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INVESTIGATION OF TECHNICAL PERFORMANCE TARGETS FOR A HYBRID PHOTOVOLTAIC / PHOTO-THERMAL SYSTEM

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Abstract

Photovoltaic / photo-thermal (PV/T) solar collector also known as hybrid PV/T or solar cogeneration systems provide the opportunity of optimizing energy generating per unit area available for solar collector installation. The objective of the present effort is to study the performance of a photovoltaic / photo-thermal (PV/T) solar collector for the conversion solar irradiation to usable electrical and thermal energy. These systems combine the primary function of a photovoltaic cell with that of a flat plate solar thermal collector. The electrical, thermal and overall efficiency is observed with the set up. Technical parameters in form of overall energy efficiency and primary energy saving efficiency have been considered. The electrical efficiency is expected to improve due to the heat removal process. The result shows that overall energy efficiency and primary energy saving efficiency was found to attain a maximum value of 73.0% and 91.0% respectively, within the period of observation at flow rate 20.83ml/s. This represents the optimum condition for the PV/T generator.

***Keywords*:-** Photovoltaic / photo-thermal (PV/T), PV module, thermal, electrical efficiency and primary energy saving

I. INTRODUCTION

Photovoltaic-thermal (PVT) systems have been promoted as a means of achieving energy security for developing and underdeveloped countries in the form of providing electrical and thermal energy [1, 2]. PV/T systems adopt a combination of helioelectrical and heliothermal technological processes in their operation. In simple terms, the PV/T system incorporates a PV (photovoltaic) module and solar thermal unit into a simple hybrid system which concurrently produces electricity and thermal energy. The different types of PVT systems have been identified as spanning; PV/T /air, PV/T /water, PV/T concentrated collector, PV/T water collectors, Building-integrated air PVT (BIPVT) and Heat-pipe-based PVT [3]. However, these different types of PV/T systems can be generally classified into two groups viz; water-based PV/T and air-based PV/T depending on the type of fluid utilized in the system with liquid PV/T collectors being the most popular due to its wide range of applicability [4].
With the increasing prominence of PV/T systems, numerous research investigations have been carried out ranging from the performance of PV/T systems with different configurations of absorber designs [5,6,7,8] , experimental comparison of two PV/T systems in production of heat and power [9], energy and exergy efficiency of PV/T water collector [10,11], influence of water based nano-fluids on PV/T performance[12,13] and, modeling and prediction of efficiencies of PV/T with and without fins [13,14]. Furthermore, the use of polysiloxane gel for reducing heat loss and improving properties of glazed PV/T collectors has been investigated [15], overheating protection design application implemented for PV/T systems[16], and the effects of PCM materials on modifying plate temperature in PV/T systems have been considered [17]. Also, in the same trend as the ordinary solar thermal system, the effect of angle of inclination on performance of PV/T system have been considered [18, 19], with results showing the series flow design giving a better performance than the parallel series flow for horizontal PV/T PV/T surface and, the parallel series flow performing better at an inclined PV/T surface than its counterpart [18]. In addition, computer aided simulation have been extended to PV/T systems with studies covering the optimization of productivity of hybrid PV/T system via thermo-electric configuration [7], Particle swarm approach and temperature distribution [19] .
The significant benefits of PV/T over the PV module or solar heater have been emphasized in its higher energy yield over a

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unit area and its reduced cost of balance of system (BOS)[21]. PV/T systems adaptability has seen its application in building integration [3, 22, 23], enhancing energy yields [16], hydrogen production [24]. The present research focuses on investigation of technical performance parameters in the form of overall energy and primary-energy saving efficiency for a hybrid PV/T system. The rest of the paper is arranged as follows: section II covers the materials and methodology implemented in this research. Results are discussed extensively in III. We conclude in section IV on the cogent points of the paper.

II. MATERIALS AND METHODOLOGY

A. EXPERIMENTAL SETUP

In structural terms, a typical hybrid PV/T system moving from top to bottom is made up of one or more glazing cover; PV module placed beneath glass cover with a minimal air gap, flow channels in form of tubes adhered to the rear of the module, absorber, insulation and frame set for support .The hybrid system under investigation is implemented via a direct box-type configuration. A standard PV module is utilized with its electrical specifications detailed in Table 1. The PV module is enclosed in a plywood box measuring 865mm $\times$ $710mm$ $\times$ 70mm with thickness 20mm and fitted with a single glass glazing.

B. EXPERIMENTAL PROCEDURE

The experiment was carried out at a location that is free from shades of any sort. Figure 1 shows the PV/T that was used. The period of observation was from 11am to 3pm. Water was chosen as the working fluid, and five different flow rates were adapted for the purpose of the experiment. A pump was employed for steady flow of the fluid. The temperature data for inlet, outlet, ambient and back of module were measured via temperature sensors. The solar radiation intensity data was measured using a solar meter model. The flow rates were each utilized for a span of 40 minutes, and readings were recorded at five minutes intervals. The flow rates have been steadily increased at different time span to account for continuous/proper* heat evacuation during the onsets of local maxima in the solar spectrum.

Table 1: Technical specifications of the PV module

Electrical characteristics		
Description	*Symbol*	*Value*
Solar cell size	A_{CELL}	*121.68cm²*
Short circuit current	I_{SC}	*4.85A*
Open circuit Voltage	V_{OC}	*22V*
Maximum power current	I_{MAX}	*4.44A*
Maximum power Voltage	V_{MAX}	*18V*
Area of PV Module	A_{PV}	*4380.48cm²*
Maximum Power	P_{MAX}	*80W*
Maximum system voltage		*1000VDC*
Nominal efficiency	η_r	*13.05%*

C. PERFORMANCE EVALUATION TARGETS OF THE PVT SYSTEM

The thermal and electrical efficiency is central to evaluating the technical parameters of the hybrid PV/T system. The thermal efficiency (η_{TH}) of the collector system is of the form:

$$\eta_{TH} = \frac{Q_u}{IA_c} \quad (1)$$

where, Q_U gives the useful heat extracted and has the mathematical expression :

$$Q_u = \dot{m}C_w \Delta T \quad (2)$$

with $\Delta T = T_o - T_i$ giving the temperature difference between outlet and inlet. Conventionally, the electrical efficiency (η_{PV}) can be expressed via the formula:

$$\eta_{PV} = \frac{P_o}{IA_{pv}} \quad (3)$$

Here, P_o indicates the measured output power and is evaluated as a product of current and the voltage. Alternatively, η_{PV} can be expressed in terms of reference temperature dependent module efficiency (η_r) and cell temperature (T_r) related as [6, 10]:

$$\eta_{PV} = \eta_r\,(1 - 0.0045\,(T_r - 25)) \quad (4)$$

Technical Parameters of the Hybrid PV/T System

Overall energy efficiency (η_{PVT}): This is quantified by the summation of thermal and electrical efficiency expressed mathematically in PV/T literature as:

$$\eta_{PVT} = \eta_{TH} + \eta_{PV} \quad (5)$$

The overall energy efficiency gives a measure of the ratio of combined energies collected to that of the incident solar radiation.

Fig. 1 PV/T unit that was used for the investigation.

Primary energy saving efficiency (η_F): This technical parameter has been proposed and utilized as a means of calculating the difference in energy grade between electricity generated by the PV module and thermal energy obtainable from the system [6,10]. It is a useful indicator for detecting quality and quantity of energy converted by the hybrid system into solar energy. It is formally expressed as:

$$\eta_F = \eta_{TH} + \frac{\eta_{PV}}{\eta_P} \quad (6)$$

with η_P effectively denoting the electric power generation efficiency of a conventional power plant and having a nominal value of 0.38.

IV. RESULTS & DISCUSSIONS

Figure 2 gives the parametric variation of the physical conditions in form of ambient temperature and solar radiation affecting the hybrid system during the course of the experiment. As seen from the curve, the ambient temperature follows closely the behavior of the solar radiation. The performance targets under consideration have been calculated using Eq. (5) and Eq. (6), for flow rate $\dot{v}$ = [10.81, 13.04, 15.98, 20.83, 5.53].

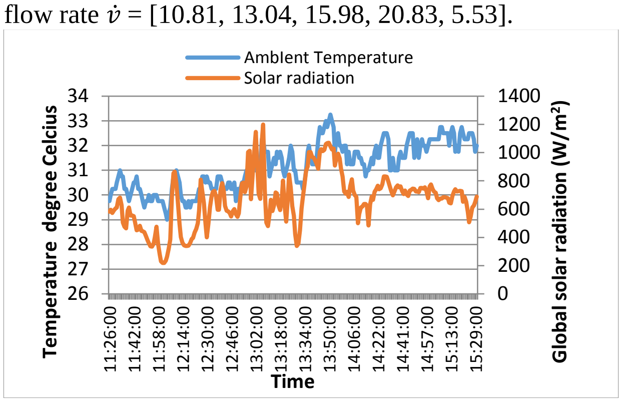

Fig. 2. Measured values of Ambient temperature, and global solar radiation.

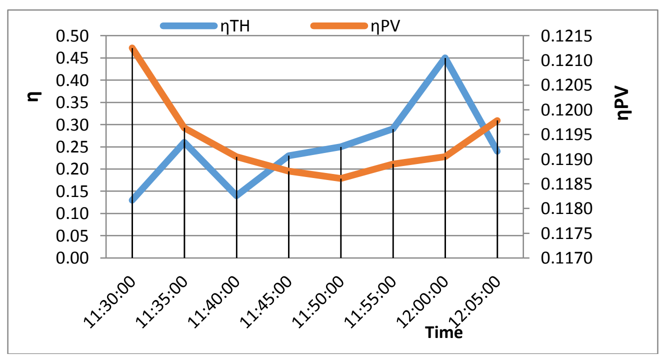

Fig. 3a - Variation of thermal and electrical efficiencies at flow rate $\dot{v}$ = 10.81ml/s

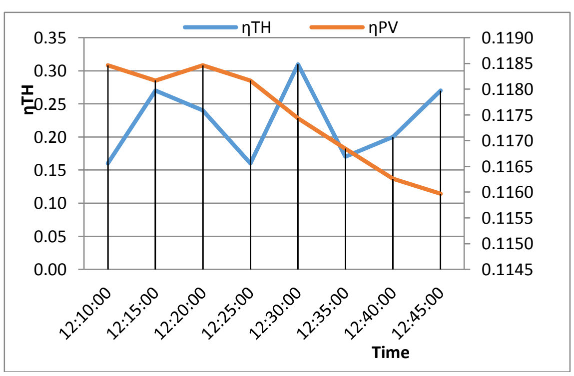

Fig. 3b - Variation of thermal and electrical efficiencies at flow rate $\dot{v}$ = 13.04ml/s

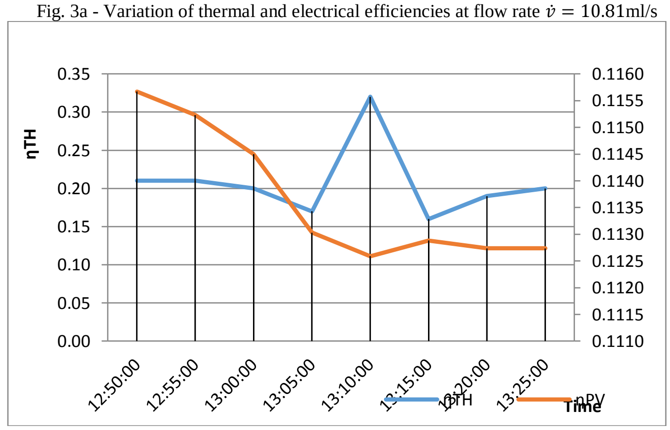

Fig. 3c - Variation of thermal and electrical efficiencies at flow rate $\dot{v}$ = 15.98ml/s

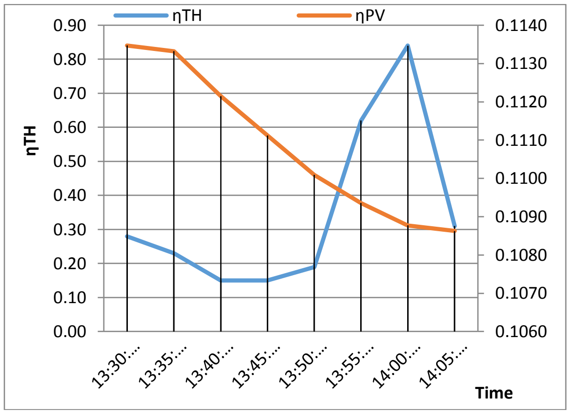

Fig. 3d - Variation of thermal and electrical efficiencies at flow rate $\dot{v}$ = 20.83ml/s

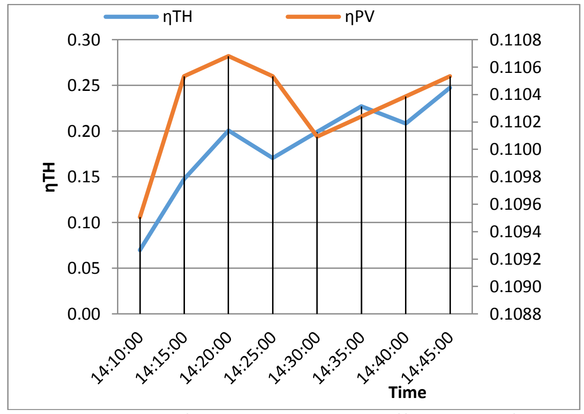

Fig. 3e - Variation of thermal and electrical efficiencies at flow rate $\dot{v}$ = 5.53ml/s

Figures 3a to 3e show the behavior of the thermal and electrical efficiencies of the system at different fluid flow rates. As seen from the figures, the maximum thermal and electrical efficiency are obtained at different periods for the hybrid system.

Figures 4a to 4e show the variations of the technical targets – the overall energy efficiency and primary energy saving efficiency i.e. η_{PVT} and η_F respectively – within the period considered. In Figure 4a, with flow rate $\dot{v}$ = 10.81ml/s, the peak values of the targets are obtained at 12:00hours with η_{PVT} =57% and η_F =76.58%. For figure 4b, with $\dot{v}$ = 13.04ml/s, η_{PVT} and η_F attains maximum values of 42% and 53.58% respectively at 12:30. With $\dot{v}$ = 15.98ml/s maximum values of η_{PVT} =42.0% and η_F =61.0% are obtained at 13:10 as depicted in figure 4c. Peak values of η_{PVT} and η_F are achieved for $\dot{v}$ = 20.83ml/s as seen in figure 4d, with η_{PVT} as 73.0% and η_F as 91.0% at 13:55. Lastly, figure 4e for $\dot{v}$ as 5.53ml/s, maximum values of 36% and 56.95% are attained respectively for η_{PVT} and η_F occurring at 14:45.

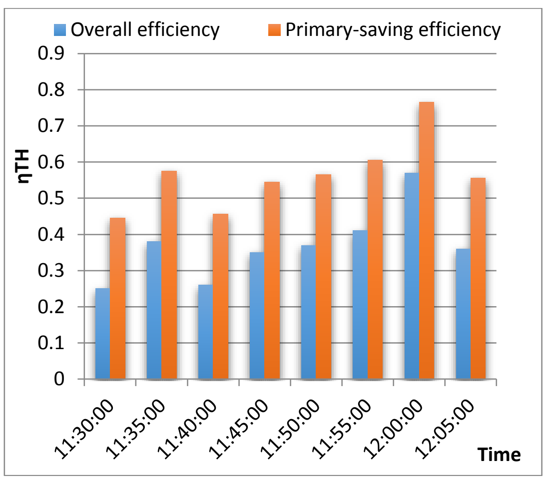

Fig. 4a - Variation of overall energy and primary-saving energy efficiencies at flow rate (a) $\dot{v}$ = 10.81ml/s

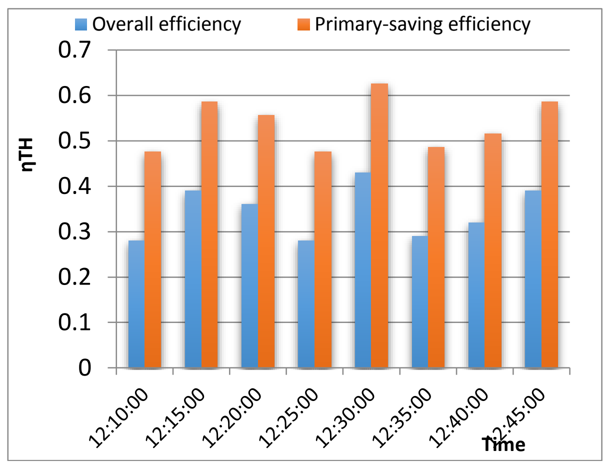

Fig. 4b - Variation of overall energy and primary-saving energy efficiencies at flow rate $\dot{v}$ = 13.04ml/s

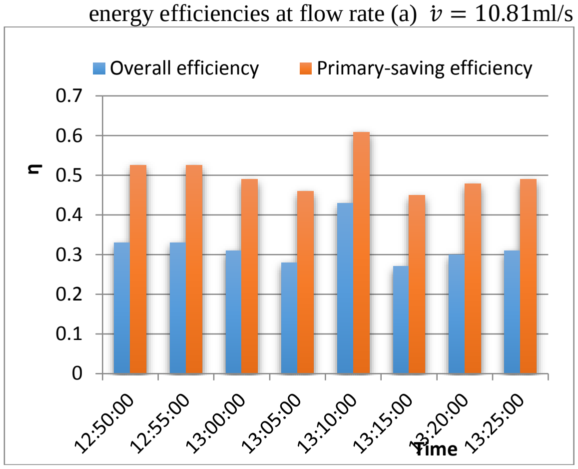

Fig. 4c - Variation of overall energy and primary-saving energy efficiencies at flow rate $\dot{v}$ = 15.98ml/s

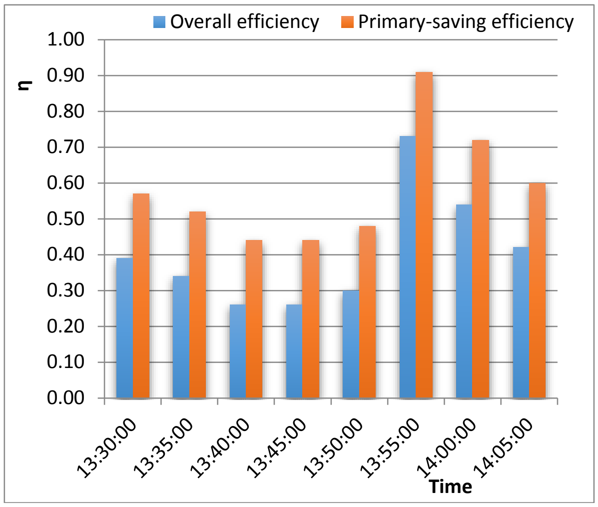

Fig. 4d - Variation of overall energy and primary-saving energy efficiencies at flow rate $\dot{v} = 20.83$ml/s

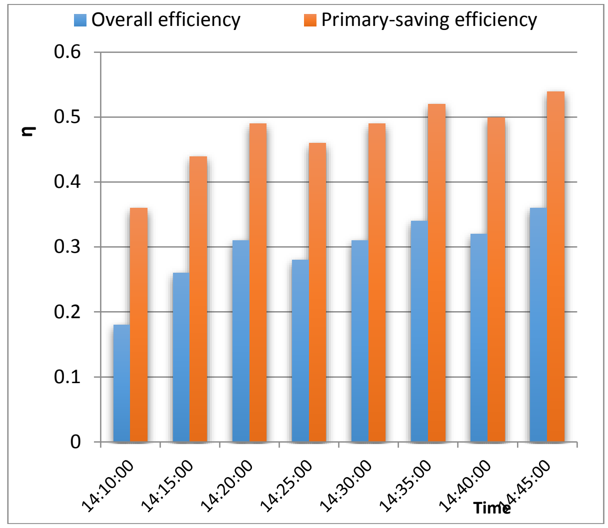

Fig. 4e - Variation of overall energy and primary-saving energy efficiencies at flow rate $\dot{v} = 5.53$ml/s

V. CONCLUSION

Technical parameters in form of overall energy efficiency and primary energy saving efficiency have been considered for a PV/T system. Overall energy efficiency and primary energy saving efficiency was found to attain a maximum value of 73.0% and 91.0% respectively, within time period 13:55 at flow rate 20.83ml/s. This represents the flow rate required to optimize energy generation. It is important to note the variation in thermal efficiencies which is much larger than those for electrical conversion. This is mostly due to overcast as can be observed in figure 2. The intermittency of solar irradiance as can be observed in figure 2 sometimes places a limitation on PV/T application in our environment. This, notwithstanding, does not negate the potentials of PV/T systems as an option for optimizing energy generation.

Table 2. Nomenclature Table

Symbol	Parameter
$\dot{v}$	volume flow rate (ml/s)
$\dot{m}$	mass flow rate (Kgs^{-1})
T_o	Outlet temperature (^{0}C)
T_i	Inlet temperature (^{0}C)
T_a	Ambient temperature (^{0}C)
Q_u	Useful thermal power from collector (W)
A	Collector area(m^2)
C_W	Specific heat of water (J/kg^{O}C)
Greek letters	
η	Efficiency

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