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Optimization of finned solar photovoltaic phase change material (finned pv pcm) system

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ABSTRACT

Heat generation during the operation of the photovoltaic (PV) cell raises its temperature and results in reduced electrical output. The heat produced in the process can be removed by attaching phase change material (PCM) at the back of the PV panel which can contain the PV temperature substantially and increase its efficiency. Fins can be used inside the PCM container to enhance the heat transfer. In literature, it is observed that as soon as PCM is melted completely, the heat extraction rate of PCM reduces which again leads to increase in PV temperature. However, the study carrying out the optimization of Finned-PV-PCM system to keep PV temperature low during operation for different solar irradiance levels is not available in literature. Thus, in the current study, the most suitable depth of PCM container is calculated for different solar irradiance levels. In addition, how it is affected with spacing between successive fins, fin length and fin thickness has been studied. The best fin dimensions are also calculated. The results show that the most suitable depth of PCM container is 2.8 cm for $\Sigma I_T = 3\,\text{kWh/m}^2/\text{day}$ and 4.6 cm for $\Sigma I_T = 5\,\text{kWh/m}^2/\text{day}$ for the chosen parameters. The best spacing between successive fins (to keep PV temperature low) is 25 cm, best fin thickness is 2 mm and best fin length is the one when it touches the bottom of the container. PV, PV-PCM and Finned-PV-PCM systems are also compared. For PV-PCM system (without fins), the most suitable depth of PCM container is 2.3 cm for $\Sigma I_T = 3\,\text{kWh/m}^2/\text{day}$ and 3.9 cm for $\Sigma I_T = 5\,\text{kWh/m}^2/\text{day}$.

1. Introduction

PV cells can convert only a fraction of the incident solar radiation into electricity. A major fraction is converted into heat and raises the temperature of the cell. The temperature rise reduces the solar to electricity conversion efficiency of the cell [1]. The studies involving phase change material (PCM) for extracting heat from PV have been reviewed.

Some works on experimental investigation of the photovoltaic-phase change material system are summarized. Huang et al. [2] have compared the performance of photovoltaic-phase change material system with fins and no fins inside the PCM container using RT25 and GR40 PCMs. The results show that the deployment of fins can reduce the PV temperature. Hasan et al. [3] have compared the behaviour of the system using five different PCMs: paraffin wax (RT20), capric–lauric acid (C–L), capric–palmitic acid (C–P), pure salt hydrate ($CaCl_2.6H_2O$) and commercial blend (SP22). It has been shown that the photovoltaic temperature can be decreased by 18 °C maximally at 1000 W/m^2 using C–P and $CaCl_2.6H_2O$. Indartono et al. [4] have proposed a yellow petroleum jelly as PCM for the operation and studied the performance of the system under the climate of Indonesia. An increment in photovoltaic efficiency from 8.3% to 10.1% has been observed. Mahamudul et al. [5] have considered RT35 PCM and carried out the study for the climate of Malaysia. The results show a decrement of 10 °C in the photovoltaic temperature using PCM. Park et al. [6] have varied the thickness of PCM layer and analysed the performance of the system for the weather of South Korea. A maximum increment of 3% in the electrical efficiency is achieved. Hasan et al. [7] have compared the behaviour of the system at two different locations: Ireland and Pakistan. The performance of the system is better at Pakistan. Hasan et al. [8] investigated the system's behaviour under extremely hot weather of the United Arab Emirates. An increase of 5.9% in the annual electricity generation is achieved. Sharma et al. [9] have integrated the RT42 phase change material in building integrated concentrated photovoltaic and reported an increase of 7.7% in the electrical efficiency at 1000 W/m^2. Huang et al. [10] have worked on investigating the system's performance considering crystalline segregation of PCM. Waksol A, RT27 and RT35 phase change materials have been considered for the

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Nomenclature

B	liquid fraction of the phase change material during phase transition
C	constant appeared in Eq. (31)
c_p	specific heat capacity (J/kgK)
D	function used to distribute the latent heat in phase change zone
F	view factor
g	gravitational acceleration (m/s^2)
G	portion of solar irradiance converted into heat (W/m^3)
Gr_c	critical Grashof number
h	heat transfer coefficient due to convection (W/m^{2}K)
I_T	instantaneous solar-irradiance on tilted plane (W/m^2)
k	thermal conductivity (W/mK)
L_{ch}	characteristic length (m)
L_f	length of fins (m)
L_h	latent heat (J/kg)
Nu	Nusselt number
p	pressure of phase change material (Pa)
Pr	Prandtl number of air
q	constant appeared in Eq. (31)
q_L	rate of heat loss (W/m^2)
Ra	Rayleigh number
Re_c	critical Reynolds number
s_f	spacing between successive fins (m)
S_h	solar irradiance transformed into heat (W/m^2)
t	time (s)
t_f	thickness of fins (m)
T	temperature (K)
T_m	melting point of phase change material (K)
u	phase change material's velocity (m/s)
v_w	velocity of wind (m/s)
x_c	critical length (m)

Greek symbols

β	inclination angle of the system (rad)
β_c	coefficient for expansion of phase change material due to temperature (/K)
γ_w	wind azimuth angle (rad)
δ	depth of the box containing phase change material (m)
ΔT	region of phase change (K)
ε	emissivity for reradiation
η_{PV}	electrical efficiency of the photovoltaic
μ	phase change material's dynamic viscosity (kg/ms)
ρ	density of the material (kg/m^3)
σ	Stefan–Boltzmann constant (W/m^2 K^4)
$(\tau\alpha)_{eff}$	effective product of transmissivity of glass cover and absorptivity of solar cell
υ	kinematic viscosity of air (m^2/s)

Abbreviation

EVA	ethylene vinyl acetate
PCM	phase change material
PV	panel of photovoltaic cells

Subscripts

a	ambient
al	aluminium
avg	averaged
b	bottom surface of PV
f	forced
g	ground
gl	glass layer
l	liquidus
n	natural
P	phase change material's layer
s	solidus; sky
t	photovoltaic top surface
ted	tedler layer
x	x direction
y	y direction
z	z direction

investigation. It is reported that the fins inside the PCM container can improve the performance. Browne et al. [11,12] have developed a pipe network inside the phase change material's container so that the storage of heat can be utilized using the flow of water through the pipes and achieved a thermal efficiency of 20%. Hachem et al. [13] have investigated the performance of photovoltaic integrated with mixed phase change material (copper, petroleum jelly and graphite powder) and pure phase change material and average increase of 5.8% and 3% respectively in the electrical efficiency have been reported. Several review works [14–18] also discuss the behaviour of photovoltaic-phase change material system.

Not just experimental work but several numerical studies have also been conducted for the thermal analysis of the PV-PCM system. Brano et al. [19] have used a finite difference method to analyse the thermal performance of the system considering RT27 PCM and found that the calculated values of the PV temperature differ from the measured ones by 7%. Atkin and Farid [20] have integrated the PCM with heat sink for PV cooling and shown a 12.97% enhancement in the photovoltaic electrical efficiency. Smith et al. [21] have estimated the power generation by photovoltaic-phase change material system across countries and found that the PCM integration for cooling of the PV is best for tropical regions. Kibria et al. [22] have used three phase change materials viz. RT20, RT25 and RT28HC and analysed the behaviour of the system and achieved an increase of 5% in the electrical efficiency.

All previous numerical studies ignored convection inside the melted PCM which certainly has a considerable impact on the performance of photovoltaic-phase change material system [23]. The following works include convection. Huang et al. [24] have analysed the photovoltaic-phase change material system for two cases, fins and without fins, inside the container considering RT25 PCM. The results show that the introduction of fins can reduce the PV temperature by 3 °C. Ho et al. [25] investigated the photovoltaic coupled with microencapsulated phase change material and found an increment in the photovoltaic electrical efficiency from 19.1% to 19.5%. Huang [26] has investigated the thermal behaviour of the system using combination of PCMs considering RT21, RT27, RT31 and RT60. RT27-RT21 combination yields better performance. Khanna et al. [27–29] have studied the effect of operating conditions on the performance of photovoltaic-phase change material system and found that the increase in the tilt of system leads to increase in the melting rate of PCM. To encounter the sudden changes in the thermal properties of PCM during phase change in the convergence of the numerical solution, Biwole et al. [30] and Groulx and Biwole [31] have implemented Dirac delta function for modelling the rapid change in the specific heat of PCM.

The aim of the above studies is to enhance the PV efficiency. Many studies are available aiming at the improvement of heat transfer inside the PCM using fins: Shatikian et al. [32] have reported that the lesser spacing/thickness of fins leads to quicker melting of PCM (keeping spacing to thickness ratio fixed) which is due to the increase in the number/surface area of fins. The simulations have been carried out for