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Research Article

Carbon Credits Earned by Hybrid Photovoltaic Thermal Array*

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Abstract In this paper, a study has been carried out to evaluate carbon credit earned by hybrid photovoltaic thermal (PVT) array. The study has been based on overall thermal energy and exergy output of PVT array. The hybrid PVT array is a proposed system consisting of 36 hybrid PVT modules connected in a series and parallel combinations. The annual energy and exergy gain has been evaluated by considering four types of weather conditions (a, b, c, and d types) of Bangalore. This paper gives the total carbon credit earned by as per norms of Kyoto Protocol Bangalore climatic conditions. We have found that the total carbon credit earned by hybrid PVT array annually in terms of thermal energy is Rs. 1.34 lakhs and in terms of exergy is Rs. 0.61 lakhs, respectively. The total annual monetary gain in terms of overall thermal energy gain and overall exergy gain comes out to be Rs. 3.83 lakhs and Rs. 1.75 lakhs, respectively.

Keywords photovoltaic; exergy; thermal energy; carbon credit; PVT array

1 Introduction

Considerable quantities of carbon are contained in the world's forests. As trees grow, they absorb or fix a quantity of carbon, which is proportional to the growth of their biomass. This observation has led many to observe that increasing the area devoted to forests, or the stock of timber in existing forests, could be a method to mitigate the increase of atmospheric carbon dioxide (CO_2), a greenhouse gas. The temperature profile of the photovoltaic (PV) module in a non-steady state condition with respect to time has been studied [5]. The overall electrical efficiency of the PV module can be increased by increasing the packing factor (PF) and reducing the temperature of the PV module by using the thermal energy associated with the PV module [2,12]. Energy consumption of a country is one of the indicators of its socio-economic development. Per capita energy consumption in India is also one of the lowest in the world. It is about 30% of that in China, about 22% of that in Brazil, and about 3.18% of that in USA. With development the per capita energy consumption is likely to increase. At present our annual economic growth rate is 8–10%, per annum. For energy India depends on oil and gas imports, which account for over 65% of its consumption; it is likely to increase further considering the economic development, rise in living condition of people, and rising prices. Coal, which currently accounts for over 60% of India's electricity production, is the major source of emission of greenhouse gases and that of acid rains. In the business-as-usual scenario, India will exhaust its oil reserves in 22 years, its gas reserves in 30 years, and its coal reserves in 80 years [6]. More alarming, the coal reserves might disappear in less than 40 years if India continues to grow at 8% a year [6]. Carbon Credit Trading (Emission Trading) is an administrative approach used to control pollution by providing economic incentives for achieving reductions in the emissions of pollutants. A credit gives the owner the right to emit one ton of carbon dioxide. International treaties such as the Kyoto Protocol set quotas on the amount of greenhouse gases that countries can produce. There are currently two exchanges for bought and sold carbon credits: the Chicago Climate Exchange and the European Climate Exchange. European and Japanese companies were the major buyers and China was the major seller of the carbon credits in 2005–06. Present market rate is fluctuating at €20–22 in the European Climate Exchange [3].

The carrier of thermal energy associated with the PV module may be either air or water. Once thermal energy withdrawal is integrated with the photovoltaic (PV) module; it is referred to as hybrid PVT system. In view of this, hybrid photovoltaic and thermal (PVT) collectors are introduced to simultaneously generate electricity and thermal power [4].

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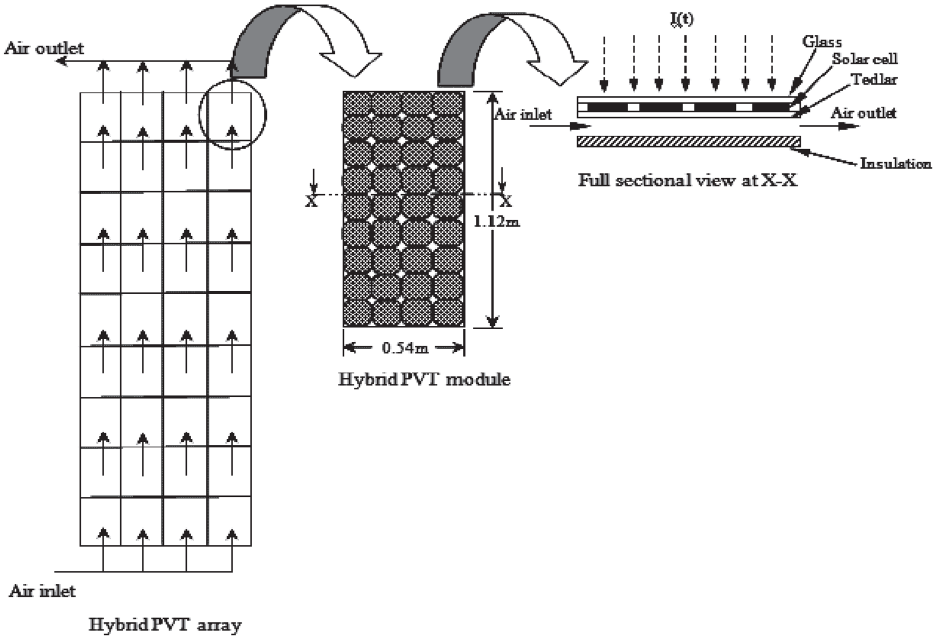

Figure 1: Typical layout of a hybrid PVT array showing flow configuration for case-I with an enlarged view of a PV module and its full sectional view (Rajoria et al. [10]).

Prabhakant and Tiwari [8] present an analysis of carbon credit earning by the Solar Energy Park (SEP) at I.I.T. Delhi, New Delhi which is based on experimental and theoretical annual performance of each system. An analysis of carbon credit earned by each district for supplying minimum subsistence electricity to each family (energy security) in India has been shown by Prabhakant and Tiwari [9].

2 System description

The system consists of a PVT array ($10.08\,\text{m} \times 2.16\,\text{m}$) having 36 numbers of PV modules (glass to tedlar) and each PV module ($1.12\,\text{m} \times 0.54\,\text{m}$) includes 36 numbers of solar cells as shown in Figure 1.

If the outlet of one PV module is connected to the inlet of a second PV module and the outlet of the second PV module is connected to the inlet of a third PV module and so on, then it is called series connection. Similarly, if the inlet and outlet of each PV module is the same, then it is called a parallel connection. A theoretical analysis and optimization is carried out on a prototype of hybrid PVT array.

3 Methodology

For analysis of overall thermal energy and overall exergy gain, the same expressions have been used as in the work of Agrawal and Tiwari [1].

Step 1: the cost of energy produced per annum is computed by multiplying the total annual power produced with unit cost of electricity.

Step 2: the carbon dioxide emission reduction is computed by multiplying the total annual power produced with a factor of 2.04 [7, 11].

Step 3: the CO_2 emission reduction of hybrid PVT array is computed by multiplying the international carbon trading price.

Step 4: the total annual monetary gain is obtained by summing value obtained from step 1 and step 3.

4 Results and discussions

The variations of overall thermal energy and exergy gain for Bangalore have been shown in Figures 2 and 3, respectively. The values of annual thermal energy and exergy gain obtained are 42259.3 kWh and 16345.9 kWh, respectively.

The variations of annual overall thermal energy and exergy gain for four different cities of India by considering a–d type weather conditions of hybrid PVT array discussed under case-III have been shown in Figures 4 and 5, respectively. It can be inferred that highest values of annual overall thermal energy and exergy gain have been obtained for Bangalore climatic conditions due to the availability of more number of clear days and moderately high values of solar intensity and moderate temperature.

4.1 Carbon credits earned by hybrid photovoltaic thermal (PVT) array for Bangalore climatic condition

Total annual carbon credits earned by hybrid PVT array have been calculated on the basis of overall thermal energy and exergy gain by the system.

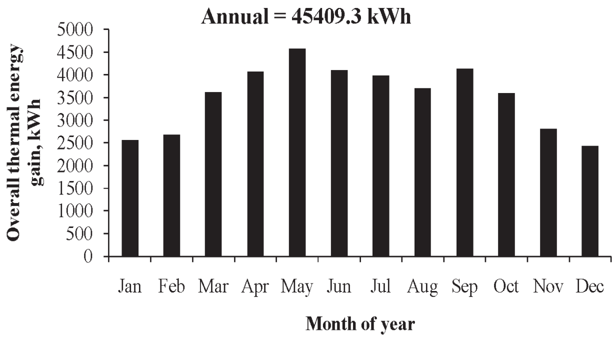

Figure 2: Monthly variations of overall thermal energy gain by combining a–d type weather conditions of a hybrid PVT array for Bangalore.

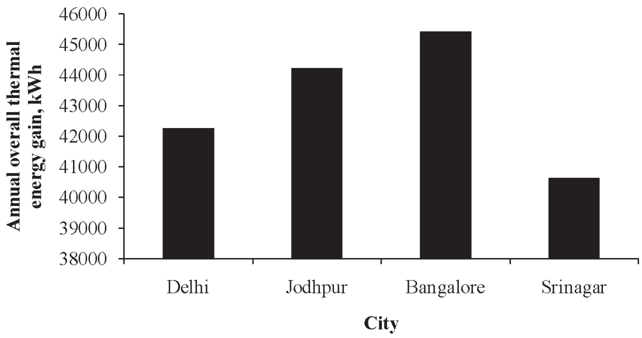

Figure 4: Annual overall thermal energy gain for four different cities of India by considering a–d type weather conditions of hybrid PVT array.

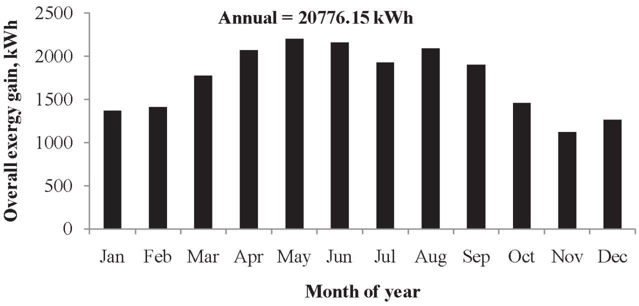

Figure 3: Monthly variations of overall exergy gain by combining a–d type weather conditions of a hybrid PVT array for Bangalore.

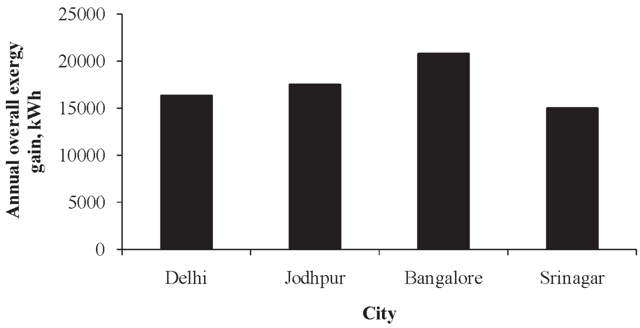

Figure 5: Annual overall exergy gain for four different cities of India by considering a–d type weather conditions of hybrid PVT array.

4.2 In terms of overall thermal energy

Total power produced per annum equals 4.54×10^4 kWh. If the unit cost of electricity is Rs. 5.5, then the cost of energy produced equals $4.54 \times 10^4 \times 5.5 =$ Rs. 2.49 lakhs per annum.

The average carbon dioxide (CO_2) equivalent intensity for electricity generation from coal is approximately 0.982 kg of CO_2/kWh at source [7,11]. However, 40% is transmission and distribution losses and 20% loss is due to considering the inefficient electric equipments used. Then the total figure comes to be 2.04 kg of CO_2/kWh.

So, the carbon dioxide emission reduction equals $4.54 \times 10^4 \times 2.04$

$$= 92.62\,\text{tCO}_2\text{e} \quad (1\text{ ton} = 10^3\text{ kg}).$$

If carbon dioxide emission reduction at present being traded @€21/tCO_2e, European Climate Exchange [3], then the carbon emission reduction by hybrid PVT array comes to

$$= 92.62 \times 21 \times 69 = \text{Rs. } 1.34\text{ lakhs per annum}$$
$$(\text{where } €1 = \text{Rs. } 69;\text{April, 2012}).$$

Total annual monetary gain equals the annual monetary gain from overall energy produced plus the annual monetary gain from carbon trading

$$= 2.49 + 1.34 = \text{Rs. } 3.83\text{ lakhs.}$$

4.2.1 In terms of overall exergy

Total power produced per annum equals 2.07×10^4 kWh. If the unit cost of electricity is Rs. 5.5, then the cost of energy produced equals $2.07 \times 10^4 \times 5.5 =$ Rs. 1.14 lakhs per annum. The carbon dioxide emission reduction equals $2.07 \times 10^4 \times 2.04 = 42.23$ tCO_2e.

If carbon dioxide emission reduction at present being traded @€21/tCO_2e, European Climate Exchange [3], then the carbon emission reduction by hybrid PVT array comes to

$$= 42.23 \times 21 \times 69 = \text{Rs. } 61.191\text{ per annum}$$
$$(\text{where } €1 = \text{Rs. } 69;\text{April, 2012}).$$

Total annual monetary gain equals the annual monetary gain from overall exergy produced plus the annual monetary gain from carbon trading

$$= 1.14 + 0.61 = \text{Rs. } 1.75\text{ lakhs.}$$

5 Conclusions

It can be concluded that under Bangalore climatic conditions the overall thermal energy gain as well as the overall exergy gain comes out to be the highest (4.54×10^4 kWh and 2.07×10^4 kWh, respectively) compared to Delhi, Jodhpur and Srinagar climatic conditions. Therefore, for Bangalore climatic condition, the annual CO_2 mitigation is 92.62 tCO_2e and annual carbon emission reduction is Rs. 1.34 lakhs, while on the basis of overall exergy the annual CO_2 mitigation is 42.23 tCO_2e and annual carbon emission reduction is Rs. 61,191. The total annual monetary gain on the basis of overall energy gain and overall exergy gain is Rs. 3.83 lakhs and Rs. 1.75 lakhs, respectively.

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