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Performance evaluation of photovoltaic thermal solar air collector for composite climate of India

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Abstract

The objective of present study is to evaluate the performance of the photovoltaic (PV) module integrated with air duct for composite climate of India. In this case, thermal energy is produced along with electrical energy generated by a PV module with higher efficiency. An analytical expression for an overall efficiency (electrical and thermal) has been derived by using energy balance equation for each component. Experimental validation of thermal model of hybrid photovoltaic/thermal (PV/T) system has also been carried out. It has been observed that there is a fair agreement between theoretical and experimental observations. Further it is concluded that an overall thermal efficiency of PV/T system is significantly increased due to utilization of thermal energy in PV module.

Keywords: PV module; Hybrid PV/T system; Air heater; Solar energy

1. Introduction

The thermal energy has a wider applications in human's life. It can be generally utilized in the form of either low grade (low temperature) or high grade (high temperature). Jones and Underwood [1] have studied the temperature profile of photovoltaic (PV) module in a non-steady state condition with respect to time. They

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conducted experiments for cloudy as well clear day condition. They observed that the PV module temperature varies between 300 and 325 K (27–52 °C) for an ambient air temperature of 297.5 K (~24.5 °C). The carrier of thermal energy associated with PV module may be either air or water. Once thermal energy requirement is integrated with PV module, it is referred as hybrid photovoltaic/thermal (PV/T) system.

Hybrid PV/T system has following applications:

(i) Water heating system [2,3]
(ii) Air heating system [4].

Chow [5] has analyzed PV/T water collector with single glazing in a transient condition. The tube below a flat plate with metallic bond collector was used. It has been observed that electrical thermal efficiency is increased by 2% at mass flow rate of 0.01 Kg/s for 10,000 $W/m^2 K$ plate to bond heat transfer coefficient. An additional thermal efficiency of 60% was also observed. Huang et al. [6] have studied experimentally unglazed integrated PV and thermal solar system (IPVTS) for water heating under the natural mode of operation. They observed that the primary energy saving efficiency of IPVTS exceeds 0.60 which is higher than for a conventional solar water heater or pure PV system. Kalogirou [7] has carried out a monthly performance of unglazed hybrid PV/T system under the forced mode of operation for climatic condition of Cyprus. He observed an increase in the mean annual efficiency of PV solar system from 2.8% to 7.7% with a thermal efficiency of 49%. Similar study has also been carried out by Zondag et al. [8]. They have referred to hybrid PV/T as a combi-panel that converts solar energy into both electrical and thermal efficiencies of which were reported as 6.7% and 33%, respectively.

Sandnes and Rekstad [9] have studied the behavior of a combined PV/T collector which was constructed by pasting single- crystal silicon cells onto a black plastic solar heat absorber (unglazed PV/T system). They recommended that the combined PV/T concept must be used for low-temperature thermal application for increasing the electrical efficiency of PV system, for e.g., space heating of a building. Zakharchenko et al. [10] have also studied unglazed hybrid PV-thermal system with a suitable thermal contact between the panel and collector. They have proved that the areas of PV panel and collector in PV/T system need not be equal for higher overall efficiency. To operate PV module at low temperature, PV module should cover the low temperature part of the collector (at cold water inlet portion). Further, unglazed hybrid PV/T with a booster diffuse reflector was integrated with the horizontal roof of a building by Tripanagnostopoulos et al. [11]. They suggested that the PV/T system with a reflector clearly gives a higher electrical and thermal output. They have also studied the performance characteristic of PV/water and PV/air systems. Infield et al. [12] have derived an overall heat loss coefficient (U) and thermal energy gain factor (g) for ventilated vertical PV module and double-glazed window (PV facades). Steady state analysis has been used to determine ventilation gains and transmission losses in terms of irradiation (solar radiation) and various heat transfer process involved in facades. It is observed that the ventilated facades ensure that the electrical efficiency of a PV module is improved due to low