Computer Modelling and Experimental Validation of a Photovoltaic Thermal (PV/T) Water Based Collector System

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Abstract. A photovoltaic thermal water based collector system is modeled by TRNSYS as a numerical model and the results validated with experimental results in this paper. The validity of the modeling approach was demonstrated by comparing its predicted collector's outlet temperature changes and daily system efficiencies with the measured data acquired from an experimental rig at Ferdowsi University of Mashhad. The main component of the TRNSYS deck file constructed for this purpose is type 50a, which is accompanied by other additional components required for the model. The predictions from the model show good compliance in outlet collector fluid temperature and system's thermal and electrical outputs with the experimental measurements. The main aim of this paper is find a good simulation for a PV/T system.

Keywords: Photovoltaic thermal, TRNSYS modelling, Experimental work.

1. Introduction

Increasing of cell temperature leads to decrease of open circuit voltage in photovoltaic systems, therefore electrical efficiency of photovoltaic systems is decreased. Adding a cooler causes the electrical and overall efficiency of a photovoltaic system can be increased. Either water or air can be used as the heat removal fluid to cool the solar cells. These systems are named photovoltaic thermal systems (PV/T). To evaluate the performance of a PV/T collector, the value of electricity versus the heat gained from the collector is important. The wasted heat recovery makes the overall output energy of the hybrid system higher than either of the individual systems, on unit collector area basis. This hybrid solar technology is at the early stage of development, and can be seen as a better alternative of the PV-only system, in terms of economic advantage [1]. TRNSYS that is retrieved from "transient simulation program" is a quasi-steady simulation model. This program was developed by the University of Wisconsin by the members of the Solar Energy Laboratory. It was written in ANSII standard Fortran-77. The program consists of many subroutines that model subsystem components. The mathematical models for the subsystem components are given in terms of their ordinary differential or algebraic equations [2].

Since 30 years ago, a large amount of research on PV/T collectors has been carried out that led to an increase in electrical and overall efficiency. Soteris A.Kalogirou Used of TRNSYS for modelling and simulation of a hybrid PV/T solar system for Cyprus [2]. It has been observed that the mean annual efficiency of the PV solar system is increased up to 4.9% and covers 49% of the hot water needs of a house, thus the mean annual efficiency of the system grows to 31.7%. T.T. Chow et al. introduced a dynamic

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simulation model of a building-integrated photovoltaic as well as water heating system [1]. They developed a numerical model based on the finite difference control volume approach and concluded that their dynamic simulation model could be highly useful in predicting the system dynamic behavior as well as the long-term energy performance.

Ji et al. presented a practical design for a heat pump with heat-pipe photovoltaic/thermal (PV/T) collectors [30]. The results showed that the PV-SAHP/HP system could reach a daily average of energy efficiency of 61.1-82.1% and exergy efficiency of 8.3-9.1% when operating in the solar-assisted heat-pump mode and daily average heat-pump COP could reach 4.01 when solar radiation was strong.

2. Description of the system

2.1 Experimental prototype

As shown in Fig.1. (a), experimental system consists of two 40 Watts mono crystalline silicon photovoltaic panel. One of them consist of a water based collector and another one has a general panel in order to contrast. Collector type is a flat plate consists of copper pipe networks. The cooler fluid (pure water) stored in a tank which is connected to a pump in order to circulate the water around the panel with 30 Lit/hr. flow rate and has a close circuit flow between a heat exchanger and the PV/T collector. This heat exchanger is a shell and tube types. Second fluid (city water) has a cross connection to shell of the heat exchanger and absorbs the heat of cooling fluid that passes from tube in counter flow side, and then is stored in a storage tank as a preheat water for feeding a consumer such as a domestic water heater with 40 Lit/hr. flow rate. Considering the fact that the water is continuously entering from the supply network, the temperature of the second fluid is kept constant at low levels for better cooling and it is an initial condition for numerical model.

2.1.1 Measurements

Fluids in inlet and outlet of the heat exchanger and collector are measured by PT100 sensors and photovoltaic (PV) surfaces are measured by a pyrometer. Electrical parts consist of batteries, DC consumers and charge controllers. Charge controllers make a connection between batteries, consumers and PV panels and control the consumption time simultaneously with batteries level that that cause to a permanent product in PV systems. Short-circuit currents, open-circuit voltages and also load currents and voltages measured with digital multimeters. Total incident radiations are measured by a solar power meter that mounted in parallel situation with the photovoltaic surfaces.

2.2 TRNSYS modeling

In this work, in computer modeling for having a same model with experimental setup, all major parts are considered, Figure.1.(b). PV/T modeled on constant losses (type 50a), heat exchanger is modeled as a shell and tube (Type 5g), and also there are two pumps: pump1, makes a circulation force at collector cooler fluid, pump2, for simulation city water flow in shell of heat exchanger. To record the numerical output results used from a data plotter in TRNSYS. In computer modeling initial and boundary conditions of each point for prediction outputs is discrete from other points.
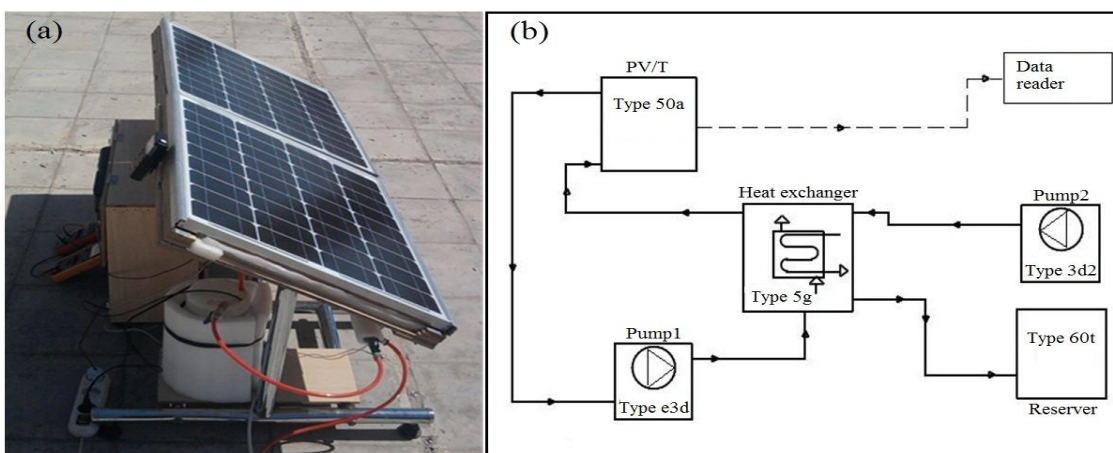

Fig. 1. (a): Experimental prototype and (b):schematic diagram of computer (TRNSYS) modelling.

2.2.1 TRNSYS input parameters

The design parameters of hybrid PV/T system in computer modelling that be assumption have an equal value with experimental prototype parameters, are given in Table 1.

Table. 1: Design parameters in computer modelling.

	Description	Value
	Collector area	0.3
	Collector fin efficiency factor	0.55
	Fluid thermal capacitance	4.174 kJ/kg.K
	Collector plate absorbance	0.9
	Collector loss coefficient	17 W/m^2.K
PV/T	Cover transmittance	0.95
	Temperature coefficient of solar cell efficiency	0.0045
	Reference temperature for cell efficiency	25°C
	Packing factor	1
	Cell efficiency	14%
Pumps	Maximum flow rate	P2: 40kg/hr. & P1: 30kg/hr.
	Maximum power	14w
Heat exchanger	Cold side flow rate	40 Lit/hr.
	Hot side flow rate	30 Lit/hr.
	Specific heat of cold side flow	4.174 kj/kg.K
	Cold side inlet temperature	26.2^{o}C

Collector's area is equal to PV's area in experimental work so packing factor that is defined as divided ratio of these two parameters is equal to 1. The values of PV's area, temperature coefficient of solar cell efficiency, reference temperature for cell efficiency and cell efficiency are gotten from PV's catalogue and experimental setup and other input parameters are obtained from trial and error with comparing of three experimental data for collector's outlet temperature and then extended for all experimental data for results validation. Notice that there are some initial conditions from experimental measurements such as cold side input temperature of heat exchanger and also total incident radiation that are measured by solar power meter.

3. Results and discussion

Experiments have done for three periods of time with same conditions from 9:00 AM to 15:30 PM that measuring done each 30min, and uncertainty analysis performed for finding accuracy implementation of experiments. Calculations show that there is less than 3% uncertainty in all measured data and calculated parameters, for example total uncertainty with 95% confidence at maximum range of electrical output power is just 2.1% and also for collector's outlet fluid temperature is around 1%. So experiments are reliable for using at numerical validation. Numerical results consist of outlet fluid temperature, electrical output, average surface temperature and useful of PV/T system. In Fig.2 prediction of the surface temperatures showed, a brief result in which there is a little difference in some points for example in 12:00 o'clock, maybe it is for using of pyrometer for measuring this temperature and many factors such as PV glass cover reflections effects on measuring. Fig.3 shows the cooler outlet fluid temperatures, and there is a good validation. By comparing numerical and experimental results of useful thermal gain from the PV/T, numerical result shows a good accordance that is shown in Fig.4 one of the reasons maybe is that computer validating is based on this parameter.
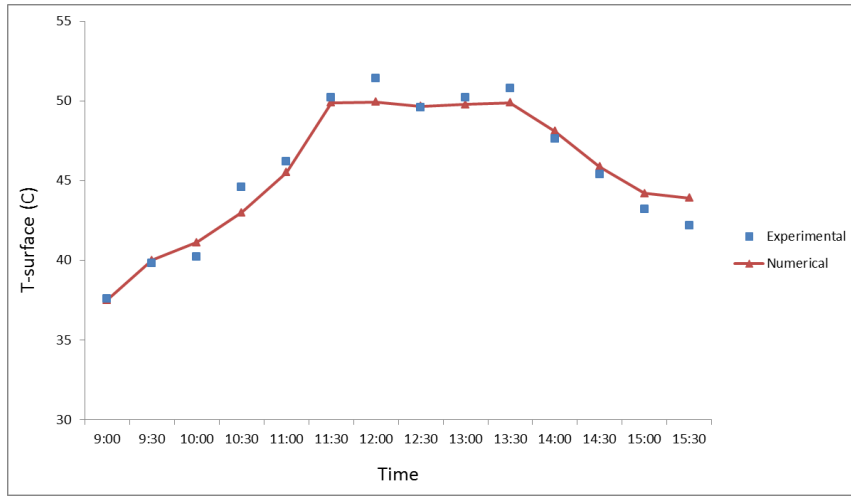
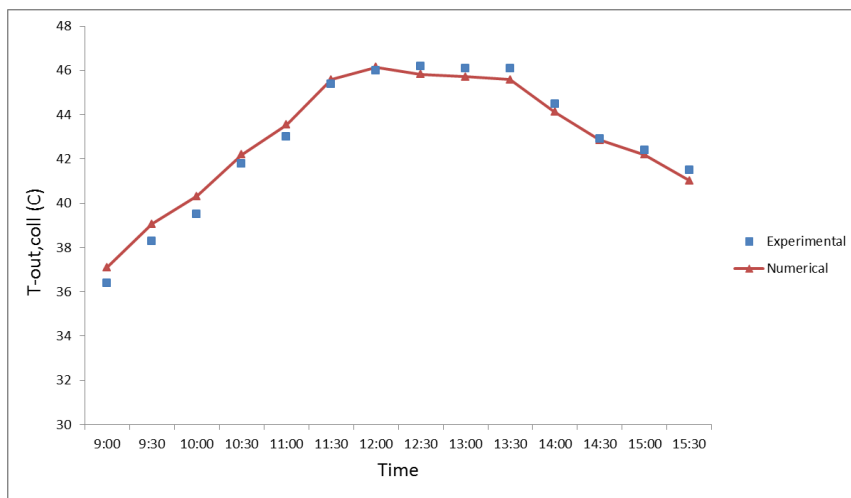Fig. 2. Numerical results with experimental validation of PV/T surface temperature.

Fig. 3. Numerical result with experimental validation of PV/T collector's output temperature.
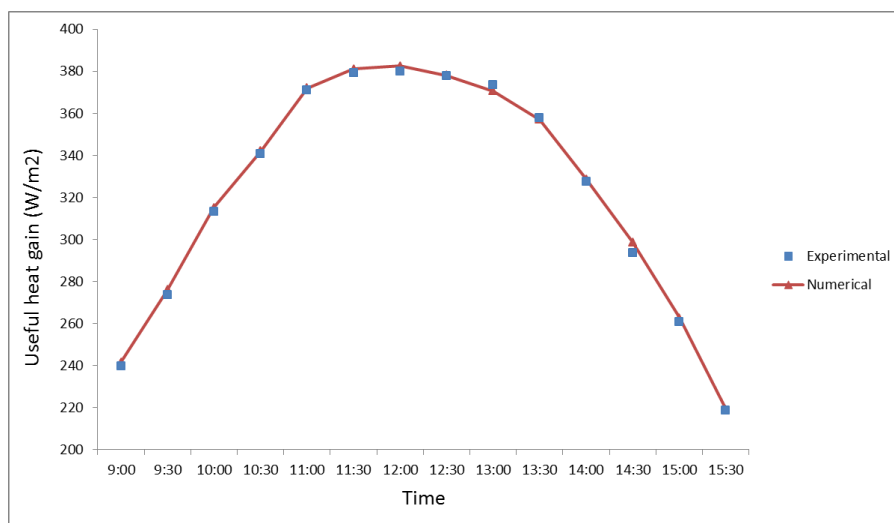

Fig. 4. Numerical results with experimental validation of usefull heat gain of PV/T per units of area.

And at the end fig.5 shows the electrical output power of photovoltaic panels. The numerical predictions are a bit more than experimental ones in all points that is acceptable, because in numerical model PV is intended as an Ideal panel but

in fact many parameters are effective on it. Considering the fact that these results are just for finding a good numerical model.
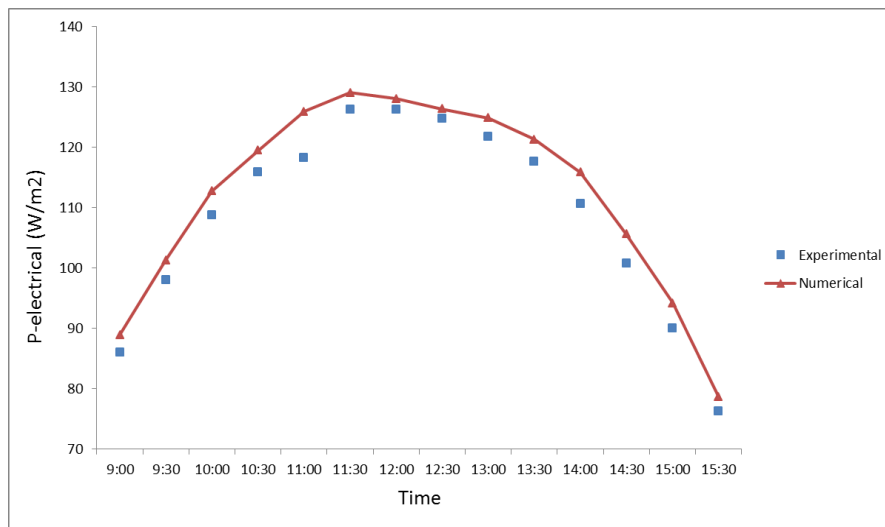

Fig. 5. Numerical results with experimental validation of maximum electrical output's power of PV/T per units of area.

The predictions from the model show good compliance in outlet collector fluid temperature and system's thermal and electrical outputs with the experimental measurements. Therefore it is a good and reliable model for

4. Acknowledgements

5. Appendix A

Here comes a formula which is used for calculating PV/T electrical output:

$$P_m = V_{oc} \times I_{sc} \times FF \tag{1}$$

In this formula V_{oc} is open circuit voltage and I_{sc} is short circuit voltage that measured each moment in experimental prototype, and FF is filled factor of photovoltaic diagram.

6. References

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