Experimental study of a thermosiphonic hybrid PV/T solar system

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ABSTRACT

Flat Plate Thermosiphonic Units (FPTU) and Photovoltaic devices are well known solar systems that provide heat and electricity, respectively. The hybrid Photovoltaic/Thermal (PV/T) solar systems can simultaneously provide electricity and heat, achieving a higher conversion rate of the absorbed solar radiation than standard PV modules. When properly designed PV/T systems can extract heat from PV modules, heating water or air, aiming to reduce the operating temperature of PV modules and to keep the electrical efficiency at a sufficient level. In this paper we present design considerations and experimental results of a thermosiphonic hybrid PV/T solar system that is investigated at the University of Patras. The system is analyzed with respect to the design and the electrical and thermal energy output for a pc-Si PV module type under the climatic conditions of Patras.

1. INTRODUCTION

Commercial photovoltaics (PV) convert, depending on the type of PV cells, 5%-15% of the incoming solar radiation into electricity, with the greater percentage converted into heat. PV modules and heat extraction units mounted together constitute the hybrid photovoltaic thermal (PV/T) solar collectors (Fig.1, left), which convert the absorbed solar radiation into electricity and heat simultaneously. The solar radiation increases the temperature of PV modules, resulting in a drop of their electrical efficiency, but their installation on flat building roofs permits their natural cooling. In the facades and tilted roofs, cooling of PV rear surface is achieved also with circulating water of lower temperature than that of PV modules, which is heated by cooling them which result to keep PV electrical efficiency at a satisfactory level. The PV/T collectors present a conflict between their electrical and thermal performance. The electrical part presents higher output for lower PV operating temperatures. On the other hand, the thermal part should provide heat removal fluid (water or air) at higher temperatures in order to adapt effectively the solar thermal applications, but this, results to electrical efficiency drop. The additional thermal output that is provided from PV/T systems makes them cost effective compared to separate PV and thermal units, considering that they cover together the same total aperture surface area as that of PV/T collectors.

An extensive study on water [1, 2, 3, 4] and air [1, 5, 6, 7] heat extraction from PV modules has been performed at the University of Patras and hybrid PV/T prototypes have been investigated. Performance improvements aim to overcome some limitations in system efficient operation and to make these new solar energy devices more attractive for applications. The water type PV/T systems (PVT/WATER) are more expensive than air type PV/T systems (PVT/AIR) and can be effectively used all seasons, mainly in low latitude countries, as water from mains is usually under 20^{o}C. The PVT/WATER systems can be installed on horizontal or tilted roof (Fig. 1, right) of buildings, or on their facades, depending on building architecture.

In this paper we briefly present the design and performance of the studied hybrid PVT/WATER systems in our laboratory. The systems have been designed and tested outdoors in order to record their electrical and thermal performance. These PV/T collectors can provide hot water and electricity in the domestic, agriculture and industrial sectors. Regarding small size PVT/WATER systems they can be applied to one family houses, multiflat residential buildings, small hotels, etc. These devices can be used alternatively to the thermosiphonic and the ICS solar water heaters, mainly in stand-alone and mini-grid application of photovoltaics. To increase system energy output we have studied also the application of booster diffuse reflectors [1,2], which increase the solar radiation on PV module aperture surface and overcome the reduction of the electrical output due to the optical losses from the second glazing.

Some aspects and results regarding plain types of glazed and unglazed PVT/WATER collectors, as well as from a combination of them with water storage tank and natural (thermosiphonic) flow, give a performance figure of this new water heating system, in laboratory scale operation. Based on these results we will develop an improved system, aiming to achieve a system of practical value.

2. PV/T SYSTEM DESIGN AND OPERATION

The hybrid PV/T solar water heaters can be effectively used for domestic water and space heating and other applications, contributing also to the electrical consumption of the buildings. The investigated PVT/WATER models consist of silicon PV modules and the heat extraction unit is a metallic sheet with pipes for the water circulation, in order to avoid the direct contact of water with the PV rear surface (Fig.1, left). This heat exchanger element is in thermal contact with the PV module rear surface and is thermally insulated to the ambient from the rear side and the panel edges.

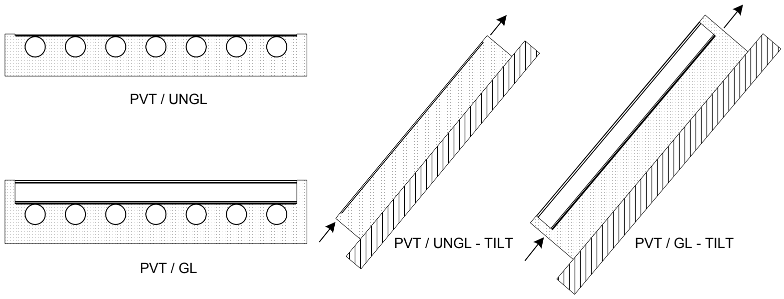

Fig. 1 Cross section of the studied PV/T models (left) – tilted roof installation (right)

PV/T solar energy systems without additional glazing (PVT/UNGL) provide satisfactory electrical output (depending on the operating conditions), but the thermal efficiency is reduced for higher operating temperatures due to the increased thermal losses from the PV module front surface. The addition of glazing (PVT/GL) increases the thermal efficiency for a wider range of operating temperatures, but the additional optical losses reduce the electrical output of the PV modules. Hybrid PV/T systems can provide electrical and thermal energy, thus achieving a higher energy conversion rate of the absorbed solar radiation. We tested outdoors PV/T prototypes consisted of pc-Si PV modules and heat exchanger of copper sheet with copper pipes, for two system types (PVT/UNGL and PVT/GL). We used commercial PV modules, which give about 8%-15% efficiency, depending on the operating temperature and the use or not of additional glazing. During the experiments the generated electricity was transmitted to a load, simulating real system operation. The steady state tests were performed outdoors and the results for the collector obtained thermal efficiency are shown in Fig.2. The glazed PV/T collector presents remarkably higher thermal output than the unglazed PV/T collector, but the electrical output of it is reduced due to additional optical losses.

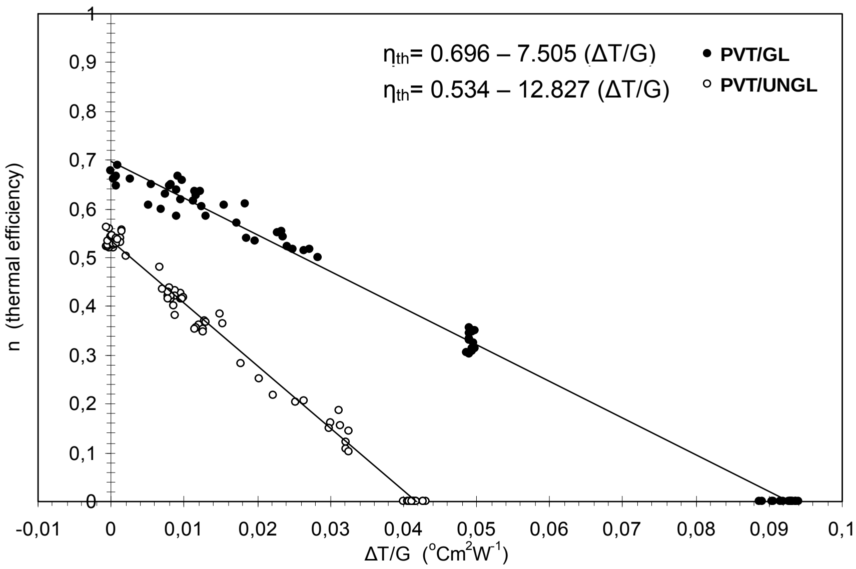

Fig. 2 Steady state thermal efficiency results of the studied PV/T models.

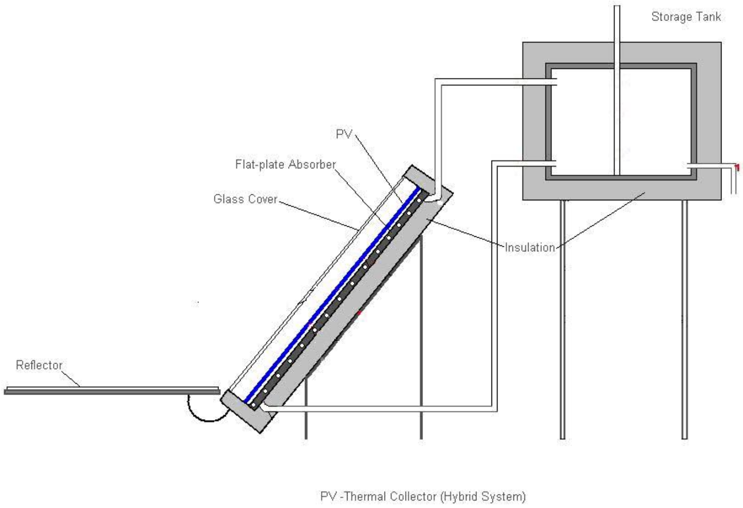

Fig. 3 Thermosiphonic type of PV/T system

Apart of the steady state operation, both PVT/WATER collectors were connected with a water storage tank for daily operation with forced (with pump) and natural (thermosiphonic) water flow. In Fig. 3 the cross section of the thermosiphonic type of the PV/T system is presented. In Fig.4 we show a daily profile for the natural water flow, showing the variation of the mean temperature of PV module (T_{PV}), circulating water (T_m), water in the storage tank (T_{ST}) and ambient temperature (T_a), including also the incoming solar radiation (G) and the wind speed (V_W). The systems were also tested with booster diffuse reflectors, which are fixed for the case of the horizontal building roof system installation [1, 2], but they can be adjusted (Fig. 3) in the case of small size units. The contribution of the reflectors is estimated positive in all cases, considering the energy output increase and their low additional cost.

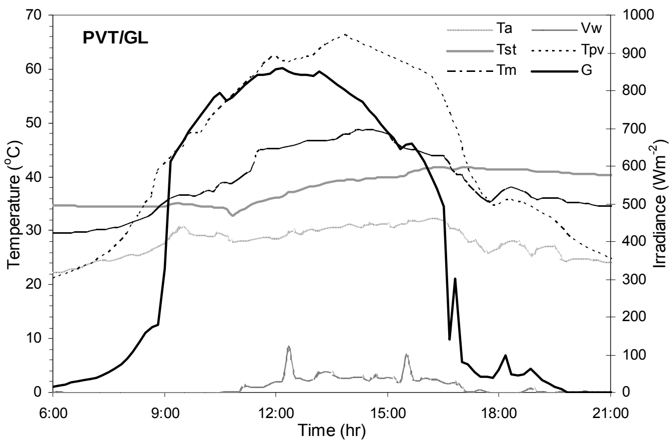

Fig. 4 Daily profile of temperatures, solar radiation and wind speed for the PVT/GL system with natural water flow operation

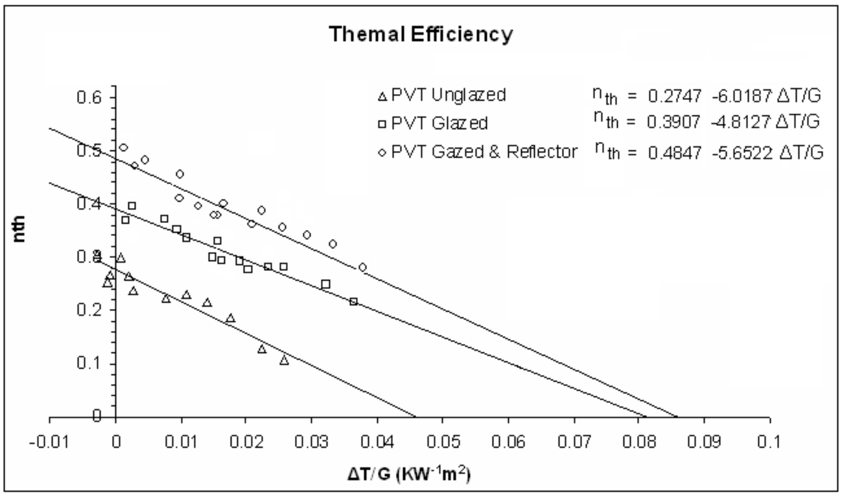

Fig. 5 Thermal efficiency results of the studied PV/T models

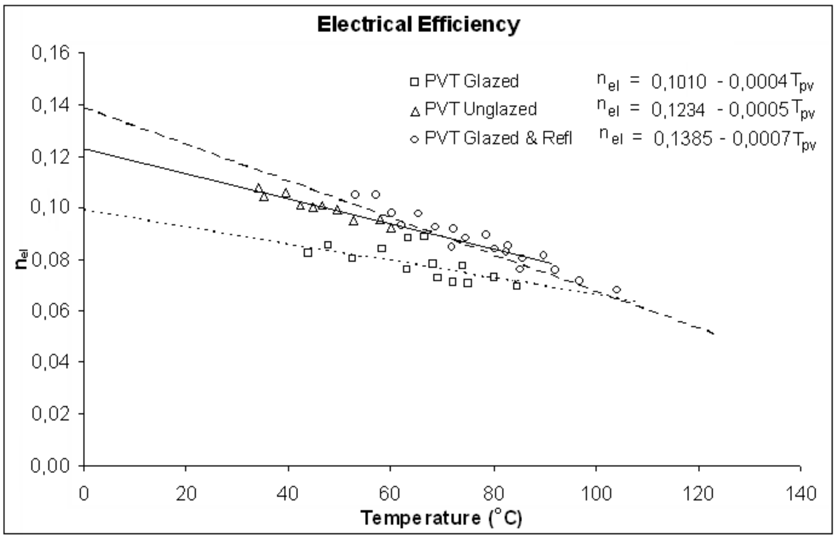

Fig. 6 Electrical efficiency results of the studied PV/T models

An interesting improvement for the increase of the provided electricity and hot water is realized by the use of the booster diffuse reflector in front of the PVT panel (as it is indicated in Fig. 3). The results from the use of this reflector are interesting and prove that it increases satisfactorily the electrical and thermal output (Figs 5 and 6). Regarding the normal type unit, system performance is usually lower than that of usual flat plate thermosiphonic solar water heaters because they can be of higher performance due to better thermal protection. On the other hand, looking forward to a wider application of

PV modules, their combination with thermal collectors in the same unit can adapt available space limitations and lower amounts of materials. In countries where water heating is successfully obtained from solar radiation (Greece, Cyprus, etc), the application of PVT collectors could be possibly the next step for favourable investments in Renewable Energy.

3. CONCLUSIONS

Hybrid PV/T solar water heaters have been studied in Physics Department at the University of Patras. These systems can be applied in houses and other type of buildings for the production of electricity and hot water and are mainly suitable for applications under high values of solar radiation and ambient temperatures. The experimental results of the outdoors tests showed that thermosiphonic type of PV/T systems can provide both hot water for domestic applications and electricity at a sufficient level.

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