Simulation of effect of Nanoparticle dispersed PCM for Cooling of Photovoltaic Panels

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Abstract: Solar photovoltaic (PV) panels are commonly and widely employed source of renewable power generation. Nonetheless, they suffer from very inferior poor light to energy conversion efficiency. This drawback is aggravated further by 0.02% for every Kelvin rise in solar cell temperature. This paper presents a modelling work on PV cooling techniques through phase change material layer integration on rear PV surface. The PCM layer can absorb the excess heat generated in the panel. Making a composite of highly conductive nanomaterial and this PCM as a layer will boost the heat transfer and maintain PV temperatures close to optimum. Vaseline (Petrolatum or soft paraffin) was selected as the PCM due to easy availability. Graphene nanomaterial was the thermal conductivity enhancer. The cooling effect of the PCM nanocomposite was tested at three different front surface temperature. It was found that addition of PCM layer brings the cooling effect at PV front. This effect further enhances on the addition of PCM nanocomposite layer.

Keywords: solar, phase change materials, nanoparticles, cooling, temperature

Introduction

Electric power production systems relying on fossil fuels are unable to satiate rapid surge in energy demands. In addition, the usage of fossils fuels causes various environmental and sustainability issues [1]. These factors have propelled extensive research in the arena of renewable energy technologies. Wind energy systems, biofuel exploration and solar energy are some of the key areas of renewable research [2-4]. In the recent decades, solar energy has garnered much attention as abundant, renewable, cleaner and economical energy source [5]. Solar photovoltaic (PV) technology is an economical electricity producing means in which solar energy is converted into electricity by photons [6]. Solar PV output has a reliance on various factors such as surrounding conditions, meteorological parameters and geographical location of the operation [7]. However, temperature prominently
effects the output performance of a PV system. It is reported that an efficiency decline of close to 0.40% occurs in solar PV panel for every Kelvin temperature [8]. Less than 20% of the solar insolation striking the PV panel is transformed into electricity and rest is wasted as heat [9]. This waste heat raises the PV front temperature and consequently decreases the efficiency. It necessitates the employment of efficient cooling systems and techniques for extraction of excess heat from the PV panels [10]. Several works have been conducted for the temperature reduction of PV panel [11]. These cooling techniques are categorized into active and passive techniques. In the case of active cooling techniques, an additional device with parasitic power consumption is used to cool the PV system. Active cooling techniques mostly comprises of forced air flow or water flow on front or rear surfaces of PV panels [13]. The amount of water required for water cooling makes it more complex and it is unsuitable for arid regions where water scarcity is an issue [14]. Additionally, utilization of air of water induces maintenance and operational challenges. Passive cooling systems does not require any power which makes those more popular avenue for research [15]. Commonly used passive cooling techniques rely on thermosiphon driven air flow [16], capillary action based water flow or evaporation [17] and, heat absorption by phase change materials (PCM). Currently use of PCM as heat absorber and temperature regulator is the most reliable and economical method for the cooling of PV panels. PCM are able to isothermally store or release large amount of heat [18]. However, the inferior PCM thermal conductivity makes this heat transfer much slower [19]. Several experiments on augmenting the PCM thermal conductivity have reported encouraging results. Zohra et al. [20] compared the utilization of a single PCM and a combination of two different PCM for heat rejection of PV panel. Solar PV panel integrated with single PCM has 34% efficiency improvement and panel integrated with combination of PCM has efficiency improvement of 42.5% compared to reference PV panel. Al-Najjar et al. [21] utilized metal foam with PCM to boost the PV front to PV rear conductive heat transfer. It was found that the PCM melting duration has a reduction of 127% and the PV temperature dropped by 12°C. Utilization of nanomaterials to escalate heat transfer in PCM for PV cooling was found to be a much effective with potential for futuristic advances [22]. Simulations from a model of nano-enhanced PV-PCM can gauge the performance of cooling without any cost and fabrication constraints. Designs with promising results from the simulations could be further implemented. Divyateja et al. [23] numerically investigated a model of PV cooling with nano-PCM cooling and reported encouraging results. Another similar numerical analysis found the heat transfer to increase by 94% [24]. Sai and Ranganathan [25] used ANSYS software for design and simulation of performance of heat flow in PV cell with rear PCM layer. In the present work, a model for PV module is built in COMSOL Multiphysics. The thermal performance of the model is analysed at two different ambient temperatures. A PCM layer and a nano-PCM layer is affixed at the PV rear layer and the analysis of temperature profiling with the reference panel is done.

2 Design and Modelling

2.1 Design
COMSOL Multiphysics software is utilized for building the geometry model. The PV model is created with the area dimensions similar to the Waree 20 W 12 V PV panels. These dimensions are 480 mm X 350 mm. The thickness is kept according to the thickness of various layers present in the panel. The image of Waree 20 W panel is presented in Fig. 1.

![Waree 20 W polycrystalline panel](image)

**Fig. 1.** Waree 20 W polycrystalline panel

There are a number of layers in a solar PV panel. The top or front layer is a tempered glass cover (A), beneath it is an ethylene vinyl acetate (EVA) laminate (B1). The third layer is the PV cell layer (C) which is sandwiched between EVA layers on both sides (B2). Fifth layer is Tedlar polyvinyl fluoride (PVF) layer (D) and sixth one is aluminium back sheet (E). The parameters of material properties this various layers are displayed in Table 1. The schematic of various layers for this PV module is shown in Fig. 2.

**Table 1.** Various layers of the PV panels and their properties.

<table>
<thead>
<tr>
<th>No.</th>
<th>Layer Material</th>
<th>Thickness in cm</th>
<th>Density in kg/m³</th>
<th>Specific Heat Capacity in J/kg-K</th>
<th>Thermal Conductivity in W/m-K</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Glass Cover</td>
<td>0.3</td>
<td>3000</td>
<td>500</td>
<td>1.8</td>
</tr>
<tr>
<td>2.</td>
<td>EVA</td>
<td>0.05</td>
<td>960</td>
<td>2090</td>
<td>0.35</td>
</tr>
<tr>
<td>3.</td>
<td>PV Cell</td>
<td>0.04</td>
<td>2330</td>
<td>677</td>
<td>148</td>
</tr>
</tbody>
</table>
The thermal profile of the various layers of the PV panel is simulated at three different temperatures. The ambient temperature for the simulation was kept at 300 K. The effect of elevated temperature at the front surface and its temperature profile through front to rear surface of the solar PV panel were studied. Three different elevated temperatures values of 320 K, 330 K and 340 K were kept for the front surface while back surface temperature was kept 300 K in all cases. The similar simulation was done with affixing of a PCM layer at the PV rear layer. The area of PCM was assumed similar to the area of the PV panel. This simulation was then repeated for all three temperature for a PCM composite layer with enhanced thermal conductivity. The commercial Vaseline was selected as PCM material and graphene nanomaterial was selected as thermal conductivity enhancer. The thermal conductivity value of Vaseline and the composite are reported to be 0.42 W/m-K and 0.86 W/m-K, respectively [26].

3 Results and Discussions

This section discusses the results of temperature simulation of the PV panel and their analysis is presented. As a method for investigation of cooling effect of PCM nanocomposite at different front surface temperatures, a PV model was built in COMSOL Multiphysics to simulate the cooling performance. The model was simulated under three different temperatures values of 320 K, 330 K and 340 K with ambient temperature value of 300 K.

Fig. 3 (a) presents the temperature trend of the solar PV layers keeping front surface temperature at 320 K and back surface temperature at 300 K. Fig. 3 (b) and Fig. 3 (c) shows the temperature trend with a rear PCM layer and rear nano-PCM layer, respectively. The front layer of solar PV panel with affixed PCM layer
has reduced temperature compared to uncooled panel. This temperature drop effect increases further on addition of PCM nanocomposite layer.

![Fig. 3](image)

**Fig. 3.** Temperature distribution of the model (a) without PCM cooling, (b) with PCM cooling layer (c) with nano PCM cooling layer, at ambient temperature of 320 K.

Fig. 4 (a) presents the temperature trend of the solar PV layers keeping front surface temperature at 340 K and back surface temperature at 300 K. Fig. 4 (b) and Fig. 4 (c) shows the temperature trend with a rear PCM layer and rear nano-PCM layer, respectively. A similar trend was found for all three arrangements.

![Fig. 4](image)

**Fig. 4.** Temperature distribution of the model (a) without PCM cooling, (b) with PCM cooling layer (c) with nano PCM cooling layer, at ambient temperature of 340 K.

Fig. 5 (a) presents the temperature trend of the solar PV layers keeping front surface temperature at 360 K and back surface temperature at 300 K. Fig. 5 (b) and Fig. 5 (c) shows the temperature trend with a rear PCM layer and rear nano-PCM layer, respectively. The temperature was reduced for both the modified arrangements. But temperature reduction was more compared to previous two cases.
This was attributed to the high temperature difference between rear and front surface.

Fig. 5. Temperature distribution of the model (a) without PCM cooling, (b) with PCM cooling layer (c) with nano PCM cooling layer, at ambient temperature of 360 K.

4 Conclusion

A model of solar PV panel was built and simulated using COMSOL Multiphysics simulation software. In contrast to experimental based study, COMSOL simulation provides the merit of reduced design time, less cost and determine the performance by variation of operating parameters. The model was constructed according to the specification and materials of Waree 20 W multicrystalline PV module. The panel rear temperature was fixed at 300 K and the front surface temperature was varied. For the cooling method, a Vaseline PCM layer was added at the rear surface. The temperature profile was simulated under the three different temperatures. PCM thermal conductivity was augmented by addition of graphene. It can be concluded from the study that the composite of Vaseline and graphene as heat absorber layer for a PV panel provides superior cooling effect.

References

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