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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 Banglore. 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.

Keywords: Hybrid photovoltaic thermal (HPVT) air collector; Life cycle cost analysis; Solar energy

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; Cartmell 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 Rekstad, 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

Abbreviations: BOS, balance of system; CRF, capital recovery factor; EPBT, energy payback time; EPF, electricity production factor; HPVT, hybrid photovoltaic thermal; LCCE, life cycle conversion efficiency; PV, photovoltaic

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Nomenclature

A	area of photovoltaic module
b	breadth
c_a	specific heat of air
D	duct depth
E	energy
E_{in}	embodied energy
E_{aegen}	annual electrical energy generated
E_{aex}	annual exergy output (thermal)
E_{outex}	annual exergy output
E_{athgen}	annual thermal energy output
E_{aegen}	annual electrical energy generated
F	future value
$F_{PS,i,n}$	compound interest factor for n years with rate of interest i
h_{p1}	penalty factor due to presence of solar cell material, tedler and EVA
h_{p2}	penalty factor due to presence of interface between tedler and working fluid through absorber plate
i	rate of interest
$I(t)$	incident solar intensity on the inclined module surface
I_{SC}	short-circuit current of the PV module
L	length
m_a	rate of flow of air mass
N	sunshine hours
n	number of days in the month
P	present value
Q	annual thermal energy output
Q_u	rate of useful thermal energy
Q_{ui}	rate of monthly thermal energy
R	uniform end of the year amount
S	future value
SV	salvage value
T	temperature
t	time
T_c	solar cell temperature
T_0	reference temperature
U_A	Unacost
U_L	overall heat transfer coefficient from solar cell to ambient through top and back surface of insulation
V_{OC}	open-circuit voltage of the PV module
$X(t)$	electricity production factor

Subscript

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

Greek letters

α	absorptivity
$\Phi(t)$	life cycle conversion efficiency
η	efficiency
η_i	instantaneous thermal efficiency
η_o	overall thermal efficiency
ζ	transmitivity
$(\alpha\tau)_{eff}$	effective absorptivity and transitivity product

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