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PERFORMANCE OF A SOLAR PANEL WITH WATER IMMERSION COOLING TECHNIQUE

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Abstract: With the increase in surface temperature of solar cells or panels their efficiency decreases quite dramatically. To overcome the heating of solar cell surface, water immersion cooling technique can be used i.e. it can be submerged in water so as to maintain its surface temperature and provide better efficiency at extreme temperatures. In this study, electrical parameters of solar cell were calculated which showed that the cooling factor plays an important role in the electrical efficiency enhancement. Solar cell immersed in water was monitored under real climatic conditions, cell surface temperature can be controlled from 31-39 ˙C. Electrical performance of cell increases up to great extent. Results are dicussed; panel efficiency has increased about 17.8% at water depth 1cm. The study can give support to the Concentrated Photovolatics System by submerging the solar cells in different mediums.
Keywords: Water immersion cooling, Electrical efficiency, solar panel, Concentrated Photovolatics.

1. Introduction

One of the most important form of renewable energy is the solar photovoltaic energy. It has undergone a huge research and development in the recent past and is still developing. A solar cell is a device that directly converts the energy in sunlight to electrical energy through the process of photovoltaics. The first solar cell was built around 1883 by Charles Fritts, who used junctions formed by coating selenium (a semiconductor) with an extremely thin layer of gold. In 2009, a thin film cell sandwiched between two layers of glass was made. Countries that have high solar irradiation reception, this source proves a highly efficient, economic and environment friendly form of energy source. There are various factors that affect the efficiency of a solar cell. Cell temperature and energy conversion efficiency are some of them. The reason for the low efficiency of solar cells is their low energy conversion efficiency. A solar cell converts a part of incident solar light into electrical energy the rest being wasted as heat. The infrared light portion of the solar spectrum attributes to this heat loss thus increasing the cell temperature. Also the photon having higher energy than the band

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gap will only contribute to the output electrical energy. Cell temperature also has a remarkable effect on its efficiency. Besides the patents and papers reviewed in [1], recently more and more patents in this area have been filed. As the operating temperature increases the electrical cell efficiency decreases. Earlier the solar cells had an efficiency of less than 1%. Many researches have been made and are still going on to enhance the efficiency of a solar cell keeping the cost constraint in mind. From improving the cell material to finding out the optimum operating conditions, the researchers have left no stone unturned in developing technologies to enhance the solar cell efficiency. The maximum efficiency of research photovoltaics is over 40%. Polymer solar cells, Dye sensitized solar cells are some of the developments from the material aspect. Cooling also provides a good solution for the low efficiency problem. Many efforts have been made to find an efficient cooling technology by analyzing the performance of solar cells using different technologies and various cooling liquids. One such technique is immersion cooling using water as the coolant. Using water as the immersion liquid in [2], panels are configured with liquid super-concentrators having outwardly disposed liquid imaging lenses. It has been found that the efficiency and output power of PV module is inversely proportional to its temperature [3].There are two main effects increase the efficiency of a commercial panel placed in water [4]:

- reduction of light reflection (due to lower refraction index)
- absence of thermal drift .

Both water and air are suitable to be used as the cooling fluid to cool the PV module in order to avoid the drop of electrical efficiency [5]. A typical value for PV efficiency loss with temperature is 0.5% /ºC though this varies with the type of cell. Solar cell were directly submerged in silicon oil also showed increase the efficiency [6] .Solar cells under high illuminations will have increases in temperature with the attendant cell efficiency drops [7] .Direct liquid-immersion cooling of CPV cells shows significant advantages compared with passive cooling and conventional active cooling [8]. Chinamhora et al (2013) [9] used a water cooling system on the front and back of the PV module and the found that the cooling system could improve the efficiency of PV module during clear days, while it had disadvantages during cloudy days. But submerging of cell has been significant way to decrease surface temperature[10].The work in this paper aims at analyzing the performance of a solar panel submerged in water at different depths for cooling and comparing the results to attain an optimum depth for maximum increased efficiency.

2. Experiment Methodology:

The experiments were carried out under the meteorological conditions of Bhopal (latitude of 23.16ºN; longitude of 77.24ºE) in India during 18/04/2014 - 23/04/2014 from 10.00 a.m. in the morning to 5.00 p.m. in the evening.

2.1 Solar PV water immersed construction

The solar PV system is constructed using 2 W polycrystalline silicon solar panel. The area of the panel is 0.033 sq. m. which is placed inside a plastic box of depth of 10.8 cm in which water is used as a an immersed fluid water. Water act as a source of heat dissipation which maintains the surface temperature of solar cell. Table (1) shows the technical specifications of the panel and fluid used for cooling.

Table (1): Technical specification of the system

1	Solar PV module type	Polycrystalline
2	Maximum power	2 W
3	Voltage at max. power (V_m)	8.20 V
4	Current at max. power (I_m)	10.50 A
5	Short circuit current (I_{sc})	0.26 A
6	Open Circuit Voltage (V_{oc})	10.50 V
7	Module area	0.033 sq. m.
8	Fluid	Water.

Fig 1 (a): Top view of the experimental setup

Fig 1(b): Panel immersed in water

Fig 1 (b) shows the immersion of polycrystalline solar cell of the area.033m^2 in water. Solar panel is fitted in plastic box and placed at the bottom of it.

2.2 Measurement:

Total Instantaneous Global Solar irradiance was measured by using portable Solar Power meter (Tenmars TN-207, Taiwan). The ambient temperature was measured with digital thermo hygrometer. The electrical parameters and characteristics of solar panel were measured by using Solar Module Analyzer (MECO 9009). The surface temperature of the panel was measured by using IR Thermometer. Water temperature was measured using a mercury thermometer. The rating of the instruments used for measurement is tabulated in the following Table (2).

Table (2): Instruments Rating

S. No.	Instrument	Accuracy	Range	Model make
1	Solar Module Analyser	+/- 1%	0-10 V 0.01-10A	MECO 9009
2	Solar Power Meter	+/- 5%	0-1999 W/m^2	Tenmars TM-207
3	Humidity/Temperature meter	0.1% R.H. +/- 0.8 ^{0}C	R.H. – 0 – 80% & 0-50 ^{0}C	Lutron HT-3006A
4	IR Thermometer	+/- 2 ^{o}C	-18 to 400 ^{o}C	Raytec MT4
5	Mercury Thermometer	+/- 1 ^{0}C	-10 ^{0}C to 110 ^{o}C	Elite

Fig. 2: Instruments used in the experiment

2.3 Experimental Procedure:

The experiments were carried out under the meteorological conditions of Bhopal (latitude of 23.16ºN; longitude of 77.24ºE) in India during 18/04/2014 – 23/04/2014 from 10.00 a.m. in the morning to 5.00 p.m. in the evening.After the installation of experimental setup, the measurements of solar irradiance, surface temperature, water temperature, short circuit current (I_{sc}), open circuit voltage (V_{oc}), maximum voltage (V_m), maximum current (I_m) corresponding to maximum power (P_m), fill factor, electrical efficiency of solar panel were carried out for the whole day without immersing it in water i.e. d = 0cm. After measurement of the mentioned parameters of SCs without the water(liquid coolant), the vessel was filled up with water and measurements were carried out again under different depths of water taking each depth constant in a day and measuring the parameters hourly.

Considering the properties of the solar cells and the cooling requirement, the liquid selected should meet the below requirements.

(1) The liquid should have good heat transfer performance.

(2) The absorption of the sunlight by the liquids should match with the spectral response of the solar cells.

(3) The liquid should be nontoxic and have good chemical stability.

(4) The liquid should be economic.

Efficiency of a solar cell is calculated by applying the following relation:

$\eta = (V_m \cdot I_m / I \cdot S) \cdot 100\%$ ......(1)

Where: V_m – maximum voltage [V], I_m – maximum current [A],

I – intensity of radiation [W/m^2], S – area of the cell [m^2].

Fill factor of solar cells can be calculated by using the following relation:

$FF = V_m \cdot I_m / V_{oc} \cdot I_{sc}$ …….(2)

Where: V_{oc}– open circuit voltage [V], I_{sc} – short circuit current [A].

Therefore, the maximum power output, P_m in Watts can be calculated as:

$P_m = V_m \cdot I_m = V_{oc} \cdot I_{sc} \cdot FF$ …….(3)

3. Results:

3.1 Variation of Climatic parameters

The surface temperature of the solar panel decreases with the increase in water submerging depth of the panel with a slight increase in between. Fig. 3 represents this variation. The surface temperature at maximum efficiency depth is 34.8°C. The fluid (water) temperature drops with the rise in submerging depth and its variation is also indicated in the same figure. The ambient temperature varies slightly during the day without much variation from 33.5^{0}C to 38.4^{0}C. The solar intensity (I) varies from 1170 W/m^2 to 670 W/m^2 during the day.

3.2 Variation of output voltage (Vo)

The variation of output voltage with time for various depths is shown in Fig. 4. It is observed that the output voltage decreases as the day passes and depends on the intensity of solar radiation. From the figure it is analyzed that the variation of output voltage of the solar panel is almost independent of the change in depth as the curves almost overlap each other except at d = 0cm i.e. without water where a different pattern is observed. The output voltage varies differently without water and is less as compared to when panel is immersed in water. The maximum output voltage i.e. 9.068 volts is observed at d = 6cm at 10:00 am.

3.3 Variation of output power (Po)

The variation of output power of the solar panel with time for different depths is shown in Fig. 5. The output power of the solar panel also decreases with time but at a certain value of time it increases after which it resumes its previous pattern with immersion. There is a slight variation in the output power with the change in depth. It starts increasing with depth and is maximum at a particular depth and then starts decreasing slightly. But without immersion in water the output power decreases with time and drops with a notable percentage of 61.05%. The percentage decrease with immersion at depth d = 1cm is 51%. Hence with time, a 10%

increase in output power of the solar panel with immersion in water is observed at depth d = 1cm.

3.4 Variation of electrical efficiency (η)

Variation of panel efficiency with time at different depths in water is indicated in Fig. 6. From the figure it is seen that the electrical efficiency of the solar panel also decreases with time, increases at a particular value and then decreases. Also it depends effectively on the immersion depth of the panel in water. It increases with depth, attains a maximum value and then starts decreasing. Aremarkable maximum percentage increase in electrical efficiency with immersion of the panel in water is obtained as 17.8% at depth d = 1cm. After this with the increase in depth it decreases.

3.5 Comparison of voltage, power and electrical efficiency of the panel with and without water

The output voltage, power output and electrical efficiency(η) of the solar panel increases with immersion in water. Without water the average output voltage, power output and electrical efficiency of the whole day were obtained as 8.011 volts, 1.346 watts and 4.04% respectively. Whereas the maximum increase in output voltage with immersion in water is observed at depth d = 4cm with the average value of the day as 8.811 voltsand power output and electrical efficiencywere observed at depth d = 1cm and the average values of the whole day were 1.418 watts and 4.76% respectively. Therefore an increase of 9.98% in output voltage, 5.34% in power output and 17.8% in electrical efficiency is achieved and the purpose of the work is fulfilled.

Table (3)

Depth (cm)	Average Surface Temperature (^{0}C)	Average Water Temperature (^{0}C)	Average Output Voltage (Volts)	Average Current (Amps)	Average Power Output (Watts)	Fill Factor	Average Electrical Efficiency (%)
0	59.4	-	8.011	0.260	1.346	0.646	4.04
1	34.8	31.5	8.75	0.234	1.418	0.692	4.76
2	32.4	31.2	8.79	0.217	1.321	0.692	4.44
3	33	31.2	8.8	0.210	1.282	0.694	4.311
4	31.2	30.9	8.811	0.205	1.252	0.693	4.211
5	31.8	30.3	8.8	0.203	1.237	0.692	4.16
6	30.8	30.1	8.78	0.198	1.2	0.690	4.03

Table (3) illustrates a comparison of the values of average values of output voltage (V_{oc}), current (I), power output (P_o), surface temperature (T_s),water temperature (T_w), fill factor (FF) and electrical efficiency (η)of the whole day of the solar panel submerged under different water depths (d).

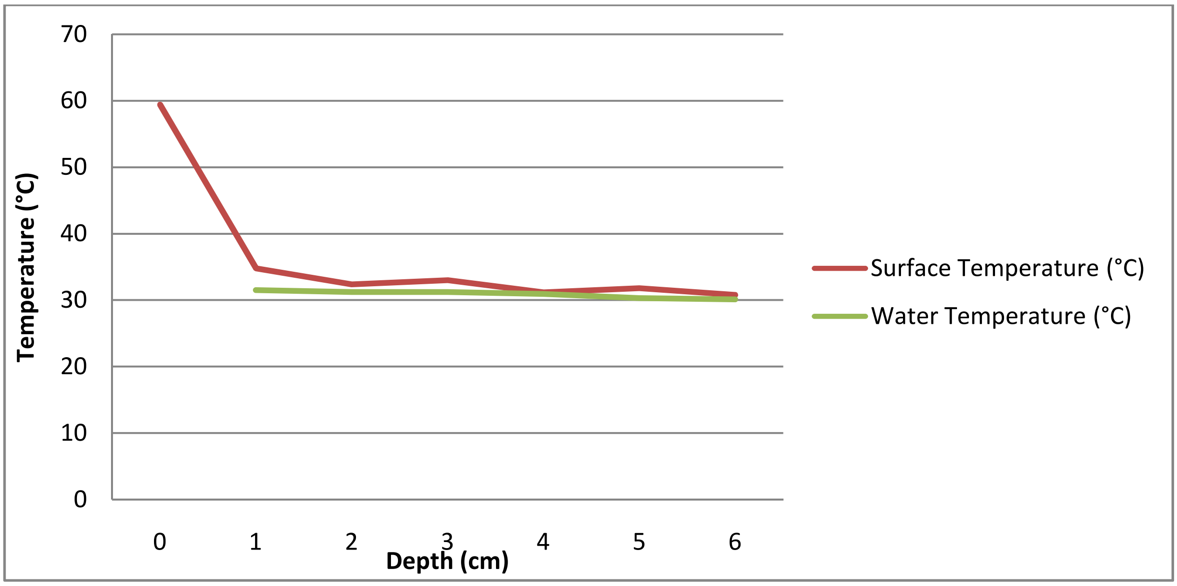

Fig. 3: Variation of surface temperature and water temperature of the panel with submersion depths of water.

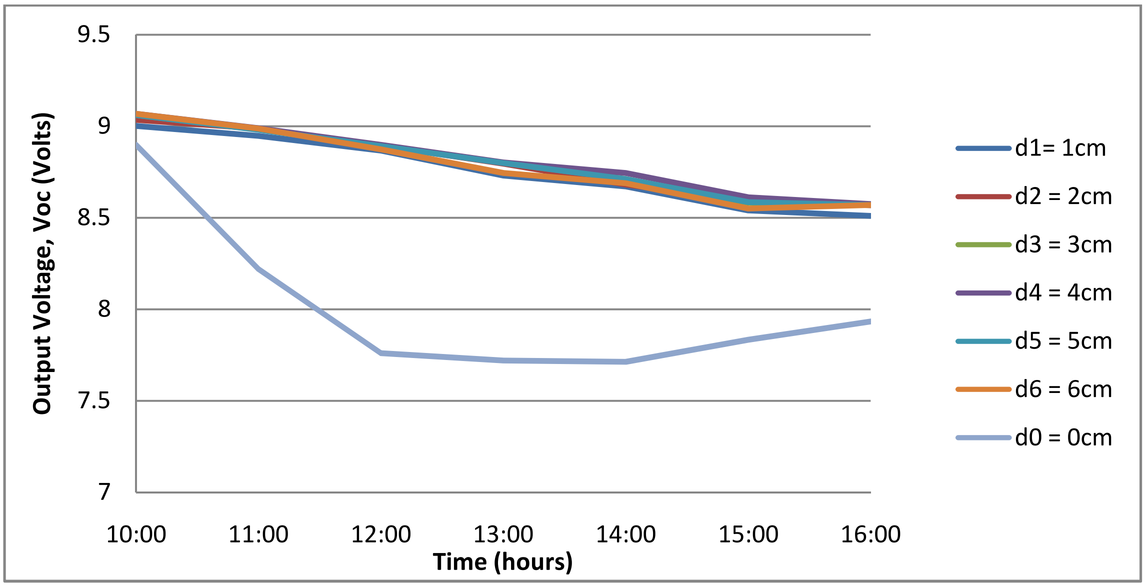

Fig. 4: Variation of output voltage of the solar panel with time at different submersion depths of water.

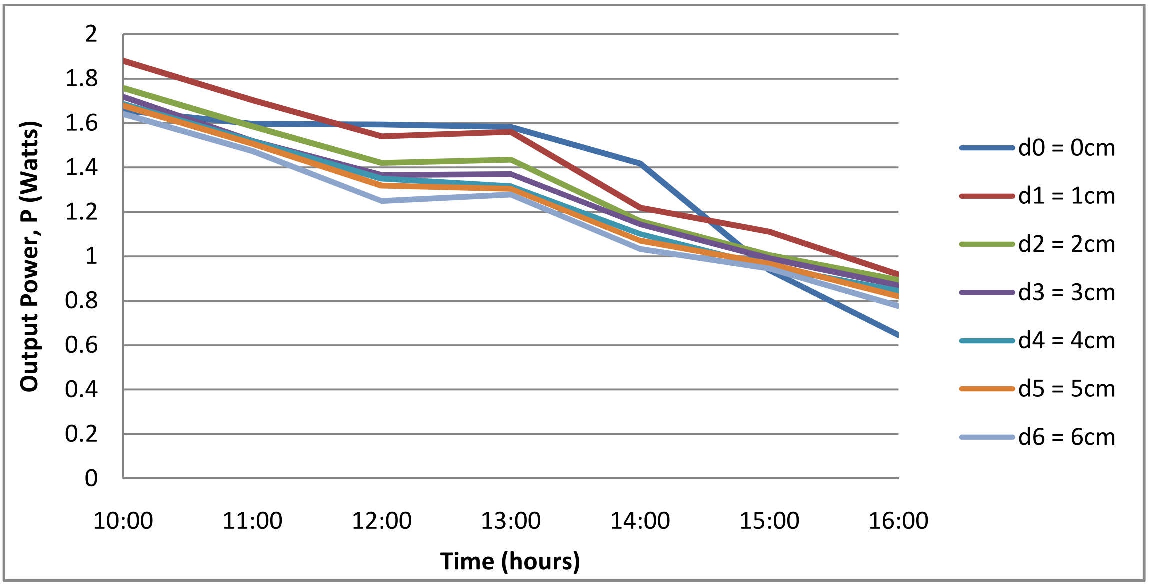

Fig. 5: Variation of output power of the solar panel with time at different submersion depths of water.

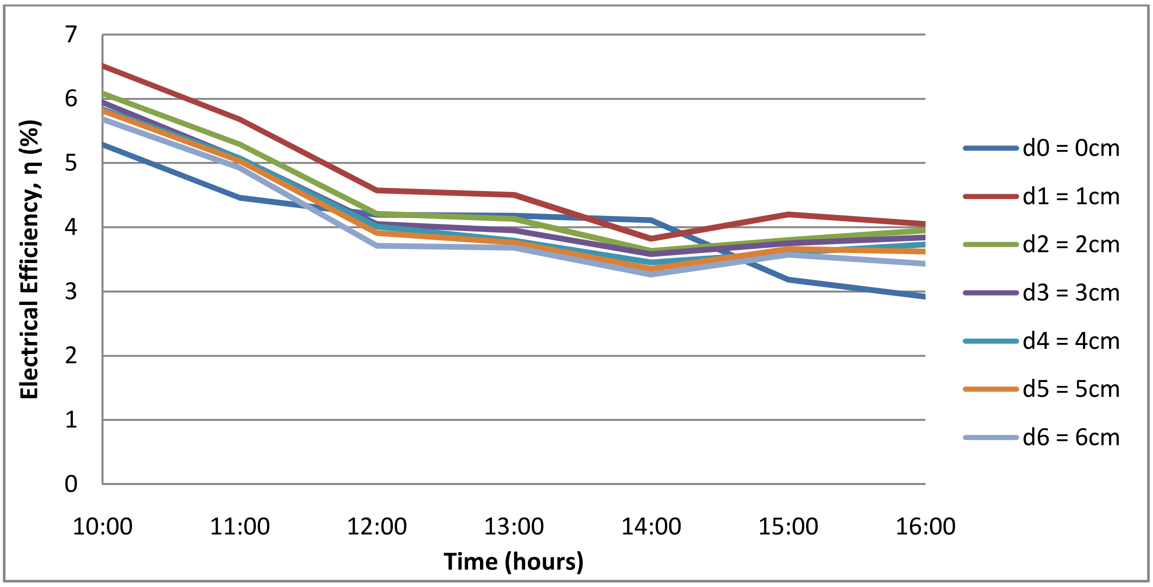

Fig. 6: Variation of electrical efficiency of solar panel with time at different submersion depths of water.

5. Discussion

This work comprises of a 2W polycrystalline silicon solar panel fiited in a 10.8cm deep plastic box which works as submerged photovoltaic system. The concept of this work is to improve the performance of a solar panel using immersion cooling technique with water as the coolant. The work aims at increasing the electrical efficiency of the panel by submerging it in water. The analysis of the test results show that there is a maximum increase in electrical efficiency of 17.8% at depth d = 1cm which clearly indicates that the performance of the solar panel is improved. The electrical efficiency depends on the intensity of solar radiation, surface temperature of the panel, ambient temperature, water temperature, orientation of the solar panel and the submerging depth of water.

5.1 Water as coolant:

The main problem faced with water used as a coolant is its conductivity. It is a conductive liquid which when decomposes into its ions may affect the electrical efficiency as the ions will also have a current. So deionized (DI) water is preferred as it has low viscosity and high thermal capacity. The resistivity of the DI water should be controlled for better performance.

5.2 Integration with large water bodies:

This technique can also be used in bigger water bodies like rivers, oceans, lakes, canals etc. Many of the reports talk about the requirement of large land area for the installation of solar photovoltaics system. This work is very useful in such conditions in which both the problems of land requirement and efficiency are solved. The photovoltaic system can be integrated with the water bodies. The PV panels are set on big floating frames, a few tens of square meters in size which can handle groups of panels. The panels are a few cm underwater, and installed close to the shore. They have minimal environmental impact, hence are highly efficient power generation. They can be controlled by bringing the structure deep down for maintenance and sea rough conditions.

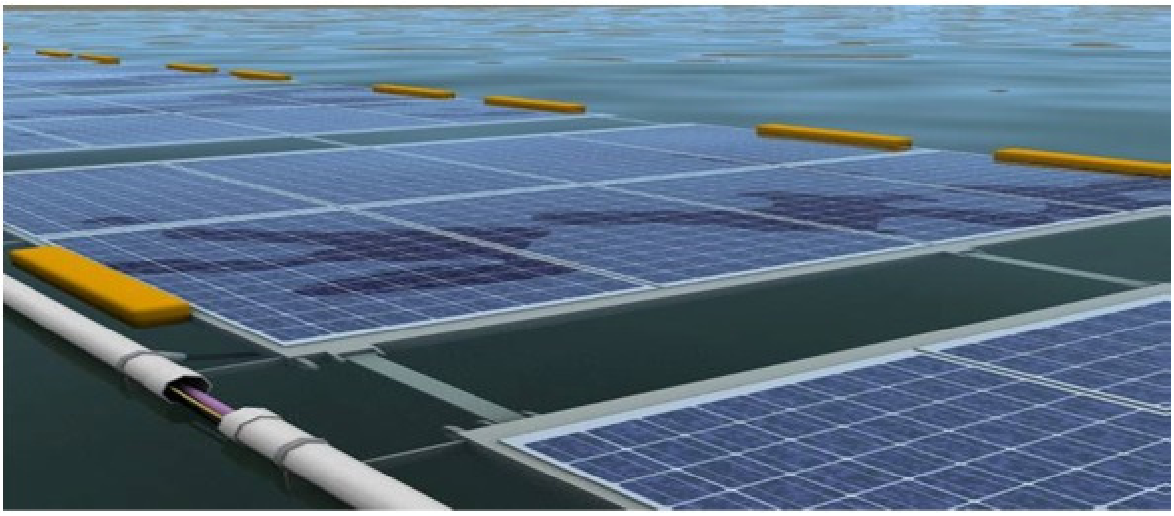

Fig. 7: A strip of submerged photovoltaic panels

6. Conclusion

This article has presented electrical performance of the solar photovoltaic using water immersion cooling technique. A preliminary study of applying this technology in a university building of MANIT, Bhopal has been described with different water depths in the outdoor environment during a period of 6 days from 18/04/2014 to 23/04/2014. The maximum efficiency of 4.76 % was obtained under1cm depth of water with the proposed design and operating conditions. The results show that as the depth increases, the surface temperature of the panel decreases and the electrical efficiency increases till a particular depth after which it begins to fall. A maximum increase of 17.8% in electrical efficiency of the panel was observed, which clearly depicts the improvement in the performance of the panel and encourages the use of water immersion cooling technique in Concentrated Photovoltaics (CPV) systems where the cell temperature increases and results in the decrease of electrical efficiency of the cell.Therefore, after this a high concentration photovoltaic system will be used with array of convex lens as concentrator. This will further increase the electrical efficiency of the panel and the system will be highly efficient.Besides water, other liquids will also be used like mineral oil, ethanol etc. in CPV work.

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