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Effect of climate on electrical performance of finned phase change material integrated solar photovoltaic

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ABSTRACT

Photovoltaic (PV) cells absorb the incident solar radiation while operation of which, majority part causes heating leading to the hampered electrical efficiency. PVs can be integrated with phase change material (PCM) to maintain cell temperature within desired limits and the effect can be improved by deploying fins. The current work aims at analysing the effect of climate on the electrical performance of finned PCM integrated PV. Modelling of system has been done which has been validated using experimental results. For the study, fins with various spacings, thicknesses and lengths are used. The main conclusions of the study are, (a) for less alterative climate, the improvement in the PV electrical output (using finned PCM) is 9.7%, 10.8%, 11.3%, 11.6% and 11.6% respectively for a spacing of 1 m, 1/2 m, 1/3 m, 1/4 m and 1/5 m. For highly alterative climate, the respective values reduce to 6.6%, 7.6%, 8.1%, 8.4% and 8.4%, (b) for warmer climate, the output increases by 10.1%, 11.3%, 11.8%, 12.1% and 12.1% while for colder climate, it increases only by 5.4%, 6.1%, 6.5%, 6.7% and 6.7%, (c) for windy climate, the power increments are significantly lesser as compared to the other case, (d) climate having higher wind azimuth results in better performance of finned PCM, and (e) for clear sky climate, performance of finned PCM is better.

1. Introduction

The temperature rise of photovoltaic (PV) adversely affects its electrical performance (Kaplani and Kaplanis, 2014; Khanna et al., 2017). In the current section, the experimental and theoretical studies for the passive cooling of PV using phase change material (PCM) have been presented.

1.1. Experimental studies

Baygi and Sadrameli (2018) have studied the thermal variations of PV using polyethylene glycol as PCM for the climate of Tehran, Iran. The results conclude that the PCM decreases the PV temperature from 60 °C to 45 °C. Huang et al. (2006, 2007) have investigated the thermal variations of an imitated PV system integrated with paraffin wax 25 PCM. The results conclude that the temperature rise of the PV can be reduced from 62 °C to 36 °C using PCM and from 62 °C to 26 °C using finned PCM. Hasan et al. (2015) have investigated the PV-PCM system for two different weather conditions (Dublin and Vehari). It is shown that for Dublin, the largest temperature drop in PV is from 49 °C to 39 °C and for Vehari, it is from 63 °C to 41.5 °C using $CaCl_2$ $6H_2O$ PCM. Indartono et al. (2014) have compared roof integrated PV and stand integrated PV systems for the climate of Indonesia using vaselinum flavum PCM. It is shown that a decrease in the PV temperature from 60 °C to 54.3 °C can be achieved for roof integrated system and from 44.8 °C to 42.2 °C for stand integrated system. Hasan et al. (2010) have analysed five different PCMs. It is shown that the largest PV temperature drop can be achieved from 57 °C to 39 °C using $CaCl_2$ and C-P. Kamkari and Groulx (2018) have investigated the melting rate of PCM by applying heat source at bottom using lauric acid as PCM and found that the horizontal position of the system leads to faster melting than that of vertical position. Sharma et al. (2016) have used paraffin wax 42 PCM integrated with asymmetric compound parabolic CPV. The PV temperature drop from 60 °C to 51 °C is shown. Sharma et al. (2017) have used a nano enhanced PCM with micro finned arrangement for cooling and shown a drop of 12.5 °C in the PV temperature. Preet et al. (2017) have analysed the PV and PVT-PCM systems at Gurdaspur using paraffin wax 30 PCM and reported a decrease of PV temperature from 80 °C to 55 °C. Browne et al. (2016a, 2016b) and Browne et al. (2015) have used eutectic mixture of capric and palmitic fatty acids as PCM. An enhancement of 5.5 °C in the water temperature is achieved using PVT-PCM as compared to PVT system. Su et al. (2018) have studied the tracking integrated CPV-T and CPV-T-PCM systems. An enhancement of 10% in the electrical efficiency is achieved using paraffin wax PCM at Macau. Many theoretical studies are also carried out by researchers (Browne et al., 2015; Ma et al., 2015; Du et al., 2013; Shukla et al., 2017; Chandel and Agarwal, 2017; Preet, 2018).

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Nomenclature

A_{PV}	aperture area of PV panel (m^2)
C_p	specific heat (J/kg K)
D	heat of fusion's distribution function during change of phase
E	electrical output (W)
F	shape factor
g	acceleration due to gravity (m/s^2)
Gr	Grashof number
h	convective heat transfer coefficient (W/m^2 K)
H_f	heat of fusion (J/kg)
I_T	incident solar flux on PV (W/m^2)
k	thermal conductivity (W/m K)
l	part of total PCM mass in liquefied form
L	length of system (m)
L_{ch}	characteristic length (m)
L_f	length of fins (m)
Nu	Nusselt number
p	pressure (Pa)
Pr	Prandtl number
Ra	Rayleigh number
s_f	distance between fins (m)
t	time (s); thickness (m)
T	temperature (K)
t_f	fin's thickness (m)
T_m	phase change material's melting temperature (K)
$T_{P,s}$	temperature below which whole PCM is fully solid (K)
$T_{P,l}$	temperature above which PCM is fully liquid (K)
t_{si}	silicon thickness (m)
u	phase change material's velocity (m/s)
v_w	wind velocity (m/s)

Greek symbols

β	inclination angle of the system (rad)
β_c	temperature coefficient (/K)
γ_w	wind azimuth angle (rad)
γ_c	solar irradiance coefficient
δ	box's depth (m)
ε	emissivity for reradiation
η	electrical efficiency of PV
μ	dynamic viscosity of phase change material (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)

Abbreviations

EVA	ethylene vinyl acetate
PCM	phase change material
PV	photovoltaic
STC	standard test conditions

Subscripts

a	ambient
al	aluminium
avg	average
c	critical
f	forced
gl	glass
gr	ground
l	liquid phase
P	PCM
s	solid phase
si	silicon
sk	sky
STC	standard test conditions
te	tedlar
x	along length
y	along depth

1.2. Theoretical studies

Brano et al. (2014) and Ciulla et al. (2012) have used forward difference model for time and first-order central difference model for the space derivative. The experimental and the computed results match significantly with maximum deviations being −6.53 °C to +7.55 °C using paraffin wax 27 as PCM at Italy. Atkin and Farid (2015) have studied the infusion of PCM into graphite for the thermal regulation. The results show an enhancement of 7% in the electrical efficiency. Kibria et al. (2016) have used fully implicit model for enthalpy formulation of PCM. For simulation, paraffin wax 20, 25 and 28 are used for the climate of Dhahran. The results conclude that after eight hours of charging, first PCM becomes liquid completely. However, for second and third PCM, only 0.8 and 0.65 portions become liquid. Biwole et al. (2013, 2018) and Groulx and Biwole (2014) have modelled the drastic shift PCM undergoes during phase change and shown that the same must be modelled and handled with care as the chances for divergence and errors are immense. Mahamudul et al. (2016) have used paraffin wax 35 and reported a drop in PV temperature from 51 °C to 41 °C at university of Malaya. Kant et al. (2016) have reported that the consideration of conduction in PCM leads to drop in PV temperature from 60 °C to 58.5 °C and the consideration of both conduction and convection in PCM leads to drop in the PV temperature from 60 °C to 55 °C using paraffin wax 35 for the climate of Uttar Pradesh. Park et al. (2014) have worked on finding the optimal melting temperature of PCM for the climatic conditions of Incheon and 25 °C is reported as the optimum one. The effect of installation direction on the optimum PCM quantity is also investigated. Su et al. (2017b) have optimized the melting temperature of PCM for maximum energy output from PVT-PCM system at Ninjangh and reported that the PCM with melting temperature of 40 °C is the best. Khanna et al. (2018a, 2017, 2018b, 2018c, 2018d, 2018f) and Al Siyabi et al. (2018a, 2018b) have worked on analysing the effect of operating conditions and optimization of PCM quantity for different working conditions, daily solar irradiance levels and system dimensions. Emam and Ahmed (2017) have analysed different configurations of PCM heat sinks and concluded that the parallel cavities are better than the series ones. Huang et al. (2004, 2011) have investigated the thermal variations of an imitated PV system integrated with finned PCM. It has been found that the temperature rise of the PV can be reduced from 87 °C to 38 °C using paraffin wax 32 as PCM and from 87 °C to 35 °C using finned PCM. Emam et al. (2017) have studied the influence of tilt angle of the concentrated PV-PCM. It is shown that the slanted system is better compared to vertical or horizontal. Cui et al. (2016) have integrated the CPV thermoelectric system with PCM and found a 25% drop in the PV temperature using NaOH-KOH PCM at Nanjing. Su et al. (2017a) have integrated air based PVT system with paraffin. It is shown that the use of PCM drops the PV temperature from 77 °C to 69 °C for the climate of Nanjing. The method of separation of variables is also applied by researchers to derive explicit analytical expressions for temperature distribution (Khanna et al., 2016) incorporating the effect of non-uniform solar flux distribution (Khanna and Sharma, 2016; Sharma et al., 2016), thermal variations (Khanna