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Optimization and Analysis of Solar Cell due to Temperature Effect

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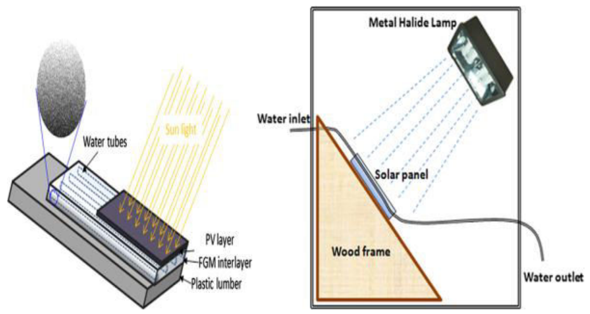
Abstract—Solar energy is one of the significant renewable energy sources. In India it is of much significance as summers are predominant for the major part of the year. It has been found out that temperature of solar panels increases twice with the ambient temperature. In Rajasthan ambient temperature reaches above 400C and the temperature of solar panel reaches to 800C. The solar panels available in India are European manufactured according to their standards which are not suitable to Indian conditions. European summers can be considered as Indian winters and it is required to manufacture solar panels suitable to Indian conditions. Further it should be noted that efficiency of solar panels starts decreasing with increasing temperature. The only parameter that changes with temperature is the Voc. Although current also changes, but the Voc change is more dominant. The rate of change of Voc is about 2mV/°C (for crystalline solar cell). The electrical power developed in the panel is because of the flow of electrons when the photons from the sunlight hits the solar panel which separates the hole and electron but at higher temperature the recombination of electron and hole takes place which gives rise to the reversed saturation current. So there is need to reduce the temperature of solar panels to have their optimum usage. One method of doing this is by providing paraffin wax on other side of the panels to absorb their heat. Copper tubes attached to paraffin wax radiates heat to water in the tank and by this way water gets heated which can be used for various purposes. Other method is by providing fan on one side of the panels to reduce their temperatures. We are conducting our research with the hypothesis that the efficiency of solar panels is inversely proportional to its temperature.

Keywords—***Open circuit voltage, short circuit current, fill factor, phase change material, photovoltaic efficiency.***

I. INTRODUCTION

Solar cell is a form of photoelectric cell which, when exposed to light, can generate and support an electric current without being attached to any external voltage source, but do require an external load for power consumption. A basic solar PV panel contains a semiconductor material covered by protective glass connected to a load. When sunlight hits the semiconductor, electrons become excited. These excited electrons are separated by an internal field inherent in the semiconductor and collected into an external circuit generating electricity. In present study we have analyze and optimize the poly-crystalline solar panel and thin film panel efficiency by controlling the temperature of the panel. The temperature of the solar panel is controlled by filling phase change material (paraffin wax), as the temperature of solar panel increases the wax starts melting and this heated wax is surrounded by copper tubes filled with water, the heated wax transfer heat to the water which in turn gets boiled and a well distilled water can be taken for use."High efficiency water distillation of humid air with heat recovery". The 100 W solar powered plant operates decentraly in a water capacity range of 2 to 20 ma/day. The high quality distillate water can be used as potable water or for agricultural applications [1]. The prediction of performance provided is particularly useful in comparing performance of different collectors and for studying a specific collector's performance with changes in environment and design parameters which can be controlled to some extent by the designer [2]. The analysis reveals that there is an increase in the output power of a solar panel by utilizing a reflecting mirror and a water circulation system, which affect the short circuit current and the open circuit voltage, respectively [3]. There is an increase of 40 mW cm2 as a result of utilizing the mirror and an increase of 0.70A was obtained. At the same time, the water circulation system helps to maintain the panel temperature around 37C, even when the reflecting mirror was utilized, and a difference of 1.20 V above the Voc of the normal panel was obtained from this system[4]. A solar cell panel for electricity generation and air/water is made flow in a duct placed below the surface on which the solar cells are mounted to extract heat from the system, thereby cooling the cells and increasing their efficiency. In a particular case considered the average values of the thermal efficiency of the PV/T collector with air/water heating for three flow rates and three duct depths. It is observed that, for water heating the thermal efficiency varies between 50 and 67%, while for air heating, it varies between 17 and 51% [5].

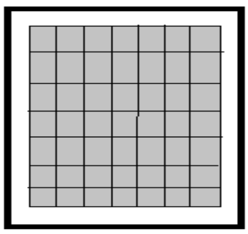


The performance of as PV/T collector can be improved if the heat-collecting plate, the PV cells and the glass cover are directly packed together to form a glazed collector. The overall performance of a PV/T system, including thermal and electric conversion, is affected by many factors. The thermal efficiency decreases with increasing hot water temperature. Increasing hot water temperature in order to meet some application requirements would in turn cause the power generation efficiency of solar PV to decrease [7]. A significant efficiency increase of these systems can be also obtained by optimal exposure of the panels to the sunlight, by using automatic solar trackers. Simple rotations of the panel based on complete tracking, by azimuth and elevation. The possible regulation angle is in the range of 30 -150° [8]. For the comparison of two simple, fast and reliable maximum power-point tracking (MPPT) techniques for photovoltaic (PV) systems: the voltage-based (VMPPT) and the current-based (CMPPT) approaches. The main advantage of this new MPPT, is the elimination of reference (dummy) cells which results in a more efficient, less expensive, and more reliable PV system [11].The effectiveness of a hybrid solar collector that generates both electric power and heat. First, experiments under constant supply temperature of brine were made and it was found that conversion efficiency ranged from 10% to 13%, and that collector efficiencies at 20 and 40ºC brine temperature were from 40% to 50% and approximately 20%, respectively. The collector efficiency of the hybrid solar collector was lower than that of the solar collector. Total energy efficiency and exergy efficiency of the solar energy utilization systems were analyzed. The total energy efficiency of hybrid solar collector is roughly equivalent to that of solar collector, and the total exergy efficiency is the highest of the three systems. The hybrid system is expected to reduce panel installation area by approximately 27% [12]. An overall efficiency of panel with length does not vary much after 3m length of system. Effect of duct depth on the variation of an overall efficiency indicates that an overall efficiency increases with increase of duct depth as expected. The optimum value of duct depth lies between 0.03–0.06 m [13]. The behaviour of a photovoltaic (PV) panel submerged in water is studied. A sizeable increase of electric power output is found for shallow water. It is important to stress that the temperature of the submerged panel is spatially homogeneous and varies very little during the day. This has a double positive effect: on the efficiency of the PV module, since the mismatch among different cell behaviours, due to non-uniform cell temperatures is avoided, and on the PV system, with a reduction on cable power losses and a more effective sizing and operation of the inverter [15]. Solar cell varies under temperature changes; the change in temperature will affect the power, output from the cells. The effects of temperature on photovoltaic module investigated and by using basic equation a relation between efficiency, sun radiation and temperature is proposed [18].

The Solar Photovoltaic system is efficient under certain weather condition. The predicted performances for specific collector's was compared with changes in environment and design parameter and make prediction that the collector's efficiency varies with change in environment condition by Blaine F Parker(1983). The effect of solar irradiation and temperature on solar panel and analysis reveals that by utilizing a reflecting mirror and a water circulation system there is an increase in power output by A.A. Al-Baali (1986). For efficient electricity generation air/water is made to flow in a duct placed below the surface on which the solar cells are mounted to extract heat from the system, thereby cooling the cells and increasing their efficiency by Jai Prakash(1993). Solar cell varies under temperature changes; the change in temperature will affect the power, output from the cells by V.JafariFesharaki (2011). A hybrid solar panel has been invented to integrate photovoltaic (PV) cells onto a substrate through a functionally graded material (FGM) with water tubes cast inside, through which water serves as both heat sink and solar heat collector by D.J. Yang (2012).From the above literature I have concluded that with the increase in ambient temperature, voltage, efficiency and power output decreases and there is an increment in reversed saturation current. So, there is a need to cool the panel when the temperature of the panel above 48˚C.

Solar PV Module

Photovoltaic modules are used in PV system for generating electricity. PV modules are available in the range of power rating that varies from small 2Wp modules to up to 300Wp modules. Also, these modules are made from different types of materials. Therefore, as a user, one should be able to identify the PV modules made out of different materials. At the same time, system installers, engineers and technicians working in the area of solar PV modules for their power ratings and various other parameter. The crystalline Si solar cell technology is known as the first generation solar cell technology. There is also a second generation solar cell technology which include CdTe (cadmium Telluride), CIGS (copper indium gallium sellenide) and a-Si (amorphous Si). These second generation technologies are also referred as the thin film technologies. These technologies are also commercially available. The PV modules that are made using crystalline Si appear bluish in colour and also have thin metal contact lines (appear white) on the top. These metal contact lines are separated by few mm. In case of thin film solar PV modules, these visible metal contacts are not there, because instead of metals, transparent oxides are used to make metal contacts. The colour of thin film PV module can be dark grey. In an isolated silicon atom, the orbit of an electron is influenced only by the charges of atom. When silicon atoms are in crystal, the orbit of each electron is also influenced by charges of many other silicon atoms around it. Since each atom has a unique position inside the crystal, no two electrons at the same orbit level but belonging to different atoms see exactly the same pattern of surrounding charges. Therefore, for silicon atoms of whole crystal, the radius of each electron of the same orbit is slightly different and hence the energy levels of corresponding orbits are different. For every orbit, there are billions of slightly different energy levels that form a cluster or band of energy levels corresponding to each orbit. When an electron in a valance band receives sufficient energy to overcome energy gap, Eg, it jumps to next higher band known as conduction band leaving behind a hole in the valence band. In an intrinsic Si crystal, there are equal number of free electrons and holes. On application of voltage across such a crystal, the free electrons move in the conduction band while holes move in the valance band. No conduction is possible if all states within an energy band are occupied or when all states are empty.



When light shines on a solar cell photo-voltage is generated. The generated voltage across the solar cell drives the current in external circuit and therefore can deliver power. In order to collect energy of a photon in the form of electrical energy through solar cells following action must be taken (a) increase in potential energy of carriers, and (b) separation of carrier. Task (a) is performed efficiently by semi-conductor material. In order to perform task (b) asymmetry in semi-conductor device is required. Asymmetry should be such that the generated electron hole pairs should get separated from each other

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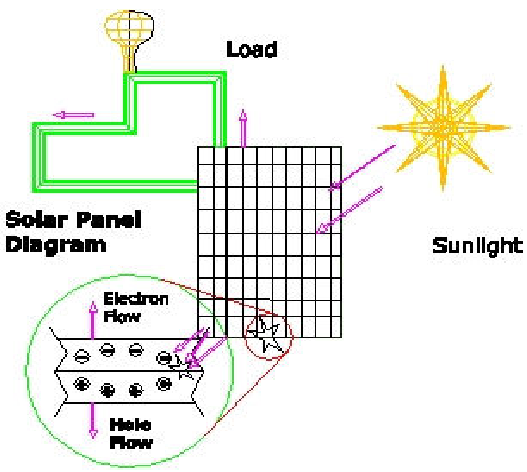


Once an electron-hole pair is generated within the junction (depletion layer), both carriers will be acted upon by the built-in electric field. Since the field directed from n top side, it will cause the holes to be swept quickly toward the n side. Once out of the junction region, these carriers became a part of the majority carrier in the respective regions and diffuse away from the junction region as their concentration near the junction has increased. This addition of excess majority charge carrier on each side of the junction results in a voltage across external terminals of the junction. If a load is connected across these terminals, the photon generated current will flow this external circuit. This current will be proportional to the number of electron hole pairs generated, which in turn, depends on the intensity of illumination. Thus, an illuminated p-n junction becomes a photovoltaic cell with positive terminals on p side.

If an electron-hole pair is generated near the junction (but not within it) then depending on how far it is from the junction, it may or may not contribute to the photocurrent. Suppose, for example, that an electron-hole pair is generated near the junction on the n-side. If the generated hole which is a minority carrier in the n-region, manages to reach the junction before it gets recombined, it will be swept across the junction on the p-side and contribute to photo current. If it gets recombined before reaching the junction, it is lost from the conduction process.

II. METHODOLOGY

The solar panels used in India are European manufactured or the technology used by the Europeans and hence its efficiency varies according to the weather condition. In winter season it has highest efficiency as compared to the summer season, as we know that the Europeans summer is somewhat like Indians winter. Therefore, there is a need to make the panel according to the weather condition according to climatic condition of the country.

Parameter of a Solar Module

The Current-Voltage relationship of a solar PV module can be given by the following equation:

$$I = I_L - [I_0 e^{\frac{q(V+IRs)}{nkT}} - 1] \quad \text{.....................eq.(4.1)}$$

Where, IL is the current generated due to light, Rs is the series resistance of PV modules, n is the ideality factor, I0 is the reverse saturation current, T is the temperature and k is the Boltzmann constant.

The various parameters of a solar PV module include Short Circuit Current (Isc), Open Circuit Voltage (Voc), Fill Factor (FF), Efficiency (η), Peak Power (Pm), Series Resistance (Rs) and Shunt Resistance(Rsh).

Short Circuit Current: The short circuit current, Isc, is the maximum current produced by a solar PV module when its terminal is shorted. Mostly Isc= IL

Open Circuit Voltage: The open circuit voltage, Voc, is the maximum voltage that can be obtained from a solar PV module when its terminal is left open.

$$V_{0c} = \frac{kT}{q} \ln\left(\frac{I_L}{I_0} + 1\right) \text{..................eq.(4.2)}$$

Power Output: The power output, Pout is the power produced by a solar module. The power output is the product of Open Circuit Voltage (Voc), Short Circuit Current (Isc) and Fill Factor.

$$P_{out} = V_{oc} \times I_{sc} \times F.F \text{......................... (eq.4.3)}$$

Fill Factor: The fill factor (FF) is defined as the squareness of the I-V curve and mainly related to the resistive losses in a solar module. It can be defined as the ratio of the actual maximum power output to the ideal maximum power output. In ideal case, its value can be 100% corresponding to square I-V curve. But it is not feasible to have square I-V. There are always some losses that reduce the value of FF. The best value of FF that can be obtained for a solar module can empirically be written as a function of Voc.

$$FF = \frac{V_{oc} - \ln(V_{oc} + 0.2)}{V_{oc} + 1} \text{..................eq.(4.4)}$$

The Fill Factor (FF) of a PV module can also be actually the area under the I-V curve. It is given in percentage.

$$FF = \frac{V_m I_m}{V_{oc} I_{sc}} \% \quad \text{..........................eq.(4.5)}$$

Efficiency: The module efficiency is given as:

$$\eta = \frac{P_{out}}{P_r} = \frac{V_m I_m}{P_r} = \frac{V_{oc} I_{sc} FF}{P_r} \%. \quad \text{...........eq.(4.6)}$$

Factors affecting efficiency of solar panel:

Loss of energy photons: The photons having energy less than the band gap energy do not get absorbed in the material and therefore, do not contribute to the generation of electron-hole pairs. This is referred as transmission loss, and is almost equal to 23% of single junction solar cell.

Loss due to excess energy of photon: In an ideal case only, photon of energy equal to the band energy is required to excite an electron from valence band to conduction. When the photon energy is higher than the band gap energy Eg, the excess energy = E-Eg is given off as heat to the material known as thermalization loss.

Voltage Loss: The voltage corresponding to the band gap of a material is obtained by dividing the band gap (potential energy) by charge

Fill factor loss: The I-V curve of ideal solar cell is square (i.e. F.F = 1), but in reality, the cell I-V curve is given by the exponential behavior. In best case, the F.F could be 0.89.

Loss by reflection: A part of incident photons is reflected from the cell surface. The reflection can be minimized by using anti-reflective coating and surface texturing.

Loss due to incomplete absorption: It refers to the loss of photons which have energy to get absorbed in the solar cell, but do not get absorbed in the cell due to limited solar cell thickness.

I. EXPERIMENTAL RESULT AND DISSCUSSION

Effect of Temperature on Solar cell

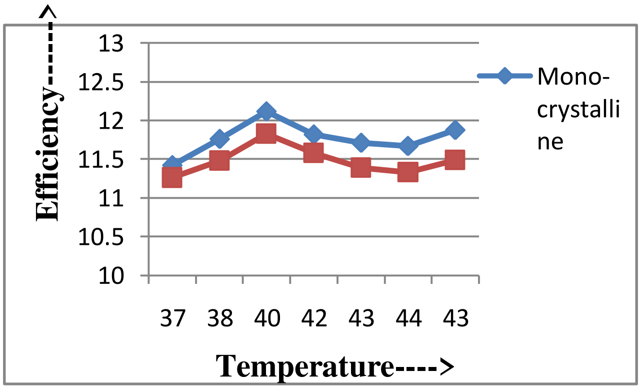
An increase in temperature causes reduction in band gap. This in turn, causes some increase in photo-generation rate and thus a marginal increase in current. However, the reverse saturation current increases rapidly with temperature. Due to this, the cell voltage decreases by approximately 2.2mV per ºC rise in operating temperature, depending on the resistivity of the silicon used –higher the silicon resistivity, more marked is the temperature effect. Also, the fill factor decreases slightly with temperature.

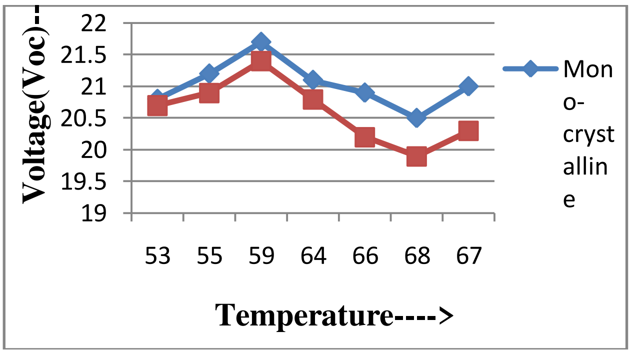
Verification of Loss in Solar Cell due to temperature effect

The verification of loss of solar cell due to temperature is performed on the both Poly-crystalline and Mono-crystalline Solar cell. The experimentation is done on 16th, 17th and 18th of April 2014. While experimentation we require two 100W Poly-crystalline and Mono-crystalline cell, charge controller, battery and loads. For measuring the electrical power output, we require voltmeter, ammeter and thermocouple. The result came out is that the efficiency of Mono-crystalline is better than Poly-crystalline Solar Panel and the efficiency of both the panel decreases with the increase in temperature after certain period of temperature and time.

Date:		16/04/2021		17/04/2021	
Time	Avg. atm. temp. (˚C)	Mono-crystalline Efficiency	Poly-crystalline Efficiency	Mono-crystalline Efficiency	Poly-crystalline Efficiency
10:00 am	37	11.17	10.87	11.5	11.37
11:00 am	38	11.41	11.01	11.83	11.69
12:00 noon	41	12.24	12.02	12.08	12.04
01:00 pm	42	12.25	11.79	12.05	11.91
02:00 pm	43	12.02	11.73	12.02	11.97
03:00 pm	44	11.59	11.57	11.82	11.76
04:00 pm	43	12	11.61	11.94	11.89

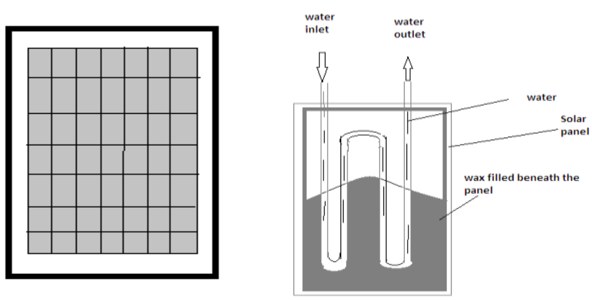
From the above table it is clear that that the efficiency of the Solar Panel whether Mon-crystalline or Poly-crystalline decreases and the investigation done by V.JafariFesharakiin (2011) that the variation of temperature throughout the day effects the panel efficiency is true. The graphs drawn from the observation taken are as follows:





Modification in Existing Solar panel: To improve the efficiency of the panel. An attempt is made for the improvement of the panel efficiency by reducing the temperature of the panel when the temperature of the panel crosses 60˚C by using heat transfer medium wax having melting temperature of 50˚C for making the system efficient wax is passed through the cooling water which provides the cooling of wax and the heat gained by the wax is transferred to the water which in turn heat up the water. The hot water from the panel can be used in domestic purpose.

Test is conducted on 40 W Poly-crystalline is used for comparing the efficiency of the existing panel and the modified panel, existing panel is having normal connection without having any cooling medium and the modified panel is filled with wax for absorbing the heat generated in the solar panel and copper tubes filled with water is circulated between the wax for absorbing the heat of wax.



The observation taken for the modified solar panel is:

Date: S.No	19/05/2021 Time	Panel Temp.	Voltage	Current	Power output	Efficiency
1	10:00 am	56	18.92	1.43	22.19	11.2
2	11:00 am	59	18.98	1.44	22.41	11.32
3	12:00 noon	63	19.03	1.45	22.63	11.43
4	01:00 pm	68	18.81	1.47	22.67	11.45
5	02:00 pm	72	18.75	1.47	22.6	11.41
6	03:00 pm	76	18.48	1.48	22.43	11.33
7	04:00 pm	74	18.65	1.47	22.48	11.35

Date:		16/04/2021		17/04/2021	
Time	Avg. atm. temp. (˚C)	Mono-crystalline Efficiency	Poly-crystalline Efficiency	Mono-crystalline Efficiency	Poly-crystalline Efficiency
10:00am	37	11.17	10.87	11.5	11.37
11:00am	38	11.41	11.01	11.83	11.69
12:00 noon	41	12.24	12.02	12.08	12.04
01:00pm	42	12.25	11.79	12.05	11.91
02:00pm	43	12.02	11.73	12.02	11.97
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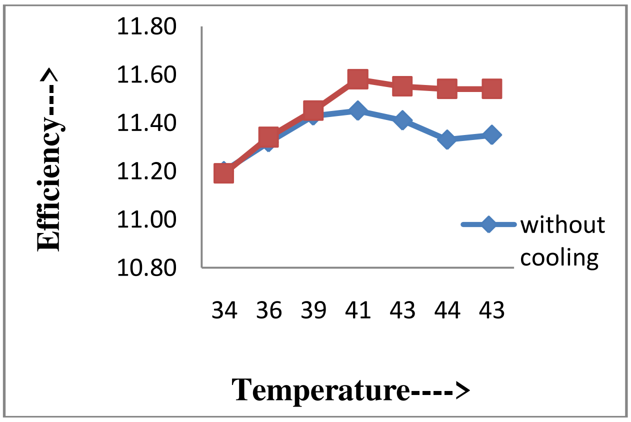

From the above facts and figures the efficiency drop, voltage drop is improved by maintaining the temperature of the panel by filling wax below the panel so that the heat generated by the increase of temperature of the panel as the day progresses and keeping the temperature of wax constant by circulating water. As the day progresses the ambient temperature increases from the morning 08:00am to 03:00pm and after that the temperature starts decreasing. The efficiency of the solar panel starts decreasing with increase in temperature, as stated in the journal "International Conference on Emerging Trends in Energy Conservation, the Effect of Temperature on Photovoltaic Cell Efficiency by V.JafariFesharaki, Majid Dehghani, J. JafariFesharaki in 2011.As we are dealing with the variation in temperature, maintaining the temperature of the panel constant by exchanging the heat of the panel is necessary. The heat generated by the increase of temperature is absorbed by the wax due to which the wax starts melting for keeping the wax to be in solid phase water is circulated through copper tubes which helps in cooling the wax. The observation taken on 18 and 19th of May 2014 shows that in the morning from 10:00am to 12:00noon the temperature and voltage increases which results in the increase in power output and efficiency. The ambient temperature in the morning at 10:00am is around 30-33˚C and the panel temperature is about 48-52˚C but after 12:00noon the temperature increases with the time but there is a decrement in voltage which directly affect the power output and efficiency of the panel. As the ambient temperature reaches 36-38˚C the temperature of the panel reaches 62-64˚C and the panel becomes inefficient. After applying cooling medium I find that the drop in voltage is very less or negligible and the temperature of the panel and wax is almost constant. By maintaining the panel temperature the efficiency, power output and voltage is improved.

1. Integrated Solar Power System is a type of solar system provided with heat exchange medium wax and water to absorb the heat generated in the panel. A pump of is used for circulating the water through copper tube for exchanging the heat generating in the wax.
2. As a result of Integrated Solar Power System was able to increase the power output, voltage and efficiency. The integrated solar power system model with wax and water as a heat exchange medium showed a good agreement with the work performed by others. The basic panel temperature in May was 59˚C.
3. An integrated solar power system with a heat exchange medium should result in reduction in voltage drop at higher temperatures. Wax and water circulating inside solar panel to have more influence on thermal performance. However, copper tube radius and air flow rate as well as cooling heat transfer rate also affect the performance of solar power system.

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