Performance Enhancement of Solar Photovoltaic Cells Using Effective Cooling

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Abstract- *The Photovoltaic (PV) cells are sensitive to temperature variations. When the ambient temperature and the intensity of solar irradiance falling on the PV cells increases, the operating temperature of the PV cells also increases linearly. This increase in operating temperature of the PV cells leads to reduction in open circuit voltage, fill factor and power output for mono and polycrystalline PV cells which are used in most of the power applications. The net results lead to the loss of conversion efficiency and irreversible damage to the PV cells materials. Therefore, to overcome these effects and to maintain the operating temperature of the PV cells within the manufacturer specified value, it is necessary to remove heat from the PV cells by proper cooling methods. The effective cooling of (PV) cells can be achieved by two methods i.e. active cooling and passive cooling.*

Keywords- Solar, Photovoltaic cells, cooling techniques for photovoltaic cell, Active cooling & Passive cooling.

I. INTRODUCTION

The growing global demand for electricity, rising fossil fuel prices and increasing apprehensions about global warming have reenergized the idea to rapidly move towards renewable energy resources, especially during last two decades. Solar energy is the most abundant energy source available on the earth. Though technologies for converting sunlight energy to power have made a lot of progress, high capital price and low conversion proficiency are the main obstacles to the common use of these technologies.

In order to increase the efficiency of solar power generation and make it a more cost-effective technology, different approaches have been attempted over the years consistently. Sun has lot of energy. We can use that energy and generate electricity by using Photovoltaic. Photovoltaic (PV) is a method of transforming sunlight into electricity with the help of semiconductor materials that show the photovoltaic effect. Photovoltaic systems are composed of a number of solar cells to supply serviceable solar power.

PV cells absorb up to 80% of the incident solar radiation, however only small part of the absorbed incident energy is converted into electricity depending on the conversion efficiency of the PV cell technology used. The remainder energy is dissipated as heat and the PV module can reach temperatures as high as 40ºC above ambient. This is due the fact that PV cells convert a certain wavelength of the incoming irradiation that contributes to the direct conversion of light into electricity, while the rest is dissipated as heat. The limited efficiency is associated with the band-gap energy of the semiconductor material. Crystalline silicon PV cells can utilize the entire visible spectrum plus some part of the infrared spectrum.

The energy of the infrared spectrum, as well as the longer wavelength radiation is not sufficient to excite electrons in the semiconductor material to cause current flow. On contrary, higher energy radiation is capable of producing current flow; however, much of this energy is similarly unusable. Consequently, radiations with high and low energies are not usable by the PV cell for electricity generation, and instead are dissipated at the cell as thermal energy. For crystalline silicon PV cells, a drop in the electrical power output of about 0.2-0.5% was reported for every 1°C rise in the PV module temperature principally due to the temperature dependence of the open-circuit voltage of the cell depending on the PV technology. Such property of PV cells is known as the Temperature Coefficient of the PV cell.

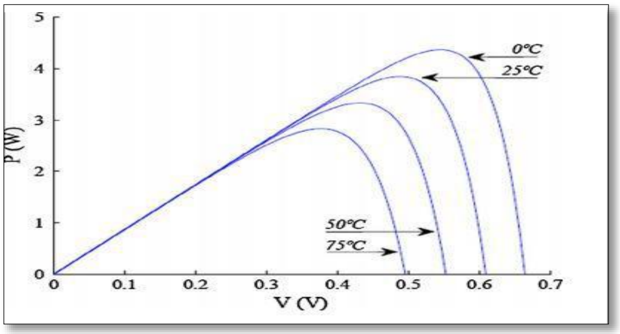


Figure: 1.1 P-V Characteristics as a function of the temperature Tm.

Therefore main obstacles that face the operation of photovoltaic panels (PV) are overheating due to excessive solar radiation and high ambient temperatures. Overheating reduces the efficiency of the panels dramatically. The P–V characteristic is the relation between the electrical power output P of the solar cell and the output voltage V, while the solar irradiance E and module temperature Tm are kept constant. The maximum power output from the solar cells decreases as the cell temperature increases, as can be seen in Fig.1.1 this indicates that heating of the PV panels can affect the output of the panels significantly. The Ideal PV characteristics solar cell for a temperature variation between 0^o to 75^o shown in Fig.1.1 which is adopted from Rodrigues [2].An automated Solar Panel water cooling system may result very efficient outcome with very few limitations.

II. LITERATURE REVIEW

The literature review was mainly carried out to know various developments related to solar PV panel cooling from last decades. This gives better understanding regarding the concept of solar PV panel cooling analysis and experimental investigation related to solar technology. Article from journal and conference where studied which included latest analysis and experimental investigation related to performance enhancement of PV module. The numbers of researches were presented by the different researcher for analysis of heat transfer through the solar PV module. Some researchers are as follows:

Dorobantu et al. [1] proposed a system to increase the efficiency of PV panels that makes a water film on the front surface of panels. The experiment was conducted on mono crystalline panel of 75W, which was cooled by a continuous film of water that pours on the working surface from the top of the panel. The cooling device for single module consists of a cylindrical tube with 25 holes, each with 1.5mm diameter. The diameter of the tube is 20mm and its length is equal to that of the panel. The panel was placed on the fixed frame with tilt angle of 35°. During the measurement the average radiation level was 780W/m^2 and rate of water flow was 33.3x10^{-6} m^3/s. The result showed that the front surface temperature was between 38.5°C and 41.5°C, the rear surface temperature was in between 50°C and 52°C and the power output was 73.11W for without cooling panel. For the panel with cooling, the front surface temperature was between 26°C and 27°C, the rear surface temperature was between 31°C and 32.5°C and the power output was 76.74W. The reduction in temperature brings a gain of 1.5V and drops of 0.2A. The net results lead to overall increase in power output of 3.5W and the percentage increase was 9.5%.

Balamurali krishnan et al. [2] investigated the performance improvement of solar PV panel by active cooling. The proposed cooling system consists of LM35 temperature sensor interfaced with PLC and placed over the panel. When the temperature of the panel reaches the 35 °C, the PLC controller actuates the water pump for 30s, which will spray the water on the top surface of the panel and provide cooling to the solar panel. The temperature was sensed after water spray and the cycle was repeated in order to maintain the temperature of the panel within the predetermined temperature. The results showed that the operating temperature of the panel was reduced by 8°C and the efficiency was improved by 3%.

Moharram et al. [3] Developed a heating rate and cooling rate models to predict the commencement of cooling of solar module by water cooling and the duration for which the water was sprayed in order to enhance the performance of the PV module and also to reduce the amount of cooling water and electrical energy needed to provide cooling. The heating model determines the maximum allowable temperature (MAT) at which the water to be sprayed to cool the solar PV module. They found from the mathematical model that the heating rate of the solar cells was 6°C/h and the cooling rate of the solar cells was 2°C/min for the water flow of 29 l/min. The experimental setup used six mono crystalline module of power output185W each and 120 water nozzles to spray water over the front surface of the module and found that the cooling rate was 2.05°C/min. They also observed that without cooling the temperature was increased from 35°C to 45°C and the efficiency dropped from 12% to 10.5%. The proposed cooling system reduced the operating temperature by 10°C in 5min and increased the solar module efficiency by12.5%. The selection of MAT was based on maintaining the efficiency of the modules at an acceptable level with least amount of cooling water and energy usage. They found that from net output energy vs. MAT, the optimum value of MAT to cool solar panels with least amount of water and energy usage was 45°C.

Zhu et al. [4] Presented an experimental study on water cooled PV module and concluded that the temperature of water-cooled PV module is lower than that of the air-cooled PV module. Therefore, the air-cooled module generates lower electrical power than the water cooled one. The flow rate induces an irrelevant effect on the electrical efficiency of water-cooled PV modules. However, the thermal efficiency of water-cooled modules increases significantly with the flow rate. The PV/T collector using amorphous silicon PV cells and an active-cooling attachment can reach high overall energy conversion efficiency.

Tang et al. [6] designed a novel micro-heat pipe array for solar panels cooling. The cooling system consists of an evaporator section and a condenser section. The input heat from the sun vaporizes the liquid inside the evaporator section and then the vapour passes through the condenser section, and finally, the condenser section is cooled down using either air or water.

Hence, the heat pipe can transfer the heat from solar panel to air or water depending on the system. Using air as a coolant was found to decrease the solar cells temperature by 4.7°C and increases the solar panel efficiency by 2.6%, while using water as a coolant was found to decrease the solar cells temperature by 8°C and the panel efficiency by 3%. Therefore, cooling by water was found to be more effective than cooling by air.

Abdolzadeh and Ameri [8] investigated the performance of photovoltaic cells which is used to drive the water pump by spraying water over the front surface of the PV panels. The experimental setup has two polycrystalline PV modules (45x2W) with 13.5% efficiency and one positive displacement type water pump. The PV cells are fixed at 10° facing south and the power produced from the array was used to drive the DC motor of the water pump. To spray water over PV cells, a tube with small holes placed on the top of the PV module is used. Temperature sensors were installed on the back of the two modules where the actual temperature is about 1.5 °C below the temperature on front of the modules. Irradiance and pump flow rate were measured by pyranometer and flow meter respectively. Data were recorded for every 15 min and the results showed that the operating temperature of the module with spray water reduced upto23 °C. The maximum operating temperature of the modules was 35 °C and 58 °C with and without spray water respectively. The mean power output of the panel with cooling increased to 66.9W instead of 55.4W without cooling. The mean flow rate of the pumping system was increased from 479l/h to 644l/h. The mean volume of water used for spraying over the cells was about only 50l/h. The PV cells achieved 12.5% mean conversion efficiency during the test day. Water sprayed also improved the optical performance by 1.8%.

Hosseini et al. [9] investigated the combination of a photovoltaic system cooled by a thin film of water with an additional system to use heat transferred to the cooling water. The experimental setup was composed of two similar but separate solar PV panels each with area of 0.44m2. The maximum power output was 60W with the maximum output voltage and current of 23V and 2.61A respectively. One of the panels was used in a combined system with a film of water running over its top surface without front glass and an additional fabricated system to use the heat generated by the panel. The other panel is a conventional PV as a reference panel and to produce a film of water over the PV panel, a tube with slit was installed on the top end of the PV panel. Water pumped to the feeding tube leaves the slit and flows over the panel as a thin film. The water collected at the lower end of the panel passed through a finned tube used as heat exchanger to utilize the heat taken by the cooling water. Thermocouples were installed on the back surface of the panels to measure the panel operating temperature. The results showed that due to water flow over the panel surface and additional cooling by water evaporation, the panel operating temperature measured was much lower in comparison to the conventional reference panel and a maximum temperature difference of 18.7 °C was observed. This temperature reduction has a noticeable improvement in electrical efficiency and the relative difference was more than 33%.

Smith et al. [11] measured an increase in power yield for concentrated cells by cooling the front side with spraying water. Mono crystalline PV panels were used, without panel specifications. Another group of panels was also measured as a test group. Concentration factor was omitted. Water flow was at maximum 0.116 kg/s. Net power gain for regular water cooling was 4.6 %, when pump consumption is taken into account. When ice water was used (2.5 °C at the entrance), largest power improvement was 24 %. When light concentration and ice water cooling was combined, power increase was 43 % greater than that of the control group.

III. COOLING TECHNIQUES FOR PV PANEL

Solar Panels efficiency decreases by half when the temperature is very high, or exceeds 45°C. That is why; the PV panels should necessarily have a cooling down system to benefit from maximum power generated. The main advantage of cooling is evident: higher electrical output. However, cooling requires a separate system which will remove heat to some extent. The principle advantage of cooling is to have a higher electrical yield generated. In any case, cooling requires a different framework which will expel heat from the system and maintain an allowable temperature. The development and maintenance of that structure can be costly and there is plausibility that its cost support could exceed the advantages of the enhanced electrical yield. Hence, overall electrical gain can be discussed in most of the studies made for example. Cooling can be recognized in two different types: active cooling is a type that requires energy (pump, motor, fan, etc.) and passive cooling, which is about using natural convection/conduction to extract the heat from the system. Active cooling by spraying the water over the front surface of the module is the best alternative in present conditions of technology.

3.1 Active cooling by spraying the water over the front surface of the module

At high operating temperature conditions, air cooling fails to accommodate the temperature rise at the surface of PV cells causing critical drop in their conversion efficiency. Water cooling offers a better alternative to air cooling utilizing coolant as heat extraction medium to maintain desired operating temperature of PV cells and a more efficient utilization of thermal energy captured. Typical reduction in the electrical unit of PV module is by 8-16% due to reflection of the sun's radiation from the front surface. Anti-reflective coating is being used to reduce this loss but they are not durable. Expensive structured surfaces were also used but there is the difficulty to clean due to the accumulation of dust and dirt. When water is passed over the front surface the refractive index becomes 1.3, [24] this reduces the reflection losses by 2.1-3.7 % additional cooling also takes place because of the evaporation of water flowing over the front surface the overall operating temperature of the PV module was reduced by 22 ℃ as compared to without cooling Electrical yield also increased to 10.4 % during the whole day.

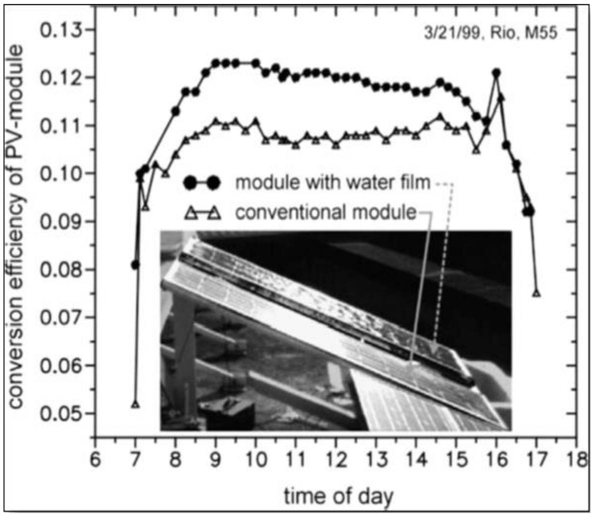


Figure: 3.1 Comparison of photovoltaic conversion efficiencies of the PV-modules [16]

IV. EXPERIMENTAL SETUP

An experimental setup has been developed to study the effect of cooling by water on the performance of photovoltaic (PV) module. The standard working temperature of PV module is 25°C but as we are studding this setup in Amravati, Maharashtra, India the ambient temperature is quite high which at peak is 48°C. So assuming MAT (Maximum Allowable Temperature) at 40°C.The setup consists of solar panel, water pump, wiping motor, wiping system, temperature sensor, controller, digital thermometer and multi meter, Panel mounting frame, storage tank and settling tank. The components above are explained in detail below.

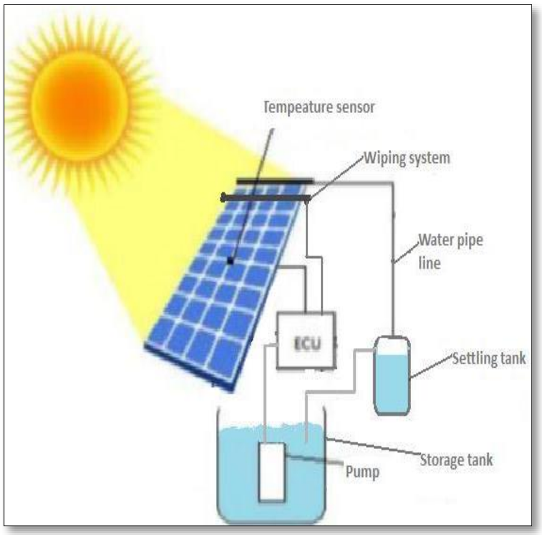


Figure: 4.1 Schematics of cooling system.

4.1 Solar Panel

Solar panels absorb the sunlight as a source of energy to generate electricity or heat. A photovoltaic system mainly consists of an array of photovoltaic modules, an inverter, a battery for storage, some interconnection wiring and optionally a solar tracking mechanism. Photovoltaic modules use light energy (photons) from the Sun to generate electricity through the photovoltaic effect. Most modules are rigid, but semi-flexible ones are available, based on thin-film cells. The cells must be connected electrically in series, one to another. Externally, most of photovoltaic modules use MC4 connector type to facilitate easy weatherproof connections to the rest of the system. The photovoltaic cell used in this project had a peak power of 50W, voltage of 21.5 V and current of 3.14 amps.

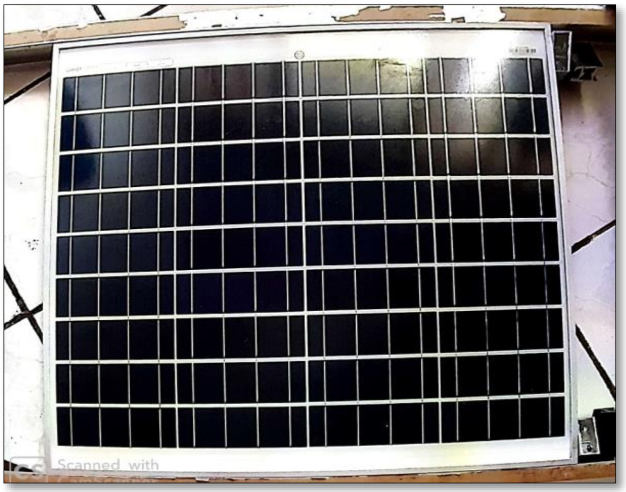


Figure 4.2: -Solar Panel

4.2 Water Pump

This solar cooling system included a miniature submersible water pump which is one of the core components of this project. This pump would activate when it received a signal from the controller. The pump used in this project was a 12V DC pump. It can take upto 120 liters per hour with very low current consumption of 220mA. Water storage was also used for the proper supply of water. The pump elevated the water head and supplied it to the solar panel through spray. Here in this system the pump was actually submerged in the water reservoir thus always in contact with water.

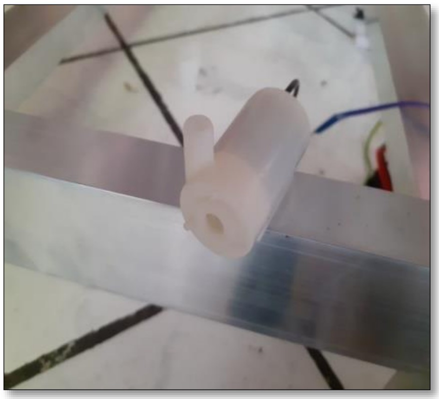


Figure: 4.3 Water pump**.**

4.3 Temperature Sensor

LM35 type of temperature sensor was used in this experiment. The LM35 device has an advantage over linear temperature sensors calibrated in Kelvin, as the user is not required to subtract a large constant voltage from the output to obtain convenient Centigrade scaling. The LM35 device does not require any external calibration or trimming to provide typical accuracies of ±¼°C at room temperature and ±¾°C over a full −55°C to 150°C temperature range. It senses temperature from the solar panel and sends it to the microcontroller which will activate the water pump in a certain temperature to prevent the temperature rise.

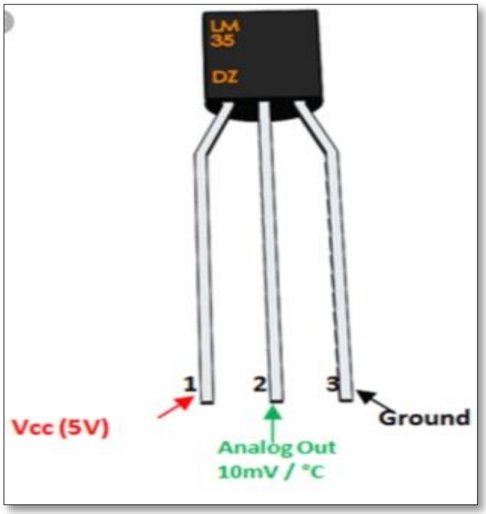


Figure 4.4: - LM35 Temperature sensors

4.4 Wiping Motor

This motor is simple 10 RPM 12 V DC motors featuring gears for the shaft for obtaining the optimal performance characteristics. This is known as Centre Shaft DC Geared Motor because their shaft extends through the center of their gear box assembly. This was used to operate the wiping system of the PV module with the help of pulley and thread mechanism. This motor operates on the power generated by the PV module.

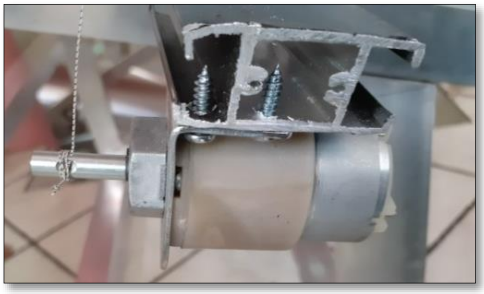


Figure: 4.5 Wiping motor.

4.5 Wiping System

It is reasonable to assume that solar panels can lose 15-25% of their efficiency if not cleaned properly. Spraying water is not enough to clean the panel. The dirt caused by birds need a proper cleaning system. The wiping system consists of 10 rpm 12 V dc motor to operate the wiper blade through the thread and pulley mechanism. The wiping blade moves left to right horizontally on the panel thus this makes it more prominent option for large array system. Wiping a panel once in a day is enough for efficient cleaning and power used for cleaning.

Figure 4.6: -Wiping system.

4.6 Controller

A microcontroller is a self-contained system with peripherals, memory and a processor that can be used as an embedded system. In this project PIC16F87XA was used as microcontroller. The PIC16F87XA is a microcontroller board based on the PIC16F874A .It has 20 digital input/output pins (of which 8 can be used as PWM outputs), 8 analogue inputs, and a 20 MHz ceramic resonator. Flash Program Memory of 14-bit words. It contains everything needed to support the microcontroller; simply connect it to solar module output to get started. It is programed to actuate the wiping motor once daily. The controller start water pump for10 seconds before the wiping motor starts for effective cleaning. It is programed to start the water pump at 45°C panel temperature till it drops to 40°C.

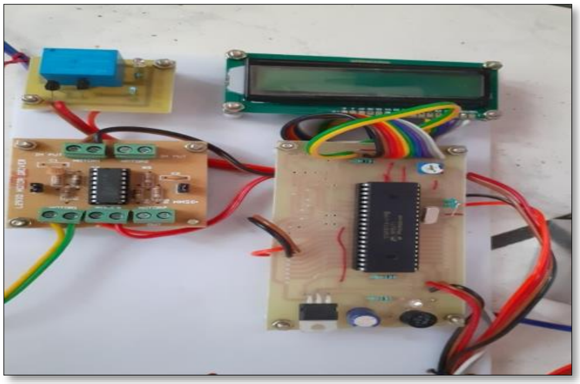


Figure 4.7: - Controller

4.7 Storage tank

It is simple cooling water storage container made up of PVC material. In actual practice the water cooling system should be coupled with the rain water harvesting. As the rain water does not contain any kind of dissolved salts it prevents the scaling of front surface of the PV panel. The water collected from the roof top is stored in an underground water tank. The underground water tank helps to maintain the temperature of water well below the ambient conditions.

V. METHODOLOGY

Solar Photovoltaic (PV) cells can absorb up to 80% of the incident solar radiation obtained from the solar band, however, only a small amount of this absorbed incident energy is transformed into electricity depending on the conversion efficiency of the PV cells and part of remainder energy increases the temperature of PV cell. High solar radiation and ambient temperature lead to an elevated photovoltaic cell operating temperature, which affects its lifespan and power output adversely. There are Number of techniques have been attempted to maintain the temperature of photovoltaic cells close to their nominal operating temperature i.e. 25°C. Spraying water on the front surface of PV cell is the best alternative among these.

Figure 5.1: -Actual setup**.**

In this project, study has focused on the comparative data of PV panel output with and without water cooling. Here polycrystalline 50W solar panel has used which is used to drive the water pump for spraying water on the front surface of PV panel as well as wiping system which is used for effective cleaning of the panel. The panel is mounted on aluminium frame at an angle of 21°. The angle of panel is calculated from the latitude and longitude of the location where project is to be executed. A water tank of 3.5 litres is provided at the bottom for cooling water storage. Submersible pump is use for lifting the cooling water from storage to the spraying tube which is attached at the top of the panel. The spraying tube 8mm outer diameter and 6mm inner diameter is made of PVC material having 10 evenly spaced holes for proper distribution of water on the surface of the PV panel.

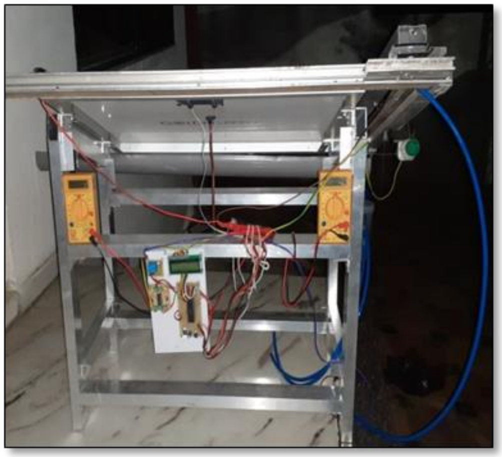


Figure 5.2: -Controller of cooling system.

Controller is use for automation of water pump and wiping motor such that at every morning the wiping system is actuated for a single wiping operation. This operation is not repeated for whole day again. The water pump is turn on for 5 second before the wiping motor starts. The wiper blade is driven by thread and pulley mechanism from right to left in horizontal plane. A temperature sensing unit LM35 is attached at the back side of the PV panel which displays the temperature of panel on the controller. The water pump starts as the panel temperature reaches 45°C and remains on till the temp drops to 35°C. The water pump is operated at constant flow rate of 120 litres /hr. The panel temperature drops gradually due to flow of water and natural air convection which result in better output of panel.

In this project desalinated cooling water is used to prevent the scaling of the panel which can affect the performance of the panel. But in case if it is not possible to use desalinated water for cooling. A filter is added to the system which is filled with water softening resin such as PUROLITE C100 this removes the salts present in the water. The resin can be used for multiple times by washing it when it gets clogged by the salts. It is best recommended to use the water cooling system of PV panel with rain water harvesting system as rain water does not contain salts.

VI. EXPERIMENTATION

6.1 PV module specification.

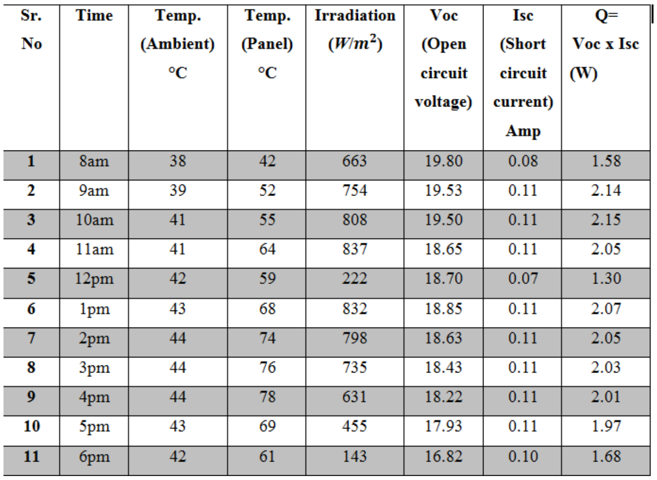
These are the predetermined data that were used in this project. These data were taken form measurement and manufacture provided sheet. The data was needed for efficiency calculation.

Model no. = GOLDI050PM
Cell type = Poly crystalline silicon.
Solar cell length=64 cm=0.64 m
Solar cell breadth= 52 cm=0.52m

Area of the cell= (0.64×0.52) m² = 0.33 m²
Maximum output= 50 W
Open circuit voltage (Voc) = 22.5 V
Short circuit current (Isc) = 3.14 A
Voltage at maximum power (Vmp) = 18.29 V
Current at maximum power (Imp) = 2.85 A
Panel efficiency = 12.86%
Fill factor = 71.91%
Maximum system voltage = 1000 V
By these basic measurements data were recorded from 22th to 24th May in between 8 am to 6 pm on the roof-top at Amravati, Maharashtra India.

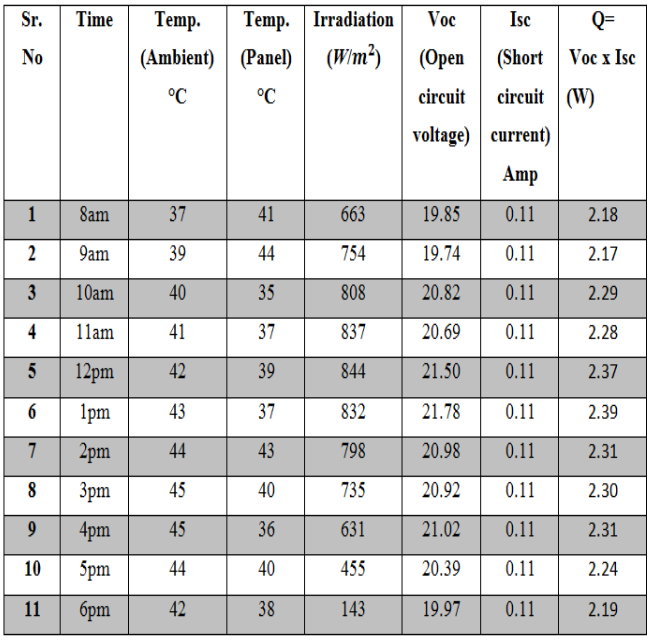
6.2 Experimental Observation results.

6.2.1 Observation Table of without cooling at constant load.



Sr. No	Time	Temp. (Ambient) °C	Temp. (Panel) °C	Irradiation (W/m^2)	Voc (Open circuit voltage)	Isc (Short circuit current) Amp	Q= Voc x Isc (W)
1	8am	38	42	663	19.80	0.08	1.58
2	9am	39	52	754	19.53	0.11	2.14
3	10am	41	55	808	19.50	0.11	2.15
4	11am	41	64	837	18.65	0.11	2.05
5	12pm	42	59	222	18.70	0.07	1.30
6	1pm	43	68	832	18.85	0.11	2.07
7	2pm	44	74	798	18.63	0.11	2.05
8	3pm	44	76	735	18.43	0.11	2.03
9	4pm	44	78	631	18.22	0.11	2.01
10	5pm	43	69	455	17.93	0.11	1.97
11	6pm	42	61	143	16.82	0.10	1.68

6.2.2 Observation Table of with cooling at constant load.



Sr. No	Time	Temp. (Ambient) °C	Temp. (Panel) °C	Irradiation (W/m^2)	Voc (Open circuit voltage)	Isc (Short circuit current) Amp	Q= Voc x Isc (W)
1	8am	37	41	663	19.85	0.11	2.18
2	9am	39	44	754	19.74	0.11	2.17
3	10am	40	35	808	20.82	0.11	2.29
4	11am	41	37	837	20.69	0.11	2.28
5	12pm	42	39	844	21.50	0.11	2.37
6	1pm	43	37	832	21.78	0.11	2.39
7	2pm	44	43	798	20.98	0.11	2.31
8	3pm	45	40	735	20.92	0.11	2.30
9	4pm	45	36	631	21.02	0.11	2.31
10	5pm	44	40	455	20.39	0.11	2.24
11	6pm	42	38	143	19.97	0.11	2.19

NOTE: - Water pump was switch off while taking readings and switch ON again after noting the reading.

6.3 Calculation.

1) Details of PV module.

- Cell type = Poly crystalline silicon.
- Maximum output = 50 W
- Solar cell length = 64 cm = 0.64 m
- Solar cell breadth = 52 cm = 0.52m
- Area of the cell(A) = (0.64×0.52) m² =0.33m²
- Tilt angle = 21°

2) When cooling system was not activated.

- Number of observations = 11
- Sum of solar irradiance = 6878 W/m²
- Average solar irradiance (Ga) $= \frac{\text{Sum of solar irradiance}}{\textit{Number of observations}} = \frac{6878}{11} = 625$ W/m²
- Sum of power (Q) = 20.76 W
- Average power $= \frac{\text{Sum of power}}{\textit{Number of observations}} = \frac{20.76}{11} = 1.88$ W
- Solar intensity on the PV panel = (Ga×A) = (625×0.33) W = 206W
- Efficiency of the solar panel when cooling system was not activated(η_1)
  $$\eta_1 = \frac{\text{Average power}}{\text{Solar intensity on the PV panel}} \times 100$$
  $$\eta_1 = \frac{1.88}{206} \times 100 = 0.91\%$$

3) When cooling system was activated.

- Number of observations = 11
- Sum of solar irradiance = 7500 W/m²
- Average solar irradiance (Ga) $= \frac{\text{Sum of solar irradiance}}{\textit{Number of observations}} = \frac{7500}{11} = 682$ W/m²
- Sum of power (Q) = 25.03 W
- Average power $= \frac{\text{Sum of power}}{\textit{Number of observations}} = \frac{25.03}{11} = 2.28$ W
- Solar intensity on the PV panel = (Ga×A) = (682×0.33) W = 225W
- Efficiency of the solar panel when cooling system was activated(η_2)
  $$\eta_2 = \frac{\text{Average power}}{\text{Solar intensity on the PV panel}} \times 100$$
  $$\eta_2 = \frac{2.28}{225} \times 100 = 1.013\%$$

4) Analysis of data with and without cooling system.

- Increase in average power output
  $$\frac{2.28-1.88}{1.88} \times 100 = 21.28\%$$
- Increase in solar panel efficiency (η)
  $$\eta = \frac{\eta 2 - \eta 1}{\eta 1} \times 100 = \frac{1.013-0.91}{0.91} \times 100 = 11.32\%$$

VII. RESULTS AND DISCUSSIONS

The both with and without cooling system solar module was tested in the month of May, 2019 at intervals of one hour between 8am to 6pm. The panel and ambient were measured by thermometer with a precision of 0.5°C. The voltage and ampere were measured by multi meter. The solar PV module efficiency of the system was calculated using standard Eq. of efficiency. The incident solar radiation intensity was taken from online data available. The hourly variation of the solar intensity vs. time graph is shown in Figures.

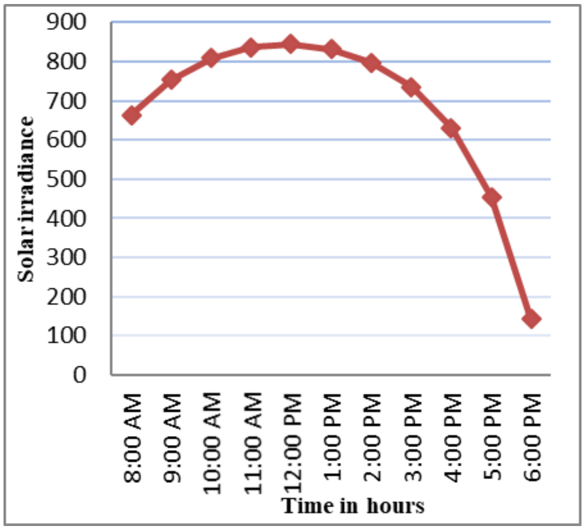


Figure 7.1: - The curve for solar irradiance against time.

The solar irradiance is increasing from 8am to12pm, reaching a maximum value of 844 W/m2 at 12.00 hour as shown in figure. The solar irradiance decreasing after 12:00 hours then PV module efficiency also decreases.

From the calculated data, it is seen that, without cooling system the overall efficiency of the solar PV cell is 0.91% and when cooling was implemented on the panel it increased to 1.013%. From these data, the overall efficiency was increased to 11.32% for constant load of 0.11 ampere.

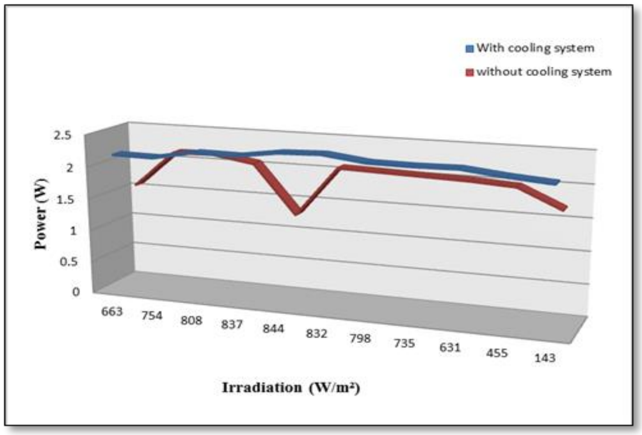


Figure 7.2: - The curves for power against solar irradiation**.**

Through the experiment and calculated data, it indicates that if the temperature is controlled to a certain limit, the efficiency of the PV panel increases. From figure7.2 it has been seen that, the output power has increased with the increase in irradiation. But the amount is significantly large in case of with cooling system which is clearly visible.

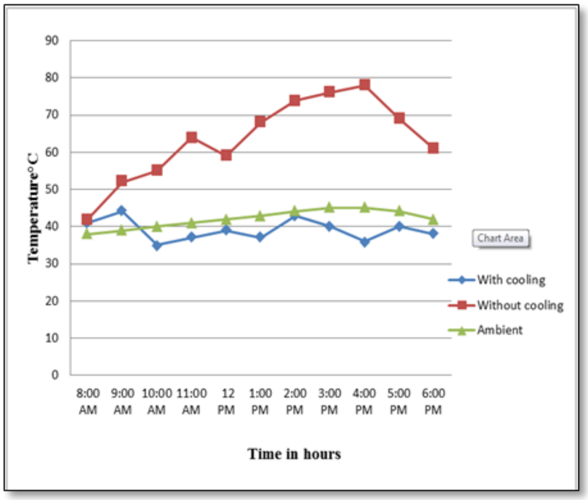


Figure.7.3:- Comparison between ambient temperature and module temperature with cooling and without cooling condition.

Figure7.3 indicates the solar panel surface temperature. The cooling system did not allow the surface temperature to increase much. But without cooling system, the surface temperature increased significantly and it caused the overall output lower than solar cell with cooling system. The selection of the maximum allowable temperature (MAT) is based on maintaining the efficiency of the panels at an acceptable level with the least amount of water and energy usage. It can be seen from the figure that 40°C is MAT for the PV cell in month of May for the location where the experiment is carried out.

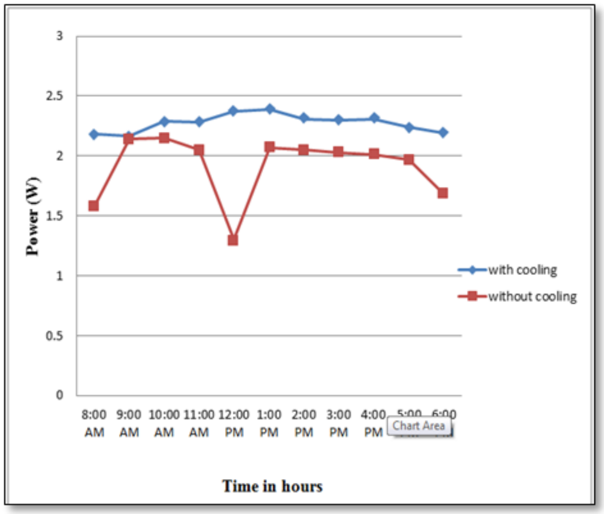


Figure.7.4:- The curves for power with and without cooling against time in hours**.**

The relationship among power, temperature and irradiation it is seen from the graphs that, temperature increase makes a negative impact on the power production. On the other hand, irradiation makes a positive impact. With the increase in irradiation, power increases. The cooling system lowers the cell temperature at high irradiation and converts the most of the irradiation to produce power and thus solar cell with cooling system increased the efficiency up to 11.32%.The system also helps to prolong the solar panel life span as high temperature reduces the cell life span and damages the cell significantly faster.

VIII. CONCLUSIONS

In this research, the performance of PV panels was enhanced by developing an efficient cooling and cleaning system. The comparison had been made between the output from the PV Module with and without using the cooling system. The objective was to cool the PV module with the least amount of water and energy. A cooling system was developed based on spraying water on the PV module. The experimental setup developed to create an effective model that significantly improved the output of the PV cell and to study the influence of cooling on the performance of PV module.

This work shows that decreasing the panel operating temperature, when subjected to cooling apparatus, is the factor responsible for the increase of the voltage and consequently the increase of the amount of energy produced. But this system can also be a part of hybrid cooling system which can be implemented in solar power plant. There was option of reusing the water. So helps in optimal use of cooling water. In overall the system consumed much power than the solar module actually could have been produced, but the same system can be implemented on larger solar PV array system and then the cooling system would be more beneficial and efficient for the solar cell.

- This model will enable the temperature to stay in the range of 35°C < T <45°C in order to benefit from a maximum efficiency and therefore a maximum power output.
- Increasing cooling efficiency by 11.32% due to the direct contact between water and PV module surface.
- Maintaining the PV module upper surface free of dust and dirt cause by birds with flow of water and wiping system.
- A cooling technique that is simple and can be added to any standard module without a significant increase in cost.

IX. FUTURE SCOPE

As the conventional energy sources are getting exhausted non-conventional energy sources like solar energy will play a major role in the field of energy. As confronted with a growing demand for electricity in recent years and the need to reduce its greenhouse gas emissions solar powered grid interactive system will play a major role in this field.

- Further research can be carried out in this area by increasing the scale of the experimental setup and trying to manufacture the cleaning and cooling system as possible.
- This research can also be used for the study of hybrid heating systems and efficiency enhancement during winters and summers respectively.
- Investigation of cooling agent having higher thermal conductivity, fast cooling rate and low evaporative index Instead of using water as a cooling agent on economical range.
- Study need to be carried in the direction of utilization of heat extracted by the cooling water from PV modules.
  Development of automated active cleaning system and implementation on large scale to monitoring it`s performance.

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