Energy Conversion and Management 114 (2016) 241–250

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

Design, modeling and performance analysis of dual channel semitransparent photovoltaic thermal hybrid module in the cold environment

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ARTICLE INFO

Article history:
Received 31 December 2015
Accepted 7 February 2016

Keywords:
Exergy analysis
Dual channel photovoltaic thermal module
Hybrid PVT system
Modeling of dual channel PVT module

ABSTRACT

In this work, thermal modeling and performance analysis of the dual channel semitransparent photovoltaic thermal (DCSPVT) module has been carried out. For extracting heat associated with the lower and upper surface of the solar cell, two channels have been proposed; (i) one is above the solar cell called upper channel and (ii) second is below the solar cell called lower channel. Firstly, thermal modeling of DCSPVT module has been developed. After that, performance analysis of the above system has been carried out for Srinagar, Indian climatic condition. Performance in terms of electrical gain (EG), thermal gain (TG), overall exergy gain (OEG), overall thermal gain (OTG), electrical efficiency (EE) and overall exergy efficiency (OEE) of the DCSPVT module (case-I) have been compared with single channel semitransparent photovoltaic thermal (SCSPVT) hybrid module (case-II). The average improvement in EG, TG, OEG, OTG of the case-I have been observed by 71.51%, 34.57%, 5.78% and 35.41% respectively as compared to case-II.

1. Introduction

The demand for energy is increasing, the security of supply of fossil resources and international agreements to mitigate climate change are key issues of modern society. These developments dramatically increased the need for the implementation of large-scale renewable energy technologies in recent years and will continue to do so in the near future. Electricity and heat are the most important energy needs in the residential sector and the public and commercial services. Most of this energy is generated carriers from the center of conventional energy like coal and natural gas. Under the study of a photovoltaic (PV) system, sometimes potential output of the PV array is predicted necessarily. The Simplified method has been developed by Evans for calculating PV array output in terms of mean monthly array efficiency by giving minimum information of the input [1]. Method for calculation of the thermal radiation exergy has been reported by Petela [2]. A review study has been carried out on a wide range of renewable energy resources. The study has been done in terms of entropy, energy, exergy balance equation and exergy efficiency. Exergetic analysis and performance evaluation have also been carried out [3]. A novel design of the hybrid photovoltaic thermal (PVT) collector has been developed and simulated and it is concluded that the proposed design is a better as compared to other hybrid collector model in terms of heat absorption and lower production cost [4]. The different type of Flat-plate PVT collectors and its application has been presented and it different research issues associated with PVT system have been discussed in detail [5]. The experimental investigation has been performed on a PVT system and ferro-fluids has been used as a coolant to improve the overall efficiency of the system. It has been reported that the overall efficiency of the system improved by 45% and 50% when 3% ferro-fluid and alternating magnetic field were applied respectively [6]. Thermal model of semi transparent double pass facade PVT module for space heating has been developed using energy balance equations and it has been observed that the annual electrical and thermal energy gains are 469.87 kW h and 480.81 kW h respectively. It has also been reported that the room temperature increased up to 5–6 °C as compared to the ambient air temperature [7]. The comparative study has been conducted on different types of PVT collectors like; glazed PVT tiles, unglazed PVT tiles and conventional hybrid PVT collectors, which is based on the overall thermal gain and overall exergy efficiency and carbon credits. It has been reported that the annual overall exergy efficiency of glazed and unglazed PVT tiles is 53.8%

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http://dx.doi.org/10.1016/j.enconman.2016.02.023
0196-8904/

and 9.6% more as compared to conventional PVT collectors respectively. It has also been observed that the annual overall thermal gain and exergy gain of unglazed PVT tiles is improved by 27% and 29.3% as compared to glazed PVT tiles [8]. A novel design of a dynamic model of air based PVT system has been presented. The model simulates real operating conditions of the system with experimental data collected from BIPV module installed in two buildings and it was concluded that the air outlet temperature and electrical power are very close to experimental data. The study in changing working conditions has also been performed on PVT system and it is inferred that the thermal efficiency increases linearly with the increase in ambient temperature while the electrical efficiency decreases [9]. A novel design and performance analysis of low concentration PV modules have been presented. It has been concluded that low concentration PV modules for building integration gives various advantages as compared to conventional photovoltaic technology. It has also been inferred that the maximum power of the low concentration PV module can be estimated by the this system [10]. Different types of solar collectors and its solar thermal applications have been discussed. Thermal energy storage system has been reviewed on the basis of material selection, design criterion and different heat transfer enhancement technologies while the solar collectors has been reviewed on the basis of heat loss reduction, optical optimization, different sun-tracking mechanisms and heat recuperation enhancement [11]. A novel design of tri-functional PVT collector has been presented. The proposed model works in two modes: (i) photovoltaic air heating and (ii) photovoltaic water heating. It is observed that the electrical and daily thermal efficiency is 10.2% and 46% respectively in photovoltaic air heating mode [12]. Performance analysis of semi-transparent hybrid PVT double pass facade has been carried out with three cases such as connected in combination series and parallel (Case A), parallel (Case B) and series (Case C). It is reported that case B is most suitable configuration on the basis of electrical energy while the case C is better on the basis of thermal energy [13]. The characteristic of PV module has been studied and comparative results have been presented between simple photovoltaic cell and module model and the study has been carried out on the basis of junction temperature and insolation and it provides an overview over the degradation and defects of photovoltaic module [14]. A comparative study has been performed on different types of PVT systems and it is reported that the PVT system is superior in exergy performance point of view as compared to other systems [15]. An experimental study has been conducted to observe the effects of forced convection on cell temperature. It is already observed that the efficiency of the PV system is based on the solar cell temperature. During the study, the PV panels are installed on the rooftop and an open air channel has been considered below the panel to regulate the solar cell temperature which makes it cost effective. It has been observed that the solar cell temperature of these modules is strongly influenced by the capability of ventilation [16]. The study has been conducted to observe the electrical and thermal performance of a PVT air collector. It has also been observed that the overall energy efficiency, thermal efficiency and electrical efficiency of the proposed system is 45%, 17.18% and 10.01% respectively [17]. An experimental validation has been done in developing the hybrid PVT transient model. The proposed model can predict the output power for any set of climate data after calibration. It is reported that, the characteristic parameters of the model have good agreement with experimental data obtained from the standard steady state and current–voltage characteristic curve [18]. Design and development of the thermal-electrical model has been presented and the observations are compared with experimental data. A study is performed to observe the effect of different design parameters like; length, duct depth, flow rate and packing factor on electrical and thermal performance [19]. The performance of PV module which is installed in the desert region, has been investigated to observe the impact of climatic conditions. Firstly, the performance evaluation of ISOFOTON 100 module has been done. After that the effect of partial shading and accumulation of sand dust on PV module has been observed for a period of two months. The experimental validation has also been conducted and concluded that the performance parameters such as V_{max}, I_{max}, V_{oc}, P_{max}, I_{sc} and fill factor of UDTS 50 modules are degraded after these years of exposition [20]. When the solar thermal collector and photovoltaic are combined, then it produces electrical energy as well as thermal energy simultaneously and called as a PVT module. A review study has been carried out on PVT module [21]. The study of the series combination of N number of PVT water collectors, partially covered with photovoltaic module for two different configurations like; photovoltaic module at the lower portion (Case A), photovoltaic module at the upper portion (Case B). During the study, the expression for EE and instantaneous thermal efficiency (TE) have been derived. The performance of both the configuration has been compared. It has been reported that both cases give nearly the same results at a moderate mass flow rate for a large number of photovoltaic thermal collectors which are connected in series [22]. The study has been performed on the glazed PVT system. During the study, optimization has been performed using Genetic Algorithm-Fuzzy System approach. Different parameter of proposed system has been optimized and overall exergy efficiency is the objective function during the course of optimization. It has been observed that the OEE obtained from the system optimized with GA-FS approach is 15.82%, which is 1.27% and 5.40% more than the efficiency of the system optimized with GA and un-optimized system respectively [23]. Optimization and carbon credit analysis has been done on the glazed PVT array. Evolutionary Algorithm is an optimization tool and overall exergy gain is the objective function during the course of optimization. There are 69.52% and 88.05% improvement in annual overall exergy gain and annual overall thermal gain respectively, then the un-optimized system for the same input irradiance and ambient temperature [24].

After the study of literature, it has been observed that lots of the work has been done on PVT module, mostly on single channel PVT module. There is no work has been carried out on a dual channel PVT module. So the effort has been made to model a novel dual channel semitransparent PVT hybrid module in which two channel has been considered. One is above the solar cell and the second is below the solar cell. Due to the proposed dual channel additional thermal energy is extracted which will reduce the solar cell temperature. Due to the reduction in solar cell temperature, electrical efficiency is improved and also the lifespan of PVT module will increase. The analysis has been done for Srinagar, Indian climatic condition and results have been compared with the results of single channel semitransparent PVT hybrid module.

2. Description of the dual channel semi-transparent PVT module

The structure and cross section view of the proposed dual channel semitransparent photovoltaic thermal (DCSPVT) hybrid module (case-I) is shown in Fig. 1. The module has the following two channels; (i) upper channel which is between glass touching above solar cell and glass cover (ii) lower channel which is between the glass below solar cell and acrylic sheet. The dimensions have been shown in Table 1. The blackened plate as an absorber is attached below the lower channel as shown in Fig. 1. Air as working fluid in the upper and lower channel has been used. The nomenclature is given in Table 2. Side view of single channel semitransparent PV module (Case-II) has been shown in Fig. 2.