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Study of Photovoltaic Thermal System

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Abstract—*The electricity and heat produced simultaneously in a photovoltaic thermal (PVT) system from solar energy is about 60-70% efficient. The traditional photovoltaic (PV) system conversion of electricity from solar energy is only about 6-15% efficient, whereas 85% of the incoming solar energy is either reflected or absorbed as heat energy, which are cooled by water or air coolant to utilize the all incoming solar energy on system. The main objectives in this study is combining two systems; Parabolic Trough as a concentrator and channel PV/T collector as a receiver. The performance study of Parabolic Trough Concentrating PVT is done and evaluated through water flow with concentrating PVT.*

1. INTRODUCTION

The most important factor consider in electrical efficiency of photovoltaic (PV) cell are related to the band gap. Photon emitted from sun with energy below the band gap energy cannot be absorbed by PV and is transmitted. Photon with energy greater than the band gap energy is absorbed and converted into electricity. But that excess energy is lost to heat in the PV. Due to this heat, some losses are occurring in PV such as ohmic losses.

Also PV cell absorb up to 80% of the solar irradiation. However, only 5–20% of the incident energy is converted into electricity. The remaining energy is converted into heat. So here we needed to use remaining 60% to 75% of incident energy to any heat cycle for high efficiency of PV cell. On sunny days PV laminates can reach temperatures as high as 35°C above ambient temperature. In PV/T system, this heat is extracted from the PV panel and made available for use in a building, e.g., for tap water heating and space heating. With an optimal design, PVT systems can supply buildings with 100% renewable electricity and heat in a more cost-effective manner than separate PV and solar thermal systems [1].

1.1 PRINCIPLE OF ELECTRICITY GENERATION BY PHOTOVOLTAIC CELLS

A photovoltaic cell comprises P-type and N-type semiconductors with different electrical properties, joined together. The joint between these two semiconductors is called the "P-N junction."Sunlight striking the photovoltaic cell is absorbed by the cell. The energy of the absorbed light generates particles with positive or negative charge (holes and electrons), which move about or shift freely in all directions within the cell. The electrons (-) tend to collect in the N-type semiconductor, and the holes (+) in the P-type semiconductor. Therefore, when an external load, such as an electric bulb or an electric motor, is connected between the front and back electrodes, electricity flows in the cell.

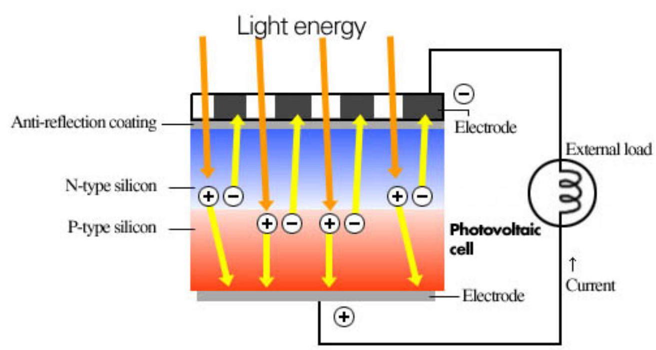

Fig. 1: Photovoltaic cell generates electricity when irradiated by sunlight.

1.2 THERMOPHOTOVOLTAICS:

Thermophotovoltaics cell uses different technology to produce electricity. Thermo- means heat, these cells converts heat into electricity; rest of it works as same as photovoltaic cells which converts light into electricity.

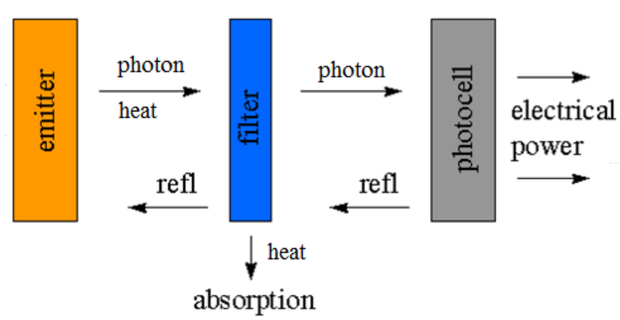

Fig. 2: Block diagram of thermophotovoltaics

The only difference between thermo-photovoltaic and photovoltaic is that thermo photovoltaic cells uses semiconductor which are designed for long wavelength, invisible light like infrared rays released by hot objects. This way of generating electricity is very neat and clean and also simpler to what we experience in power generation using generators, steam turbines etc.

1.3 PARABOLIC TROUGH COLLECTOR

A parabolic trough is a type of solar thermal energy collector. It is constructed as a long parabolic mirror (usually coated silver or polished aluminum) with a Dewar tube running its length at the focal point. Sunlight is reflected by the mirror and concentrated on the Dewar tube. The trough is usually aligned on a north-south axis, and rotated to track the sun as it moves across the sky each day.

The first practical experience with PTCs goes back to 1870, when a successful engineer, John Ericsson, a Swedish immigrant to the United States, designed and built a 3.25-m2-aperture collector which drove a small 373-W engine. Steam was produced directly inside the solar collector (today called Direct Steam Generation or DSG). From 1872 to 1875, he built seven similar systems, but with air as the working fluid

To deliver high temperature with good efficiency a high performance solar collector is required. System with light structure and low-cost technology for process heat application up 400°C could be obtained with parabolic trough collector (PTC). PTC can effectively produce heat at temperature between 50°C and 400°C.

Parabolic trough is made by bending a sheet of reflective material to parabolic shape. When the parabola is pointed towards the sun, parallel rays incident on the reflector and reflected on to the receiver. The concentrated radiation reaching the receiver tube heats the fluid that circulates through it, thus transforming the solar radiation into useful heat. It is sufficient to use a single axis tracking of the sun. The collector can be oriented in an east west direction, tracking the sun from north to south, or in a north-south direction, tracking the sun from east to west.

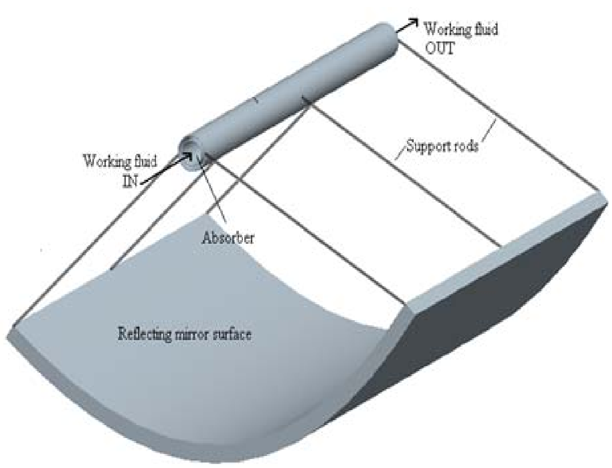

Fig. 3: Parabolic Trough Collector.

2. LITREURE SURVEY

A concentrated photovoltaic thermal (CPVT) system is a combination of photovoltaic (PV), solar thermal systems and solar concentrators which produce high grade electricity and heat from one integrated system. In other words, Those PV panels, solar thermal systems and solar concentrators operating side by side are therefore, the space required for separated system is high compare to the combined system [2]. These are alternative ways to improve the cost effective of combined system. Among many others, there can be selections among trough concentrating, Fresnel linear concentrator, parabolic concentrator, air, water or evaporative collectors, monocrystalline / polycrystalline / amorphous silicon (c-Si/pc-Si/a-Si) or thin-film solar cells, flat-plate or concentrator types, glazed or unglazed panels, natural or forced fluid flow. Accordingly, available installations are ranging from PVT air and/or water pre-heating system to hot water supply through PV integrated heat pump, and to actively-cooled PV concentrator through the use of economical reflectors.

Theoretical and experimental studies of PV/T were documented as early as in mid 1970s [3]. In the PV/T system heat removing from the PV cell by means of heat absorbing medium such as water, flowing in pipes.

The heat removed from cells by water is used as the hot water for domestic purpose. By this the overall efficiency is higher and lower packaging cost due to its compact design [4]. During some severe cold days in winter, anti-freeze liquid can be used. But it cannot be used in summer because the heat transfer rate in liquid is less, so the performance of the anti-freeze liquid is slightly less in summer.

The detailed physical model for the flat-plate PVT/water (PVT/w) collector system performance is evaluated. The fin-width to tube-diameter ratio was investigated and the total efficiency was found in the range of 60-80% [5]

3. PROBLEM IDENTIFICATION

There are two main problems associated with using the solar radiation concentrators in TCPV/T systems, as discussed below:

In TCPV/T systems, the efficiency of the system is based on the proper focusing of solar radiation over the surface of the receiver (PV cell). Whereas in the existing work PV cell are arranged in horizontal plane and solar radiation is focused on to it in inclined direction, by this arrangement the PV cell does not receives solar radiation in perpendicular direction which may causes some reflection losses.

Concentration of solar radiation on the surface of PV cell increases the cell's temperature. Cooling of the cell by natural convection is generally effective under one sun condition in most locations. However, under a concentrated radiation the conventional natural cooling methods fail to maintain the cell's temperature at a reasonable level, as a result the efficiency substantially drops. Attempts have been made to actively cool cells, for example by running water. This then will require the availability of water and the added cost of complexity of a pump.

4. A NEW DESIGN FOR CPVT

Table 1: New design of CPVT through the comparative study on literature review

Parameter	Types	Description
Glass	glass cover	The double covered design (of which the cell efficiency is unfavorable). [6]
PV cell	Si	0.4% per 0C rise for Si cells. Efficiency is 11.98 [4]
Design of PVT	Channel below-transparent-PV design	The channel-below-transparent-PV design gives the best efficiency. The thermal efficiency is 0.63 and electrical efficiency is 0.09 [7]
Working fluid	Water	Compare to air, water is good thermal absorber [8]
concentrator	Reflective mirrors	Improved the overall efficiency of PV/T, when PV cells were focused on reflective mirrors. [9]
Collector	Parabolic Trough	Parabolic trough can provide high temperature heat from 200 to 250°C for SEGS (Solar Electric Generating Systems) plants and CPS plants and many other applications [8]

5. METHEDOLOGY

The main objective of the work is to increase the TCPV/T system efficiency by, reducing the reflection loss of solar radiation and added cost of complexity of a pump.

The following methodology is used to solve the problem:

As the existing TCPV/T system does not focus the reflected solar radiation in perpendicular direction there are chances for loss in reflected radiation to reduce this reflection loss, the receiver of my proposed work is designed in V-shape, which receives the radiation in perpendicular direction, hence there will a minimum loss of reflected rays by this system efficiency can be increased.

As the receiver is covered by PV cells, cooling is more important to avoid the drop in cell efficiency due to the increase in temperature. To reduce the added cost and complexity of a pump, in here for the coolant flow in natural circulation is achieved, by varying the height of the storage tank. And also theoretical calculation is done to valid the mass flow rate and corresponding calculations are made.

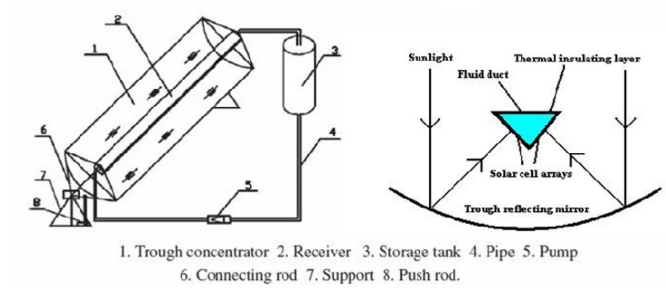

Fig. 4: Schematic diagram of the proposed TCPV/T system

6. PROPOSED INSTRUMENTATION

To investigate the performance of the TCPV/T system for its electrical and thermal efficiency, the following parameters has to be measured temperature of water, output current and voltage, solar intensity, air velocity and mass flow rate of the cooling fluid. The following are the instrumentations proposed measure the various parameters of the system.

6.1 THERMO COUPLE

K – Type thermocouple is used to measure the temperature (water, glass, basin, air vapour, and condensate) ranges between 0-100°c. It is used to sense the increase in temperature of cooling fluid at the reciver outlet.

6.2 DIGITAL MULTIMETER

It is used to measure the amount of current and voltage generated in the system, which are displayed in the digital display. Maximum up to 20V can be measured.

6.3 ANEMOMETER

It is used to measure the velocity of the wind speed. Ranges between 0-15 m/s.

6.4 SOLAR METER

It is used to measure the solar radiation in a particular place. It measures the solar radiation and shows in digital form. this measure ment is used to calculate a dryer and collector efficiency. Ranges between 0-2500 w/m^2 .

7. RESULT AND DISCUSSION

The input temperature of solar cell depends on the solar radiation availability. The graph shows the variation of temperature with respect to solar radiation for PVT and CPVT. From the graph it is clear that, the temperature of CPVT is higher than PVT because concentrator concentrates the solar heat in one place. Concentration of solar radiation onto the surface of a PV cell increases the electric energy output, which, in turn, can make the system more economical. Depending on the degree of concentration, some of the PV cells, which can be regarded as a high-technology product, are replaced by a solar radiation concentrating system which can be manufactured by low-medium technology

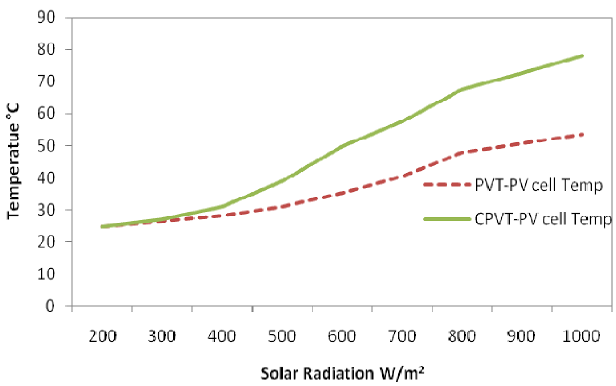

Fig. 5: PV cell Temperature for PVT and CPVT

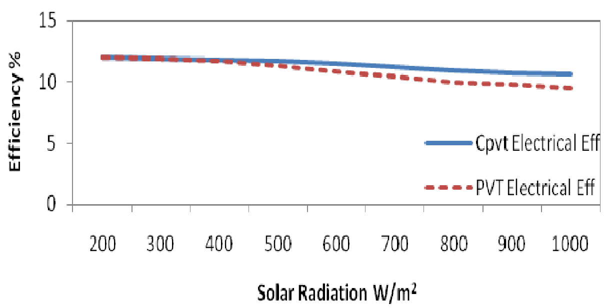

Fig. 6: Electrical efficiency of PVT and CPVT

According to the graph, the electrical efficiency is decreased when solar intensity is increased. This is because of intensity convert into heat in the PV cell instead of convert into electricity which is shown in Fig. 6. The ohmic loss occurs in the electricity generation in PV cell, this can be avoided by using coolant flow below or above the PV cell. Coolant (water or air) removes heat from the PV cell and efficiency is increased. We designed a PVT system with coolant flow of water below the PV cell which is transparent to PV cell

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