Exergoeconomic and Envirnoeconomic Analysis of Building Integrated photovoltaic Thermal (BIPVT) System and its Optimization

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Abstract: This paper gives an idea about advantage of semitransparent photovoltaic system over opaque system. In an inclined system. Considering different parameters of the cell, room, duct and tedlar effect has been made to increase the overall efficiency of the total system. Thermal Model has been designed and mathematical analysis has been done. Electrical as well as thermal energy calculation has been compared with other system from different outputs of different places. If we compare a normal PV system definitely the hybrid PVT system has an edge over PV as in PVT system we consider thermal energy too. A soft computing technique has been developed to optimize the exergy of the system by varying the velocity and length of channel. For the proposed system, it has found that air at 4.5 m/s and channel length of 0.2083 m gives maximum exergy. A total thermal energy gain of 54716kWh and electrical energy gain of 15838kwh is obtained.

Keywords: Building Integrated PVT (BIPVT), Electrical and Thermal Exergy, Optimization, Energy.

1. Introduction

Due to the fast application of PVT system now a days this system taking replacement in the field of Solar system. Agrawal et.al [1] calculated the benefit of BIPVT system over normal PV system after calculating the payback system. Agrawal et.al [2] delivered an conclusion of glazed PV system after doing experimental work over normal photovoltaic system. Chauhan and Sanjeev [3] tried to express the thing in a better way after applying soft computing techniques. Nayak, Tiwari [4] calculated the energy of a glass fitted house both in horizontal and tilted way and concluded that inclination of panel gives better result. Gaur et al. [5] after taking different material they have shown results and conclusions. Chow [6] pointed out the issued related to the decrement of application of solar energy. Tiwari, Sodha [7] made a research on unglazed PVT module. Solanki et. al [8] et al. elaborated calculated the volume as well as velocity of air flowing inside the duct. Rajoria [9] et al. analyzed the system and described the output of the parameter related to efficiency. Rajoria et al. [10, 11] elaborated the characteristics of different inter related parameter of hybrid systems. Singh S et.al [12] applied genetic algorithm technique to improvise the system efficiency and also optimized the system. Joshi AS, Tiwari GN [13] Comparative study of double pass flat and compound parabolic concentrated PVT system with and without fins.Vats and Tiwari [14] Derived the analytical expression for room air temperature of building integrated semitransparent photovoltaic thermal (BISPVT) and building integrated opaque photovoltaic thermal (BIOPVT) systems Dubey S, Tiwari GN [15] explained about the characteristics of different material.

2. Description of BIPVT System

From the literature review and different application we know that a any photovoltaic system gives better result when that is being placed inclined as maximum solar intensity can be absorbed at that position. Since research work has been done for cold climatic condition of Srinagar that to in the month of January. A total no of 48 modules has been considered that are being placed in 8rows and 6 columns. A dc fan of 120W is connected to blow the air in the duct to reduce the cell temperature. Each module is capable of giving an output of 150watt.
Table 1: Technical design of the system

| Parameters          | Technical specification |
|---------------------|-------------------------|
| $V_{out}$           | 425 V                   |
| Efficiency          | 17.1%                   |
| Room Size           | 5.580 m x 4.810 m       |
| Wall                | 2765 * 6238 mm          |
| Covered module space| 11.060 m x 6.144 mm     |
| Inclination of System| $35^0$                |
| Efficiency(Ref)     | 16%                     |

Table 2: Parameter values

| Parameters | Technical specification |
|------------|-------------------------|
| Length of one module | 1.650 m       |
| Wide of one module   | 0.800 m       |
| Overall Electrical Output | 150 W   |
| Duct depth           | 0.255 m       |
| $C_{air}$            | 1008          |
| $C_r$                | 0.38 [22]     |
| Ambient Temp         | 25 $^0$       |
| $H_{out}$            | $5.70 + 3.8 V_a (Watt/m^2)$ |
| $h_{ins}$            | 2.8 (Watt/m²) |
| $h_{td}$             | $2.80 + 3 V_{air} (Watt/m^2)$ |
| $K_{cs}$             | 0.040 (Watt/m²) |
| $K_{Gl}$             | 0.80 (Watt/m²) |
| $K_{ins}$            | 0.0350 (Watt/m²) |
| $K$                  | 0.380 (Watt/m² K) |
| $L_{cs}$ (mm)        | 0.3           |
| $L_{Gl}$ (mm)        | 34            |
| $L_{ins}$ (mm)       | 11            |
| $L_{td}$ (mm)        | 3             |
3. Thermal /Mathematical design of proposed system:

Zondag (2002) proposed a theory to calculate cell efficiency given by,

\[ \eta_{ca} = \eta_{ref} \left[ 1 - \Phi_{ref} (T_c - T_a) \right] \]  

(1)

Reference and ambient values are set by the researcher

\[ E_{out} = \eta_{ca} * I(t) * bL * \eta_{pv} \]  

(2)

Electrical equivalent of thermal energy

\[ E_{eth} = \frac{E_{out}}{C_f} \]  

(3)

Thermal energy of hour, day and year is given by

\[ Q_{hourly} = \frac{E_{out}}{C_f} + Q_u \]  

(4)

\[ Q_{daily} = \sum_{j=1}^{n} \frac{(\eta_{ca})^j I(t) j^{bL \eta_{pv}}}{C_f} + \sum_{j=1}^{n} (Q_u)_j \]  

(5)

\[ \eta_{TH} = \frac{\sum_{j=1}^{n} (\eta_{ca})^j I(t) j^{bL \eta_{pv}}}{\sum_{j=1}^{n} (Q_u)_j} \]  

(6)

\[ \text{Thermal Exergy} = Q_u \left( 1 - \frac{T_a}{T_{airout}} \right) \]  

(7)

\[ \text{Net Exergy Gain} = E_{out} + Q_u \left( 1 - \frac{T_a}{T_{airout}} \right) \]  

(8)

**Figure 2** Change in ambient temp and intensity
\[
\left[ \text{Amount of heat received by} \right]_{\text{solar cell}} + \left[ \text{Amount of heat received by} \right]_{\text{non packing area}} = \left[ \text{Amount of heat loss from} \right]_{\text{PV module to air as the top loss}} + \left[ \text{Amount of heat loss from} \right]_{\text{PV module to back surface/teflon}} + \left[ \text{rate of Electricity produced} \right]
\]
Figure 5 Electrical efficiency variation w.r.t time

Figure 6 Monthly variation of electrical output

Figure 7 overall Energy (Electrical)

Figure 8 Thermal energy
Figure 9 Overall exergy efficiency variation month wise.

Figure 10 Variation of Depth of channel w.r.t Exergy efficiency

Figure 11 Variation of Exergy efficiency w.r.t Channel length

Figure 12 Variation of Exergy Efficiency w.r.t Velocity of Air
Energy balance equation:
\[ \tau_g[\alpha_c \beta_c + (1 - \beta_c) \alpha_T] I(t) bdx = [U_r(T_c - T_a) + h_{Td} (T_c - T_{bs})] bdx + \eta_{ca} I(t) bdx \] (9)

Simplifying
\[ T_c = \frac{h_r T_{bs} + U_r T_a + l(t) (\alpha)_{\text{eff}}}{U_r + h_r} \] (10)

\[ \text{[Rate of heat gain from PV module to tedlar to] \quad [Rate of heat loss from tedlar to air side in the duct]} \]

\[ h_{Td} (T_c - T_{bs}) bdx = h_{air} (T_{bs} - T_{air}) bdx \] (11)

Substituting \( T_c \) in Eq. (11)
\[ T_{bs} = \frac{h_{air} T_{air} + U_r T_a + h_{p1} l(t) (\alpha)_{\text{eff}}}{U_r + h_{air}} \] (12)

Inside duct flowing of air energy balance can be derived as
\[ h_{air} (T_{bs} - T_{air}) bdx = M_{air} c_{air} \left( \frac{dT_{air}}{dx} \right) dx + U_{bb} (T_{air} - T_{ar}) bdx \] (13)

\[ h_{air} \left[ \frac{h_{p1} h_{p2} l(t) (\alpha)_{\text{eff}} - U_r (T_{air} - T_c)}{U_r \ h_{air}} \right] bdx = M_{air} c_{air} \left( \frac{dT_{air}}{dx} \right) dx + U_{bb} (T_{air} - T_{ar}) bdx \] (14)

\[ T_{airout} = \left[ \frac{U_{bb} T_{air} + U_{tair} T_a + h_{p1} h_{p2} (\alpha)_{\text{eff}}}{U_{ti}} \right] \left( 1 - e^{-\frac{bu_{tij}}{M_{air} c_{air}}} \right) + T_{ar} e^{-\frac{bu_{tij}}{M_{air} c_{air}}} \] (15)

\[ T_{air} = \left[ \frac{U_{bb} T_{air} + U_{tair} T_a + h_{p1} h_{p2} (\alpha)_{\text{eff}}}{U_{ti}} \right] \left( 1 - \frac{1 - e^{-\frac{bu_{tij}}{M_{air} c_{air}}}}{\frac{bu_{tij}}{M_{air} c_{air}}} \right) + T_{ar} \left( 1 - e^{-\frac{bu_{tij}}{M_{air} c_{air}}} \right) \] (16)

Thermal energy can be calculated by:
\[ Q_u = n_{pv} * M_{air} c_{air} (T_{airout} - T_{ar}) \] (17)

\[ n_{pv} * M_{air} c_{air} \left[ \frac{U_{bb} T_{air} + U_{tair} T_a + h_{p1} h_{p2} l(t) (\alpha)_{\text{eff}}}{U_{ti}} - T_{ar} \right] \left( 1 - e^{-\frac{bu_{tij}}{M_{air} c_{air}}} \right) + U_{bb} (T_{air} + T_{ar}) A_{roof} = M_r c_{air} \left( \frac{dT_r}{dt} \right) + (UA)_c (T_{ar} - T_a) + 0.33 N_0 V(T_{ar} - T_a) \] (18)

Equation of room temperature:
\[ T_{ar} = \frac{f(t)}{a} (1 - e^{-at}) + T_{ri} e^{-at} \] (19)
\[ f(t) = \frac{1}{M_{air}} \left[ \{(UA)_{l} 0.33N_{o}V\}T_{a} + \left( \eta_{pv} M_{air} C_{air} \left[ \frac{u_{air}T_{a} + h_{p1} h_{p2}l(t)(\alpha \tau)_{eff}}{u_{ti}} \right] \right) \right] \left( 1 - \frac{-bu_{ti}l}{e^{\delta_{air}C_{air}}} \right) + U_{bb} \left( \frac{u_{air}T_{a} + h_{p1} h_{p2}l(t)(\alpha \tau)_{eff}}{u_{ti}} \right) \left( 1 - \frac{1-e^{-bu_{ti}l}}{M_{air}C_{air}} \right) A_{roof} \]  

(20)

The present work has been analyzed with the use of “MATLAB-15”.

4. Results and discussion

- Figure 2 shows that if a solar panel is kept in horizontal and inclined position, then the later one absorbs more solar intensity as compared to horizontal.
- With a design of 48 solar modules each panel can generate a total power of 150 watt, figure 3 gives a conclusion about electrical and thermal output i.e. almost 7.1KWh and 6.2 KWh respectively.
- If we compare a normal PV cell with a hybrid or BIPVT system which consider thermal energy as one of the factor then the later gives better result which can be shown from Figure 4.
- Considering different weather condition and calculating energy for the whole year, it has found that energy of 1888kWh has been generated in increment in electrical energy for the present system.
- There is an improvement in Overall Exergy efficiency to 18% which is greater by 0.8% as compared to previous system which can be seen from figure 9.
- Optimization of the system has been done for overall exergy efficiency by varying velocity of air, channel length and depth of the duct which can be seen from Figure 10 to Figure 12.

5. Conclusions:

The paper can be summarized as:

a. As we all know that with the increment of solar intensity the efficiency of cell increases, the current system gains an increment in energy at 1pm.

b. At velocity of air of 4.5m/s and 0.2083m Length of channel the system reaches maximum exergy efficiency of 18% which can be shown from figures 10-12.

c. A total thermal energy of 54716kWh has been generated annually from this system.

d. There is an improvement in both electrical and thermal efficiency as compared to previous systems from 16% to more than 17%.

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Appendix

\[(\alpha \tau)_{eff} = \tau_{g} [\alpha_{c} \beta_{c} + (1 - \beta_{c}) \alpha_{T}] - \eta_{c} \]

\[U_{T} = \left( \frac{1}{Kg} + \frac{1}{h_{o}} \right)^{-1} \]
\[ h_T = \left( \frac{L_T}{K_T} \right)^{-1} \]
\[ h_{p1} = \frac{h_T}{U_T + h_T} \]
\[ U_T = \frac{U_T h_T}{U_T + h_T} \left( \frac{1}{h_T} + \frac{1}{U_T} \right)^{-1} \]
\[ U_{bb} = \left( \frac{1}{h_{air}} + \frac{1}{L_i} + \frac{1}{h_T} \right)^{-1} \]
\[ h_{p2} = \frac{U_T h_{air}}{U_T + h_{air}} \]
\[ U_{tair} = \left( \frac{1}{h_{air}} + \frac{1}{U_T} \right)^{-1} \]

\[ U_L = (U_{bb} + U_{tair}) \]

\[ (U_A)_{Lm, de} = \frac{A_d}{\left( \frac{1}{h_o} + \frac{1}{h_T} + \frac{1}{k_d} \right)} \]
\[ (U_A)_{Lm, win} = \frac{A_{win}}{\left( \frac{1}{h_o} + \frac{1}{h_T} + \frac{1}{k_{win}} \right)} \]
\[ (U_A)_{Lm, wall} = \frac{A_{wall}}{\left( \frac{1}{h_o} + \frac{1}{h_T} + \frac{1}{k_{wall}} \right)} \]

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