STUDY OF PHOTOVOLTAIC/THERMAL SOLAR ENERGY SYSTEMS

A dissertation submitted in partial fulfillment of requirement for the degree of Bachelor of Science in Electrical and Electronic Engineering

ISLAMIC UNIVERSITY OF TECHNOLOGY
Organization of Islamic Cooperation (OIC)

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DEPARTMENT OF ELECTRICAL AND ELECTRONIC ENGNIEERING
ISLAMIC UNIVERSITY OF TECHNOLOGY, BANGLADESH.

STUDY OF PHOTOVOLTAIC/THERMAL SOLAR ENERGY SYSTEMS

A Thesis Presented to
The Academic Faculty

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ABSTRACT

Aiming the improvement of usage of solar thermal energy PV modules is widely used throughout the world. Due to the lack of desired level efficiency the numerous researches are carried out to escalate the output of PV modules one of the form of developed PV modules is PV/T solar system. The temperature of PV module increases while absorbing solar radiation causing the decrease of electrical output after certain level. The hybrid Photovoltaic/Thermal (PV/T) solar system enhances the output of PV module facility the harvest of both thermal and electrical energy using the same solar radiation absorbed by the same surface area. In this experiment the design of PV/T dual system is developed, using both air and water circulation as heat extraction medium modifying the air channel. The shape of painted black ribbed surfaces at the bottom of air channel has been used as trapezoidal, Saw tooth backward ,Saw tooth forward and Flat plate as reference. The capacity of all set up is similar and having same dimensions. The process of natural convection is applied to circulate the air and water to increase the system efficiency. The variation in the net output is studied due the difference of air channel.

NOMENCLATURE

A_a	Aperture Area, m_2
Cp	Specific Heat at Constant Pressure, J/Kg.K
G	Incoming Solar radiation W/m_2
m	Mass Flow Rate,Kg/s
K	Thermal Conductivity, W/m.K
Q_{ab}	Heat Energy Absorbed W/m_2
TMS	Thin Metallic Sheet
WHX	Water Heater Exchanger
T_{PV}	PV Module Temperature, $_o$C
T_{WHX}	Water Heater Exchanger Temperature, $_o$C
T_i	Input Fluid Temperature, $_o$C
T_o	Output Fluid Temperature, $_o$C
T_{amb}	Ambient Temperature, $_o$C
T_{air}	Air Temperature in Channel, $_o$C
T_{rib}	RIB Temperature, $_o$C
ΔT_w	Temperature difference of water(T_o -T_i), $_o$C
ΔT	Temperature difference,(T_i -T_{amb}) $_o$C
η_{th}	Thermal Efficiency
V	Voltage, Volt
I_o	Current, Amp
$\eta_{elecrical}$	Electrical Efficiency

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DECLARATION

Department of Electrical and Electronic Engineering

Submitted for B.Sc. in Electrical and Electronic Engineering

The thesis has not published anywhere in full or in parts. All items or sub-items that appear on this thesis paper are referenced, where needed. The thesis cannot be copied without the permission of the authors.

Above declaration is true. Understanding these, the thesis has been submitted for evaluation.

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The thesis is in acceptable. It fulfills all criteria set by the department.

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Head of the Department

Chapter 1

IntroductIon

1.1 Introduction

Energy is required in almost every aspect of human activities and development of any nation in this world. Increasing fossil fuel price, energy security and climate change have important bearings on sustainable development of any nation. The increase in fossil fuel prices has created an inflationary pressure in the economic field which influenced the increase in interest rates and investments. One of the drastic approaches taken by researchers all over the world is to introduce a backup or replacement source of energy. One of the promising energy is the renewable energy technologies -in this case, solar energy, which commonly known as Photovoltaic technology (PV). The photovoltaic technology has its own advantages comparing to other sources, such as, operate in noiseless mode, totally clean and green energy, highly credibility system with life span expectation between 20-30 years and very low maintenance system. There are many applications of photovoltaic technology, such as, for heating purposes for water and space, solar drying and building integrated skins (facades)

1.2 Limitations of Conventional PV module:

In recent years building integration of photovoltaic modules has become more and more popular in the industrialized part of the world, where national support programmes has accelerated the dissemination of grid connected PV systems. The installation of a building integrated PV (BIPV) system has certain advantages compared to a traditional PV system mounted in a separate structure. Function as a rain screen, sun shading device and a visually attractive cladding of the building are the most popular “added values” the house owner gets from the BIPV system. Traditional (silicon) photovoltaic modules will produce more electricity the cooler they are. Typically power increases with 0.2-0.5% per °C decrease of temperature, but when a PV module is integrated in a facade or roof, it will normally get warmer than a module mounted in free air. It is thus logical to remove the excessive heat from the module, giving the reason for the growing interest in “solar co-generation” or photovoltaic/thermal (PV/T) collectors. If the surplus heat from the PV module can not only be removed, but be used to fulfill thermal energy needs of the building, an extra added value could be achieved. The status of commercial PV modules is that only 10-15% of the incident solar energy is transformed to electricity. The potential heat production from a given surface is thus much higher than the electrical performance, but it is an open question if this heat can be used in a sensible way.

There seem to be several obstacles:

- Most buildings need heating in winter when the solar gain is at its lowest

- The heat is needed at a higher temperature than the surrounding air, leading to increased module temperature unless a heat pump is used.
- The heat is needed at a higher temperature than the surrounding air, leading to increased module temperature unless a heat pump is used.
- For heating of domestic hot water, a heat exchanger is needed.
- The collectors could become very hot and thereby damaged if circulation of cooling media is blocked.
- The construction may be too complex and thus expensive compared to separate PV and thermal collectors.

The obvious advantages are:

- The total area used to extract a given amount of electricity and heat may be smaller than for two separate systems
- The materials used for a PV/T plant, and thus the total energy and economy balance, may be better than for separate units.
- The roof or facade will have a more uniform look.

1.3 Hybrid Photovoltaic/Thermal (PV/T or PVT) Solar Energy Systems:

In heating, photovoltaic module is combined with solar thermal absorber collector to produce a hybrid system. It is known fact that the efficiency conversion of solar energy to electrical energy using photovoltaic cells is limited by several factors. Firstly, conversion efficiency falls as the temperature of the photovoltaic cells rise and secondly, the photovoltaic cells are only responsive to a portion of solar spectrum, which is equivalent or higher than the band gaps of the solar radiation. This is one of the main reason that make the usage of photovoltaic in tropical countries is less choice. Photovoltaic Thermal technology (PV/T) has been developed since 70's. Basically the solar energy technology can be broadly classified into two systems; photovoltaic energy system and thermal energy system. The term PV/T refers to solar thermal collectors that use PV cells as an integral part of the absorber plate. The system generates both

thermal and electrical energy simultaneously. The first air hybrid collector was employed by the University of Delaware. The hybrid collector which was integrated by Böer et al.
Integrate the solar collector to building roof, known as "Solar One" house. Since the first hybrid collector being studied, variety of studies about the PV/T system has been carried out throughout the world. The studied mostly focusing on the air and water based as the medium to the heat transfer. Amongst the PV/T solar collectors that being studied, the most popular is the air type solar collector with photovoltaic module, even though it is most popular, this type of collector has less in usage compared to the water collectors. The PV/T solar collector system has been designed to generate the electricity and at the same time to produce hot air and hot water. The hot air and hot water gained can be used for other purposes in low heat temperature processes.

There are three basic types of hybrid PVT system:

- PVT/air system: where air is used for heat extraction from PV panel rear surface. Thus electricity and hot air is output.
- PVT/water system: where water is used for heat extraction from PV panel rear surface.
Thus electricity and hot water is output.
- PVT/dual (air and water) system: where both air and water is used for heat extraction.
Thus the output is both hot air and water with electricity.

In PVT system application, the main priority is to produce electricity so the operating temperature should be within certain range to keep the electrical efficiency at sufficient level. This requirement limits the effective operation range of the PV unit for low temperatures thus the extracted heat can be used mainly for low temperature applications. The PVT solar system can be effectively used in the domestic and industrial sectors.

- Considering water as heat removal fluid, it can be used in residential buildings, hotels, hospitals etc.
- Considering air for heat extraction, it is used for space heating, natural ventilation

etc.

The system can be suitable for building integration for providing hot water/air depending on the season and the thermal need of the buildings. Water cooled PV/T system are practical system for water heating in domestic building buts but their application is limited up to now. Air-cooled PV/T systems have already been applied in buildings, integrated usually on their inclined roofs or facades.

By using these systems the electrical output of the PV is increased, while avoiding building overheating during summer and covering part of the building space heating needs during winter. For residential use, in most cases the temperature of water needed is above ambient temperature. This water is mainly for kitchen use, bathroom use etc. For commercial sector, in swimming pools of hotels, hospitals etc.

In this study a hybrid PVT/dual system is designed with modifications in the air channel opposite wall and the positioning of water heat exchanger. The PVT system can effectively operate at locations in low latitudes where favorable weather condition exists or marginally in medium latitudes to avoid freezing.

Chapter 2

Literature review

2.1 Literature on PV/T system:

Many theoretical and experimental works have been done for the improvement of hybrid PV/T solar system since its appearance in 1980's.

Among the first, Kern and Russell 1978, give the main concepts of these systems with results, by the use of water or air as heat removal fluid. Hendrie, 1979, present a theoretical model on PV/T systems using conventional thermal collector techniques, Bhargava et al. 1991 and Prakash 1994, present results regarding the effect of air mass flow rate, air channel depth, length and fraction of absorber plate area cover by solar cells (packing factor, PF) on single pass. Sopian 1996, Garg and Adhikari 1997 present a variety of results regarding the effect of design and operation parameters on the performance of air type PV/T system.

In the above works the calculated thermal efficiencies of liquid type PV/T systems are in the range of 45% to 65%, the higher values derived for systems that include thermal losses suppression by using air gap with glazing. Regarding air type PV/T systems, the thermal efficiency depends strongly on air flow rate, air duct depth and collector length. For higher values of air flow rate, small air duct depth and long PV/T systems, thermal efficiencies up to

about 55% are given by the theoretical models. The packing factor is an important parameter in

the most of the above papers.

Because of their easier construction and operation, hybrid PV/T systems with air heat extraction are more extensively studied, mainly as an alternative and cost effective solution to building integrated PV system (BIPV). Following the above referred studies, test results from PV/T systems with improved air heat extraction are given by Ricaud and Roubeau (1994) and from roof integrated air-cooled PV modules by Yang et al (1994)

An experimental study of façade integrated photovoltaic/water heating system is done by Chow T.T. (2006). This work describes an experimental study of a centralized photovoltaic and hot water collector wall system that can serve as a water preheating system. Collectors are mounted at vertical facades. Different operating modes were performed with measurements in different seasons. Natural water circulation was found more preferable than forced circulation in this hybrid solar collector system. The thermal efficiency was found 38.9% at zero reduced temperature and the corresponding electrical conversion efficiency was 8.56% during the late summer of Hong Kong.

In China, the energy performance of PV/water-heating collector systems with natural circulation of water has been examined by the author T.T. Chow, J Ji, W. He (2005 and 2006)

based on the weather conditions of Hong Kong and Hefei. These studies showed that the use of a flat box type thermal absorber is very effective. In Hong Kong for a stand along PV/T collector system with mono-crystalline solar cells, the daily thermal efficiency was found 48.3% in winter

and 45.4% in summer at zero reduced temperature (i.e. when the initial temperature in the storage tank is as cold as the mean ambient temperature on the day of measurement). This was for water storage to collector area ratio (M/Ac) of 96.6 kg/m

2

and at a desirable tilt angle.

Design and performance improvement of hybrid PV/T systems with water or air as heat removal fluid has been carried out at the University of Patras, Greece including modifications that contribute to the decrease of PV module temperature and to improve the total energy output (electrical and thermal) of the PV/T systems (Souliotis,2008). Two systems (PVT/UNGLAZED and PVT/GLAZED) were tested outdoors, consisted of pc-Si PV modules and heat exchanger of copper sheet with copper pipes.

Also, PV/T solar water heaters of ICS (Tripanagnostopoulos et al, 1998) and of thermosiphonic (Tselepis and Tripanagnostopoulos, 2002) type have been studied. The diffuse reflection is suggested to increase both electrical and thermal output of PV/T systems (Tripanagnostopoulos et al, 2006) systems, compared with standard PV modules, give an idea about the positive environmental impact of the suggested systems.

Design concepts, prototypes and test results for water and air cooled PV/T systems with and without additional glass cover are extensively presented in Tripanagnostopoulos et al, 2002. The test results of thermosyphon type PV/T systems indicated that, compared to the unglazed systems, the glazed systems for water heating improved the thermal efficiency up to about 30%, but reduced the electrical efficiency by about 16%.

Tripanagnostopoulos et al, 2007, at the University of Patras, Greece has done an extended research on PV/T systems aiming at the study of several modifications for system performance improvement. A new type of PV/T collector with dual heat extraction operation, either with water or with air circulation is presented. Experiments with dual type PV/T models of alternative arrangement of the water and the air heat exchanging elements were performed. The most effective design was further studied, applying to it low cost modifications for the air heat extraction improvement. The modified dual PV/T collectors were combined with booster diffuse reflectors, achieving a significant increase in system thermal and electrical energy output.

2.2 Scope of present work:

In this experiment will study the performance characteristics of the Hybrid PV/T Solar system with modification in the air channel. The test will be carried out in the month of June, July and August in the IUT campus, Gazipur, Bangladesh.

Though many research works has been carried out on this topic but most of them used single heat extraction medium. So we have not adequate data to investigate the performance characteristics of this type of hybrid PV/T solar system. In 2010,a research work has been done under the supervision of Professor Dr. Md. Abdur Razzaq Akhanda, Head, Mechanical and Chemical engineering department as undergraduate project. It was by using the ribs of semicircular, rectangular and triangular shapes. So we will compare our data with that experimental data to study the variation in performances.

Chapter 3

Design ConCept

3.1 General Discussion

The PVT system can effectively operate at locations in low altitudes where favorable weather condition exists or marginally in medium latitude to avoid freezing. This system needs special arrangement for air and water circulation through the real surface of the PV panel. This is made by combining the air and water heat extraction method together. The concepts of designing such an arrangement are given below:

- Water circulation and the heat extraction can be done by flowing water through pipes in contact with the flat sheet placed in thermal contact with the PV module rear surface.
- For air circulation an air channel is usually mounted at the back of the PV modules. Air of lower temperature than that of the PV modules, usually ambient air is circulating in the channel and thus both PV cooling and thermal energy collection can be achieved.

The usual heat extraction mode is the direct air heating from PV module rear surface by natural or forced convection and the thermal efficiency depends on channel depth. The heat extraction by natural airflow depends on the temperature difference between the inserting air in the channel and the PV module. The operation of PV system with high rate of forced airflow gives satisfactory results regarding heat extraction. In natural airflow the flow rate is not usually as higher as in the forced airflow application.

The smaller channel depth with high flow rate increase heat extraction, but increase also pressure drop, which reduces the system net electrical output in case of forced air flow, because of the increased power of the fan. In applications with natural convection, the smaller channel depth decrease air flow and these results to an increase of PV module temperature. In these systems large depth of air channel of minimum 0.1 m is necessary along with natural convection.

Considering these factors, in this project Natural Convection is applied instead of forced convection to increase the system net electrical output and thereby the overall system efficiency.

The heat extraction can be increased using larger heat exchanging surface area in the air channel to promote the convection heat transfer to the circulating air. In order to increase radiation heat transfer, the PV rear surface as well as the opposite channel wall surface should be of high emissivity to transform the infrared radiation to convection heat transfer mechanisms and to heat efficiently the circulating air.

Usually PV panels are constructed with:

- Crystalline-Silicon (c-Si)
- Poly-Crystalline-Silicon (pc-Si)
- Amorphous Silicon (a-Si)

Crystalline-Silicon (c-Si) PV Panel

By far, the most prevalent bulk material for solar cells is Crystalline-Silicon (c-Si), also known as “solar grade silicon”. Bulk silicon is separated into multiple categories according to crystallinity And crystal size in the resulting ingot, ribbon or wafer.

Poly-Crystalline-Silicon (pc-Si) PV Panel

Poly-Crystalline-Silicon is also a key component of solar panel construction. It is made from cast ingots – large blocks of molten silicon carefully cooled and solidified. Poly-Crystalline-Silicon, also called polysilicon, is a material consisting of small silicon crystals.

Amorphous Silicon (a-Si) PV Panel

Amorphous Silicon (a-Si or α-Si) is the non-crystalline allotropic form of silicon. It can be deposited in thin films at low temperature on to a variety of substrates, offering some unique capabilities for a variety of electronics.

The ratio of the additional cost per PV module area is different and almost double for a a-Si compared to c-Si or pc-Si modules. So for cost effectiveness pc-Si has been selected for this project.

3.2 Experimental Setup & Modification:

Four experimental setups were fabricated with similar design and dimensions except the shape of the ribs. All works were done in the mechanical workshop of IUT. The whole setup is constructed in a wooden box. PV panels are set at the top of the box. TMS is placed at the middle part of the box on top of which pipes are set for water circulation. Air channel of 0.1 m height is kept under the water heat exchanger. Different ribbed plates (Trapezoidal, Saw tooth (forward),Saw tooth (backward) and flat) of same height and dimensions are placed on opposite wall of the air channel. The whole inner portion of the box is insulated.

For the improvement of the Hybrid PVT system some modifications have been proposed in this project:

- The first is to place a thin flat Metallic Sheet (TMS type modification) inside the air channel and along the air flow. This TMS element doubles the heat exchanging surface area in the air channel and reduces the heat transmittance to the back air channel wall of the PVT system.
- Painted black Ribs may be placed at the bottom surface of the air channel to increase the heat transmittance by radiation from the TMS back surface to air channel wall and overcome the lower heat transfer from wall to circulating air.
- We have used four types of Ribs.

  Trapezoidal Ribs.

  Forward saw tooth Ribs.

  Backward saw tooth Ribs.

  Flat Pate Ribs.

Fig 3.1. Schematic diagram of the setup with trapezoidal ribbed plate

Fig 3.2. Schematic diagram of the setup with saw tooth forward ribbed plate

Fig 3.3. Schematic diagram of the setup with saw tooth backward ribbed plate

Fig 3.4. Schematic diagram of the setup with flat ribbed plate

Fig shows the schematic diagram of the four experimental setups with different ribs. The main components of the setup are:

- PV panel
- Wooden box
- Water Heat Exchanger (WHE) & the Absorber (TMS)
- Ribbed plate at the opposite of air channel
- Water storage tank
- Insulation
- Steel frame
- Stand

3.3 Components of the Experiment Setup

The various components of the setup are discussed here in details:

Solar Photovoltaic Panel

For this project Polycrystalline-Silicon (pc-Si) PV panels are used. It has a rating of 50 watts and $0.45m^2$ aperture area. Its approximate dimensions are (839 × 537 × 50)mm

The selection of the pc-Si PV panel is based on the justification discussed in the Design Concept portion. To facilitate the experiment the suitable and available PV panel has got the above mentioned dimensions and aperture area.

Copper Tube

For circulating water copper tubes are used in the project. As copper has higher thermal conductivity. It will increase the net heat transfer rate which is a necessary requirement of the project. For the high rate of heat transfer and sufficient rate of water flow in the water heat exchanger the optimum diameter of the copper tube is taken as

1

2

◌ ″diameter.

Copper Pipe

For the header of the copper tubes a copper pipe of 1

1

2

◌ ″ diameter is used. The diameter of

the header is found by calculating the cross-section area of the copper tubes corresponding to header cross-section area to maintain a uniform flow rate through all the tubes.

GI Sheet

For the TMS and RIB GI sheet of 22 gauges is used. The GI sheets are painted black to increase the heat absorbency, which will improve the heat transfer with air and water.

The shape of the RIBs are varied in the four setups to observe the variation in the heat transfer rates and thereby the performances of the setups. The shapes of the ribs are Trapezoidal, Forward saw tooth, backward saw tooth and Flat Plate in the four setups. The shapes can be clearly distinguished from the setup diagrams in the previous pages.

Insulated Material

For insulation Glass Wool is selected. It is easily available and suitable for the project. The glass wool is applied at the inner surface of the wooden box carrying the PV panel and outside of the water storage tank to avoid any kind of heat transfer to and from the setup which may decrease the efficiency of the PVT system.

Wooden Box

The whole setup is constructed in a wooden box with a dimension suitable to the dimension of PV panel. Here Gamari wood is used for better longevity of the setup. A section in the lower part of the wooden box is cut in a rectangular shape in order to make air channel under the PV panel.

Water Storage Tank

For water storage a 30 liters water drum is used for each setup. The drums are kept in a suitable height so that the natural convection of water flow in the experimental setup can be maintained.

Stand and Frame

For keeping the PV panels and the water storage tanks in a stable position steel frame and stand is made. The height of the stand is selected in such a way that natural convection of water can be maintained from the water storage tank and the frame for the PV panel is just a little bit tilted so that natural convection of air flow can be obtained and to get the maximum solar radiation as well.

Nylon Tube

For circulation of water between the water heat exchanger and the water storage tank nylon tube is used. The dimension of the nylon tube is 1.25 inch.

Thermocouple & Selector Switch

In order to get accurate temperature reading thermocouple is used. Thermocouples are connected at different positions in the experimental setup. A selector switch is used in each setup and it is connected with the thermocouple to get the thermocouple temperature reading in a digital thermometer.

For the performance test of the Hybrid PVT system the four systems are to be tested simultaneously at outdoors under sunny weather condition.

The following image gives the practical view of the experimental setups:

Fig 3.5 The Installed setup in IUT campus

The interior constructional view is presented in the following image:

Fig 3.6. Interior view showing the TMS with water heat exchanger

Chapter 4

Method of AnAlysis

4.1 Performance Test: Related Terminologies

The following measurements are to be recorded for the study of the performance test:

For the performance test of the Hybrid PVT system the four systems are to be tested simultaneously at outdoor under sunny weather condition.

The following measurements are to be recorded for the study of the performance test:

- Input fluid temperature (T_i)
- Output fluid temperature (T_o)
- Ambient air temperature (T_a)
- Water Heat Exchanger Temperature (TWHX)
- Air temperature in the air channel (T_{Air})
- PV module temperature (T_{pv})
- Incoming solar radiation on PV module (G).
- Aperture area (A_a)
- Close Circuit Voltage (V)
- Close circuit current (I_o)

4.2 Performance Test: Comparative study

To compare the performances between the four experimental setups the data obtained form the experiment are to be plotted in graphs..

- PV Module Temperature vs Time graph.
- Air Temperature in the Air Channel vs Time graph.
- Water Outlet Temperature vs Time graph.
- Electrical efficiency Vs Time graph.
- Thermal efficiency Vs Time graph.

4.3 Equations

- Heat energy absorbed in one hour for the projected area can be calculated by-

[illegible]

= [illegible]

Δ[illegible]

Where, [illegible] = Mass of water in the tank, kg

[illegible] = Specific Heat at Constant Pressure, J/kg.k

Δ[illegible]

= Temperature Difference of water in one hour, (To

- Ti

),

o

C

 Solar radiation received in one hour for the projected area –

ဖ× ܘ=ܑ

× 3600 (ܬ)

Where, ܘ = Incoming solar radiation, W/m

2

ဖ

= Aperture area, m

2

 Thermal efficiency (ηth

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Δ ؚ

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ܣ× ܡ

ؘ

□ Electrical efficiency (η

electrical

)

η

electrical

=

ܥ× ٍ

□

ܥ

Where,‚‥ = Voltage

ܥ

□

= Current

Chapter 5

Result and discussion

5.1 PV panel temperature:

Temperature of PV panels (Tpv

) of different setup with time is shown in fig: 5.1. As the PV panel

receives the solar energy directly on top of setup, panel temperature raises very quickly with time. The figure shows similar patterned temperature rises with slight difference between the

four setups. PV panel temperature rises from 9 AM to 1.30 PM at noon and then decreases rapidly. In a moderate sunny day of September the maximum temperature of PV panel was found 51 ^{o}C for flat plate rib, 49 ^{o}C for trapezoidal rib and 48 ^{o}C for saw tooth backward and forward rib.

So for saw tooth backward and forward the cooling of PV module is high. For flat plate cooling is low. The trapezoidal rib shows the medium cooling of PV module.

5.2 Water Outlet Temperature:

Temperature of water outlet for different setups with time is shown in fig 5.2. Water flows inside the heat exchanger and absorbs heat from the water Heat exchanger and the temperature of the Water increases. A thermo couple is attached to the outlet water pipe to measure the Outlet Water Temperature. The temperature of water outlet increases with time in similar pattern from 9am to 3 pm then deceases with time. In a moderate sunny day of September 2011 the maximum water outlet temperature was found for saw tooth backward and forward 38.5 ^{o}C , for trapezoidal it was 37 ^{o}C and for flat plate it was 36 ^{o}C.

Saw tooth backward and forward rib both gives the same temperature rise of water which was maximum and the flat rib gives the minimum rise of water outlet temperature. For trapezoidal rib it was in the middle.

5.3 Air Temperature in the Air Channel

Temperature of the air channel (T_{air}) of different setups with time is shown in Fig 5.3. In the air channel convection was used for the flow of air. Air flowing inside the Air channel absorbs heat radiated from the Water Heat Exchanger and Rib. Two thermo couple was used to take the average temperature of the air channel. The figure shows the pattern of temperature rise in the air channel. From 9 am to 2pm the temperature rises and after 2pm it decreases with time.

In a moderate sunny day of September 2011 for saw tooth backward and forward the air temperature raised to maximum 36 ^{o}C, for trapezoidal 34 ^{o}C and for flat plate 33 ^{o}C.

So the air temperature raises more in saw tooth backward and forward rib and for flat rib it is low. For trapezoidal it is in between them.

5.4 Thermal Efficiency Comparison

Thermal efficiency for all setups with time is shown in fig 5.4. It was found that thermal efficiency was increased rapidly for all the setups. But with the time it decreased. For the recirculation of same water through the pipes and reservoirs the temperature difference between the inlet and outlet decreased with time.

For saw tooth backward and forward rib the thermal efficiency was found maximum 30 %, for trapezoidal rib 28% and for flat rib 23%.

So for saw tooth backward and forward shows the highest efficiency among the four ribs.

5.5 Electrical Efficiency Comparison

The electrical efficiency with time for all four setups is shown in fig 5.5. We have measured the electrical efficiency of the PV panel with load. A 20 Watt bulb was set with each setup. The voltage and current was measured with multimeter.

It was found that as the temperature of the PV panel decreases more in saw tooth backward and forward rib, the electrical efficiency increases more. For saw tooth backward and forward rib the maximum electrical efficiency was 9.2%. For trapezoidal rib it was found 8.5%. For flat rib it was found 8.4%

PV panel temperature vs time Graph:

Time. Hour

Fig 5.1. PV panel temperature vs time

0

10

20

30

40

50

60

9::00

AM

10::00

AM

11::00

AM

12::00

AM

1::00

PM

2::00

PM

3::00

PM

4::00

PM

5::00

PMTpoCFlat

Trapezoidal

Saw tooth forward

Saw tooth backward

To

O

C

Water outlet temperature Vs Time Graph:

Time, hour

Fig 5.2 Water outlet temperature vs time

T

a

O

C

Air temperature Vs Time:

Time, hour

Fig 5.3 Air temperature vs time

Thermal efficiency Vs Time:

Time,hour

Fig 5.4. Thermal efficiency vs time

0

0.05

0.1

0.15

0.2

0.25

0.3

0.35

9::00

AM

10::00

AM

11::00

AM

12::00

AM

1::00

PM

2::00

PM

3::00

PM

4::00

PM

5::00

PMηFlat

Trapezoidal

Saw tooth forward

Saw tooth backward

ηelectric %

Electrical efficiency Vs Time Graph:

Time,hour

Fig 5.5 Electrical efficiency vs time

Chapter 6

ConClusion & ReCommendations

6.1 Conclusion

The study of PV/T system using different rib in the air channel shows variation in the performance of the PV module. The shape of the rib influences the cooling of PV module which has significant effect in electrically generation. From our experimental analysis we can come to a conclusion mentioned here:

- Among the four ribs used in the air channel (flat, trapezoidal, saw tooth backward, saw tooth forward) saw tooth backward and saw tooth forward gives the same results. The efficiency was highest for saw tooth rib(backward and forward). For flat rib efficiency was low in all conditions. For trapezoidal efficiency is below the saw tooth rib but above the flat rib.
- With the increase of sunlight the temperature of the PV panel increases rapidly. Better cooling of PV panel give higher efficiency..
- The experiment was done in Autumn season with moderate sunny and partially cloudy day. The performance of the PV/T module was not at the desired level. So PV/T system is not suitable for Autumn season.
- Temperature in the Air channel increases very little. The experimental setup design was not suitable for the air heating system.

- Thermal efficiency increased rapidly at the beginning of the day and decreased after 2pm.As the same water was circulated through the heat exchanger and reservoir, the difference between inlet and outlet temperature decreased with time.
- The convection process involved in air channel is not efficient in cooling PV panel.

6.2 Recommendations

From the experimental analysis of the project PV/T solar energy system is found very significant in terms of net output. The temperature rise in water and air was not high for the limitations of experimental setup. The following recommendations are propounded for the better investigations of the system.

- The study of the system should be conducted in the summer season of the year to get the better performance.
- To get more solar energy input reflector can be integrated with the setup.
- The electrical efficiency of the PV module should be measured under different load conditions to get accurate result.
- There was a significant amount of gap between the heat exchanger and PV panel. So to facilitate better heat coadunation this gap should be minimized with little fabrication.
- For more accurate and detail results Data logger can be installed in the experimental

setup.

- The water should be removed with time from the reservoir to get the actual water temperature rise in this PV/T system.

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