Experimental Analysis of the Photovoltaic Solar Panel Using Water Spray Cooling

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Abstract

This experiment gives an alternative cooling method of photovoltaic (PV) solar panel using water spray. The PV panel has a specific experimental setup at Sultanpur (India) explained in detail. This set up tested in a geographical location with different climate conditions. It was found that by spray cooling, the temperature of the panel decreases on average 53℃ to 23℃ in both case of up and bottom cooling and total power was increased by 15.3%.Apartfrom that effectiveness of the system also increased by its cleaning effects. The efficiency of this solar PV, as well as water-based crystalline, gets reduced with the increase of panel temperature. It was also observed from the experiment that the efficiency of PV cells dropped by 0.5% with anincreaseof1℃ofpaneltemperature.

Keywords. Experimental analysis, photovoltaic solar panel, cooling, water spray method, efficiency.

1. INTRODUCTION

Photo-voltaic (PV) cells are widely adopted as one of the most significant sources of renewable energy applications that can utilize solar energy by converting solar irradiance into direct current (DC) electricity [1,2]. According to the PV cells manufacturing materials, converting of solar irradiance into direct electricity can be achieved with various conversion efficiency atratingvaluesbetween7and40% [2,3].From the solar radiation incident on the surface of PV cells, a range of about 80% can be absorbed, however, only a small portion of the absorbed incident solar energy is converted into electrical energy based on the conversion efficiency of the PV cell manufacturing technology [4]. The remainder of absorbed energy is overheating the PV cells and according to many researchers, the operating temperature of the PV cells above the ambient atmospheric temperature byabout40°C [5–7].

The reason for overheating is since PV cells convert a certain band of the coming irradiance spectral wavelength that is responsible for light direct converting into electrical energy, while the remaining spectral wavelength is overheated by the PV cells [8]. Elevated temperatures of the PV panels are considered one of the most critical issues especially in hot climatic regions causing a series drop in PV electrical conversion efficiency by about 0.5%/1 °C for every degree rise of the PV panel temperature and reducing the lifetime of the PV cells [9].

Thus, an integral cooling system of PV cells during operation is the task of great significance to enhance the performance of the PV cells with an efficient conversion process, particularly in sunbelt regions. Furthermore, the presence of the cooling system will help in decreasing the overall cost of solar cells, prolong the PV cell's lifetime, encourage solar cell industries, and ensure maximum output power from the installed PV cells [10]. The cooling method is water and air normally. Air takes less amount of energy compared to water cooling however the cooling capacity of water is more, water can be circulated for recoiling purposes and warm water can be used for domestic purposes like bathing washing, etc. It is experimented and checked out that the surface of the solar cell is not allowedabove46℃.Whenexplosivesperiod4hoursofthewater-basedcoolingsystem. Module constructed such that solar energy Impact on more area and cooling Medium also [11].

The main cooling system for reducing solar panel temperature is an active and passive cooling system. The case of active cooling requires coolant like air and water which is worked with a favor electric motor. Where in the case of passive cooling there cooling is divided into three main categories passive cooling of the air, passive cooling of water, and conductive cooling natural convection is done by heat exchange sink, heat pipe, etc. are used in passive cooling. Modern cooling technologies include phase change material (PCM) nanotechnology (nanofluid) sinks thermoelectric generators microchannel.

Previously different cooling techniques were discussed such as solar panel air cooling was invented when the panel was cooled by air then panel temperature decreases to 4℃ and its efficiency increases about 2.6% while in the case of water the temperature decreases to 8℃ and system efficiency increase up to 3% [12]. Shelby et al. [13] examined that the efficiency of solar panel water cooling is more than air cooling also it was also examined that the total power output of photovoltaic panels increases 33.3%, 25.9%, and 27.7% with the help of water spray cooling. The panel temperature falls from 57.1% to 24.7℃ and 26.4℃ by water spray cooling. While PCM absorbs or releases significant quantities when it is realized to change their physical state, PCM has high absorber capacity latent heat before phase change solidifies or melts [14]. Apart from this Lupu et al. [15] examined that heat pipe cooling improved the thermal efficiency of the PV panel by 13.9%. Apart from this heat pipe uses sealed pipe which should have a high value of thermal conductivity like as copper-silver etc. The heat pipe converted solar panel heat to air or water this lowered system heat and improved system efficiency. Apart from that other cooling techniques were discussed previously such micro-channel heat exchanger [16], solar panel nano fluid cooling [17], and solar panel evaporative cooling [18].

It was observed from the literature survey that various research was present on solar panel water spray cooling but only a few manual works achieved above 25% efficiency. The novelty of this study is to analyze the PV panel cooling system and its thermal aspect for Sultanpur (India). Effects of the number of the nozzle, the distance between nozzle and panel, angle of the spray nozzle, and angle of the panel concerning the surface on system performance have been examined.

2. EXPERIMENTAL SETUP AND PROCEDURE

An experimental setup has been developed to study the performance of a photovoltaic panel with spray cooling. The main component soft his experiment area solar panel nozzle strainer, motor pump, and a tank. The solar panel is located at some angle from the earth's surface. It is situated on the four pillar tidewaters pulled from the tank by an electric motor which has some power after pulled arthritis sprayed by a nozzle on the surface of the solar panel. After's praying the cooled the panel temperature, therefore, panel t temperature falls from the rated temperature, water is full slides on the panel surface so that with cooling action, cleaning action also done. Water falls into the tank after sliding downs. This water, again and again, recalculates via a softer pipe. The water distribution system is located on a flexible pipe around 4 mm India meter on which the nozzle is fixed. The distance between the nozzle and panel surface is around 80mm from the front and back side150mm.

In general water spray cooling is more efficient than the other cooling media. Except for that water submerged method in which higher efficiency was obtained. Water spray also acts as a self-cleaning agent from a good cleaning action technique. The surface of the panel is made bless coefficient of reflex ion material. Less reflection means more light is observed by the surface and also it has low weight than other materials. When the solar light falls on the surface of a photovoltaic cell them most infra radiation is absorbed by the surface. The remaining light is generated into electricity by the photovoltaic cell. The solar panel water spray cooling system remains on the roof of hostel of KNIT Sultanpur India for several days during June 2021. The geographical location of this place is the latitude, longitude & altitude respectively, is 26.270 N& 82.070E and 95meters above the sea-level. The schematic diagram and photograph of setup are showninFigure1 and Figure 2 respectively.

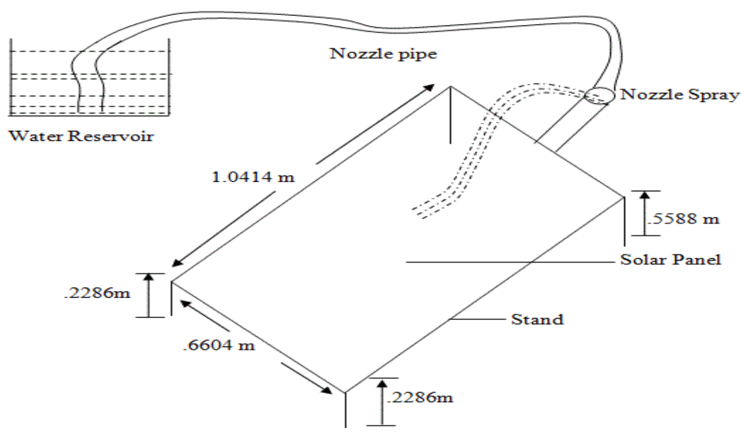

Figure 1. Schematic diagram of solar panel water spray cooling system

Figure 2. Photograph of Solar Panel Water Spray Cooling System

The main components used in the solar panel water spray cooling system and their specifications are described as

2.1 ***Solar panel stand****:* a stand is necessary for holding the panel. It has four legs in taper form. It is constructed by iron material and parts are welded having dimensions 1.0414m X0.6604m. The length of the small and bigger leg is 0.2286m and 0.5588m respectively. It has a nozzle mouth from bigger legs at height. The nozzle diameter mouth is 1.51mm as displayed in figure.

2.2 ***Nozzle pipe:*** A PVC material pipe is used for transferring water from the bucket to the nozzle mouth. It has a length of 1.5m and 1.38mm in diameter as shown in Figures 1 and 3. *Motor:* The motor is used for the conversion of mechanical energy into hydraulic energy. It generates flow with power and according to the load manages the pressure. An AC motor 18W, 165-230V/50Hzis used for pulling water from the reservoir and send to the nozzle pipe. Its photograph is shown *Nozzle:* for spraying water, a 1.38m diameter nozzle is used. It is made of steel materiality has many small holes for spraying to water. *Solar panel:* Photovoltaic modules use for the generation of electricity by use of light energy (photons) mast modules use thin-film cells or water-based crystalline silicon cells. All cells one electric cell is so connected that mechanical damage and vibration do not take place. A 12V power solar panel is used for cooling purposes.

Its length is 1.0414 m and its width is0.6604 m. This solar panel is fixed on the solar panel stand. The panel absorbs solar energy and converts it into electrical energy as illustrated in Figure (2.1) and (2.3).

2.3 Water reservoir: A water reservoir is used for the flow of water. It is used for the continuous supply of water. The motor is fully dipped inside it and pulled waterbrain.

Figure 3. The Component Used in The Experimental Setup

Apart from this for calculating the performance and characteristics of the solar panel water cooling spray following instruments are used.

2.4 *Temperature sensor:* *the* temperature at the required places was measured by the digital sensor and shown by Figure 4. This sensor can be used to measure the temperature in the range of -50℃ to 110℃ with accuracy $\pm$ 1℃.

2.5 Whirling hygrometer: whirling hygrometer is used for measuring dry bulb temperature and wet bulb temperature. It can measure the dry bulb and wet bulb temperature to 20 Fahrenheit can be seen in Figure 4.

2.6 *Anemometer:* the wind velocity affects the temperature of the solar panel; its speed is measured by an anemometer as shown in Figure 4. The range of velocity of the anemometer is

0to 45 m/s with a range of operating temperature– 10℃ to 50℃ and humidity 40% RH – 85%RH respectively.

2.*7 Voltmeter:* voltmeter is used for measuring to voltage and the current value of the solar panel. It can measure the maximum voltage is 600V and the maximum currents 10A.It has three polls one is voltage, and another is current and in between to this neutral pole.

2.*8 Electronic digital caliper :*electronic digital calipers used for measuring the dimension of different sections. It can measure in both units like mm and inch. It can measure maximum dimensions int he ranges of 150mm. Its photograph can be configured 4.

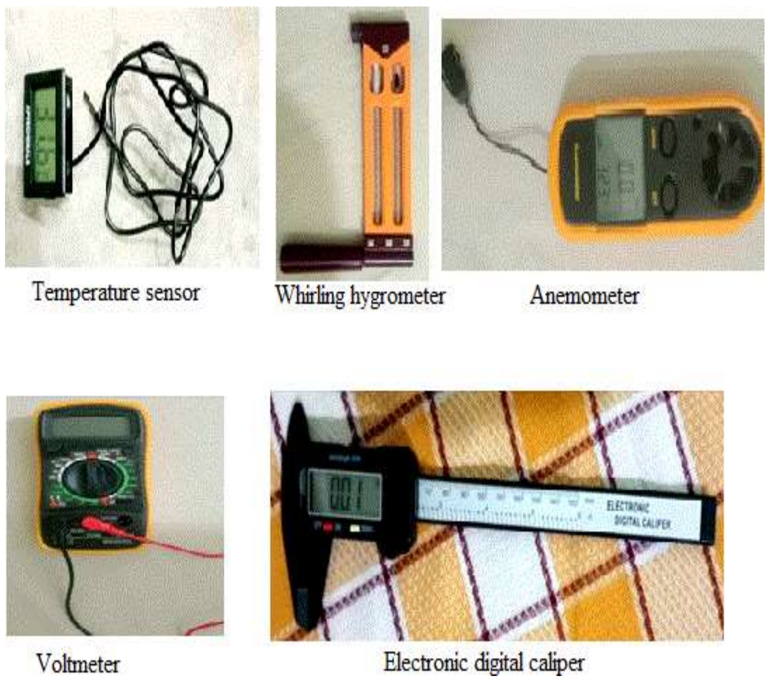

Figure 4. Instrument Used in The Experimental Setup

In summer conditions the temperature of solar panels generally gets very high consequently the value of power output becomes decreases. We are cooled to solar panel and getting reached to anormal temperature of the solar panel so in this way the efficiency of my system becomes improved.

2.9 Working Procedure

First, a water reservoir is taken, and solar panel put on a solar panel stand generally sliding on a panel and going out from panel surface for pulling to water from reservoir an AC motor issued which is pulled water from reservoir and water goes inside the nozzle and the water comes out from nozzle in the form of a spray. Become water expands during spray so its temperature becomes down in some amount. The panel so in this way, cleared to the panel surface and cooled it. We have taken reading every 5 to 10-minute interval and noted voltage, current, DBT and WBT reading, and air velocity because velocity affects the panel temperature by the process of forced convection. The water spray cooling technique aim stoa cheval overtemperatures of solar panels in this way increasing the photovoltaic panel power output. If we wantto apply water spray on both sides of the panel front and backward both then suppose $G_S$is the incoming solar irradiation $A_P$is the total solar panel area. Now we are interested in convertinguse of full power output of this incoming solar radiation. Solar energy of this in radiation is wanted into uncreative solar.

According to this Figure 5, it can be seen Q is the total heat loss, in convection Q_C,$Q_E$is the total evaporation heat and $Q_R$is the radiation heat l loss.

Then the total solar irradiation is expressed as

$$Q_{SOLAR} = \alpha \, G_S A_P (1)$$

Where, α,$G_S$and$A_P$absorptive coefficient, solar irradiation, and panel area, respectively.

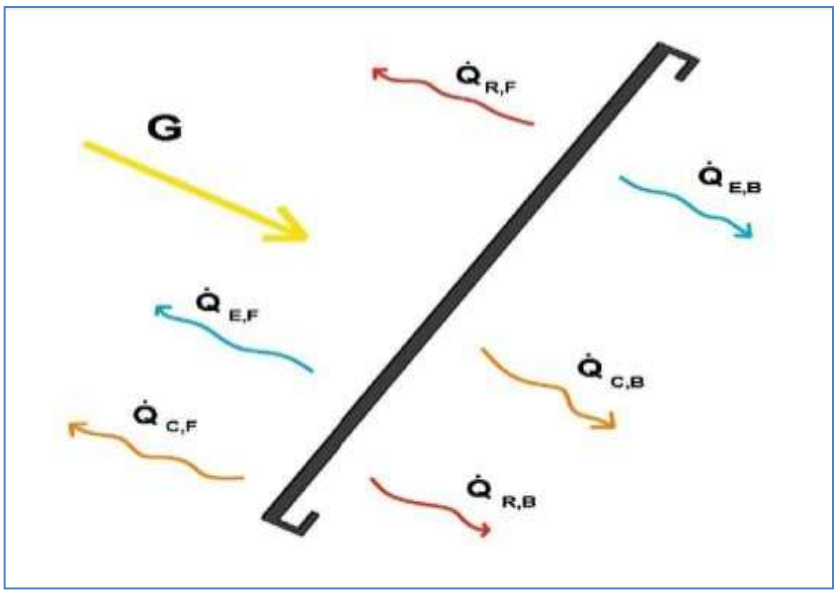

Figure 5.Net Heat

Loss from Solar Panel Overall photovoltaic heat loss Q_{LOSS} can be calculated by

$$Q_c + Q_R + Q_E = Qloss \qquad (2)$$

Where Q_C, Q_R, $Q_E$are convection heat loss, radiation heat loss, evaporation heat loss respectively

If we total heat loss considered the heat exchange by front and back side of the PV
Total convection heat loss is

$$Q_{CF} + Q_{CB} = Q_C \quad (3)$$

Convection heat loss from the front side isa also calculated by given below

$Q_{CF} = Front\ A_P\ (T_{PANEL\ FRONT}$ - $T_{PANEL\ FRONT}$) (4)

Same as from back side

$Q_{CB} = h_{back\ side}\ A_P\ (T_{PANEL\ BACKSIDE}$ - $T_{AIR\ BACKSIDE}$) (5)

Total radiant or heat loss is expressed as.

$$Q_{RF} + Q_{RB} = Q_R (6)$$

Total heat radiation QRc ana also be calculated by

$$Q_R = \sigma\ \varepsilon A_P F_{XY}\ (Tx^4 - Ty^4) \quad (7)$$

Where x subscription denoted that front side any description denoted that backside, and F_{xy}, T_X, Ty, σ, AP andε are view factor of both side, front side temperature, backside temperature, StefanBoltzmann Constant, panel area, emissivity respectively.

Thetotalevaporationheatlossdependsonbothrelativehumilityandsurroundingairtemperature and the velocity of air respectively. Total heat loss evaporation depends on applied water flow temperature i.e., the boundary layer of the photovoltaic panel this can be explained.

$$Q_E = Q_{EF} + Q_{EB} (8)$$

The evaporation heat loss also can be written as.

$$Q_E = e\ A_P\ (P_S - P_R) r \quad (9)$$

P_S, Pd is the partial pressure the total evaporation heat loss depends on the relative humidityvelocity of the air and the temperature of the water spray and the purpose of the spray of water is to increase overall heat refection by evaporation it strongly depends on evaporation coefficient.

(e) (where evaporation coefficient greatly depends on the air velocity in case of turbulent flow it directly depends on the convection heat transfer coefficient).

Furthermore, depends on surrounding air temperature relative humidity as well as the temperature of the thin boundary layer.

Also following equations has been considered for the performance calculation During cooling of PV, panel water is sprayed forcefully by the pump. Hence it is clear that heat transfer via force convection.

According to Newton's cooling law

$$Q = h\ A_S (T_W - T_F) \quad (10)$$

Here T_W and Tf is the temperature difference between wall and fluid, Q is related to overall heattransfer.

According the second energy balance

$$Q = m\ C_P (T_E - T_O) \quad (11)$$

First, we check that flows laminar or turbulent by the Reynolds Number

$$R_e = \frac{\rho v d}{\mu} \quad (12)$$

P is the density of the fluid, v is the velocity of the fluid and μ is the dynamic viscosity.
The velocity of fluid can be determined by

$$m = \rho AV \quad (13)$$

Nusselt number can be calculated as.

$N_U = 0.332\, Re^{1/2} Pr^{1/3}$ (laminar) (14)

$N_U = 0.0228\, Re^{4/5} Pr^{1/3}$ (turbulent) (15)

Heat transfer coefficient(h)can be determined by

$$N_U = \frac{h_d}{K}$$

Where, d is hydraulic length
Efficiency of the system can be calculated as.

$$\eta = \frac{output\ power}{A_P G_S}$$

3. RESULTS AND DISCUSSIONS

In this section performance of the system were discussed without cooling and with cooling on after the other.

3.1 Performance testing without cooling

The results of experiment were recorded without cooling of solar panel in the month of 10th July2021 as shown listed in Table 1. The wind velocity, DBT, WBT, module power has been recorded at some stage in the test and were used within the calculation of the efficiency of the PV module. The panel temperature initially at60.6℃ (1:00 PM) is increased and reaches the peak point of day 62.3℃ (2:00PM). During the experiment, the panel temperature was fluctuated, according to wind velocity and environmental conditions. The minimum temperature of the panel is 59.8℃ at 2:30 PM. After this time the temperature becomes down gradually. Here it can be seen that the value of voltage become decreases with temperature and the value of current also decrease with higher cell temperature. It has been observed that that the module efficiency slightly decreases with increase in temperatures. At 1:00 PM, initial temperature of the solar panel was 60.6℃ and corresponding efficiency was observed as

2.88%. When temperature slightly decreases to 60.1℃, then efficiency slightly improved to 2.919%. All variation were listed in Table 1

Table 1. Recorded data of solar panel without Cooling on10th-July-2021

Time	1:00PM	1:15PM	1:30 PM	1:45 PM	2:00PM	2:45 PM	3:00PM
Temp (℃)	60.6	60.1	60.8	61.2	62.3	61.8	59.8
Voltage(V)	19.08	19.30	19.24	19.11	19	19.03	19.28
Current (A)	1.04	1.06	0.98	0.93	0.63	0.58	0.08
DBT (℃)	89	89.1	90	90	91	89.9	88
WBT (℃)	82.5	82.4	83	83	83.5	03	82.9
Air velocity(m/s)	1.1	1.2	1.1	1.3	1.08	1.2	1.08
Output power(W)	19.84	20.458	18.85	17.77	12.92	11.03	20.822
Efficiency (%)	2.88	2.919	2.69	2.536	1.84	2.33	3.027

It was also observed that the current first increased with the voltage and after some value of the voltage, it decreased. Keeping constant all other parameters, the as the voltage increased corresponding temperature also decreased which leads to the decrease of the current. The maximum current was foundat1. 06Vofvoltage. It can also be seen in Figure 6, the dropping grate of the current was faster corresponding voltage from 0.58V to0.55V. As discussed previously in this reason rate of temperature drop was also sharp.

Figure 6 shows the temperature variation of solar panels with time. Itis observed that the maximum temperature is between 1:00 pm to 2:30 pm on July 10th, 2021. Because at this time the high amount of solar radiation was received in India. Therefore, energy transformation rate was also high. It can be observed that solar panel temperature fluctuated with the environmental condition and wind velocity also.

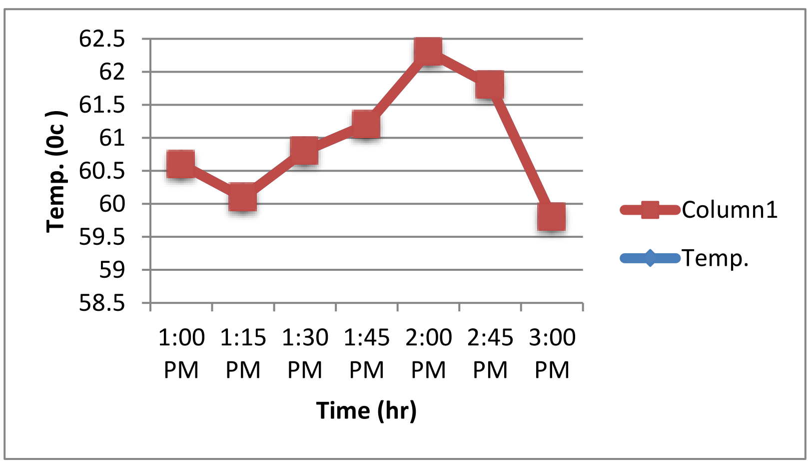

Figure 6. Variation of Temperature with Time

Figure 6 shows the relation between voltage and power output. The maximum power was achieved at the time 3:00PM, where minimum temperature was found. The maximum power was obtained as 20.822W at 59.8℃ of temperature. It can be seen from the Figure 6 that power out decreased with the voltage and found maximum a voltage of 19.28V. It is concluded that when the panel temperature tends to maximum then their power output becomes minimum.

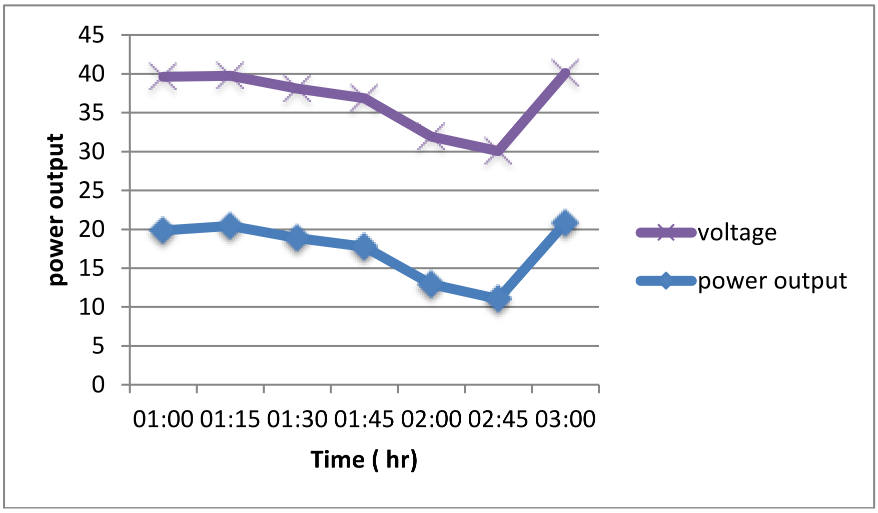

Figure 7. Variation of Power Output with Voltage

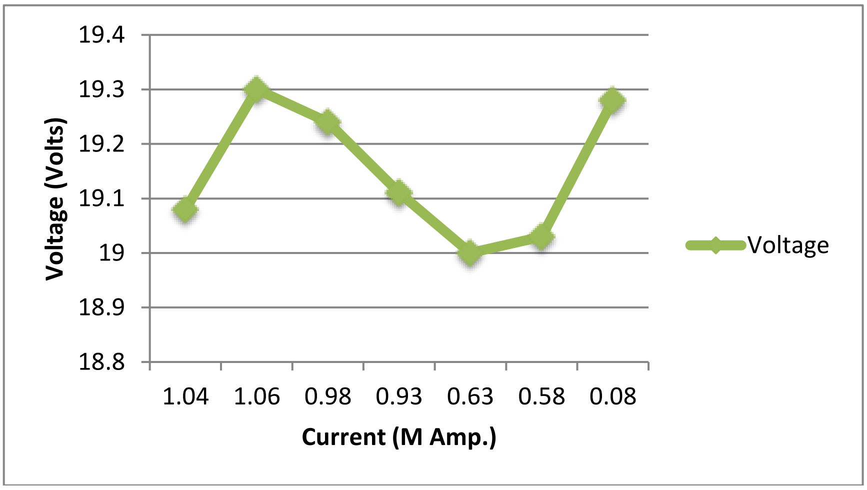

Figure 8. Variation of Current with Voltage

It was observed that when the panel temperature reached to maximum value corresponding electrical efficiency also obtained its maximum value as can been seen in Figure 9. In this experiment, the maximum efficiency occurred at the lowest temperature which is 59.8℃ at the maximum temperature 62.3℃ efficiency is the lowest value which is 1.84%.

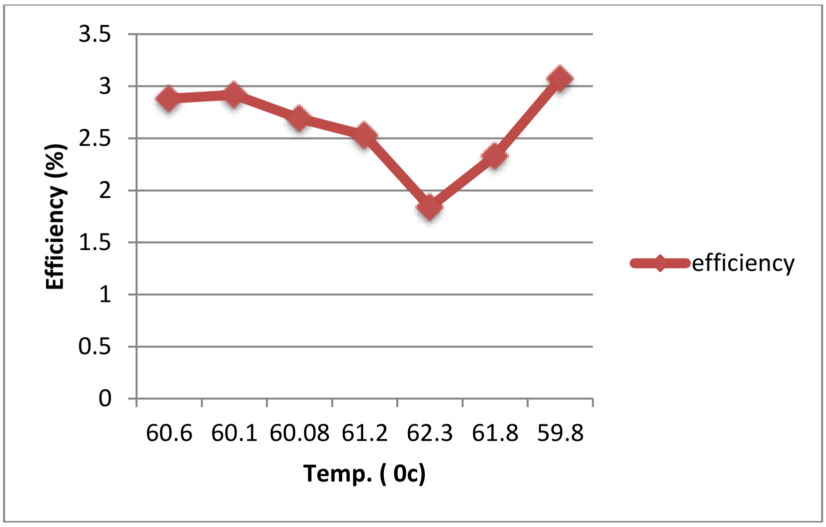

Figure 9. Variation of Electrical Efficiency with Temperature

3.2 *Performance analysis of the system with cooling*

In this section all measurements were taken with cooling of the solar panel on 12th July 2021 Sultanpur India. The wind velocity, DBT, Titmouse power has-beens recorded atmometer in the test and were used within the calculation of the efficiency of the PV module. The panel temperature initially at 45°C (1:00 PM) is lowered and reaches the lowest point of day42.8°C (3:15 PM). During the experiment, the panel temperature was fluctuated, according to wind velocity and environmental conditions. The minimum temperature of the panel is 42.8°C at3:15 PM. After cooling the temperature become down gradually. Here It was seen that the value of voltage decreases with temperature and the value of current also decreases with higher cell temperature. After the experiment, It can also be seen that the module efficiency gradually increases with temperature. At 1:00 PM my initial temperature of a solar panel is 45°Cand my efficiency is 13.5%. When the temperature slightly decreases to 42.8^{0}C, then efficiency slightly improved to 15.662%. At 1:15 PM my efficiency is 14.64% after 15-minute temperature become44.6°Ctemperature lowest by 0.2°Cmy and efficiency become improved to 15.2% from 14.64% another worthies when temperature become improved by 0.28% hence it can be said that the panel temperature should by a moderate temperature value at a higher temperature value its efficiency become lowered. Therefore, solar panel must be cooled for achieving better performance and efficiency.

Table 3.2 Recorded data of solar panel without cooling on 12th, July-2021

Time	1:00 PM	1:15 PM	1:30 PM	1:45 PM	2:00 PM	2:15 PM	2:30 PM	3:00 PM	3:15 PM
Temperature (°C)	45.0	44.9	44.6	44.5	44.3	46.3	46.3	43	42.8
Voltage(V)	20.6	21.9	21.2	20.9	21.9	19.6	20.6	22.1	22.3
Current(A)	4.54	4.75	4.96	4.84	4.90	4.75	4.58	4.80	4.83
DBT (°C)	80	79.9	79.8	79.7	79.8	80	80	79.9	79.9

WBT (°C)	74	73.9	73.8	73.8	73.7	74	74	73.9	73.9
Air Velocity (m/s)	1.1	1.09	1.33	1.08	1.45	1.06	1.3	1.09	1.8
Output Power (W)	93.5	100.7	105.152	101.156	107.31	91.14	95.264	106.08	107.709
Efficiency (%)	13.5	14.64	15.29	14.709	15.60	13.25	13.856	15.42	15.662

Figure 10. shows temperature variation with time. The maximum temperature was observed as46.23°C between the whole test range i.e., between 1:00 PM to 3:15 PM on July 12th, 2021. The Figure 6andFigure cane compared and due to spray water cooling temperature of the panel decreased sharply. The minimum temperature was found as 42.8°C at the 3:15 pm while in previous test i.e., without cooling it was 59. 75°C at the same time. Apart from this panel temperature fluctuated with the environmental condition and wind velocity also as can be seen in Figure 10.

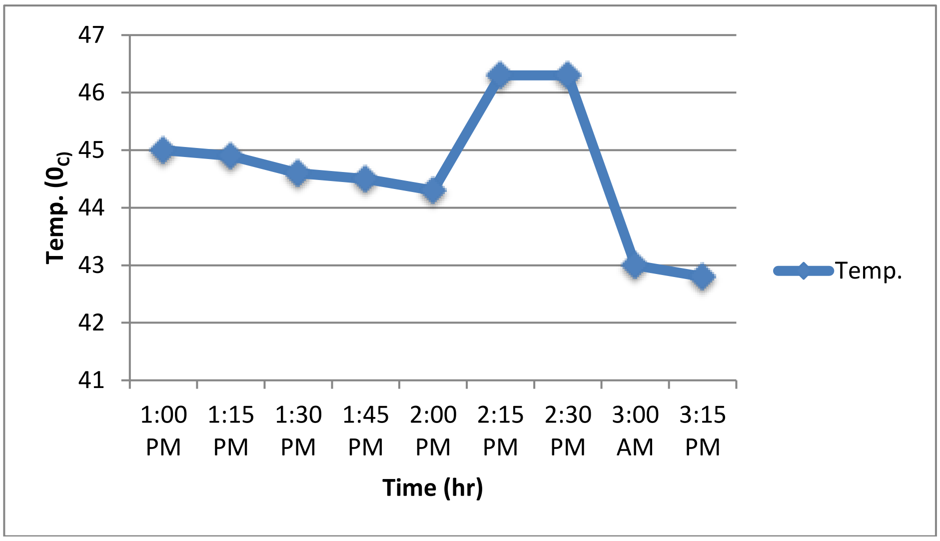

Figure 10. Variation of Temperature with Time

Figure 11 shows the variation of electrical power with voltage. Maximum was observed at the 3:15 PM when the temperature was minimum of all-temperature readings. It can see in the table 3.2 at 42.8°C voltage is a maximum of 22.3 volts and here maximum power output was obtained as 107.709 W. It is concluded that when the panel temperature tends to maximization then their power output becomes minimized. Comparing the Figures 7 and 11, it was observed that due to cooling effect the efficiency was improved. As discussed above, the electrical efficiency decreased with panel surface temperature.

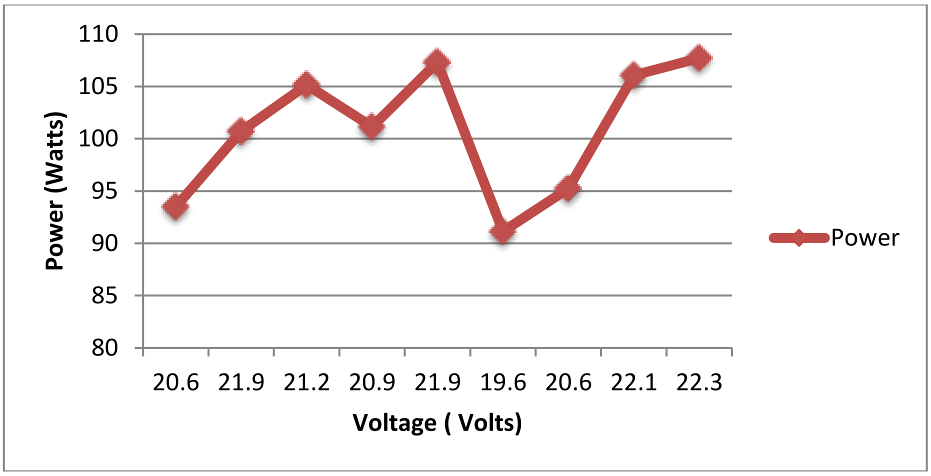

Figure 11. Variation of Power Output with Voltage

Further current variation with the voltage can be seen in the Figure 12. The pattern of variation was same as in without cooling conditions. It was observed that the maximum current value occurred at maximum value of the voltage. As the panel temperatures lowered then both temperature and voltage became maximum. As comparison to the figure 8, it was seen that with cooling the current was obtained more than the without cooling.

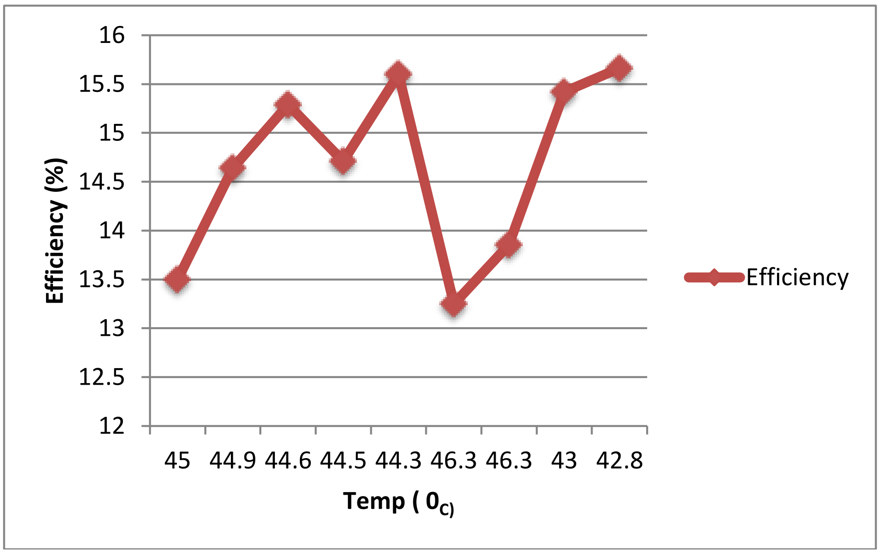

Figure 12. Variation of electrical efficiency with temperature

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