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Water and phase change material based photovoltaic thermal management systems: A review

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ABSTRACT

Photovoltaic panels are semiconductor materials having electrical efficiency in between 4% and 46% depending upon its material. About 50% of total solar radiation absorb by photovoltaic panel convert into heat causing high operating temperature of photovoltaic panel (PV) results to drop in its electrical performance and permanent structural damages called thermal degradation if a thermal stress remains in PV panel for long. So cooling of photovoltaic panel is very essential for better performance and long life of photovoltaic module. Many researchers have investigated performance of photovoltaic module by using different cooling arrangements having different thermal absorber design, different coolants and different phase change materials (PCMs). Detailed review of various methods related to water based photovoltaic/thermal system (PV/T) and photovoltaic panel with phase change material (PV-PCM) system has been discussed and reported in this paper. This review paper can help to find new cooling arrangements, different thermal absorber design and different phase change materials for improving performance of photovoltaic/thermal system. It has been observed from the literature that photovoltaic panel with phase change material (PV-PCM) is proficient solution for cooling of photovoltaic panel. But problems associated with phase change material are its low thermal conductivity and nocturnal solidification which affect its readiness and thermal drop performance for same day and next day therefore, performance of photovoltaic panel with phase change material (PV-PCM) system can be enhanced by inserting heat transfer elements within PCM and extracting heat from PCM to regulate temperature of phase change material to maintain its heating storage capacity. Extracted heat from PCM can be use for space heating or water heating applications.

1. Introduction

Global energy requirements are increasing day by day. Out of total energy requirements around 75% are fulfilled from fossil fuel which led to increased carbon emission in environment, causing global warming. Sun is abundant source of energy which provides $3,850,000 \times 10^{18}$ J of energy which can easily fulfil all the requirements of energy. Photovoltaic cells converts dispersed and concentrated solar radiation into direct current (DC) by striking photons on photovoltaic semiconductor panel. Layers of photovoltaic panel consists of tempered glass, a outer covering of photovoltaic panel, which is about 5 times stronger than ordinary glass having about 95% of solar absorptance and iron content in the form of iron salts with limestone used for its protection from top. Second layer of photovoltaic panel is ethylene and vinyl acetate (EVA) which is having properties of both elastomeric and thermoplastic materials and having good clarity, gloss, low temperature toughness, low thermal expansion coefficient, stress-crack resistance and hot-melt adhesive waterproof properties and provide resistance to UV radiation. Rise in temperature of photovoltaic panel cause degradation of ethylene-vinyl acetate layer (EVA). Mohammed and Ahmed [73] carried out an experimental investigation in Saharan region to investigate degradation of photovoltaic panel and reported that after the long exposure of photovoltaic panel caused discoloration or browning of ethylene-vinyl acetate layer and formation of hot spots in solar cells. Browning of photovoltaic panel happened due to long exposure of photovoltaic panel above 50 °C which reduced its optical transmissibility and formation of hot spot formation in photovoltaic module formed caused cell failure, interconnection failure, partial shading and cracking of photovoltaic cell. Third layer of photovoltaic panel is layer of photovoltaic cells mainly consist of silicon solar cells, which are used for generation of electricity, absorb up to 80% of solar radiation available in solar spectrum. But certain percentage of solar radiation generates electricity but rest generates heat that cause high temperature in photovoltaic panel. Photovoltaic panel have 74% absorption factor which led to drop in its electrical efficiency. Porous silicon layer which is anti-reflection coating placed over silicon

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Nomenclature

A	area (m^2)
C_p	heat capacity (J/kg K)
I_c	current (Amp.)
I	global solar radiation (W/m^2)
I_{sc}	short circuit current (Amp.)
m	mass flow rate (kg/s)
V	voltage (volts)
V_{oc}	open circuit voltage (volts)
P	power (watts
T	temperature (°C)
β	temperature coefficient of photovoltaic cell

Dimensionless parameters

$\eta_{electrical(pv)}$	electrical efficiency of photovoltaic panel
$\eta_{electrical(pv/T)}$	electrical efficiency of photovoltaic/thermal system
E_f	performance efficiency
FF	fill factor
β_c	packing factor

Subscripts

c	cell
e	electrical
i	inlet
o	outlet
P	power
oc	open circuit
mpp	maximum power
pv	photovoltaic
pv/T	photovoltaic thermal
ref	reference
sc	short circuit
th	thermal

photovoltaic cell to increase absorption factor thus its electrical efficiency increases. Santbergen, Zolingen [82]. Silicon nitride having nanometres thickness as anti reflection coating also applied over silicon cells to reduce reflection losses and to increase electrical efficiency [10]. Poly vinyl fluoride polymer known as tedlar which is a fluoropolymer, provides excellent adhesion to EVA, durable, weather resistant, good hydrolytic stability, high dielectric strength, protect from physical damages and insulates electric connection of photovoltaic panel [7] is mostly used. Tedlar has high reflectivity which reflects incident light to non-active layer of photovoltaic cell results to increase in generated current but in case of photovoltaic/thermal system, this results to high reflection losses hence reduction in usable heat [27,28].

Wysocki and Rappaport [98] firstly described about effect of temperature on performance of photovoltaic panel in which photovoltaic conversion was investigated in temperature between 0 °C and 400 °C with photovoltaic materials having bandgap between 0.7 ev and 2.4 ev. It was found that maximum conversion efficiency occurs in materials with higher band gap. It was reported that as temperature is increased, the maximum efficiency shifted to materials with a larger band gap. Luque and Hegedus [70] described that temperature of photovoltaic panel rises because photons with energy smaller than band gap will not absorbed by active solar cell material. These photons reach at back surface of solar cell and reflected back from front side of photovoltaic panel. Those photons which are absorbed at back surface of photovoltaic panel generate heat. Photons with energy above band gap generate one electron-hole pair per photon. Excess energy between photon energy and band gap generate heat in crystal lattice. Energy transferred to electron-hole pairs does not completely convert into electricity, but part of it converts into heat by internal recombination and ohmic losses. Every solar cell is having its own threshold photon energy below which energy conversion does not happen. Photons of longer wavelength do not generate electron-hole pairs but only dissipate their energy as heat in cell [79]. Igari et al. [57] experimentally investigated degradation rate of amorphous silicon photovoltaic module by exposing crystalline silicon photovoltaic to 85 °C environmental conditions at Setagaya site of Tokyo. It was found that rapid degradation occurred about 100 days from beginning of exposure. Berman et al. [13] carried out experimental investigation by keeping 189 Solarex SX-146 photovoltaic modules for five years in a mirror-enhanced, grid connected photovoltaic system in Negev desert of Israel. After five years, it has been observed that mean maximum power value of browned photovoltaic panel dropped by 9% as compared to new photovoltaic module and ethylene-vinyl-acetate (EVA) changed to yellow-brown colour as compared to blue colour in beginning of test. EVA layer delaminated resulted to 1% drop in electrical efficiency of photovoltaic panel per year. Akhmad et al. [3] reported that electrical efficiency of mono-crystalline photovoltaic cell was dropped to 4.8% and electrical efficiency of poly-crystalline photovoltaic cell was dropped to 2% after the exposure of five years in experimental environmental field. Fesharaki et al. [30] described that efficiency of photovoltaic cells vary with temperature variation, carried out simulation investigation to measure effect of temperature on electrical efficiency and developed relation between efficiency and temperature as shown in Fig. 1.

Vokas and Christandonis [95] described that in order to lower temperature of photovoltaic panel and improve its electrical efficiency, cooling of photovoltaic panel is must required. Photovoltaic/thermal system (PV/T) lowers temperatures of photovoltaic panel with solar thermal attachment which embeds behind photovoltaic panel and obtains thermal efficiency simultaneously. There are two methods of cooling of photovoltaic panel i.e. hydraulic cooling of photovoltaics and Hybrid integrated photovoltaic/thermal system. There are basically two cooling techniques uses in photovoltaic/thermal system i.e. passive cooling and active cooling. Passive cooling extracts heat from PV panel and discharge it to environment using natural convection, whereas, in active cooling, external source of power is used for extraction of heat. Air and water are basically two common cooling medium used for heat extraction. Choice of cooling medium depends upon design requirement and area environmental situations (Fig. 2)

2. Hydraulic cooling of photovoltaics

In this system, in order to lower temperature of photovoltaic panel, water flows over front surface of photovoltaic panel. Krauter [68]

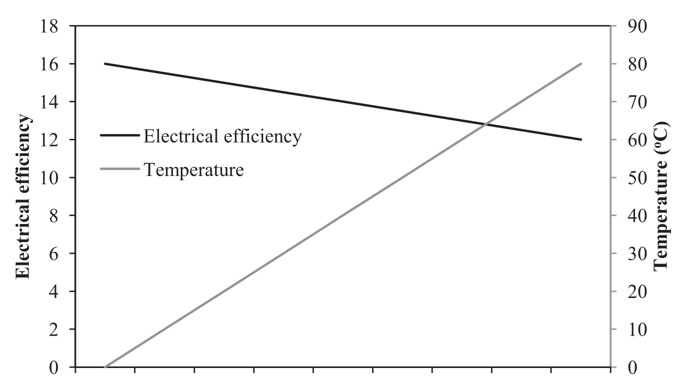

Fig. 1. Photovoltaic cell efficiency versus temperature [30].