iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH
IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 8 Issue: IV Month of publication: April 2020

DOI: http://doi.org/10.22214/ijraset.2020.4034

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC VALUE: 45.98; SJ IMPACT FACTOR: 7.429
Volume 8 Issue IV Apr 2020- Available at www.ijraset.com

Performance Review of Photovoltaic Thermal System

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Abstract: This paper reviews the performance of integrated Photovoltaic thermal systems as compared to conventional solar systems. The major purpose of the review study is to understand the photovoltaic thermal performance to solve the issue of the decrease in electrical efficiency when solar radiation increases the temperature of PV modules. It has been observed from the studies that PVT systems are more efficient than other solar setups but, there are exceptions according to need. In a need of thermal energy, thermal solar setup is more efficient and for electricity generation, Simple PV system is way more efficient, economical etc. Depending upon the weather conditions also, Hybrid PVT systems are found more efficient in winter as compared to operation in summer.

Keywords: Photovoltaic thermal system, Electrical Efficiency, Thermal Efficiency, conventional PV system, Solar Radiations, Hybrid PVT System, Performance analysis.

I. INTRODUCTION

The Energy that is generated from resources that are naturally replenished on a human timescale is termed as renewable energy. This form of energy replaces conventional fuels. Fulfilling today's growing needs and minimizing or tranquilizing climate concerns are may be very significant to the efficient and economic harnessing of clean solar power. In the past few years, the developments in solar energy technology enabled extensive and efficient use by converting it to thermal energy and electricity. Hybrid type technology which is the system that harnesses solar energy presently, also abbreviated as PV/T collectors combine the two techniques for generating thermal energy and electricity simultaneously from the single solar collectors. The PV/T collector formed by a glazed or unglazed PV layer at the top and an absorber layer beneath it which absorbs heat from the PV layer. The inlet and outlet valve are designed in the absorber layer for fluid circulation. The fluid type may be liquid (like water or water-ethylene-glycol mixture) or air is circulated to extract the heat through the absorber layer. In the last 35 years, a significant amount of research and development work on PVT technology has been conducted with a gradual increase in the level of activities. Several methods have been put forward to com-pare PVT systems using numerous factors including economics, carbon dioxide emissions, the energy produced and exergy efficiency [1-5]. Erdil et al.[6] along with Kalogirou et al. [7] calculated the economic feasibility of a PVT system and conclude that their systems were cost-effective. However economic analysis mostly used to determine the cost viability of the system. Using carbon dioxide emissions, especially the dynamic life cycle emissions [8], as a method for energy system rating is useful in the context of stabilizing global CO2 concentrations. However, in a given specific location trying, to make a system more energy-efficient reduces the CO2 emissions of the system during operations, which further reduces the complexities of varying geographic emission intensities due to fuel mix in a region[9] Energy Analysis of the systems shows PVT systems produce more energy than either a PV or thermal collector system per unit area[10], although work and studies have been tested using different flow rates, glazes and designs to determine whether PVT systems are superior or not[11-14]. However, like the other two comparisons, energy lacks the ability to compare electrical energy and thermal energy since energy analysis only looks at the quantity of the energy and not the quality. So. Exergy Analysis, defined as the maximum useful energy in a specific reference state, typically the surroundings, analyzes both the quantity and quality. This further allows improved analysis and optimization of systems since exergy, unlike energy, is not conserved, but rather destroyed by irreversibilities in real processes. The PV/T system as described produces electricity and heat (air or water preheating), that will contribute to improve the efficiency of PV/T modules by extracting the heat lose by using (air/water) as a removal fluid and take this advantage for use in many applications [15]. Several studies have been done about using air or water PV/T systems some of the research found that use the water system seems desirable because of the nature of this fluid allowing better recovery of the heat. This paper reviews the experimental performance and economics of photovoltaic thermal hybrid collectors at different locations and in different environmental conditions observed to overcome the issue of the decrease in electrical efficiency due to an increase in the temperature of PV module due to an increase in solar radiations.

II. EXPERIMENTAL MODELS

Various models are being tested in the evaluation depending upon the locations of experimentation. Four solar energy system Models are tested in the three different locations of America i.e Denver, Detriot and Phoenix are as shown in figure 1, an open-source numerical simulation tool, Scilab has used in creating these models and analyzing the data through these models [16]. The data base 1991-2005 update typical meteorological year 3 (TMY3) of National Renewable Energy Laboratory National Solar Radiation was used [17].

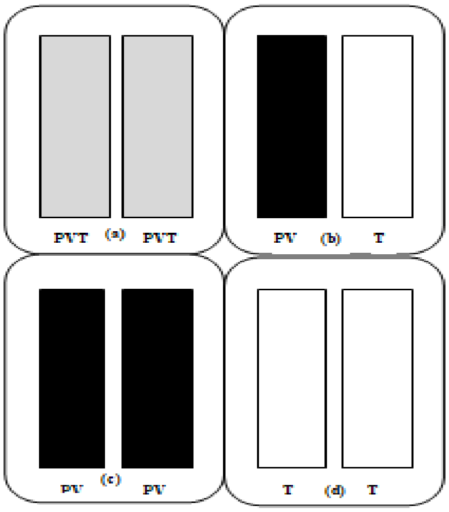

Figure 1: Equal Area Solar Energy System

The model designed are defined as

1) PVT x2
2) PV+T
3) PV x2
4) T x2

All the system used in experimentation has the same total area. The PVT system model is a air heater with a PV panel as absorber (Air Collector) as they have lower operating costs and minimal use of material. The solar thermal system was designed as tube and sheet system model but air as the fluid was used to have the same medium as the PVT system for some simple comparisons.

These Locations were chosen because of their distinct and representative average ambient temperature and irradiance values, with Detroit has both low temperatures and low solar flux (9.2^{0}C and 3.63 kWh/m^2/d), Denver representing low temperatures and high solar flux (8.2^{0}C and 4.58 kWh/m^2/d) and Phoenix presenting high temperatures and high solar flux (16.90C and 5.48 kWh/m2/d) [18]. The air temperature, wind speed and solar irradiation on hourly basis were used in the simulation.

The PVT system designed as an air heater with a PV panel as the absorber since air systems are typically preferred due to the lower operating costs and minimal use of material [19].

For the studies done at Iraq and UAE similar systems has been taken into considerations but depending upon the temperature conditions and atmosphere conditions some differences has been made to balance the system operations.

III.ANALYSIS RESULTS

A. System Analysis at American Locations

In [20], illustrated that the efficiency conversion of photovoltaic (PV) module is affected by environmental changes, mainly by variations in the temperature and radiations. To minimizing these changes and effects by keeping the efficiency conversion at its highest level, several devices and techniques are implemented viz.Maximum Power Point Tracking(MPPT) and PV Cooling systems can provide the same. This paper reviews the results obtained using these techniques, by combination of systems, with the intent of achieving greater efficiency conversion level.

Four Generic models are presented of such system[21] stated that an exergy analysis was performed comparing a conventional following system

1) Photovoltaic solar thermal hybrid (PVTx2) system,
2) Photovoltaic and thermal(PV+T) system side by side,
3) Two module photovoltaic (PV) system and
4) Solar thermal (Tx2) system Two Panels Connected.

All the systems with identical absorber areas for applications with a limited roof area determine the superior technical solar energy systems. For exergy analysis, according to difference in average monthly temperature and solar flux, three locations namely Detroit, Denver and Phoenix were simulated. The Yearly Total Exergy results obtained explains how PVT systems outperform the other system at all three locations.

System / Location	Detroit	Denver	Phoenix
PVT System	1.71	1.74	1.77
PV+T System	1.01	1.03	1.05
PV System	1.60	1.63	1.63
T System	0.42	0.44	0.46

Table 1: Yearly Total Exergy (MWh) for Solar Energy model at Different Cities of America

According to studies done at three locations of America, the evaluation results shows clearly that for applications with limited roof area PVT systems are superior choices.This research also suggests that greater optimization is required for PVT systems.

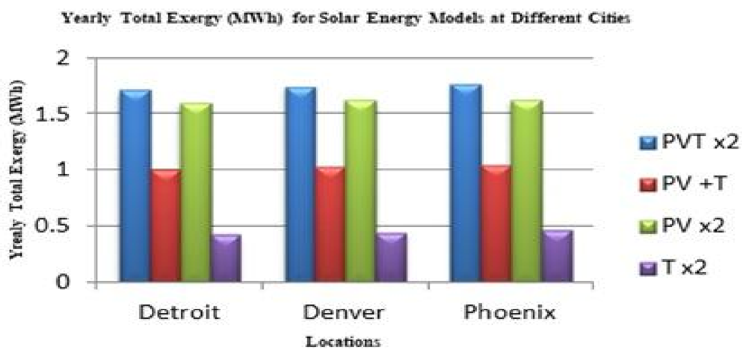

Figure 2: A comparison of Yearly Total Exergy (MWh) for Solar Energy Models

To further improve the exergy performance of PVT systems, geographical optimization should be further investigated with
a) Potential improvements found in the PV materials,
b) Flow rate and
c) Improved thermal loss reductions

The analysis showcases the following results for all the three locations:
i) PVT systems outcompete the PV+T systems 69% in all locations.
ii) PVT systems produce more exergy between 6.5% to 8.4% when matched against the purely PV systems.
iii) Create four times as much exergy as the pure solar thermal systems.

Results for all three locations concluded that PVT hybrid systems that are able to cannibalize all the thermal and electrical energy generated are superior in exergy performance to either PV+T or PV only system.

B. Solar System Evaluation in Iraq

[22] simulated and analyzed selected case studies in Iraq. to judge important characteristics: collector flow, heat removal factors, PV maximum power point, its temperature coefficient, overall power and efficiency, and in terms of design, operating and climatic parameters of the hybrid collector, an improved mathematical thermo-electrical model was derived. This current model is obtained with some additions and corrections in radiations and convection heat coefficients for the highest loss and for the airway with more applicable sky temperature correlation, unlike earlier PV/T thermal models. Using improved boundary conditions and translation equations for better convergence and accuracy the well-known 5 parameters electrical model pf PV module was solved.

The voltage temperature coefficient pf the PV module was included within the boundary conditions for convergence stability. The module parameters were taken to be obsessed on solar radiations and PV cell temperature for improved accuracy. The developed model is verified with previously published experimental results and theoretical simulations; proved to be most accurate with reference to the share errors and correlation coefficients. Investigation are done for the different parameters of the PVT collector like cell and air temperatures, thermal gain, PV current, and voltage, and fill factor. The results identified the important consequences of most significant operating conditions on the performance of the hybrid collector, these important operations conditions includes temperatures like sky, inlet and cell temperatures, airflow rate and incident radiation.

Efficiencies / Weather (Location)	Electrical	Thermal	Overall
Winter (Baghdad)	12.3%	19.4%	53.6%
Summer (Fallujah)	9%	22.8%	47.8%

Table 2: Results collected for PV/T model at Iraq

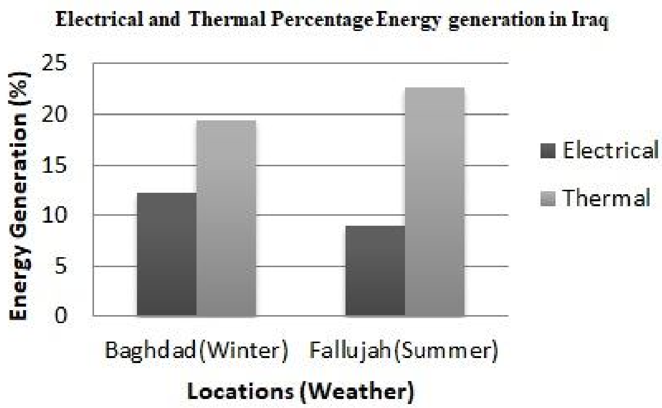

Fig 3: Percentage Electrical & Thermal Generation at Different Locations & Weather Conditions

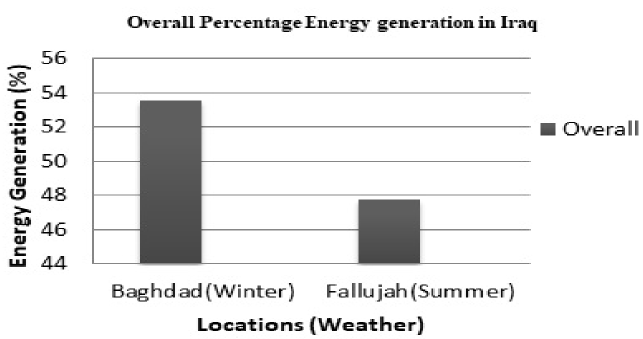

Fig 4: The Overall Energy Generation in Winter & Summer

These graphical representations draws the results that the PVT system is efficient when operated in Winter season as maximum (more than 50 %) efficiency has been obtained when system is made functional during winter season. On the other side during the summers the overall efficiency decreases below the 48% (observed: 47.8%) making the system functionality not economically feasible to some extent.

C. Results of Evaluation in RAK, UAE

[23] Said about the emerging technology that combines the PV and solar thermal collectors (hybrid Collectors) by producing heat and electricity simultaneously for the climate of RAK, UAE. Following the collector output model presented in European standard EN12975-2, Thermal performance evaluation has been done and electrical performance evaluation is done by analyzing the effect of water circulation on the performance of PV/T collectors.

In its conclusion, the author observed that by combining thermal and electrical aspects of solar panels, an increase in electrical output is experienced due to the fact that the water circulation through the collector. Minimize the overall temperature of solar cells, which leads to increase performance in terms of electricity production. An increase in electrical output is observed when there is a flow through the collector comparing to the case where there is no flow through. In UAE, providing the ambient conditions and economic factors like electricity unit prices, simulations of systems designed for residential operations revealed that PV/T systems are cost-wise less efficient than alternative solar energy systems.

On the basis of the study done at various locations around the world, the following conclusions have been drawn regarding the thermal characteristics, electrical characteristics as well as overall characteristics of the PV/T system:

1) *Thermal Characteristics*
a) Due to the lower heat loss coefficient, the gain efficiency and collector efficiency and heat removal factors were found to be better in the summer than that in the winter. Due to very high solar radiation in the summer of Fallujah City, the thermal gain is considerably higher (2.7 times at midday).
b) Due to smaller thermal energy available at low solar radiation (as in the morning and afternoon of winter day) as compared to the electrical energy absorbed and heat loss, the thermal efficiency variations during day time in the winter was larger than that in the summer.
c) For both cases, the collector flow factor is relatively high. This indicates that the airflow in the duct is adequate. However, high heat loss results in the low collector efficiency factor and consequently, low heat removal factor.
d) The radiation heat coefficient in the air duct was found to be comparable to the convective heat coefficient of the fluid (air). This contributes to reducing the collector efficiency factor.
e) It was found that the heat loss is mainly due to top losses from the collector; due to the radiation heat transfer from glass to ambient because of low wind speed,70% of these losses occurs. The latter is much reduced when sky temperature is closer to the ambient temperature. In fact, the top losses are very much reduced using a glass cover at an appropriate spacing from the PV module.

2) *Electrical Characteristics*
a) Due to the negative temperature coefficient of efficiency, the efficiency in winter is higher than that of in summer as the output power in the winter is less than that in the summer (1.7 times at solar noon).
b) Maximum power point tracker technique is used, the electrical loads need to be decreased when the climate changes from winter to summer in order to maintain the operation of the module at the maximum powerpoint.
c) It is observed that the fill factor gives a measure of the maximum electrical efficiency, as it is higher in the winter than that in the summer.

3) *Overall Characteristics:* During the effective hours of the day, the thermal gain and its efficiency are found to be higher than the electrical output power and its efficiency respectively in the winter and summer. This is due to the high heat loss in the collector. Thus, the overall equivalent efficiency in the winter is higher than that in the summer.

IV. CONCLUSIONS

There is a demand for both electricity and heat, the benefits of PV/T systems are reaped most at that times as it is observed that electricity output of a PV/T collector is greater than similar-sized PV collector, taking thermal output to that having a PV/T is most advantageous for the demand for heat.

When the only demand is heat generation, due to greater thermal performance and better economic feasibility of solar thermal systems, the solar thermal systems are more appropriate, cost-efficient and effective. A PV system design would be more suitable due to lower costs in the case of electricity demand, although PV/T systems offer better performance in electricity production. Hybrid photovoltaic thermal (PVT) [24] systems consist of PV modules and heat extraction units mounted together. They convert the solar radiation absorbed during operations into electricity and water or air circulating through vessels that are heated by cooling the PV modules. For heat extraction water dependant PVT systems are more expensive than air type PVT systems and can be used in all weather conditions, mainly in low latitude applications, as water from mains is usually less than 200C. It is concluded that the

PVT operation is also dependent upon the weather condition, During winter weather conditions, PVT tends to be more efficient in operation with more thermal generation and approximately nearly equal electricity generation. In summer, there is a huge gap between the thermal energy and electrical energy generation i.e, thermal generation is nearly equal to 22% and electrical generation is merely 9%.

Further, they concluded that the applications of the PVT/WATER system are effective in electrical output, reducing cost payback time (by 2.5 and 4.5 times regarding that of the typical PV modules). These investigations show that PVT/WATER systems are of application interest and wider use of photovoltaic.

V. ACKNOWLEDGMENT

We acknowledge the support, suggestions received from the anonymous referees for detailed literature review.

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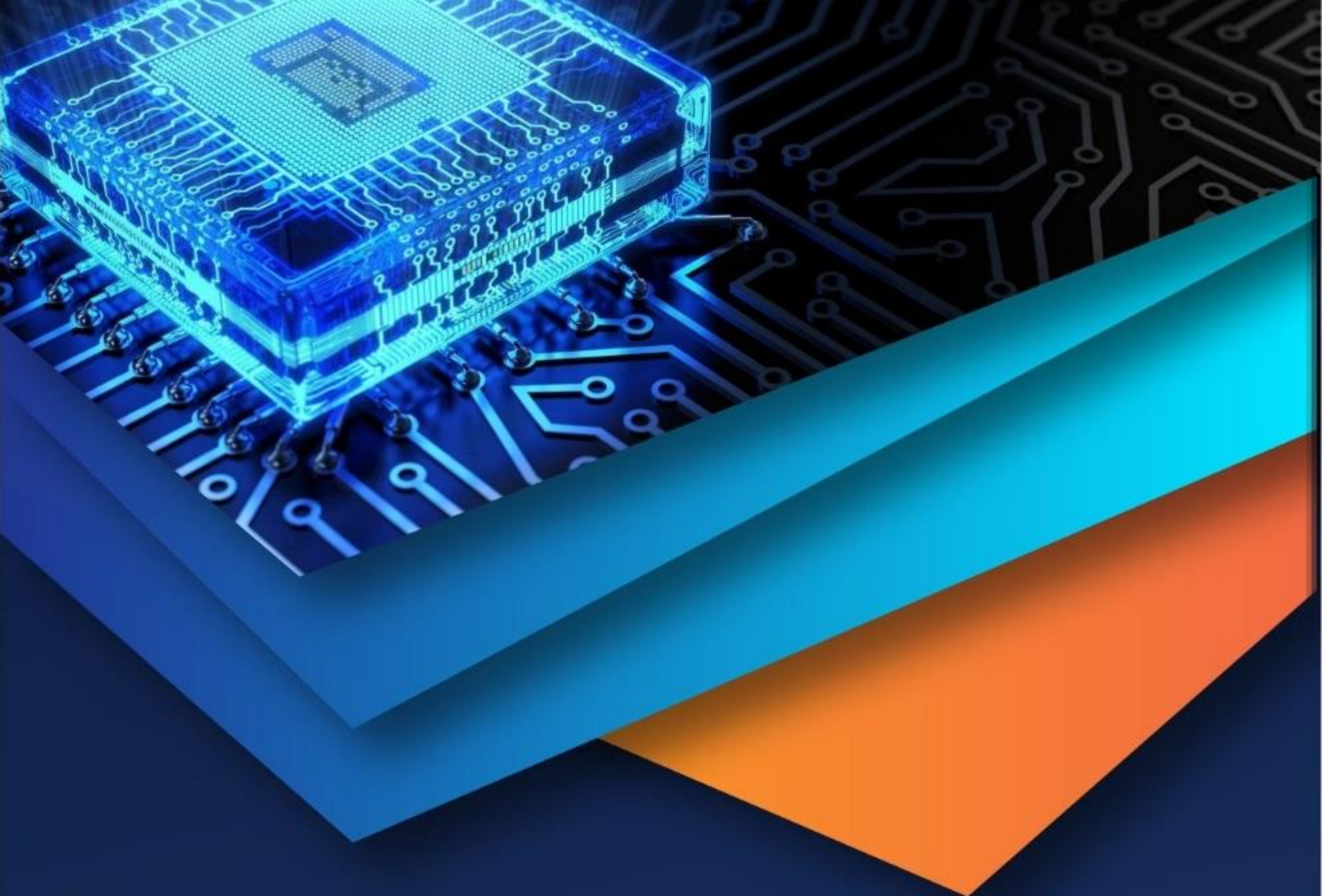

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