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Experimental analysis of solar photovoltaic unit integrated with free cool thermal energy storage system

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ABSTRACT

The increase in operating temperature of the solar photovoltaic (PV) module results in loss of conversion efficiency. Active or passive based cooling methods are commonly used to remove heat and thus the performance of PV module is enhanced. In this paper, cooling of solar PV module is achieved with the help of free cool thermal energy stored in the phase change based storage system in the night and early morning hours. The performance of the solar PV system combined with free cool thermal energy storage system containing encapsulated phase change materials is studied. The free cool energy is stored when the ambient air available during early morning hours is in the range of 20–25°C and allowed to flow over the encapsulated phase change materials (PCMs). The HS29 PCM used as PCM in the storage tank stores the cool energy at a temperature range of 29–30 °C and the same is supplied through the bottom of the PV panel during day time hours to keep the panel at a lower temperature. The instantaneous energy and cumulative energy stored in the storage tank during charging process and the cooling potential during the operational hours of the solar panel with different mass flow rates of air is studied and the results are presented.

1. Introduction

The depletion of fossil fuels and the degradation of the environment in recent years necessitate the use of renewable energy resources. Among the various renewable energy technologies, solar Photovoltaic (PV) technology has rapidly matured in the recent years. The contribution of solar PV for the generation of electrical power has increased steadily due to its simplicity. However, solar PV is not able to convert all the solar radiation falling on it to electrical power, because majority of the incident solar energy is reflected or dissipated as thermal energy that reduces the electrical efficiency (da Silva and Fernandes, 2010; Braunstein and Kornfeld, 1986). To increase the conversion efficiency and to overcome the thermal degradation of PV panels, an effective cooling method has to be adopted (Radziemska and Klugmann, 2002; Han et al., 2013; Boer, 2011). For effective cooling of PV panels a fluid stream is passed through them, which is technically called as a hybrid PV/T collector. The commonly used PV/T technologies are (i) air cooled PVT panel (Tripanagnostopoulos et al., 2002; Tiwari and Sodha, 2007; Garg and Agarwal, 1995; Tonui and Tripanagnostopoulos, 2008) (ii) water cooled PVT panel (Huang et al., 2001; Kalogirou and Tripanagnostopoulos, 2006; Chow et al., 2006) (iii) refrigerant-based PVT (Ji et al., 2008; Zhao et al., 2011) and (iv) heat pipe-based PVT (Tang et al., 2009).

The increase in PV panel temperature is about 1.8 °C at each interval of 100 W/m^2 when the solar PV is not cooled, but when it is cooled with atmospheric air the increase in the temperature is around 1.4 °C only at each interval of 100 W/m^2. The increase in efficiency of air cooled solar PV is about 4–5%, when it is effectively cooled (Teo et al., 2012). Hernández et al. (Hernández et al., 2013) improved the electrical parameters of a PV panel with air as cooling medium. The authors concluded that there is a percentage increase in electric energy yield by 15% and decrease in panel temperature of 15 °C. Kaiser et al. (Kaiser et al., 2014) experimentally studied the cooling of building integrated photovoltaics (BIPV) with air as cooling medium and empirical correlations were formed for the same system. The authors claimed an increase in the power output of 19% for BIPV.

The increase in performance of PV panel by using water as an effective coolant has gained its importance. Krauter (Krauter, 2004) increased the electrical efficiency of PV panels by producing films of water on the front side of the panels and concluded that there is a percentage increase in electric energy yield of PV panels by 9%. Odeh and Behnia (Odeh and Behnia, 2009) experimentally analysed the cooling of PV panel by incorporating a water flow on it and also numerically analysed the same system in TRNSYS for various geographical locations. The authors concluded that there is a percentage increase in electric energy yield of PV panels by 15% at peak incident radiations

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Nomenclature

BIPV	building integrated photovoltaic
CTES	cool thermal energy storage
EES	engineering equation solver
HDPE	high density polyethylene
HS	hydrated salt
INR	indian rupee
PCM	phase change material
PVC	polyvinyl chloride
PV/T	photovoltaic/thermal
PV	photovoltaic
Pt	Platinum
RPM	revolutions per minute
TRNSYS	transient system simulation
$\dot{m}$	mass flow rate "kg s^{-1}"
c_p	specific heat capacity "J kg^{-1} K^{-1}"
N	number of measurements
Q_{cum}	cumulative energy gain "J"
$\dot{Q}_{ins}$	instantaneous energy "W"
T_{ic}	inlet temperature of air in CTES tank "°C"
T_{oc}	outlet temperature of air in CTES tank "°C"
Δt	time interval during each measurement "s"

and annual performance of PV panel was enhanced by 5%. Yang et al. (Yang et al., 2012) studied a novel water cooled solar PV/T system experimentally first and later numerically modelled the same in finite element analysis method. The authors concluded that there is a percentage increase in electric energy yield of 13.8% for the PV system considered, and the simulation results are concurrent with experimental values. Bahaidarah et al. (Bahaidarah et al., 2013) experimentally investigated the electrical and thermal characteristics of water cooled PV panel and validated the same system in Engineering Equation Solver (EES) numerical model. The authors concluded that there is a 20% decrease in module temperature and 9% relative increase in electrical efficiency. Elnozahy et al. (Elnozahy et al., 2015) experimentally investigated the performance of self-cooled and cleaned PV panel and the same is compared with PV panel without coolant and cleaning system. The authors reported that the electrical efficiency of self-cooled and cleaned PV panel is 11.7% and 9% for PV panel without coolant and cleaning system. Nizetic′ et al. (Nižetić et al., 2016) has experimentally studied water spraying cooling technique on both sides of PV panel. It is confirmed by the authors that there was a percentage increase in electric energy yield of 16.3%. Bahaidarah (Bahaidarah, 2016) experimentally studied the cooling of PV panel with jet impingement for the months of June and December and the same was numerically modelled. The authors found that there was a percentage increase in electric energy yield of 51.6% for the month of June and 49.6% and for the month of December respectively.

For uniform cooling and to remove heat uniformly from PV panels, various channels are used by researchers. Rahimi et al. (Rahimi et al., 2015) analysed a comparative study of single and multi-header micro channels for cooling of PV cells. The authors concluded that removal of heat and power output for PV panels with multi header channels was comparatively higher than PV panels with single header channel. Baloch et al. (Baloch et al., 2015) investigated experimentally and numerically the performances of a converging channel heat exchanger for PV cooling. The percentage increase in electric energy yield was found to be 35.5% respectively.

Passive methods are nowadays used to cool the PV panel for the reduction of power consumed by auxiliary devices in active cooling system. Chandrasekar et al. (Chandrasekar et al., 2013) experimentally investigated the cooling of PV with the combination of cotton wicks, water and nano fluids. Al_2O_3/water and CuO/water have module efficiency of 10.4%, 9.7% and 9.5% respectively. Alami (Alami, 2014) studied the effects of evaporative cooling on efficiency of PV modules. The authors stated that there is a percentage increase in electric energy yield of 19.1% for cooled PV module. Chandrasekar et al. (Chandrasekar and Senthilkumar, 2015) experimentally demonstrated PV module cooled by heat spreaders with cotton wicks. The authors claimed that the PV module with cooling technique showed a percentage increase in electric energy yield of 14% and 12% decrease in module temperature.

Recently the application of PCM to cool PV panel has gained importance. Stritih (Stritih, 2016) experimentally investigated PV integrated with PCM and simulated the same for a specific geographic location. The authors stated that the experimental results showed a percentage increase in electric energy yield of 9.2% and maximum energy generation efficiency of 2.8%. They also concluded that simulation results showed a percentage increase in electric energy yield and energy generation efficiency of 4.3–8.7% and 0.5–1% respectively. Japs et al. (Japs et al., 2016) experimentally studied the effects of paraffin PCM with an improved thermal conductivity and standard thermal conductivity on cooling of solar PV panel. The authors concluded that the PCM with a higher thermal conductivity had significantly lower temperatures after charging and a corresponding higher yield.

From literature review the increase in electric energy yield of PV panel from various cooling techniques are given in Table 1.

Though there are numerous studies on cooling techniques for solar PV modules, there are limited studies on solar PV collector integrated with phase change material (PCM) based latent heat energy storage system. The objective of the present work is to study the performance of solar PV system cooled using free cool thermal energy stored in the storage tank containing encapsulated HS29 PCM. The cooling potential for the solar PV system is evaluated under two different conditions and with different mass flow rates of air.

2. Experimental investigation

The description of system components, PCM details, measurements and experimental procedure are discussed in this section.

2.1. System description

The experimental setup shown in Fig. 1 consists of a PV panel, CTES

Table 1
Increase in electric energy yield of PV panel from various cooling techniques.

Sl.no	Author	Cooling technique/ medium	Increase in electrical energy yield (%)
1	Hernández et al. (2013)	Air	15
2	Kaiser et al. (2014)	Air	14
3	Krauter (2004)	Water	9
4	Odeh and Behnia (2009)	Water	15
5	Yang et al. (2012)	Water	13.8
6	Elnozahy et al. (2015)	Water	26
7	Nižetić et al. (2016)	Water	16.3
8	Bahaidarah (2016)	Water	51.6
9	Rahimi et al. (2015)	Water in microchannel	28
10	Baloch et al. (2015)	Water in converging channel	35.5
11	Chandrasekar et al. (2013)	Cotton wicks with water, nanofluids	15.8
12	Alami et al. (2014)	Evaporative cooling	19.1
13	Chandrasekar and Senthilkumar (2015)	Head spreader with cotton wicks	14
14	Stritih (2016)	PCM	9.2