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Perfomance Enhancement and Analysis of Photovoltaic Panels by Water Cooling

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***Abstract*— Photovoltaic solar energy is one of the renewable sources of energy. A photovoltaic cell converts only a small fraction of the irradiance into electrical energy. The balance is converted into heating of the cell. In this paper, an attempt is made to remove the heat from the solar cell with water cooling which can be utilized in some other areas. Studies are carried out to analyse the performance of the solar cell with respect to electrical efficiency and thermal characteristics. The study shows that a photovoltaic system with water cooling on top surface of the panel was designed, and experiment was performed in order to study the electrical and thermal performance of the system. From the experimental result it was found that, for 1 minute cooling time the electrical efficiency is increased by 3.578% on an average. When the experiment is performed with 5 minute cooling time the electrical efficiency is increased by 7.706% on an average.**

Keywords—Photovolatic cell; Photovoltaic thermal collector; Solar panel; Solar intensity.

I. INTRODUCTION

Today, the industry’s production of photovoltaic (PV) modules is growing at approximately 25 percent annually, and major programs in the U.S., Japan and Europe are rapidly accelerating the implementation of PV systems on buildings and interconnection to utility networks. Photovoltaic modules are solid-state devices that convert sunlight directly into electricity without an intervening heat engine or rotating equipment. Photovoltaic panels convert solar radiation to electricity with peak efficiencies in the range of 5–20%, depending on the type of the PV cell. The efficiency of the solar cells drops with increasing operating temperatures. Temperature increment is one of the main problems associated with photovoltaic systems, which results in significant reduction in cell efficiency and increases the chances of cell degradation. In hybrid photovoltaic thermal solar systems the reduction of the PV module temperature can be combined with a useful fluid heating. In hybrid photovoltaic thermal solar systems the reduction of the PV module temperature can be combined with a useful fluid heating.

Tripanagnostopoulos et al. [1] described a Hybrid PV/T experimental models based on commercial PV modules of typical size and presented the outdoor test results of the systems. The results showed that PV cooling can increase the electrical efficiency of PV modules, increasing the total efficiency of the systems. Numerical computations have been carried out by Tiwari and Sodha [2] for climatic data and design parameters of an Integrated Photovoltaic and Thermal Solar (IPVTS) system. Based on energy balance of each component of IPVTS system, an analytical expression for the temperature of PV module and the water have been derived. Chow [3] described an experimental study of a centralized photovoltaic and hot water collector wall system that serves as a water pre-heating system. Different operating modes were performed with measurements in different seasons. Natural water circulation was found more preferable than forced circulation. The thermal efficiency was found 38.9% and the corresponding electricity conversion efficiency was 8.56%. With the PVT wall, the space thermal loads can be much reduced both in summer and winter, leading to substantial energy savings. Sarhaddi et al. [4] developed a detailed thermal and electrical model to calculate the thermal and electrical parameters of a typical photovoltaic thermal (PV/T) air collector. The thermal efficiency, electrical efficiency and overall energy efficiency of PV/T air collector are found to be 17.18%, 10.01% and 45%, respectively. Jin-Hee Kim et al. [5-6] designed, an air-based PVT collector with a mono-crystalline PV module and its electrical and thermal performance was analyzed with the experimental results. The results indicated that the thermal and electrical efficiencies of the PVT collector were, on average, 22% and about 15%, respectively. With a water-type PVT collector it was found that the respective thermal and electrical efficiency of the Building Integrated Photovoltaic Thermal (BIPVT) collector

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are 30% and 17%. Heating system with a BIPVT collector is very useful in buildings, and its effectiveness was confirmed in this study.

In the present paper, a PV/T system is designed and fabricated by water cooling on the top surface of the solar panel. A comparison of the output characteristics of the PV/T system before and after water cooling is performed.

Efficiency is a measure of PV cells, defined as the maximum electrical power output divided by the incident light power as given below.

$$\eta_{el} = \frac{P_{max}}{P_{in}} = \frac{I_{max}\,V_{max}}{AI(t)}$$

Where, P_{max} is maximum power output

P_{in} is power input

I_{max} is current at maximum power output

V_{max} is voltage at maximum power output

A is cell area

I(t) is solar intensity

The performance of the solar cell depends on the cell temperature. The change in temperature will affect the power output from the cells. The voltage is highly dependent on the temperature and an increase in temperature will decrease the voltage as shown in Fig.1.

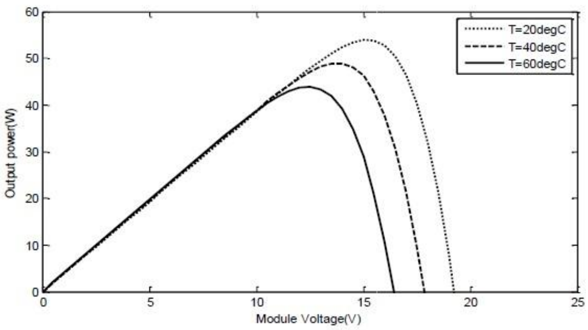

Fig. 1. Effect of PV cell temperature on the output power

II. EXPERIMENTAL SETUP

An experimental setup has been fabricated to study the effect of cooling by water on the performance of photovoltaic panel. The setup, shown in Fig. 2, comprises of solar panel fitted with a water spraying system from the water tank which is placed above the panel height. Water is sprayed over the panels using water nozzles, which are installed at the upper side of the panels. The readings are collected to evaluate the performance.

Fig. 2. Experimental setup

The primary stage of the experiment is conducted with a mass flow rate of 0.606 litres/sec where the cooling period of the photovoltaic cells was one minute. In the next stage cooling period is increased to five minutes by keeping the same mass flow rate. The cooling process was done at intervals of one hour.

The maximum power generated is estimated from the Power Vs Voltage characteristic using regression analysis, by varying a 20 Ω rheostat. Solar intensity is measured using a solar power meter. The temperature distribution of the panels is measured using an infrared thermometer and thermocouple located at the back of the panels.

III. RESULTS AND DISCUSSION

A preliminary investigation is done to identify the temperature effect in the solar panel by estimating the solar cell temperature at different time during the day time for 4 days. Solar panel of 20W used for conducting experiments. These results are plotted in Fig. 3.

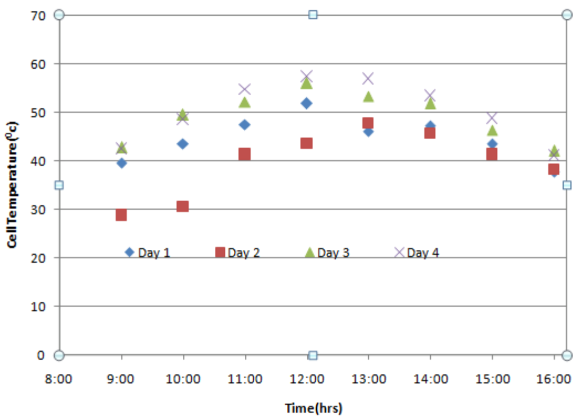

Fig. 3. Hourly variation of cell temperature

From the initial experimentation results it is seen that peak cell temperature is approximetly 60^{o}C. During the initial and final stages of the experimentation time the temperature was quite low. So the experimentation time period is reduced to 10:00 am - 2:00 pm and also the interval to 1 hour for better analysis, shown in Tab. I.

TABLE I. EXPERIMENTAL OBSERVATION OF SOLAR PANEL BEFORE COOLING (FOR ONE MINUTE COOLING TIME)

Time (hrs)	Solar intensity (W/m^2)	Cell Temp. (^{o} C)	Back Surface Temp. (^{o} C)	Max. Power (W)	Electrical Efficiency (%)
10:00	684	53.1	49.8	11.779	10.189
11:00	835	58.6	54.0	14.095	9.808
12:00	960	65.3	58.4	15.000	9.516
13:00	995	66.3	59.7	15.787	9.388
14:00	869	64.4	59.1	14.238	9.372

The experiment is repeated for the same time duration with the cooling of solar panel for 1 minute cooling time. The results are shown in Tab. II.

TABLE II. EXPERIMENTAL OBSERVATION OF SOLAR PANEL AFTER COOLING (FOR ONE MINUTE COOLING TIME)

Time (hrs)	Solar intensity (W/m^2)	Cell Temp. (^{o} C)	Back Surface Temp. (^{o} C)	Max. Power (W)	Electrical Efficiency (%)
10:01	715	45.4	43.7	13.860	10.648
11:01	846	47.1	46.3	14.981	10.469
12:01	970	54.2	49.8	16.430	9.772
13:01	998	55.4	51.7	16.026	9.502
14:01	869	54.1	50.7	14.214	9.577

The power-voltage curves before and after cooling (for one minute cooling time) is depicted in Fig. 4 and Fig. 5.

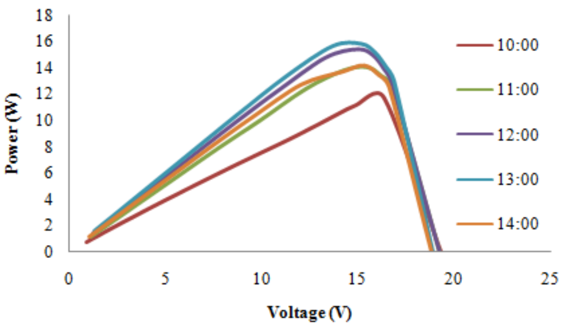

Fig. 4. Power-Voltage curve before cooling (for one minute cooling time)

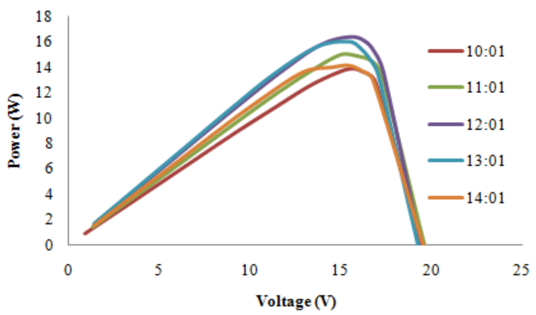

Fig. 5. Power-Voltage curve after cooling (for one minute cooling time)

The variation of back surface temperature of the solar panel is shown in Fig. 6. The temperature is reduced by the application of cooling water when compared to the temperature without cooling.

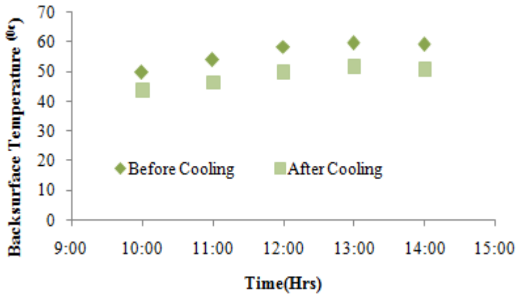

Fig. 6. Comparison of back surface temperature before and after cooling (for one minute cooling time)

Fig. 7 shows the variation of cell temperature and electrical efficiency before and after cooling conditions. Solar cell perfomance decreses with increase in temperature. Both electrical efficiency and power output of depends up on the cell temperature. It is found that as cell temperature decreases the electrical efficiency tends to increase.

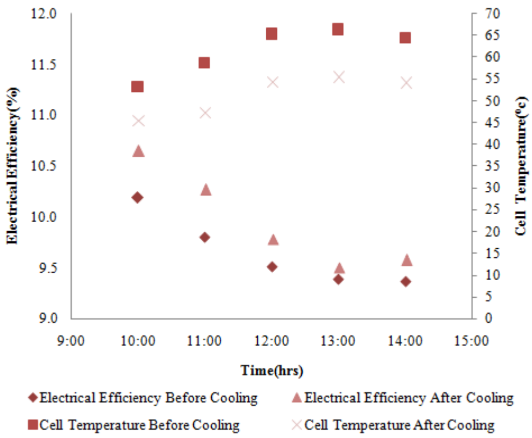

Fig. 7. Variation of cell temperature and electrical efficiency before and after cooling (for one minute cooling time)

The experiment is performed with five minute cooling interval for the same mass flow rate of cooling water. The results are shown in Tab. III. and Tab. IV.

TABLE III. EXPERIMENTAL OBSERVATION OF SOLAR PANEL BEFORE COOLING (FOR FIVE MINUTE COOLING TIME)

Time (hrs)	Solar intensity	Cell Temp.	Back Surface	Max. Power	Electrical Efficiency

	(W/m^2)	(^{o} C)	Temp. (^{o} C)	(W)	(%)
10:00	615	42.8	42.2	10.729	10.323
11:00	773	57.5	51.9	9.693	9.693
12:00	803	58.6	53.3	9.662	9.662
13:00	764	54.7	52.6	9.805	9.805
14:00	635	53.9	52.5	9.834	9.834

TABLE IV. EXPERIMENTAL OBSERVATION OF SOLAR PANEL BEFORE COOLING (FOR FIVE MINUTE COOLING TIME)

Time (hrs)	Solar intensity (W/m^2)	Cell Temp. (^{o} C)	Back Surface Temp. (^{o} C)	Max. Power (W)	Electrical Efficiency (%)
10:05	675	33.2	33.9	12.268	10.754
11:05	778	41.9	41.3	14.346	10.599
12:05	823	42.1	42.2	15.308	10.597
13:05	714	42.3	39.8	12.980	10.351
14:05	631	38.1	38.3	11.075	10.385

The power-voltage curves before and after cooling (for 5 minute cooling time) is depicted in Fig. 8 and Fig. 9.

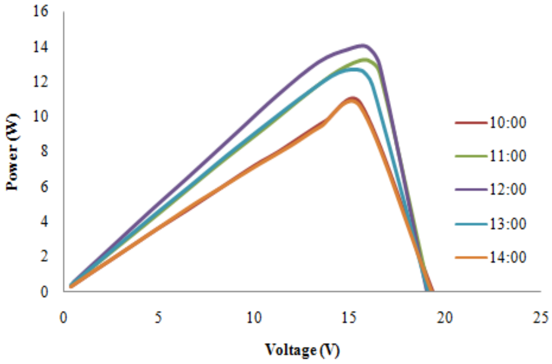

Fig. 8. Power-Voltage curve before cooling (for five minute cooling time)

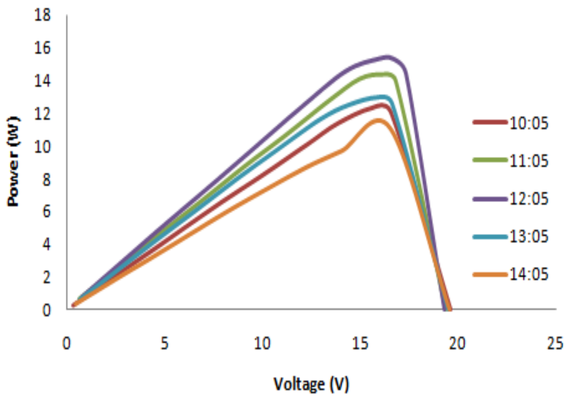

Fig. 9. Power-Voltage curve after cooling (for five minute cooling time)

The variation of back surface temperature of the solar panel is shown in Fig. 10. The temperature is reduced by the application of cooling water when compared to the temperature without cooling as in the previous case.

Fig. 10. Comparison of back surface temperature before and after cooling (for five minute cooling time)

Fig. 11 shows the variation of cell temperature and electrical efficiency before and after cooling conditions. It is found that as cell temperature decreases the electrical efficiency tends to increase.

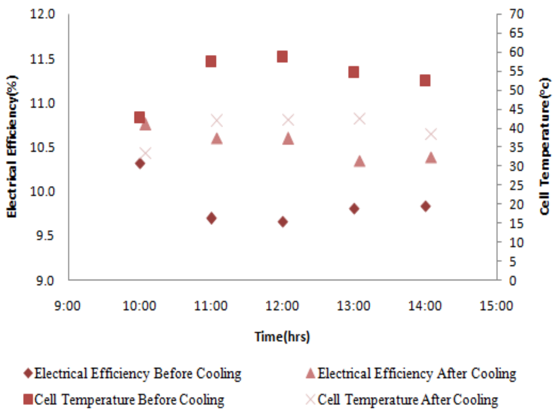

Fig. 11. Variation of cell temperature and electrical efficiency before and after cooling (for five minute cooling time)

The results of increase in electrical efficiency with one minute cooling time are compared with the results from five minute cooling time. The increase in the temperature of cooling water is after extracting heat from the solar panel is depicted in fig.12

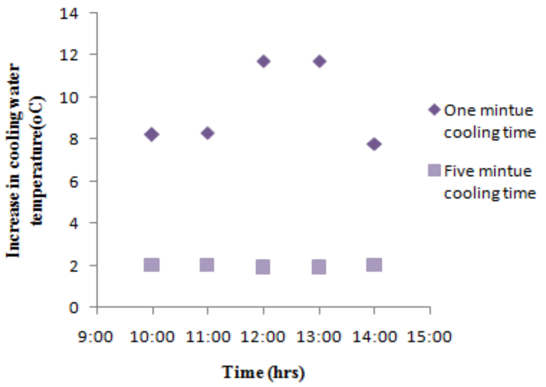

Fig. 12. Comparison of increase in cooling water temperature

IV. CONCLUSION

In this study, a photovoltaic system with water cooling on top surface of the panel was designed, and experiment was performed in order to study the electrical and thermal performance of the system. From the experimental result it was found that, for one minute cooling time the electrical efficiency is increased by 3.578% on an average. When the experiment is performed with 5 minute cooling time the electrical efficiency is increased by 7.706% on an average. An increase in cooling water temperature was observed for both one minute cooling and five minute cooling. Therefore, it concludes that the cooling the panel with proposed model increases the electrical performance and removes the waste heat generated, which can be utilized for other applications.

V. REFRENCES

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