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Numerical analysis of using hybrid photovoltaic-thermal solar water heater in Iran

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Introduction

Electrical performance of solar cells decreases with increasing cell temperature, basically because of growth of the internal charge carrier recombination rates, caused by increased carrier concentrations. Hybrid Photovoltaic/thermal (PVT) systems produce electrical and thermal energy simultaneously. PVT solar collectors convert the heat generated in the solar cells to low temperature useful heat energy and so they provide a lower working temperature for solar cells which subsequently leads to a higher electrical efficiency.

Recently, in Iran, the reforming government policy in subsidy and increasing fossil fuels price led to growing an interest in use of renewable energies for residual and industrial applications. In spite of this, the PV power generator investment is not economically feasible, so far. Hybrid PVT devices are well known as an alternative method to improve energy performance and therefore economic feasibility of the conventional PV systems. The aim of this study is to investigate the performance of a PVT solar water heater in four different cities of Iran using TRNSYS program.

Materials and Methods

The designed PVT solar water system consists of two separate water flow circuits namely closed cycle and open circuit. The closed cycle circuit was comprised of a solar PVT collector (with nominal power of 880 W and area of 5.6 m^2), a heat exchanger in the tank (with volume of 300 L), a pump and connecting pipes. The water stream in the collector absorbs the heat accumulated in the solar cells and delivers it to the water in the tank though the heat exchanger. An on/off controller system was used to activate the pump when the collector outlet temperature was higher than that of the tank in the closed cycle circuit. The water in the open circuit, comes from city water at low temperature, enters in the lower part of the storage tank where the heat transfer occurs between the two separate circuits. An auxiliary heater, connected to the tank outlet, rises the fluid temperature to the set point.

The performance of the designed system has been investigated in different cities (including Tabriz, Tehran, Kerman and Bandar-Abbas) during 4 seasons of year using Transient System Simulation (TRNSYS) program. The performance parameters included electrical and thermal energy generation and solar fraction. Solar fraction, which expresses the share of energy supplied by solar radiation on the collector in total thermal energy consumption, was obtained from equation 1.

$$SF = \frac{Q_{load} - Q_{aux}}{Q_{load}} \qquad (1)$$

where Q_{load} and Q_{aux} are the total thermal energy consumption (kWh) and energy supplied by the auxiliary heater (kWh), respectively.

Results and Discussion

The results showed that the average daily electricity generation in the cities for summer and winter were 4.65 and 2.67 kWh day^{-1}, respectively. The annual electricity generation of the designed system is almost constant in the various cities. In winter, in spite of lower solar intensity and sunny hours, lower average temperature of solar cells in Kerman leads to a slightly better electrical performance than Bandar-Abbas. The highest cell

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temperatures, in Bandar-Abbas between 12 noon and 1pm, were found to be 33, 37, 31 and 25 ^{o}C in spring, summer, autumn and winter, respectively.

Thermal energy generation was significantly different at various cities and seasons. In winter, the designed system provides a little fraction (below 10 percent) of thermal demands in Tabriz and Tehran. This is mainly because of the low ambient temperature and solar intensity. The PVT system had a maximum average thermal energy of 16 kWh day^{-1} and solar fraction of 0.5 which were observed in Bandar-Abbas. Tabriz, because of the lowest ambient temperature, had the least thermal energy generation and solar fraction. The maximum average solar fraction obtained in summer was about 60% while its lowest value in winter was 24%.

Conclusions

In the present study, a hybrid PVT solar water heater with nominal power of 880 W was proposed for application in Iran. The system was comprised of a PVT solar water collector, an auxiliary heater, a pump and connecting tubes. Technical feasibility of applying the proposed system in different cities was investigated using TRNSYS program. The results are summarized as follows:

The annual electricity generation of the designed system was almost constant in the various cities.

The highest and lowest values of average electricity generation in summer and winter were determined to be 4.65 and 2.67 kWh day^{-1}, respectively.

The PVT system had the maximum average thermal energy of 16 kWh day^{-1} and solar fraction of 50%, which was observed in Bandar-Abbas.

Keywords: Electrical energy, Photovoltaic-thermal, Solar fraction, Thermal energy