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Overall energy, exergy and carbon credit analysis of N partially covered Photovoltaic Thermal (PVT) concentrating collector connected in series

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ABSTRACT

In this paper, overall thermal energy gain and exergy gain have been analyzed for four different cases (case (i) 25% PV coverage area, case (ii) 50% PV coverage area, case (iii) 75% PV coverage area and case (iv) 100% PV coverage area, on each collector) of N-numbers of partially covered Photovoltaic thermal (PVT)-compound parabolic concentrator (CPC) water collector connected in series. The analysis is computed by considering a, b, c and d type weather conditions for New Delhi climate condition, India. A transient model of N-PVT-CPC water collectors connected in series has been developed using basic thermal energy balance equations. Six collectors has been optimized for desired temperature range. An attempt has been taken to select an appropriate configured partially covered N-PVT-CPC water collector. On the demand of electrical and overall exergy, case (iv) has been found to be appropriate because net annually overall exergy is 752.77 kW h and net annual electrical energy is 683.40 kW h which is maximum. On the other hand, when the demand of thermal gain is needed, case (i) is first choice due to it has been given 5203.02 kW h overall thermal energy gain which is five times greater than case (iv). The enviroeconomic study examines CO_2 emission per annum is reduced by energy generation and how much money is saved. For case (i), 153.90 $/annum on overall thermal energy basis and 22.25 $/annum on the basis of overall exergy for case (iv).

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1. Introduction

Due to environmental issues and limited fossil fuel resources, more and more attention is being given to renewable energy sources. Solar energy is becoming an alternative for the limited fossil fuel resources. One of the simplest and most direct applications of this energy is the conversion of solar radiation into heat, which can be used in solar systems application. The challenge is accepted to reduce CO_2 and other gas emissions by solar energy. Solar energy has the capability to meet a significant proportion of the global energy demands by Tiwari (2005). In the solar thermal system, the PVT collector is heated by the sun and the heat is then transferred to a working fluid and enhance the electrical gain, also. Generally, PVT water collector system consists of the Photovoltaic module, absorber collector in the formed of copper tubes, the glass cover casing (transparent) and insulated channel box. Kern and Russell (1978) introduced the Photovoltaic thermal collector for the first time where he found electrical as well as thermal energy. Working fluid like air and water can be used just below PV module to decrease the temperature of operating solar cells which increase the electrical output of PV module. Prakash (1994), Tripanagnostopoulos (2002), Zondag et al. (2002), Jones and Underwood (2001), Chow (2003) and Infield et al. (2004) presented that the electrical efficiency of PV module is completely reliant on temperature of PV module, which can be bring down by allowing water/air to flow below it. Two types of PVT water heating namely tube-in-plate configuration and parallel plate configuration. Tube-in-plate configuration has been presented by Zondag et al. (2002) and parallel plate configuration has evaluated by Chow (2003). Tiwari and Sodha (2006) established a theoretical thermal model for an experimental validation of performance evaluation of integrated photovoltaic thermal solar (IPVTS) water heater. It is found in the conclusion that it is fair agreement between the theory and experiments analysis for solar cell and outlet water temperatures within accuracy of about 5%.

Agrawal and Tiwari (2011) evaluated annual overall energy and exergy gain of three PVT based systems under constant mass flow of air in terms of design and climatic parameter. In this comparative study, the results of micro channel photovoltaic thermal module and single channel photovoltaic thermal module was carried out. Analysis was made on the basis of considering four weather conditions for different climatic conditions of India. Khelifa et al. (2015)

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Nomenclature

α_c	absorptivity of the solar cell	K_g	thermal conductivity of glass (W/m K)
$\dot{m}_f$	mass flow rate of water (kg/m^2)	$I_b(t)$	beam radiation (W/m^2)
τ_g	transmissivity of the glass	T_a	ambient temperature (°C)
C_f	specific heat of water (J/kg K)	L_i	thickness of insulation (m)
β_0	temperature coefficient of efficiency (K^{-1})	K_i	thermal conductivity of insulation (W/m K)
L_r	total length of receiver area (m)	$(\alpha\tau)_{eff}$	product of effective absorptivity and transmissivity
L_a	total length of aperture area (m)	F'	collector efficiency factor
L_{rc}, L_{rm}	length of receiver covered by glass or PV module (m)	T_{fi}	inlet water temperature (°C)
L_{ac}, L_{am}	length of aperture covered by glass or PV module (m)	T_f	water temperature (°C)
η_c	solar cell efficiency	η_o	efficiency at standard test condition
η_m	PV module efficiency	$U_{tc,a}$	overall heat transfer coefficient from cell to ambient (W/m^2 K)
b	breath of receiver (m)		
b_o	breath of aperture (m)	$U_{tc,p}$	overall heat transfer coefficient from cell to plate (W/m^2 K)
A_{rm}	area of receiver covered by PV module (m^2)		
A_{rc}	area of receiver covered by glass (m^2)	h_{pf}	heat transfer coefficient from blackened plate to water (W/m^2 K)
A_{am}	area of aperture covered by PV module (m^2)		
A_{ac}	area of aperture covered by glass (m^2)	β	packing factor of the module
L_g	thickness of glass cover (m)		

discussed the analysis of a hybrid solar collector photovoltaic thermal (PVT). It is basically theoretical and experimental validation, it is found fair agreement in the analysis. A compound parabolic concentrator (CPC) is a non-imaging concentrator that is essentially two half parabolas. A CPC has advantage of the fact that for a tilted parabolic reflector, the parabola's half that is closer to the sun will focus the sun's rays below the parabola's focus. As such, by truncating the parabola's half that is now further from the sun and then reflecting the resulting half parabola about an axis of symmetry, a CPC curvature is created. Proell et al. (2016) focused on the influence of the CPC reflectors on the electrical incidence angle modifier of c-Si cells in a PVT hybrid collector. Comparison has taken to enhance the PV efficiency by different geometry configuration in PVT collector. They presented standard CPC (S-CPC) and lowering the absorber CPC (LA-CPC) on design basis. The efficiency losses of the S-CPC for high incidence angles are mainly due to a non-uniform illumination of the PV cell. High angular losses occur due to multiple reflections in LA-CPC, which compensate the positive effect of the flux homogenization.

Agrawal and Tiwari (2013a) compared different type of photovoltaic thermal (PVT) air collector namely: unglazed hybrid PVT tiles, glazed hybrid PVT tiles and conventional hybrid PVT air collectors have been carried out for the composite climate of Srinagar (India). Annual overall thermal energy and exergy gain of unglazed hybrid PVT tiles air collector were 27% and 29.3% higher to glazed hybrid PVT tiles air collector, respectively and 61% and 59.8% higher to conventional hybrid PVT air collector, respectively. Agrawal and Tiwari (2013b) studied enviroeconomic analysis and energy matrices of glazed hybrid photovoltaic thermal module air collector. Carbon credit analysis (Trading of carbon emission) is a special methodology used to minimize the emission of carbon particle by providing economic incentives for getting reductions in the emissions of pollutants. One credit reveals that manufacturer has a opportunity to emit one ton of CO_2 equivalent (1 credit = 1 t CO_2e). Prabhakant and Tiwari (2008) estimated the carbon credits earned by solar energy park, IIT Delhi including PVT system and suggested to develop such type of park in India to mitigate CO_2 and earn the carbon credit. Chaurey and Kandpal (2009) discussed the CO_2 mitigation potential of solar home system (SHS) in India. It has observed in this study that carbon cost could reduce the effective burden of SHS to the user by 18.5% approximately, if carbon prices are at \$10/t CO_2 without transaction costs. Azzopardi and Mutale (2010) presented life cycle analysis for future photovoltaic systems using hybrid PV cells and it is observed that comparative study for sustainability of electricity generating systems namely CO_2 emissions per unit generated during life time are found to be lower than current commercially available PV modules. Tiwari et al. (2011) studied the analytical expression of outlet temperature and obtained energy or exergy of series connected N partially covered PVT flat plate water collectors at lower portion.

Rajoria et al. (2015) discussed exergetic and enviroeconomic analysis of semitransparent PVT array based on optimum air flow configuration and its comparative study. They compared three cases of series parallel combination of PV modules. Four different climatic conditions of India (Delhi, Bangalore, Jodhpur and Srinagar) have taken for annual energy and exergy analysis. It is found that semitransparent PV module array (case-C) has 28.8% and 12.1% lower cell temperature which enhanced the electrical efficiency 9.9% and 3.1% higher than case-A and B respectively, and the average outlet air temperature for case-C is also increased by 40.6% and 19.1% than case-A (opaque PV module array) and case-B (solar cell tile array), respectively. Case-C has found a better performer in CO_2 mitigation or enviroeconomic cost than the other two cases.

Al Imama et al. (2016) performed the solar collector with compound parabolic concentrator and phase change materials (PCM). CPC integrated into PVT collector and a PCM tank with CPC was integrated into one unit. It is concluded that thermal efficiency of solar collector varies from 40% to 50% for clear day and around 40% for semi-cloudy day. The overall efficiency of the PVT collector has found between 55% and 63% for clear-day and around 45–55% for semi-cloudy day whereas the difference between corresponding top loss value is around 0.5 W/m^2 K from clear day to semi-cloudy day. Rajoria et al. (2016) presented a latest approach on cash flow diagram to investigate the effect of energy payback time and earned carbon credits on life cycle cost of different PVT array systems. Here, three cases was compared on the basis three energy matrices: the energy payback time (EPBT), the energy production factor (EPF) and the life cycle conversion efficiency (LCCE). The annualized uniform cost increased by 7.0% for lowest value and 16.5% for highest value on both annual energy and exergy basis.

Tripathi et al. (2016) derived outlet fluid temperature and temperature dependent electrical efficiency of PV module at Nth

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