Performance Study of Solar Photovoltaic/Thermal System at High Altitudes

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***Abstract*—** The increasing installed area of solar technologies around the world gives us an idea about the unlimited potential available in solar energy. A thermosiphonic solar PV/T water heating system which could be used for domestic purpose has been designed constructed and tested using locally available materials. Solar energy is received by the PV surface which then utilize a small fraction of the incident solar radiation to produce electricity and the remainder is turned mainly into waste heat in the cells, this waste heat is utilized by attaching a copper pipe, and attached at the back of the PV panel to extract heat from the PV panel, thereby increasing its electrical efficiency, and an insulated casing is placed at the back of the heat exchanger to reduce heat loss to the environment. A water tank is then added to the system so that water flows from the tank to the heat exchanger, gets heated and flows into a water storage tank through thermosyphon principle.

Keywords*— *PV/T; Design of PV/T Systems; Thermosyphon; Poly-crystalline PV Panel.

I. Introduction

The increasing solar technologies around the world provide us an idea about the unlimited potential available in solar energy. This combined with the increasing non-renewable energy prices and continuous power outages, favor decentralized power generation among local consumers and small scale industries. However, the low power yield of the sun powered PV module, the low power yield of the sun oriented level plate warm authority and restricted usable without shadow space on structure rooftop tops could be overwhelmed by the high by and large electrical and warm proficiency of a sun oriented Photovoltaic Thermal (PV/T) framework, which consolidates the electrical and warm parts in a solitary unit region. The design of high performance photovoltaic/thermal solar system involves many parameters related to thermal, economic and reliability issues. Photovoltaic/Thermal (PV/T) collector which combines between the collection of thermal energy and generation of electrical energy is a promising solution to achieve a better exploitation for the solar energy. PV/T gatherers can deliver more vitality per unit surface territory in examination with PV modules and sun oriented warm authorities, around 15– 20% of the sun powered radiation gotten by the PV boards is changed over to electrical yield and the remainder of the sun powered vitality winds up warming the PV cells, which results in a few issues. The working temperature that can be come to by a PV board and because of the created electric power is emphatically affected by the atmosphere of the site. One of the very affecting parameters on the working temperature and the power drop from a PV framework is the climatic conditions. The most basic time frame for PV board efficiency decline is in routines of most elevated sun based light dimensions and least wind air speeds. The other issue that can result from the high cell temperature is the ability of achieving the full harm because of overheating of the board. So, cooling of the PV panels is a very important task that should be taken seriously into consideration. Cooling of PV can be used for heating of a fluid at the same time so we can improve the electrical efficiency and at the same time cultivate some thermal energy. This combination gave rise of combined system. Many types of hybrid collectors are available, where the PV is the common part. These types like the PV/T flat plate collector, PV/T concentrator collector, and PV/T heat pipe collector. The most popular collector type in the recent years is the hybrid PV/T flat plate solar collector. The PV/T collector is composed of the PV panels, the absorbing surface which is mainly flat plate, the flow channels, cooling fluid, and the storage medium. Each of these components may affect the performance of the PV/T.

II. THE PVT/WATER SYSTEM CONCEPT

The water type PVT systems (PVT/WATER) are more expensive than air type PVT systems and can be effectively used all seasons, mainly in low latitude applications, as water from mains is usually under 20^{o}C. On the other hand, the ambient air temperature during the day is over than 20^{o}C for almost half a year, limiting therefore the application of air type PVT systems in terms of effective electricity production to a shorter period. The PVT/WATER systems can contribute to the electrical consumption of buildings and can be divided in low, medium and high temperature applications. The low temperature applications up to about 45°C are associated with water preheating, heating of swimming pools and heat pump applications. The medium temperature systems may produce water of temperatures between 45°C and 65°C for domestic water heating, space heating and other thermal needs. Systems that produce water above 65°C can be used for space cooling and industrial processes, but so far there is no such known application. Most of the investigated PVT models consist of silicon PV modules and the heat extraction unit is a metallic sheet with pipes for the water circulation, to avoid the direct contact of water with the PV rear surface. The heat exchanger is in thermal contact with the PV module rear surface and is thermally insulated to the ambient from the rear side of the heat exchanger element and the panel edges.

The additional thermal output that is provided from the PVT systems makes them cost effective compared to separate PV and thermal units of same total used aperture surface area. In PV/T system applications the production of electricity is the main priority, therefore it is necessary to operate the PV modules at low temperature in order to keep PV cell electrical efficiency at a sufficient level. This requirement limits the effective operation range of the PV/T thermal unit in low temperatures, thus, the extracted heat can be used mainly for water preheating. In case of using PV modules without additional glazing (UNGLAZED type), they 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 a glazing increases significantly the thermal efficiency (GLAZED type) for a wider range of operating temperatures, but the additional optical losses from it reduce the electrical output of the PVT system. The electrical output of PV/T systems is of priority, as the cost of PV modules is several times higher than the thermal unit. The different performance of the two subsystems regarding temperature affects system cost and optimised modifications for both electrical and thermal efficient operation must be considered. Thus it is necessary to take into account the cost in relation to the increase of system electrical and thermal energy output. Monocrystalline or polycrystalline silicon (c-Si or pc-Si) PV modules are almost double the cost per system aperture area than amorphous silicon (a-Si) PV modules. Therefore, the addition of the thermal unit is of lower relative cost for PV/T system based on c-Si or pc-Si (about 8%-10%) than of a-Si PV modules (about 15%- 20%) of same size. In addition, the thermal unit additional cost must be offset by the corresponding increase in electrical efficiency and thermal output in order to make the PV/T system cost effective.

III. Electrical Efficiency

The atmosphere, introduction and temperature are the components influencing the electrical exhibition of a given PV/T framework. The PV cell at the most noteworthy temperature will restrain the electrical productivity of the entire module. The coolant liquid should move through a straightforward and dependable structure, to keep up a low and uniform PV module temperature, with least parasitic power utilization. The electrical productivity of the PV board is somewhat littler than the electrical effectiveness of the combi-board because of the lower temperature of the PV cells in the combi-board, in which the channel temperature was kept consistent at roughly 18%C, which suggests that the electrical addition because of cooling of the PV cells by the water is bigger than the optical misfortune because of reflection at the glass spread in a combi-board. Higher electrical proficiency can be acquired in winter months, because of the low surrounding temperature. Additionally, high wind speeds lead to an expansion in the electrical proficiency because of more prominent warmth misfortunes. In spite of the fact that the electrical productivity is ordinarily 40% of the warm proficiency, the essential vitality investment funds are practically equivalent.

IV. Thermal efficiency

Expanding the transmittance absorptance item improves the warm effectiveness. The PV module has a high reflection coefficient, because of the high refractive file of the semiconductor material. The counter intelligent covering of the sun oriented cells is upgraded for a shorter wavelength to enhance the photocurrent. In any case, the reflection for a more extended wavelength is high, contrasted with the low impression of frightfully specific coatings utilized in traditional warm authorities, prompting a decreased warm exhibition. The assimilation of the more drawn out wavelengths can be expanded by the utilization of a silicone encapsulant. Diminishing the zone secured by the PV cells results in an expansion in warm proficiency, however results in a slight decrement in the electrical productivity.

In any case, expanding the authority surface builds the accessible radiation, yet additionally prompts an expansion in the warmth loss of the framework. The general warm proficiency increments with a lessening in the profundity of the air conduit, due to increasingly warm vitality extraction from the back surface. The breeze speed additionally decides the warm productivity of the PV/T gatherer. The day by day high warm productivity could accomplish around 40% in an aluminum amalgam level box type PV/T authority, when the underlying water temperature is equivalent to the every day mean encompassing temperature. A half increment in warm proficiency with synchronous increment in electrical productivity were seen by typifying the silicon PV cells legitimately on the blade type heat sink in a PV/T air gatherer

V. PV/T collector technologies

There are a few type of PV/T authorities, and the ideas are different to the point that is looks bad to examine 'PV/T frameworks' moving forward without any more particular. Different audits have additionally discovered that a progressively exact language should have been characterized so as to describe the various frameworks. When all is said in done, a qualification can be made between PV/T gatherers with fluid warmth exchange medium (PV/T-fluid), PV/T authorities with air as the warmth exchange medium (PV/T-air) and focusing PV/T gatherers. What's more, the gatherers can be made utilizing PV innovations, for example, crystalline of flimsy film PV, and distinctive sun powered warm advances, for example, level plate authorities, cleared cylinder authorities or warmth channels. For level plate PV/T modules, a refinement is made among secured and revealed authorities.

The classification is for this situation to some degree confounding, since the two sorts are really secured by a defensive glass sheet like the one utilized for PV modules. The secured or coated PV/T gatherers have an extra straightforward spread at a separation from the safeguard surface for warm protection. The fundamental thought of PV/T gatherers is to use the waste warmth from sunlight based cells, yet there is additionally a quandary: the sun based cell yield is most astounding when the modules are cool, while the temperature ought to be high to boost the warm yield.

VI. DESIGN AND DEVELOPMENT

Block diagram of the system

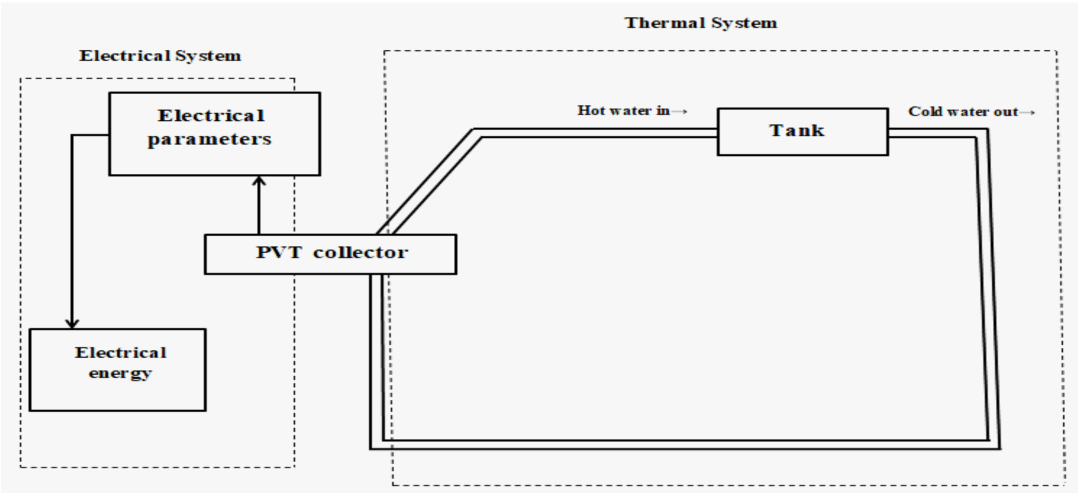

Fig 1. Block diagram of the experimental setup for PV/T system

The block diagram represents that the overall setup of the system. The storage system consisted of a tank. The incoming fluid from fluid tank is made to flow into the panel by a throttling valve provided at the inlet. The fluid flow occurs due to thermo-siphoning through the collector tubing by maintaining a temperature difference between the inlet and outlet. The external connection to collector inlet and fluid tank outlet are done using steel pipes. The storage system is kept at a height of 10 cm above the plane of the solar panel.Solar panels of capacity 270 W are used for all testing in this work. The PV/T panel is kept at an angle of 15 degree. The electrical and temperature tests on the PV/T panel are carried out. By using digital thermometer the temperature of panel, inlet and outlet temperature of tank are measured. The mass flow rate of the fluid flowing through the tube is measured by taking a tapping in the upper tube, and measuring the volume of the fluid falling in a tank.

A. Proposed Design

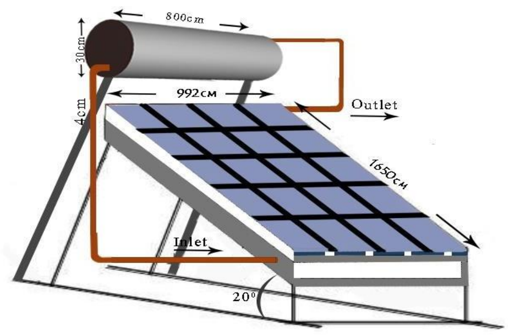

Fig 2 Proposed design

The PV/T panel used for present studies has area 1650 mm 992 mm and thickness 40 mm. The PV panel is placed above a frame of length 1650 mm and breadth 992 mm.The cooling system kept inside the frame consists of 15 segments of copper tubes with diameter 1.cm.The copper tubing is fixed to the aluminium plate in the form of serpentine tube arrangement. The two ends of the tube are taken out from both sides and connected to a storage tank of capacity80 L. The absorption unit is attached to the solar panel with thermally conductive silicon adhesive sealant. The whole assembly is kept in a wooden box with thermo coal to reduce heat loss to environment.

B. Selection of absorber

In a PVT system, the absorber represents the main functional components which collect the incident solar radiation and transfer it to the coolant fluid minimizing the losses to the outside and casing its thermal capacity must not assume to high values in order to allow fast reaction time in relation to the variable condition and to optimize the possibility of available energy use even to low quanties, from the thermal point of view the main absorber features are

- High absorption coefficient in the solar spectrum
- Low emissivity in the infrared spectrum
- Good thermal conductivity
- Good heat transfer coefficient of the coolant fluid
- Low thermal capacity

Table1:

Absorber material	Thickness (mm)	Weight per unit area (kg.m²)	Thermal conductivity	Thermal capacity
copper	0.3	2.5-3	386	350
Aluminium	0.6	2	164	900
Steel	2	15-20	50	450

Among the absorber material thermal conductivity of copper is comparatively higher than the aluminium and steel, hence we decided to choose copper as the absorber material.

C. PIPE SPACING AND SIZING

The effect of tube spacing as a design factor in the performance of a natural-circulation solar water heater for copper was investigated by: (Agbo, and Okeke, 2007). The collector performance in terms of the collector efficiency and the collector fin efficiency are both obtained theoretically, experimentally and by a computer aided simulation based on the Hottel-Whiller model of the system. The result indicates that the tube spacing varies inversely with both the collector efficiency and the fin efficiency for the copper absorber plate. Performance is optimized with a tube spacing not exceeding 12 cm. Spacing between pipes was chosen to be 11cm. The statement above and value of Agbo and Okeke is in line with the value (0.11m) used for tube spacing in this research. Because copper plate is used in this research, a copper pipe was chosen, whose diameter is (1cm), thickness of 2mm, overall length of 15m and pipe spacing of 10cm.

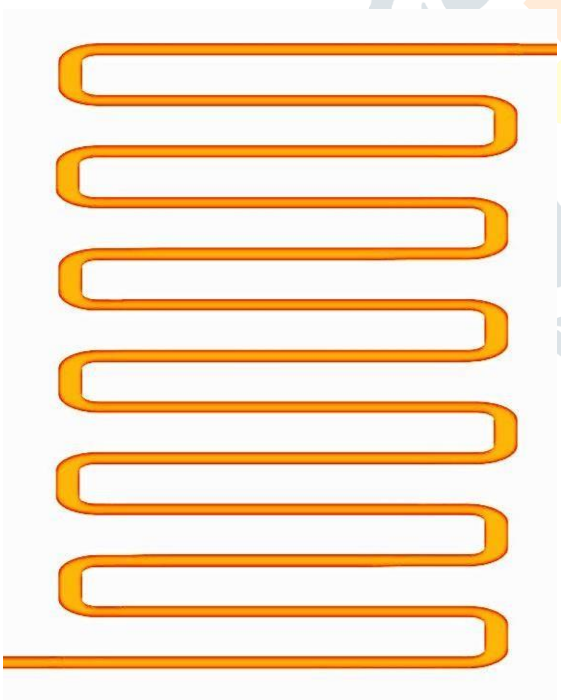

Fig.2. Spiral Arrangement

D. TANK SELECTION

The volume of the tank=lbh

b=Breadth of the tank

l=Length of the tank

h=height of the tank

We are choosing rectangular tank with length= 58cm,breadth=38cm and height = 38cm

The volume of the tank=58×38×38

=833752Cm^3

=80liters

This value is agreed by (Adegoke and Bolaji, 2000), that for a better performance of a thermosyphon water heating system, every 1m2collector area should raise a tank of 60-90 liters capacity. Hence, 80 liters water tank capacity for the 1.28m2collector area.

The tank is made up of acrylic sheet with length 58cm, Breadth 38CM And height 38 cm. the insulation of the tank is done By thermocoal with 2cm thickness

E. CALCULATION OF THE PVT PARAMETERS

Thermal parameter

Determining the mass flow rate of fluid M = dm/dt
The fluid temperature rise ($\Delta T = To - Ti$)
The specific heat of fluid Cp = 4190 J kg-1 k-1 for water.

Qu=MCp(To-Ti)

The thermal efficiency is determined as a function of the solar radiation (GT), the input fluid temperature (Ti), and the ambient temperature (Ta).

Thermal efficiency (ηth)=$\frac{MCp(To-Ti)}{Ac*Gt}$

Ac = Collector area
Gt = Irradiance on the collector surface

Electrical parameter

The characteristic V-I test was conducted on both the PV/T and controlled PV panels. The Rheostats were connected as a variable resistive load (R) with the panels separately and by varying the R value, the values of voltage and current are noted.

Electrical efficiency(ηele)= $\frac{Im*Vm}{Gt*Ac}$

Here Im and Vm are the current and voltage of the PV module operating under a maximum power.

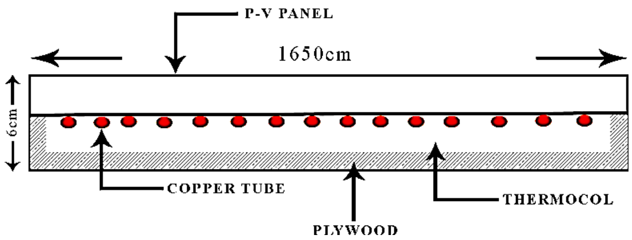

Fig.3. cross sectional view

The cooling system kept inside the frame consists of 15 segments of copper tubes with diameter 1.cm.The copper tubing is fixed to the aluminium plate in the form of serpentine tube arrangement. The two ends of the tube are taken out from both sides and connected to a storage tank of capacity80 L. The absorption unit is attached to the solar panel with thermally conductive silicon adhesive sealant. The whole assembly is kept in a wooden box with thermo coal to reduce heat loss to environment

Fig.4. spiral arrangement

Fig 5 tank

EXPERIMENTAL SETUP

Fig 6. Experimental setup

VII. EXPERIMENTAL PROCEDURE

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VIII. RESULT AND DISCUSSION

The experimental observation of the PV/T system were carried out with in the month of May, 2019 in order to study thermal and electrical behavior of the system for different weather condition,

Table2:

Time	Panel temperature (℃)	Inlet fluid temperature (℃)	Solar Insolation (W/m²)	Outlet fluid temperature (℃)	Voltmeter reading (V)	Ammeter reading (A)	Electrical output (W)
8:30	33.7	28	387	34.5	30	1.7	51
10:30	40.8	28	534	42.8	32	2.5	80
11:30	35	28	360	34.5	28	1.6	44.8
14:00	33.7	28	326	33.5	28	1.2	33.6
15:00	37.6	28	495	38.5	32	2	64

Figure 5 shows the variation of panel, inlet and outlet temperatures

with respect to time of the PV/T system on 8TH May 2019

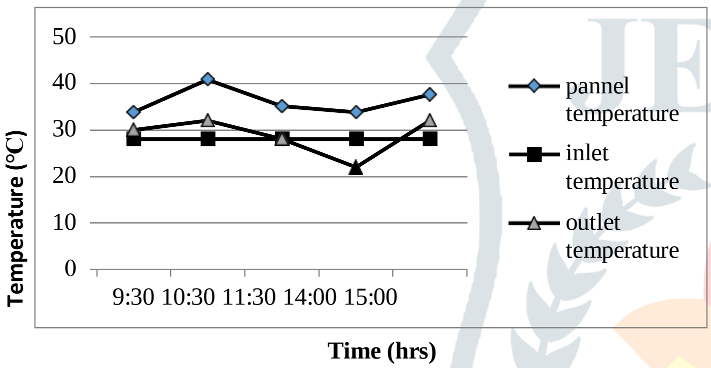


Figure 7variation of panel, inlet and outlet temperature

The figure illustrates the trends of measured inlet temperature, outlet temperature and panel temperature. It can be seen in the figure above that the outlet temperature and panel temperatures vary as dependent on the solar irradiance conditions. It has been found that, when the maximum water temperature of 42.8℃ for cloudy day was seen that the inlet temperature was 28℃.

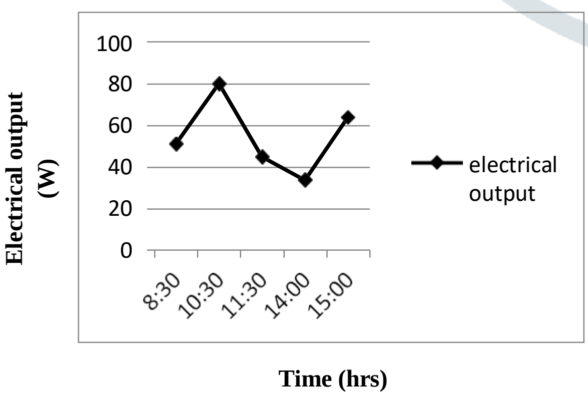


Fig 8 variation of electrical output of the PV/T system on 8th May 2019

Thermal and Electrical Performance of the PV/T System on 8th May 2019

Time	Solar Insolation (W/m²)	Electrical efficiency (%)	Thermal efficiency (%)
8:30	387	8.1	21.6
10:30	534	9.2	35.7
11:30	360	7.6	23.26
14:00	326	6.5	21.7
15:00	495	8.4	27.3

The PV/T collector thermal and electrical efficiencies were calculated using equations and the variation of the efficiencies on a 8th May is shown in figure

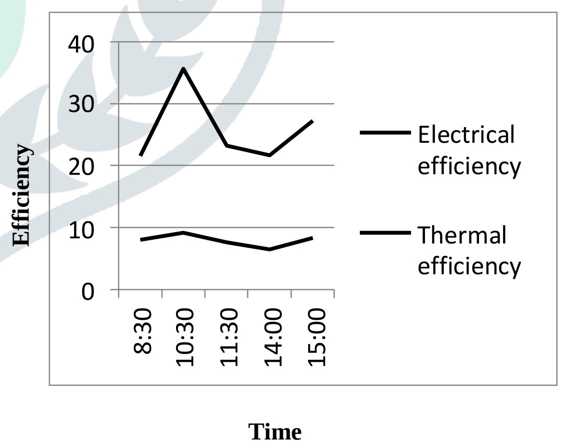


Fig 9 variation of electrical and Thermal efficiency with respect to time

IX. Comparison between PV/T and PV Module

I-V Graph of PV and PV/T system

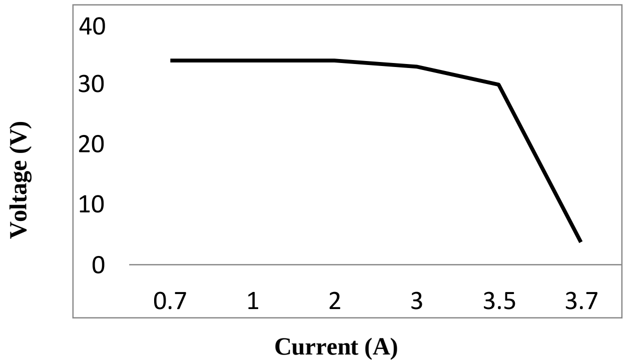


Fig I-V Graph of PV/T syste

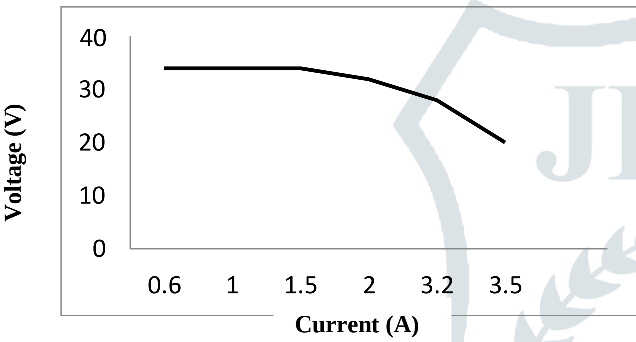
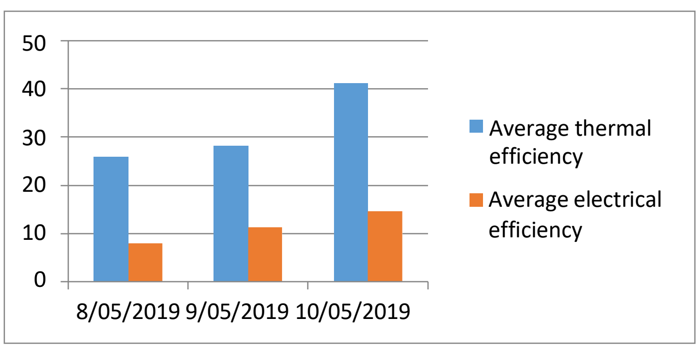


Fig I-V Graph of PV system

The comparison between PV/T and PV module are done on 9th may 2019 at 1:30 pm from the observation the panel temperature can reduce from 38.8℃ to 36℃ . The maximum thermal and electrical efficiency of the PV/T system on the day are 23.2% and 12.1% respectively which gives a total efficiency of 35.3%. The maximum electrical efficiency of the controlled PV module for the same sunny day was found to be 10.35%. The above results showed that when the solar radiation increased, the electrical output also increased.

The studies have been done over a pure PV and PV/T systems with an aim to check and compare their performance characteristics. Cooling of PV panel is done using water. Experimental research on PV/T water collector show that water cooling improves the electrical efficiency by 1.75% and 23.2% thermal efficiency additional to the system.

X. Daily average thermal and electrical efficiency of the PV/T system



The efficiency of the system shown in above figure indicates that the electrical efficiency seems to be more stable than the thermal efficiency. The average electrical efficiency of the PV/T module range is around 7.96%-14.58%. From the graph, it can be easily seen that the thermal efficiency fluctuates significantly, unlike electrical efficiency. The reason could be that the thermal efficiency is a function not only of solar irradiation but also of the ambient temperature, heat losses to the surrounding and other meteorological parameters. Due to those factors, the variation of the thermal efficiency of the system is understandable. It can be concluded that the overall efficiency of the PV/T system is much higher than the PV system. This is also implied that the PV/T system can adequately harness the solar energy.

XI. CONCLUSION

The report concludes that the efficiency of the panel decreases with increase in temperature, so the panel needs to be cooled. The usage of thermal energy for domestic purposes is another way to improve the efficiency of the system, thus it can be concluded that the cooled panels should have more efficiency. The experimental studies have been done over a pure PV and PV/T systems with an aim to check and compare their performance characteristics. Cooling of PV panel is done using water. Experimental study on PV/T water collector show that water cooling improves the electrical efficiency by 1.75% and 23.2% thermal efficiency additional to the system.

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