THERMO-ECONOMIC ANALYSIS OF A HYBRID PHOTOVOLTAIC/THERMAL (PV/T) SYSTEM FOR DIFFERENT CONFIGURATION SETTINGS

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ABSTRACT

Solar energy can be harvested thorough solar PV (SPV) conversion as well as solar thermal energy conversion. A hybrid photovoltaic/thermal (PV/T) system has the capability to convert solar energy into both electricity and thermal energy simultaneously. These systems can provide the heating demand of buildings while generating electricity, which becomes ideal for building applications of urban energy systems. Performance analysis of such systems becomes essential to design PVT systems matching with the operating conditions. In this study, a thermo-economic model is developed to evaluate sensitivity of design, operating and climatic parameters for a hybrid PV/T system. Five main configurations of the PV/T system are considered based on the heat transfer fluid and the arrangements of glass and Tedlar layers of PV/T collector. The effect of the packing factor of the PV/T collector on the behaviour of thermal and electrical efficiency and the sensitivity of heat transfer fluids (water and air) were analysed using the thermal model. Subsequently, effect of temperature coefficient on the performance of PV/T collectors in terms of efficiency are studied for five different types of PV cells (i.e. m-Si, a-Si, p-Si, CdTe, CIS, HIT).

Keywords: hybrid PV/T system, thermo-economic model, performance evaluation

INTRODUCTION

The increase of energy consumption related to building applications and its growth rate have resulted in a higher tendency of using efficient and eco-friendly energy conversion technologies. Renewable energy technologies minimize emission levels of obnoxious gasses and global warming. Solar energy is a renewable energy source that can be used to generate both electrical and thermal energy. A PV/T (photovoltaic/thermal) system is a hybrid solar system that combines photovoltaic and thermal systems which produce both electricity and thermal energy simultaneously from one integrated system. Energy requirement of building applications for electricity, heating and cooling can be met through generating electrical and thermal energy from this PV/T system.

A substantial amount of research on PV/T systems has been carried out based on theoretical models which were subsequently validated using experimental setups. Sarhaddi et al. [1] carried out a performance evaluation of a PV/T air collector with a glass to tedlar PV module. A detailed thermal and electrical model was developed to calculate the thermal and electrical parameters of a typical PV/T air collector. The two configurations of air collector with glass to glass PV module, Case I (air flow above the absorber plate) and Case II (air flow below the absorber plate) were analysed by S. Dubey et al. [2] for five different cities of India. Tiwari et al. [3] have showed that PV/T air collector with glass to glass type PV module can be used to obtain higher efficiency than the glass to tedlar type PV modules. An analytical model was used in this regard which was experimentally validated later. Sobhamayan et al. [4] optimize the exergy efficiency of a PV/T water collector through a similar analytical module coupled with an exergetic analysis. These studies clearly portray the technical feasibility of PVT technology.

Thermo-economic analysis on the parameters that affect the system performances has been an area of interest for a wider research community in the recent past [5]. The PV/T air collector configuration has been analysed considering several types of collectors and it has been concluded that the configuration of a PV/T air collector should be optimized based on the specific priority needs for electrical or thermal output [6]. In addition to the collector configuration, the collector parameters have been analysed to improve the performance. The effect of packing factor of PV/T air collector to electrical and thermal efficiencies has been analysed [7]. A numerical analysis and an experimental validation have been done to evaluate the influence of packing factor of a PV/T water collector on the performance. The performances of three types of PV/T water collectors were determined for different mass flow rates of water and its effect on the operating temperature of the collector bas been analysed [8].

In this study, a mathematical model for the PV/T system is developed and it is used to evaluate sensitivity of design, operating and climatic parameters for the system. The effect of the type of PV module and packing factor on the behaviour of the average annual thermal and electrical efficiency is analysed. Further investigations are carried out by clustering the weather conditions of the year into three sections based on the solar irradiation and wind speed. The three clusters of weather conditions are sectioned considering the weather distribution throughout the year. The clusters considered based on the solar irradiation and wind speed are;

- Case 1 - High solar irradiation and low wind speed
- Case 2 - High solar irradiation and high wind speed
- Case 3 - Low solar irradiation and low wind speed

MATHEMATICAL MODEL FOR PV/T SYSTEM

A summary of the developed model is shown in Figure 1 including the PV/T collector configurations. Hourly solar irradiation, wind speed and ambient temperature are taken using TMY2 climate file as the input for the model.

Energy flow model

The energy analysis of the PV/T system is carried out to develop the mathematical model. A concise description about the mathematical model is presented in this study. Analytical expressions for thermal energy production and thermal efficiency of PV/T collector are obtained by formulating energy balance equations for each component i.e. PV module, absorber plate and heat transfer fluid flowing through the duct. An expression for the fluid outlet temperature ($T_{f,out}$) is derived using the energy balance equations. The rate of useful thermal energy for a heat transfer fluid having a specific heat capacity C_f flowing at a mass flow rate of $\dot{m}$ is calculated. $T_{f,in}$ is the fluid inlet temperature and G is the solar irradiance which are input parameters. The thermal efficiency (η_{th}) of the PV/T collector with length L and width W is obtained as Eq. 1;

$$\eta_{th} = \frac{\text{Rate of useful thermal energy}}{\text{Rate of solar energy incident on the panel surface}} = \frac{\dot{m}C_f\left(T_{f,out} - T_{f,in}\right)}{WLG} \quad (1)$$

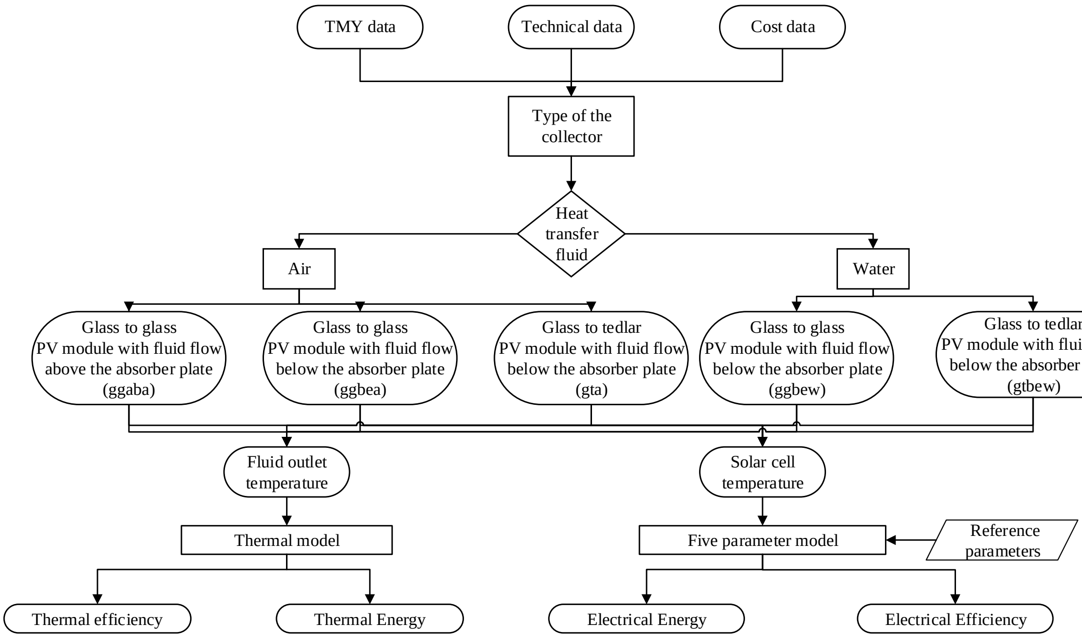

Figure 1: Overview of the mathematical model

The electrical efficiency of the PV/T collector is derived using five-parameter photovoltaic model. A set of nonlinear equations that can be solved with numerical methods are derived to plot the I–V characteristic curve. The values of maximum power point voltage and maximum power point current (V_{mp}, I_{mp}) are obtained from solved I–V characteristic curve. The electrical efficiency (η_{el}) of the PV/T collector is obtained as Eq.2;

$$\eta_{el} = \frac{\text{Actual electrical output power}}{\text{Rate of solar energy incident on the panel surface}} = \frac{V_{mp}I_{mp}}{WLG} \quad (2)$$

RESULTS AND DISCUSSION

The objective of this study is to analyse the effect of the parameters on the performance of PV/T system.

Type of PV module in the PV/T collector

Six types of PV modules (m-Si, a-Si, p-Si, CdTe, CIS, HIT) which are mostly used by researches are taken into consideration to analyse the effect on the performance of the PV/T collectors. The thermal, electrical and overall efficiency variations are considered with respect to type of PV module. Overall efficiency variation is shown in Figure 2.

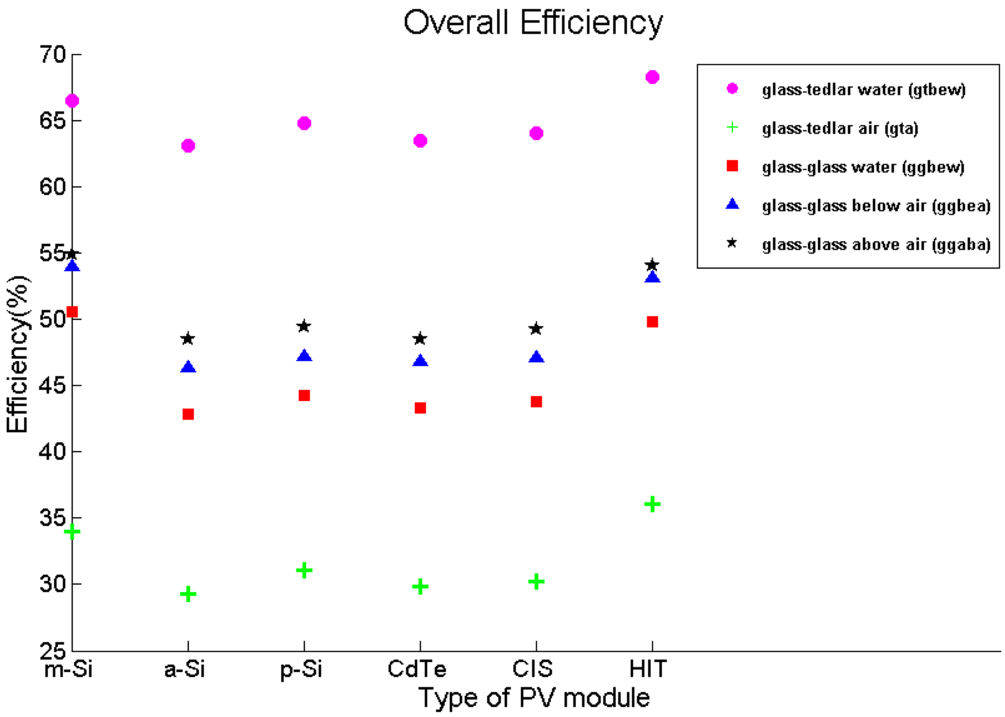

Figure 2: Overall efficiency

It is observed that a PV/T collector with an amorphous silicon (a-Si) PV module has given the highest thermal efficiencies for both glass-tedlar type collectors (gtbew, gta). However, the electrical efficiency is very low for a-Si for all the collectors. The temperature coefficient of a-Si is low, which can be taken as the main cause for lower efficiency levels. For the three types of glass-glass collectors (ggbew, ggbea, ggaba), the PV/T collector with a mono crystalline (m-Si) PV module has shown the highest thermal efficiency. The electrical efficiency varies in the range of 12%-14% which is due to the higher temperature coefficient of m-Si. With respect to the electrical efficiency it can be concluded that any configuration type of collector with hetero junction with thin layer (HIT) PV module has a higher electrical performance. The maximum electrical efficiency of 16.8% is witnessed for glass-tedlar water type configuration (gtbew), which is a promising rate of electrical performance. However, HIT results reductions in thermal efficiency. HIT has shown the lowest rates of thermal efficiency for all the configurations of collectors. At standard test conditions HIT technology has very high module efficiency which is 17%. This has resulted in high electrical performance for HIT. However the higher temperature coefficient of HIT has resulted in hampering its thermal performance. The overall performances of the collectors are investigated by analysing the overall efficiencies. Due to the higher electrical performance of HIT, for all configurations HIT PV type has resulted highest overall efficiency. The m-Si with relatively higher performance in both electrical and thermal factors, all collectors with m-Si has shown higher overall performance.

Packing factor

The packing factors of 25%, 38%, 62.8%, 75%, 83% and 98% are considered for the analysis. Further investigations are carried out for the three cases which consider the weather distribution of the year. The evaluation of overall efficiency of the five collectors in a range of packing factor can be presented in Figure 3.

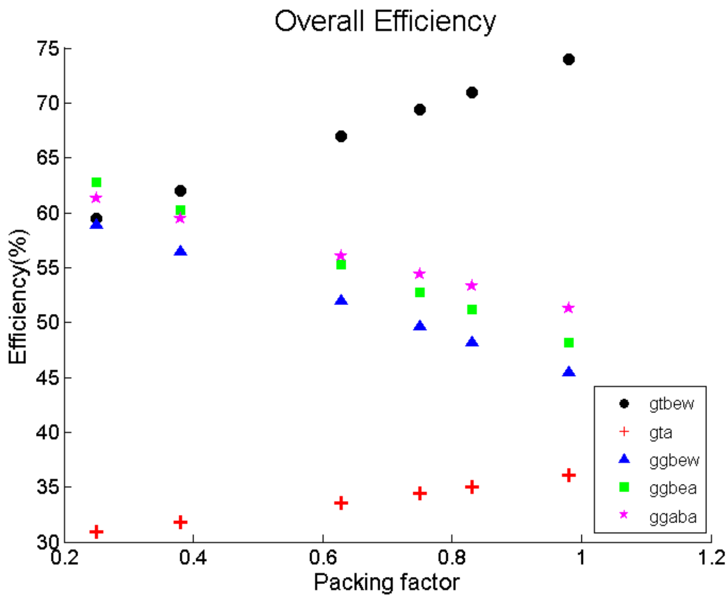

Figure 3: Overall efficiency

For all three types of glass to glass collectors (ggbew, ggbea, ggaba), the thermal efficiency has decreased with the increment of the packing factor. This is because the radiation absorber area from the thermal segment of the collector reduces due to the covering of the PV panel. However, for the glass to tedlar collectors (gtbew, gta), the thermal efficiency has increased with the packing factor increment. The tedlar layer effectively absorbs the heat from the PV module and transfers it to the thermal element and thermal efficiency increases. If the packing factor is raised too much the thermal exit temperature will get higher due to absorbing high amount of thermal energy so it will increase the cell temperature, which causes the decrease in the electrical efficiency.

Further investigations showed that the lower wind speeds and higher irradiation levels have resulted in lower electrical efficiencies. When wind increases with lower irradiation, electrical efficiency increases. Higher wind speeds with high-medium irradiation levels has produced the best electrical efficiencies. Low wind and higher irradiation have resulted in the best thermal efficiencies. Higher wind with high-medium irradiation levels has reduced the electrical efficiencies. When wind increase with lower irradiation, thermal efficiency decreases drastically.

CONCLUSION

The results showed that a PV/T collector with an amorphous silicon (a-Si) PV module has given the highest thermal efficiencies for both glass-tedlar type collectors (gtbew, gta). However, the electrical efficiency is very low for a-Si for all the collectors. For the three types of glass-glass collectors (ggbew, ggbea, ggaba), the PV/T collector with a mono crystalline (m-Si) PV module has yielded the highest thermal efficiency with an average level of electrical performance. With respect to the electrical efficiency it can be concluded that any configuration type of collector with hetero junction with a thin layer (HIT) PV module has a higher electrical performance.

For all three types of glass to glass collectors (ggbew, ggbea, ggaba), the thermal efficiency has decreased with the increment of the packing factor. However, for the glass to tedlar collectors (gtbew, gta), the thermal efficiency has increased with the packing factor increment. If the packing factor is raised too much, the thermal exit temperature will get higher due to absorbing high amount of thermal energy resulting to an increase the cell temperature, which causes the decrease in the electrical efficiency.

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