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Improving Electrical Power Efficiency of Solar PV System under Different Modes of Circulation by Circulating Fluid

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ABSTRACT

This paper gives the improvement in efficiency of solar photovoltaic module. The major factor which is given more concentration is temperature of solar cell, which is inversely proportional to the electrical efficiency of the PV module. Improved efficiency is achieved by circulating fluids through heat extracting pipes by heat exchanging method. To reduce the panel temperature, the solar PV is combined with thermal exchange unit. The fluid is allowed to circulate through the thermal exchange unit and the heat is exchanged with the tubes through conduction and convection process under different modes of circulation. By this we achieve the reduction in panel temperature which in turn increases the solar PV efficiency. Experimental result shows increase in electrical efficiency by comparing at circulating and non-circulating modes of fluid and also the efficient use of heat extracted from the PV module for general application and in low power generation when viewed at large scale.

Keywords: PV module; Extracting pipe; Circulating modes;

1. INTRODUCTION

According to the energy needs to the society there are requirements of alternative energy to generate power to fulfill the demands in power industry. In turn it gives to the importance of non renewable energy resources like wind, solar etc. solar energy will be one of most important supplies of energy specially when other sources like coal, diesel etc have depleted. Solar energy has the greatest potential of all the sources of renewable energy sources [1]. The solar energy which is received in the form of radiation can be converted into other forms of energy such as heat and electricity. Solar energy is to be utilized in various commercial and industrial sectors in the form of thermal energy and electrical energy or combined form and so the solar energy is to be harnessed using solar collectors for thermal energy and solar cell to obtained electrical energy. The solar thermal energy is used to heat water or other fluids, and can also power solar cooling systems. The combined thermal and electrical power generation can be obtained by collecting solar thermal and irradiance on solar photovoltaic (PV) systems, which generate electricity and thermal energy. Figure 1.1 and figure 1.2 shows a typical water PV/T and air PV/T for solar thermal efficiency improvement [1].

Chapter 1 deals with the introduction of solar power and collectors[2], chapter 2 explains about the solar cell operation ,equivalent circuit test system its characteristics and explains about PV cell temperature with its characteristics .,chapter 3 deals about the heat exchanging unit ,chapter 4 gives about the circulating system and chapter 5 gives the test system observation and calculation and analysis of efficiency of PV under different modes of circulation with and without circulating fluid. Chapter 6 gives the conclusion.

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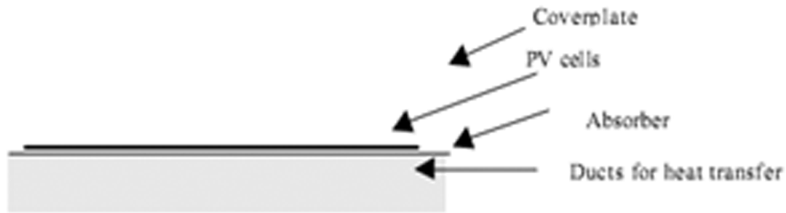

Figure 1.1 A typical water PV/T collector

Figure 1.2 A typical air PV/T collector

2. PHOTOVOLTAIC SYSTEM

2.1. Solar panel

The generation of an electromotive force as a result of absorption of ionizing radiation called the photovoltaic effect. The devices which convert solar radiation into electrical power are solar cell as in figure2.1.the solar cells are made of semiconductors. When the photons are received ,free electrical charges are generated which are collected at contacts. Each of the individual solar cells will produce power with the current directly and the combination of solar cells designed to increase the power output is termed as solar module or array as shown in figure 2.2.

Figure 2.3 shows the test system which the current voltage characteristics can be measured at various irradiance conditions to obtain the maximum power can be extracted from the panel. The equivalent circuit of a solar pv system in single diode model is shown in figure 2.3.The open circuit voltage and short circuit current is calculated and plotted as IV characteristics which is shown in figure 2.5.

There are different variables influencing the accessibility of sun powered radiation, for example, the Performance of a PV framework relies on upon the measure of daylight striking it, which implies that atmosphere conditions significantly affect the measure of solar radiation. Most present day PV modules are 14% to 16%

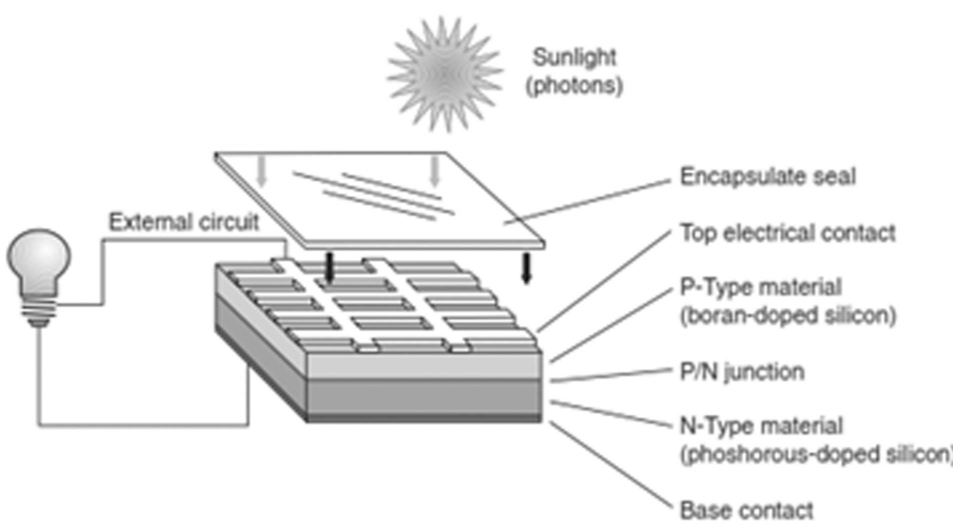

Figure 2.1 solar PV cell structure

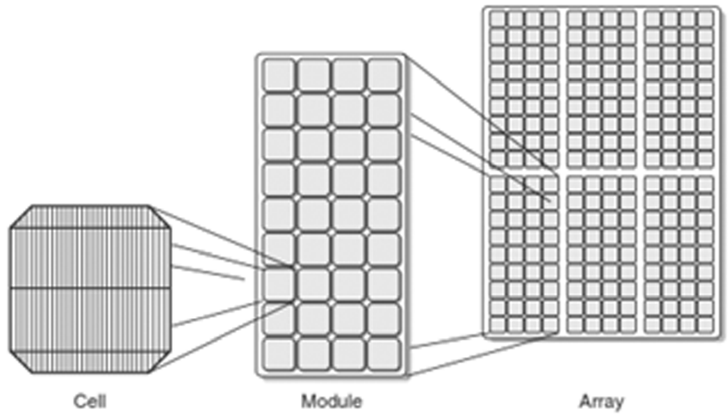

Figure 3.1 solar PV cell, module and array

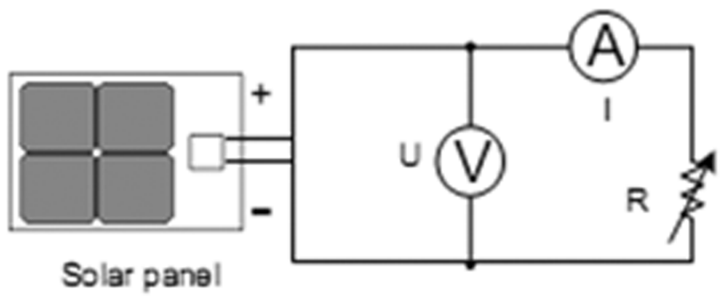

Figure 2.3 Output characteristics test system of solar panels.

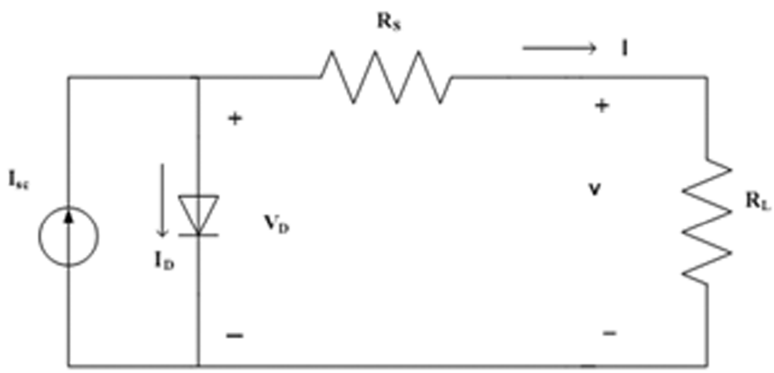

Figure 2.4 PV cell - equivalent electric circuit

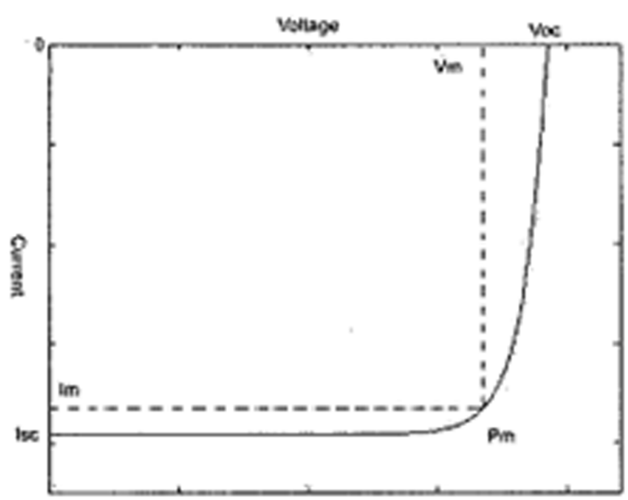

Figure 2.4 characteristic curve of the solar cell

proficient in changing over sunlight to power. Each surface on our planet gets daylight, however the particular sum fluctuates by geographic area in connection to the equator, time of day, period of the year, the rooftop's position in the neighborhood scene, and climate. The angle of the sun in the east-west direction, or the azimuth, is the largest factor in determining the total amount of sunlight exposure a PV system will receive. The maximum power obtained by solar energy ie solar intensity is during day time approximately 10 a.m. and 4 p.m. Another important factor is the shading in the PV system which reduces the power production. So shading analysis should be done and to analyze the effect of temperature due to the shading [3]. Solar azimuth and roof shading analysis software tools, such as Solar Pathfinder™ and Solometric Suneye™, have been developed to quantify the PV potential for specific locations. These tools analyze solar radiation data and calculate the effect to increase the installed capacity of solar roofing systems. It is also important to consider, potential sources of shading, such as tree growth or new structures that may arise in the future. The software gives report on calculated values of temperature shading effect [4], maximum power, open circuit voltage, short circuit current etc.

2.2. PV Cell Test conditions and temperature

By comparing with fixed conditions the solar panels are rated before using for its applications. The maximum efficiency is obtained only at the Standard Test Conditions (STC).The conditions are temperature of the cell, solar irradiance, and mass of the air.

The magnitude of the reduction in temperature is inversely proportional to V_{OC}; when the temperature is increased there is small reduction in voltage when the cells have higher values of V_{OC} [4]. The cell

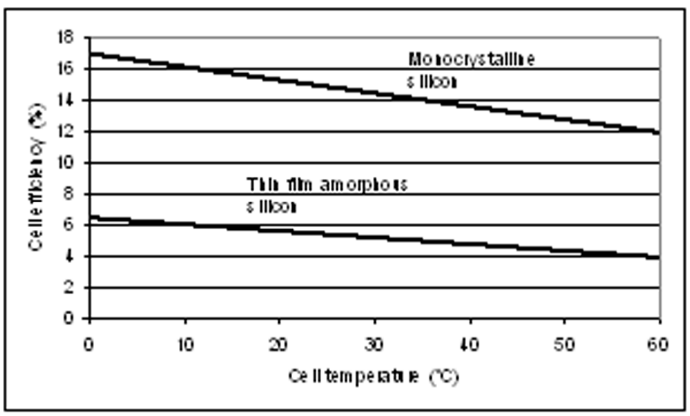

Figure 2.5 Graph For Cell Efficiency (%) Vs Cell Temperature

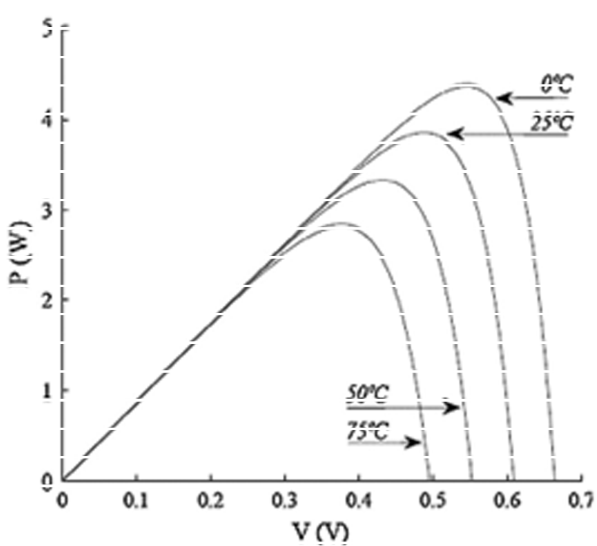

Figure 2.6 P–V characteristics as a function of the module temperature Tm, adopted from [2].

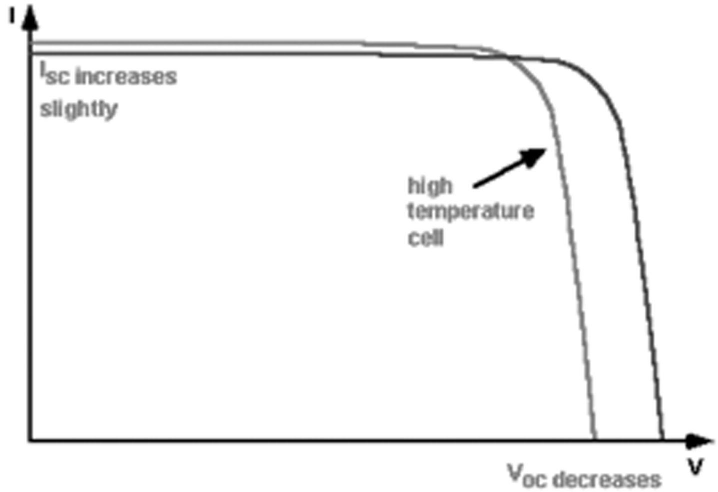

Figure 2.7 The effect of temperature on the IV characteristics of a solar cell.

temperature gives effect on efficiency in which the material used for solar cell if it is mono crystalline silicon the efficiency decreases with increase in temperature i.e. the efficiency is around 16-18 % for lower temperature and in thin film amorphous material the efficiency will be around 7-8% which is illustrated in figure 2.5 and figure 2.6.

In a solar cell, the parameter most affected by an increase in temperature is the open-circuit voltage [5]. The impact of increasing temperature is shown in the figure 2.7.

The figure above shows I-V curves that might typically be seen for a crystalline silicon solar cell at various temperatures.

3. HEAT EXCHANGING UNIT

Based on the temperature of the panel, the heat ids exchanged from panel to the pipes based on the heat transfer process[5] .the process is chosen to reduce the temperature of the panel there by increasing the efficiency of the PV cell.

3.1 Pipe Adhered

The heat pipe array is adhered on the rear sides of the solar panel as shown in the figure 3.1.some of the important parameters for heat exchanging unit are discussed below:

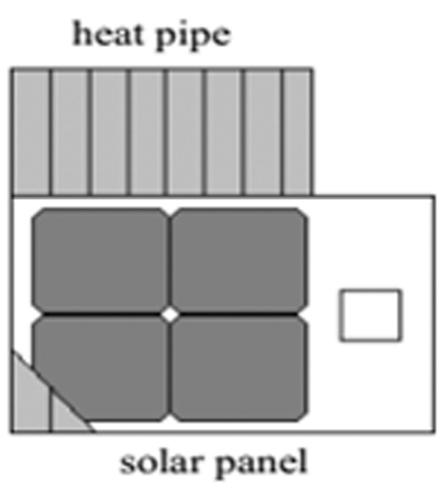

Figure 3.1 Diagrammatic Representation of Heat

3.2. Heat transfer

Initially the temperature of the panel and the tubes are at the atmospheric temperature[4]. When the panel is exposed to the sunlight, electrical conduction takes place along with the emission of heat. Due to the continuous exposure of the panel to sunlight, temperature of the panel increases drastically. The efficiency of the solar panel decreases when the temperature of panel increases. This high operating temperature is a flaw for hot developing countries like India. By this setup we discuss about the solution for increasing the efficiency and also utilizing the temperature. The photoelectric conversion efficiency of a solar cell is about 6-15% in commercial application. The temperature increase of 1°C corresponds to the reduction of the photoelectric conversion efficiency by0.14%-0.2%. The overall life of the panel will b reduced when there is increasing in temperature Therefore solar cell cooling is of essential importance.

3.3. Properties of Heat Transfer material:

The selection of appropriate materials is to conduct, transfer heat fast and efficient [7]. Selection of heat transfer material is based on following properties such as Creep crack strength, specific heat, alloyable, thermal conductivity etc. One important property to be considered is high thermal conductivity. We choose copper as the heat transfer material. Here we use copper since it has high thermal conductivity, Good Corrosion resistance because it corrodes at pH<7.0 and economical.

3.4. Economic aspects of tube making

Cylindrical tube is more economical and is always available. The bending of the tube is also easier. On considering the economical aspect, cylindrical tube is chosen but in economical aspect cylindrical copper tubes are easily available and it is flexible too. Thus the chosen cylindrical copper tubes as a heat transfer material to reduce the temperature of the panel [7].

3.5. Arrangement of Heat pipe

The dimension of the copper tube that we have chosen was given below: Length: 10 meters Diameter: 0.5mm volume of hollow tube: 1.962ml Tube's curvature angle: 15° shown in Figure 4.1

Length of the tube is decided by the dimension of the panel. The tubes with smaller diameter is chosen due to the following reason,

- More number of copper tube rows can be arranged with minimum curvature angle accompanied. The rate of heat transfer is more even and efficient as the hollow area is smaller and volume of water flow is lesser.
- The time of heat transfer rate is also appreciable. Tube's curvature angle (15^o) is the minimum curvature angle for the given diameter of copper tube.
- The tube is placed over the rear side of the panel. The tubes can be run over the panel either in horizontal or in vertical manner.
- When the tubes were placed horizontally, the tube will pass at the rear side of each of the solar cell in the panel.
- In case of vertical arrangement some portion of array of tube runs beside the surface of panel. Bent tubes are fixed in and Inlet hole, outlet hole and power output holes are drilled on the panel frame.
- In order to take the heat away from panel, water is circulated inside the copper tube.
- Water tends to move up by capillary action and it comes down by the gravitational force.
- The temperature of the water in outlet is higher than the inlet water temperature. Thus due to

material copper and liquid water transfers some amount of heat from panel. As the temperature reduces the electrical power efficiency is increased.

4. CIRCULATION SYSTEM

4.1. Tube arrangements

For a single solar cell the arrangement of tubes for observing the efficiency improvementArea of standardized single solar cell is 16 cm (length × 6.5 cm (breadth) = 104 cm2 On vertical arrangement of tube along the breadth area of contact surface area is Breadth × contact size of tube (length) × No.of times the tubes running over the cell 6.5 cm × 0.1cm × 6 = 3.9 cm2 On horizontal arrangement of tube along the length area of contact surface area is Length × contact size of tube (length) × No.of times the tubes running over the cell 16 cm × 0.1cm × 3 = 4.8 cm2 Therefore horizontal arrangement of tubes is preferred for more contact surface area [6, 7].

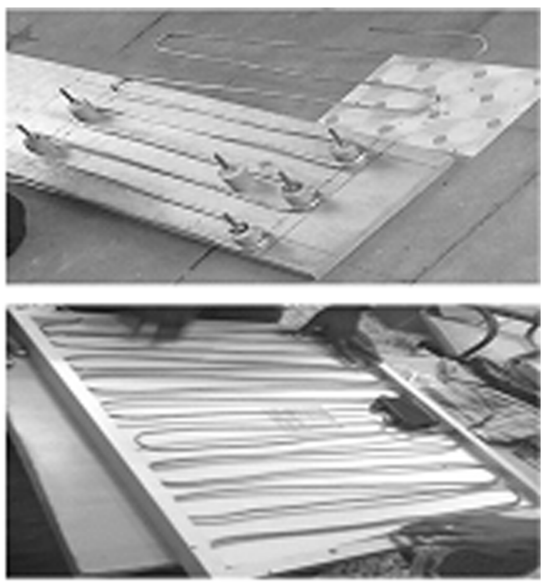

Figure 4.1 Tube Arrangements

Figure 4.2 completed test model of PV system with cooling tubes

Here a single tube is completely bent into zig- zag structure for required length of 10 meters for a panel of dimensions 65 × 55 cm as in Figure 4.1 and the aluminum frames are fixed to maintain the tube intact with the panel as shown in Figure 4.2. Since only one tube is used there won't be any discontinuity problem and the water, which is taken in, stay for a long time so that heat extraction will be good. So by this method we get considerable increase in electrical efficiency and also rise in water temperature.

Normal temperature water is made to flow through the heat exchange pipes continuously.

4.2. Cirulation methods

We have undergone three types of water circulation were the efficiency varies in every method. They are Continuous flow of water, timely stopped flow, and closed loop flow.

Continuous flow of water: Normal temperature water is made to flow through the heat exchange pipes continuously for a time of 1 hour.

Table 4.1
Readings under Continuous Flow of Water

Parameter	*Initial condition*	*Final condition*
Panel temperature	46 deg (avg)	40.1 deg(avg)
PV voltage	13.2 V	15.6V
Water temperature	30 deg	34.4 deg

Timely stopped flow: Water is made to flow with a stagnated period of 2 minutes at an interval of every 40 seconds.

Table 4.2
Readings under Timely Stopped Flow

Parameter	*Initial condition*	*Final condition*
Panel temperature	46 deg (avg)	42.1 deg (avg)
PV voltage	13.2 V	14.4V
Water temperature	30 deg	40.2 deg

Closed loop flow: The water is made to flow through the tubes in a circular manner. The hot water is stored at the top of the tank and cold water at the bottom enters in. The water in the tank is drained out at every half an hour. (Depending on the tank capacity)

Table 4.3
Readings under Closed Loop Flow

Parameter	*Initial condition*	*Final condition*
Panel temperature	46 deg (avg)	40.6 deg (avg)
PV voltage	13.2 V	15V
Water temperature deg	30 deg	38.2

5. EFFICIENCY CALCULATION AND RESULTS

Equipment of experiment is fixed as per the setup and exposed to sun light. First the experiment is conducted without circulating the water and all the parametric valves are noted. These values are taken for the time duration of one hour at 11 am to 12 am (before noon) and 4 pm to 5 pm (after noon). On the next day during same interval of time fortunately same value of irradiance is obtained so the experiment is now conducted with the circulation of water. Water is made to circulate through the heat pipes for one hour. Approximately 10 liters of water is flowed through the pipes. For both the cases the values are noted are tabulated. With the tabulations, calculations are made and increase in electrical efficiency [8], power efficiency and water temperature are calculated. Table 5.1 and Table 5.2 gives the tabulation for observation for efficiency without circulation and with circulation of water.

Table 5.1
observation for Efficiency without circulation of water

Irradiance 2 (W/m)	*PV (temp) (○ c)*	*Panel*			*battery*		*load*		*Electrical Efficiency %*
		V (v)	*I (A)*	*P (W)*	*V (v)*	*I (A)*	*V (v)*	*I (A)*	
985	41	19	1.9	36.1	13	1.28	12.2	0.72	10.22
420	39.3	13.9	1.01	14.03	13.2	1.86	11.6	0.53	9.32

Table 5.2
observation for Efficiency with circulation of water

Irradiance2 (W/m)	*PV (temp) (○ c)*	*Panel*			*Battery*		*Load*		*Hot water*	*Rise in water*	*Electrical Efficiency*
		V (v)	*I (A)*	*P (W)*	*V (v)*	*I (A)*	*V (v)*	*I (A)*	*(temp) (○ c)*	*(temp) (○ c)*	*%*
982	37.6	20.9	2.2	45.98	13.2	1.86	12.5	0.73	36	2.8	13.06
420	36.1	17.1	0.98	16.75	13.2	1.86	11.4	0.63	35.4	2.2	11.10

The graphs gives the details of the power, efficiency and voltage with irradiance for the improvement of efficiency when the fluid water is circulated at continuous mode. Graph 5.1 shows that the PV voltage Vs irradiance is increased during the circulation of fluid.

From the Figure 5.2 the PV power is increased due to irradiance and is still more increased when the fluid is circulated through tubes.

5.1. Increase in Electrical Efficiency

According to the tabulation taken increase in electrical efficiency can be calculated by the relation Increase in efficiency = Electrical efficiency in with water circulation mode – Electrical efficiency in without water circulation mode

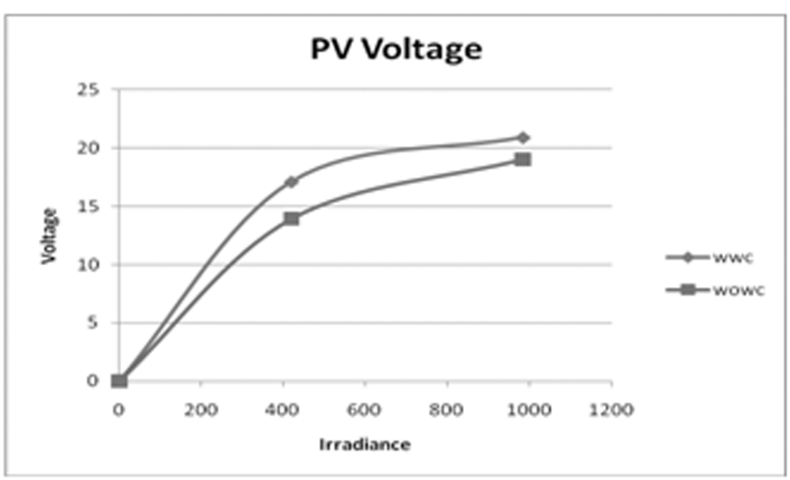

Figure 5.1: PV voltage - irradiance

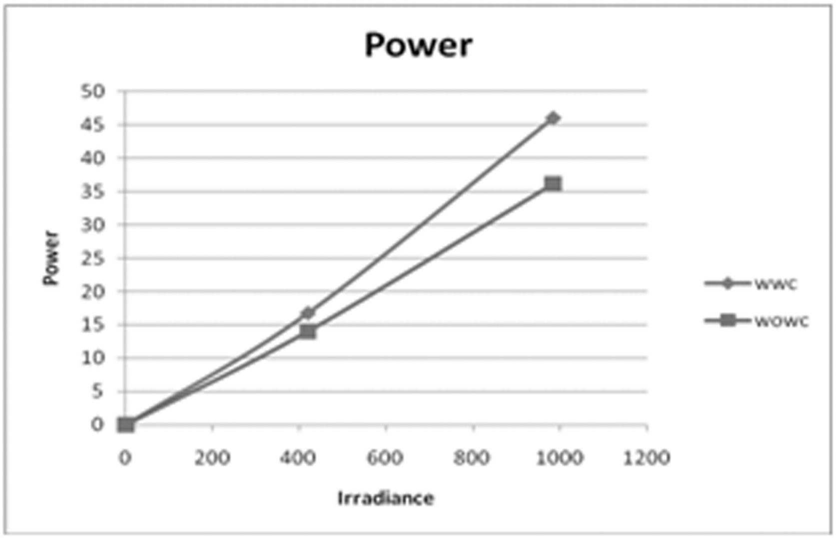

Figure 5.2: PV power- irradiance

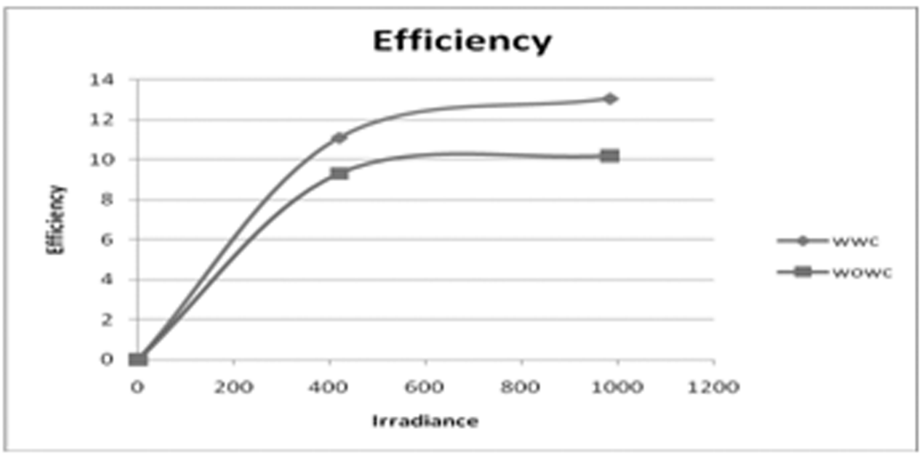

Figure 5.2: PV efficiency- irradiance

From the figure 5.3 the efficiency gets increased when the fluid water is circulated compared with the water is not circulated through copper tubes[10]. At normal irradiance of 985 W/m2 increase in electrical efficiency is about 2.84%. At low irradiance of 420 W/m2 increase in electrical efficiency is about 1.78%. Increase in power output of the panel is calculated as follows.

Increase in power output = Power output in with water circulation mode–Power output in without water circulation mode.

At normal irradiance of 985 W/m2 increase in power output is about 9.88W. At low irradiance of 420 W/m2 increase in power output is about 2.72W.

6. CONCLUSION

This paper is totally concentrated on one major factor, temperature of solar cell, which is inversely proportional to the energy efficiency of the PV module. Improved efficiency is achieved by circulating fluids through heat extracting pipes by heat exchanging method. To reduce the panel temperature, the solar PV is combined with thermal exchange unit. In practical setup the fluid is allowed to circulate through the thermal exchange unit and the heat is exchanged with the tubes through conduction and convection process under different modes of circulation. By this we achieve the reduction in panel temperature which in turn increases the solar PV efficiency. Experimental result shows increase in electrical efficiency by comparing at circulating and non-circulating modes.

Even though timely stopped circulation is more efficient both in electrical efficiency thermal efficiency it is economically costly. It needs the use of micro controller and relay for calculating the start and stop time of flow of water. In the case of timely stopped circulation a bidirectional valve one is used for the closed loop and another for thermal tank. A microcontroller and a relay is needed for operating the valve which accordingly rises the economic valve than the improvement in the electrical efficiency. So finally continuous flow circulation method is selected as it is economically best and good with electrical and thermal efficiency.

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