Life cycle cost analysis of HPVT air collector under different Indian climatic conditions

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Abstract

In this communication, a study is carried out to evaluate an annual thermal and exergy efficiency of a hybrid photovoltaic thermal (HPVT) air collector for different Indian climate conditions, of Srinagar, Mumbai, Jodhpur, New Delhi and Bangalore. The study has been based on electrical, thermal and exergy output of the HPVT air collector. Further, the life cycle analysis in terms of cost/kWh has been carried out. The main focus of the study is to see the effect of interest rate, life of the HPVT air collector, subsidy, etc. on the cost/ kWh HPVT air collector. A comparison is made keeping in view the energy matrices. The study reveals that (i) annual thermal and electrical efficiency decreases with increase in solar radiation and (ii) the cost/kWh is higher in case of exergy when compared with cost/kWh on the basis of thermal energy for all climate conditions. The cost/kWh for climate conditions of Jodhpur is most economical.

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1. Introduction

Increasing cost of fossil fuels has compelled scientists to look for different options to meet energy requirements keeping in view that such options are economical, abundant in nature and have low maintenance cost. Over the years, scientists have studied various options available such as nuclear energy, wind energy, bio mass, fuel cell, solar energy, etc. Studies have shown that amongst available sources of energy, solar energy appears to be freely available, more economical and truly environment friendly than other sources of energy available.

Solar energy can be utilized as electrical energy, thermal energy or a combination of both. Hybrid photovoltaic thermal (HPVT) air collector system can collectively generate electrical and thermal energy. Efficiency of photovoltaic (PV) system can be increased by withdrawing the thermal energy available at the bottom of the PV module.

The HPVT system can be used as air collector/water collector. A HPVT air collector consists of a PV module with an air duct mounted below the PV module. The air is passed through the duct by using a fan. The air gets heated by using the thermal energy available at the bottom of the PV module. In case of HPVT water collector, water is used in place of air. Thus, an HPVT system can be used as

(1) Air collector: (Hegazy, 2000; Infield et al., 2004; Tripanagnostopoulos et al., 2002; Prakash, 1994; Carmell et al., 2004; Bhargava et al., 1991; Tiwari and Sodha, 2006, 2007; Chow et al., 2007a; Tiwari et al., 2006).

(2) Water collector: (Zondag et al., 2002; Kalogirou, 2001; Garg et al., 1994; Chow, 2003; Chow et al., 2006, 2007b; Tripanagnostopoulos et al., 2002; Zakherchenko et al., 2004; Sandnes and Rekkstad, 2002; Tiwari and Sodha, 2006)

Kalogirou (2001) observed an increase of mean annual efficiency from 2.8% to 7.7% with a thermal efficiency of 49% of an unglazed HPVT air collector under forced mode
of operation for the climatic conditions of Cyprus. A similar study has been conducted by Zondag et al. (2002). They referred to an HPVT system as a combi-panel that converts solar energy into electrical and thermal energy and observed electrical and thermal efficiencies as 6.7% and 33%, respectively. Sandnes and Rekstad (2002) observed that the HPVT system concept must be used for low-temperature thermal applications and for increasing their electrical efficiency. Zakherchenko et al. (2004) have also studied unglazed HPVT system with a suitable thermal contact between the panel and the collector and then observed that the area of PV panel and collector in HPVT system need not be equal for high overall efficiency. Tripanagnostopoulos et al. (2002) studied an integrated unglazed HPVT system with a booster diffuse reflector with the horizontal roofing of a building and concluded that the system yields distinctly clear higher electrical and thermal outputs. Infield et al. (2004) derived an overall heat loss coefficient and thermal energy gain factor for a combination of a ventilated vertical PV module and PV

Nomenclature

\begin{itemize}
\item \textbf{A} area of photovoltaic module
\item \textbf{b} breadth
\item \textbf{c}_a specific heat of air
\item \textbf{D} duct depth
\item \textbf{E} energy
\item \textbf{E}_{in} embodied energy
\item \textbf{E}_{gen} annual electrical energy generated
\item \textbf{E}_{aex} annual exergy output (thermal)
\item \textbf{E}_{outex} annual exergy output
\item \textbf{E}_{athgen} annual thermal energy output
\item \textbf{F} future value
\item \textbf{F}_{PS,i,n} compound interest factor for \textit{n} years with rate of interest \textit{i}
\item \textbf{h}_{p1} penalty factor due to presence of solar cell material, tedler and EVA
\item \textbf{h}_{p2} penalty factor due to presence of interface between tedler and working fluid through absorber plate
\item \textbf{i} rate of interest
\item \textbf{I}(\textit{t}) incident solar intensity on the inclined module surface
\item \textbf{I}_{SC} short-circuit current of the PV module
\item \textbf{L} length
\item \textbf{m}_a rate of flow of air mass
\item \textbf{N} sunshine hours
\item \textbf{n} number of days in the month
\item \textbf{P} present value
\item \textbf{Q} annual thermal energy output
\item \textbf{Q}_u rate of useful thermal energy
\item \textbf{Q}_{ui} rate of monthly thermal energy
\item \textbf{R} uniform end of the year amount
\item \textbf{S} future value
\item \textbf{SV} salvage value
\item \textbf{T} temperature
\item \textbf{t} time
\item \textbf{T}_c solar cell temperature
\item \textbf{T}_0 reference temperature
\item \textbf{U}_A Unacost
\item \textbf{U}_L overall heat transfer coefficient from solar cell to ambient through top and back surface of insulation
\item \textbf{V}_{OC} open-circuit voltage of the PV module
\item \textbf{\lambda}(\textit{t}) electricity production factor
\end{itemize}

Subscript

\begin{itemize}
\item \textbf{a} air
\item \textbf{admin} administrative section
\item \textbf{aegen} annual electrical energy generated
\item \textbf{aex} annual exergy output
\item \textbf{athgen} annual thermal energy output
\item \textbf{del} delivery
\item \textbf{dstr} distribution
\item \textbf{gendaily} energy generated daily
\item \textbf{eff} effective
\item \textbf{eqp} equipment
\item \textbf{fac} construction operation and maintenance of manufacturing building
\item \textbf{fuels} fuels
\item \textbf{gen} generated
\item \textbf{in} input
\item \textbf{inst} installation
\item \textbf{lbr} labor
\item \textbf{mfg} manufacturing
\item \textbf{mpe} material production energy
\item \textbf{out} output
\item \textbf{om} operations and maintenance
\item \textbf{outex} exergy output
\item \textbf{r&d} research and development
\item \textbf{salv} salvage
\item \textbf{use} useful
\end{itemize}

Greek letters

\begin{itemize}
\item \textbf{\alpha} absorptivity
\item \textbf{\phi}(\textit{t}) life cycle conversion efficiency
\item \textbf{\eta} efficiency
\item \textbf{\eta}_i instantaneous thermal efficiency
\item \textbf{\eta}_o overall thermal efficiency
\item \textbf{\zeta} transmissivity
\item \textbf{(\alpha\tau)_{eff}} effective absorptivity and transitivity product
\end{itemize}
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