature of the PV panel indicates low power consumption and low efficiency. During low PV panel temperature, high output voltage results in high power production.

3. PHASE CHANGE MATERIALS (PCM)

In heat systems, the erratic existence of the solar power renders thermal energy storage technologies and their usage important. They can be classified as appropriate thermal, chemical thermal and latent thermal storage technologies (Ibrahim et al. 2017). The heat storage depends on the mass production of the material, the specific heat and heat transition, such that a larger vessel and greater processing capacity are typically needed in the case of sensible heat storage. Chemical thermal energy conservation requires reverse reactions in order to retain and extract thermal energy (Zalba et al. 2003). This technology delivers a greater amount of energy than rational or latent heat storage systems. It's all in the growth and testing stages, though. In the storing of latent heat, while introducing or removing power, PCM requires turning the state into a state between solid and liquid. Organic, inorganic and eutectic of varying melting / solidification points are the relevant PCMs (Bruno, 2004). These PCMs have been applied to many domestic and trade usages in a successful way such as building room heating, solar air / water heating , cooling, etc. (Alva et al. 2017). The structure of the physical subgroups of PCM is shown in Figure 2.

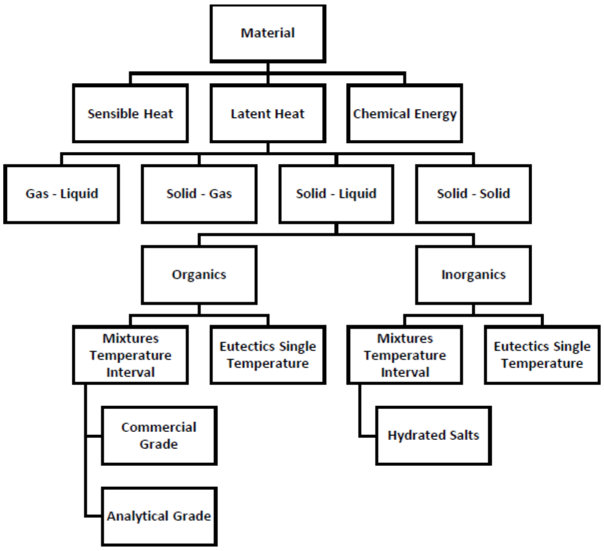

Figure 2. PCM classification (Zalba et al. 2003)

3.1 PCM Selection Criteria

No material may satisfy all the desired product characteristics as a thermal storage medium. The option of a PCM for thermal storage device architecture will, however, comply with a range of requirements regulated by physical , electrical, kinetic and chemical properties (Vitorino et al. 2016).

3.1.1 Thermos-physical properties (Souci and Houat, 2017)

Melting point temperature of PCM should not exceed the application running temperature. The size of storage is considered as an important point in the cost of design. So the latent temperature increase per unit volume for the specified PCM, the smaller volume of the container is needed. This causes the energy can be stored in a smaller volume. With the use of high specific heat PCM, efficient heat conservation may be enhanced. The thermal conductivity of the material controls charging and discharging of the stored material energy, thus, higher is better. A small change in volume occurs and low vapor pressure is produced at operating temperature during the transformation phase.

3.1.2 Kinetic properties

PCM should have a high nucleation rate in order to prevent supercooling the liquid phase. It is better if the PCM crystal growth is high to increase the heat recovery (Park et al. 2014).

3.1.3 Chemical properties

PCM have a general chemical properties such as: Stable during long life cycles, not corrosive in containers. PCMs are preferred not to be poisonous, non-flammable and non-explosive in order to be safety. Reversible at freezing / melting period (Pielichowska and Pielichowski, 2014).

4. MATHEMATICAL MODEL for PV-PCM

The working temperature of the PV panel is regulated by complex processes. That involves the internal proceedings of semiconductor content through the bombardment of radiation by the solar cell inducing power, external thermal discharges from the PV devices, and heat energy by heat transfer methods, which in effect increase the plain temperature in various ways, including load and radiation. The following assumptions were made for photovoltaic research about the conceptual photovoltaic framework, environmental conditions and additional factors.

- Isotropic and homogeneous properties of each layer in PV modules.
- Radiation on the front of the panel is spread similarly.
- The panel surface which affects the absorption is not covered by dust or other agents.

The mathematical model beads on the block diagram of PV-PCM shown in Figure 3 and expressed in Equation (1) (Huang et al. 2004).

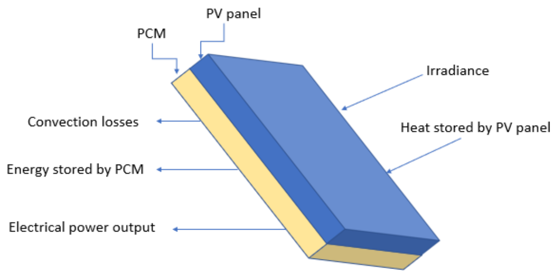

Figure 3. Physical model of PV-PCM system (Mahamudul et al. 2016)

$$C_{PV}\frac{dT_{PV}}{dt} = [\text{effective irradiance } (I_{reff}) - \text{Radiation}(Q_R) - \text{Power}(P_E) - \text{Convection}(Q_C) - \text{heat stored by PCM}(Q_H)] \quad (1)$$

Where C_{PV} is the specific heat capacity of PV panel, T_{PV} is the temperature of the PV module, Q_H is the heat stored by PCM plate and Q_C is the convection loss.

The difference between the energy input and output is equal to the temperature change rate of the PV panel's multiplying by specific heat capacity (C_{PV}) of the PV panel. Calculate the PV-PCM device temperature over time period (dT_{PV}/dt) can be obtained from Equation (2) (Mahamudul et al. 2016):

$$\frac{dT_{PV}}{dt} = \frac{[\emptyset \cdot \alpha - \sigma\varepsilon_p(T_{PV}^2 + T_s^2)(T_{PV} + T_s) - C_{FF} \cdot \left(\emptyset\frac{\ln(K_1\emptyset)}{T_{PV}}\right) - (h_{ff} + h_{fn} + h_{rear}) \cdot (T_{PV} - T_{amb})]}{C_{PV}} - \frac{\text{conduction}}{C_{PCM}} \quad (2)$$

Where $\emptyset$ is total irradiance, α is the absorption capacity, σ is the Boltzmann constant, ε_p is the emissivity of the module, T_S is the sky temperature, C_{FF} is the fill factor with a constant value (1.22 km^2), K_1 is a constant with a value ($10^6 mW^{-1}$) and T_{amb} is the ambient temperature.

The general effective heat capacity for PCM can be expressed as in equation (3) (Kravvaritis, Antonopoulos, and Tzivanidis, 2011):

$$C_{p\,eff.}(T_m) = \frac{\left(\frac{h}{h_r}\right) M(T_{r,i} - T_{r,i+1})(T_i + T_{i+1} - 2T_a)}{(T_i - T_{i+1})(T_{r,i} + T_{r,i+1} - 2T_a)} - N \quad (3)$$

$$M = (m_{tr}c_{ptr} + m_r c_{pr})S_t/mS_{tr} \quad (4)$$

$$N = m_t c_{pt}/m \quad (5)$$

Where Cp,eff is the general effective heat capacity for PCM (J/kg K), Tm is the PCM temperature at the middle of time step (ti+1 - ti) (K or oC), h is the convection heat transfer coefficient (W/m2 K), hr is the reference convection heat transfer coefficient (W/m2 K), is the reference fluid temperatures (K or oC), is the ambient temperature (K or oC), mr is the reference fluid mass (kg), m is the PCM mass (kg) and St is the tube surface (m2). While the subscripts, t is refers to tube, r is refers to the reference fluid and s is refers to solid state.

5. SIMULATION RESULTS AND DISCUSSION

The proposed system simulated using three types of commercial paraffin of PCM materials from Rubitherm® Technologies GmbH (Rahimi et al. 2014) which are: RT15, RT35 and SP25E2 (Mahamudul et al. 2016). The specification of PCM materials are listed in Table 1.

Table 1. PCM materials properties

PCM type / Property	RT15		RT35		SP25E2	
	Solid	Liquid	Solid	Liquid	Solid	Liquid
Density (kg/m^3)	880	770	860	770	1500	1400
Specific heat (kJ/kgK)	2.0	2.0	2.0	2.0	2.0	2.0
Thermal conductivity (W/mK)	0.20	0.20	0.20	0.20	0.50	0.50
Phase change temp.	15°C		35°C		25°C	
Latent heat (kJ/kg)	155		160		180	

While the effective heat capacity for the three types of PCM are shown in Figure 4.

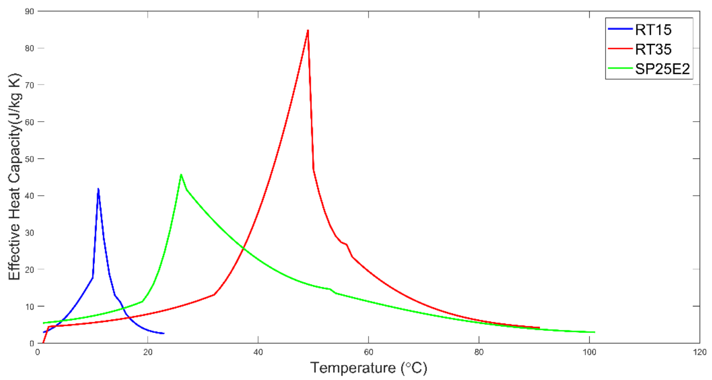

Figure 4. Effective heat capacitance of PCM

The effective heat capacity of the three materials is calculated by the properties shown in Table 1. RT15 at 10 oC, RT35 at 50oC and SP25E2 at 27oC have maximum effective heat capacity.

The PV panel temperature for both cases with and without using PCM is shown in Figure 5.

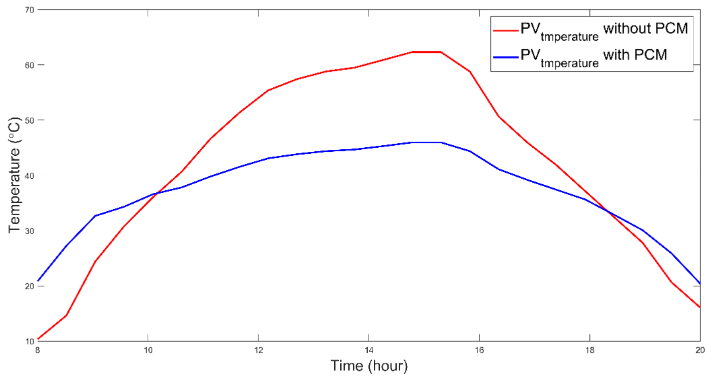

Figure 5. Temperature of PV panel with and without PCMM

It's clear that the PCM interfacing to PV panel makes two effects on the panel temperature according to the surrounding temperature, in the range less than the PCM melting temperature the effect is considered as a drawback because the temperature of the panel increased more than the ambient temperature as shown in Figure 5 for the intervals before 10:00 o'clock and after 18:00 o'clock. While, during the interval in which the ambient temperature is more than the melting temperature for the PCM, the performance of the PCM in correct way to reduce the panel temperature. The panel temperature reduced when ambient temperature is about 30C for the interval (10:00 – 18:00), so that this result may be compared with that achieved by (Huang, Eames, and Norton, 2004) where the temperature reduction started in about 35 oC when (RT35) was used as shown in Figure 6. The results comparison leads to that the effect of the high temperature PCM (TR35) is the most influence on the system performance. Because the effect of lower temperature PCM (RT15 & SP25E2) has been canceled.

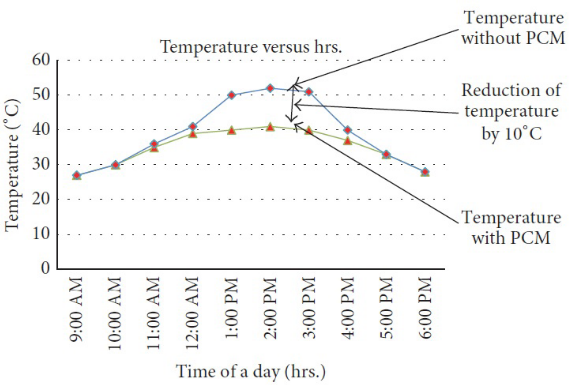

Figure 6. Experimental differences in temperature of the PV module with PCM and Without PCM (Huang, Eames, and Norton, 2004)

The PCM using affects the PV panel maximum power point in same way of its effect on the panel temperature because of the relation between the panel voltage and panel temperature, therefore the MPP in the rage of temperature less than the PCM melting temperature is adversely affected, while in the range of temperature more than the PCM melting temperature is increased more than that MPP for the same panel without using PCM. Figure 7 shows the MPP for the PV array for the two panels with and without PCM interfacing.

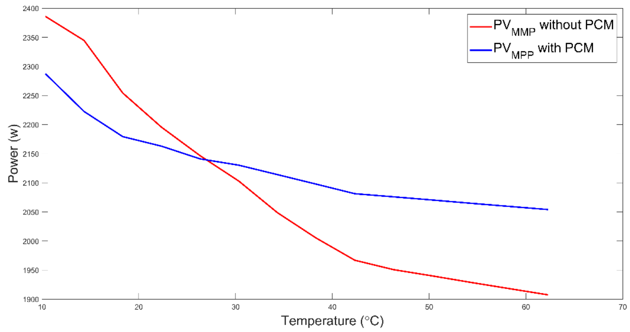

Figure 7. Phase change material effect on MPP

The effect of using PCM on the open circuit or no-load voltage Voc is shown in Figure 8. The effect of PCM interfacing on the panel voltage also contains two regions depending on ambient temperature, when the temperature less than the PCM melting temperature the open circuit voltage less than that for PV panel without PCM. While in the temperature increasing more than the melting temperature of PCM the voltage performance being better.

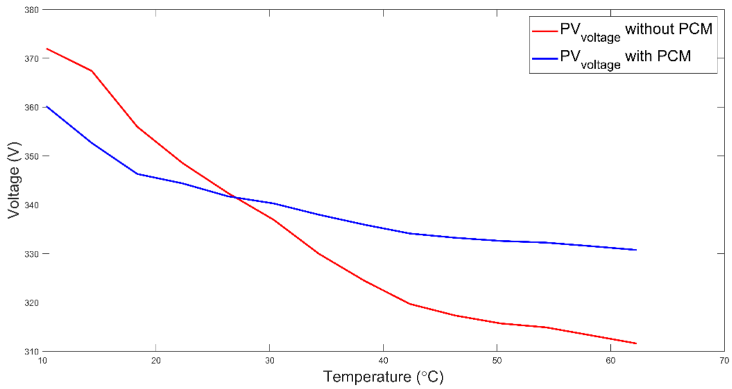

Figure 8. Phase change material effect on voltage

PV voltage and power curves for the PV panel for different temperatures are plotted in Figure 9 and Figure 10, it is clear that the PV panel voltage in high temperature case is less than the voltage at low temperature. In Figure 9 PV panel voltage curves for three temperature levels and the corresponding power curves are also plotted in the same figure. The open circuit voltage of the PV panel in case of high temperature (Figure 9) is around 500 volt, and the MPP between 400 and 425 volt

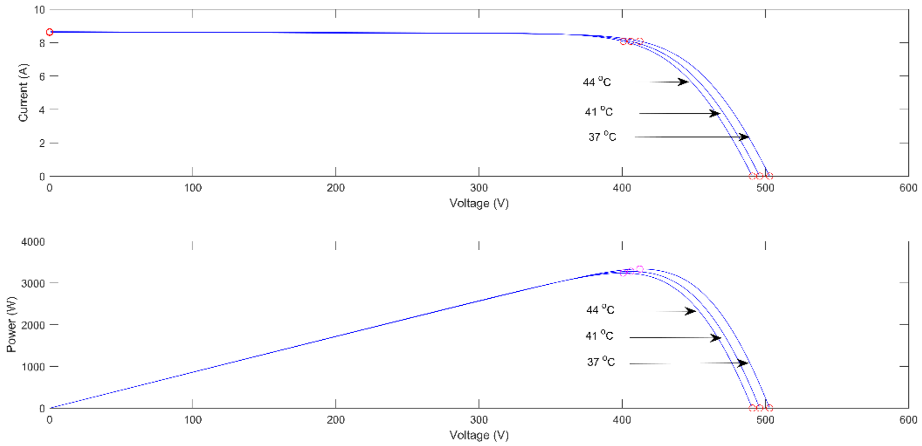

Figure 9. Power and voltage curves in high temperature case.

Selected temperatures from our simulation results are used for plotting power and voltage curves for the same PV panel as shown in Figure 10. In this case it's clear that the MPP in the range 425-490 volt while the open circuit voltage is in the range of 510-560 volt.

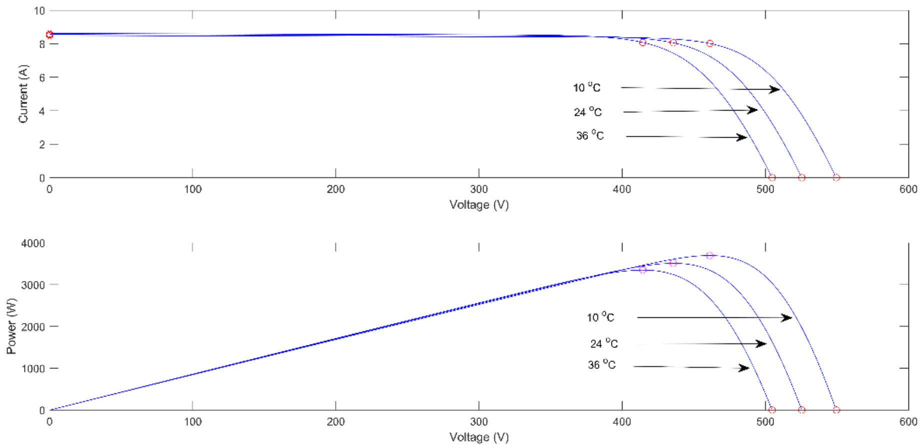

Figure 10. Power and voltage curves in low temperature case.

This study represents a mathematical verification for the experimental results proposed by (Mahamudul et.al 2016) when using phase change materials to overcome wide temperature range. The reduction of temperature in the experimental results is about 10°C, while in this article it's about 20°C.

6. CONCLUSIONS

The mathematical modeling and simulation prove that the use of phase changing materials has the capability of regulating the PV modules temperature in a specific range. The PCM materials introduced an advantage of PV panel regulation within a specific temperature range. While there is a drawback of using these materials, which is that the rising of panel temperature in range less than the melting temperature of PCM. The PV panel voltage and maximum power MMP are also affected by using the PCM with same manner of temperature regulation. The contribution of this article is the introduction of using three types of PCM materials in the same PV panel and simulates the proposed system. The simulation results was compared with other work proposed by Mahamudul et al. (2016). The comparison shows that our proposed method has a temperature reduction higher than that of Mahamudul et al. (2016).

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