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Thermal Design and Evaluation of Cooling Configuration of Solar Photovoltaic Panel

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Abstract

A review on thermal design and evaluation of cooling configuration of solar Photovoltaic panel by using Computational Fluid Dynamics (CFD) approach has been carried out. The temperature factor has major impact on PV panel efficiency in compare to other atmospheric factors and hence it has been studied. From literature survey it has been observed that, the module temperature of noon hours in a day will be high and cooling configurations has to be undertaken to cool PV panel temperature to the range of 30°C – 35°C (normal operating cell temperature) by using water as cooling medium since increasing temperature will results in reducing the efficiency by decreasing mobility of charge carriers.

1. Introduction

Energy is the ability of human beings or a system to do work. All things happen in and across of all will be in the form of flow of energy. Based on availability, energy resources are classified into two categories. They are renewable energy and non-renewable energy.

Among different forms of renewable energy, solar energy has been considered as major one. The solar energy radiated from sun in the form of radiation is called solar radiation and it can be converted and used in the form of heat and electricity. The sunlight that reaches the earth surface has a great effect on the temperature distribution during the daytime and the influence by solar radiation is estimated from the positions of the sun and the object of interest. The solar photovoltaic effect is a physical phenomenon used for converting light energy into electricity. For photovoltaic effect, the materials used are depends on their ability of carrying the current. In conductor, the band gap is less and the electrons present in the outer shell are not bound to specific site and they are free to move in random ways hence it cannot be used for photovoltaic effect. In insulators, the band gap between valence band and conduction band is high and the outer shell electrons are tightly bound to specific site hence it cannot be set free by small amount of energy from sunlight. But the semiconductor characteristics lie between conductors and insulators. It contains 4 or 5 electron in the outer shell and can be set free by supplying additional energy[8].

In a semiconductor like silicon, four valence electrons at each atom are tied in a chemical bond and there will be no free electrons at absolute zero temperature. If one side of silicon is doped with pentavalent impurities like arsenic and phosphorous. There will be excess of electrons called N-type, where electrons are majority charge carriers. When other side of semiconductor is doped with trivalent impurities like boron, there will be deficiency in electrons called P-type, where holes are majority charge carriers. When photon strikes the silicon plate, electrons are released from chemical bond and tend to move from N-type to P-type and holes from P-type will tend to move to N-type to compensate, thus generates electric flow. Flow of electrons from N-type to P-type is extracted through external conductor.

The factors affecting solar PV cell efficiency are solar irradiation, wind speed, temperature etc. Among all temperature affect has major impact. The main parameter

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which is affected by increasing temperature is open-circuit voltage.

The Figure 1 shows power and voltage output for different temperatures. As the temperature of PV module increases at noon time, the band gap and fill factor of semiconductor reduces. Thus the open circuit voltage will be reduces. Hence efficiency of PV panel will degrades gradually.

Two predominant factors causing efficiency of PV panel to drop as the temperature rises are, free passage of electrons is restricted because of lattice vibration and PV junction begins to lose its power to separate charges. If temperature of PV cell increases beyond to room temperature, lattice vibrations occurs at free passage of electrons and disturb the flow of electrons. This degrades the PV cell performance. If PV panel reaches 300^{0}C, the thermally agitated charge will not carry energy due to the destruction of PV junction. During sunrise and sunset time the temperature of PV cell will be lower. Thus, the P and N type semiconductor would not exhibit doping character and the electrons doesn't excites from silicon material. Hence flow of electrons will reduce. Hence efficiency will decrease. Hence temperature of PV panel has to be maintained to maximum allowable temperature for better efficiency[9].

2. Literature Survey

The different literatures on PV cell performance are explained as follows.

This paper reveals about reducing efficiency results in reducing electric yield with increase in temperature.

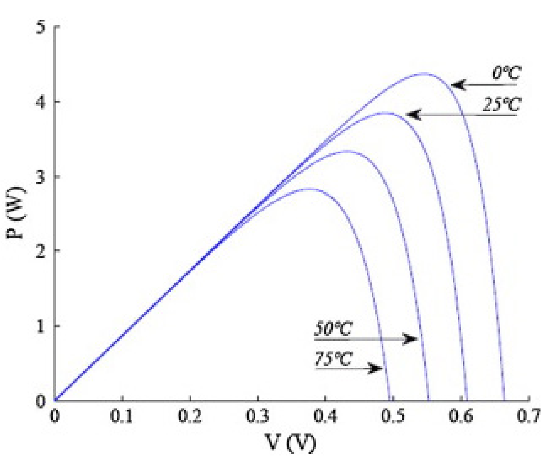

Figure 1. Power and voltage output for different temperatures.

Because, the efficiency and voltage will be decreases as PV cell temperature increases. Here, it has been made an effort of reducing cell temperature by active cooling and reducing reflection loses to some extent by using optical filters. Through optical filters the solar radiation (electromagnetic radiation) frequency affects on solar insulations have been studied. At finally it has been concluded that increasing temperature reduces the band gap of semiconductor, thus affects the properties of material and leads to decreasing of open-circuit voltage, fill factor and efficiency of solar cell gradually and also proposed non-pressurized cooling system and low cost solar tracking system for better solar radiation[1].

The main objective of this project is to cool the solar PV panel, especially located in hot regions by using as least as possible amount of water. A mathematical model has been proposed to determine when to start cooling, how long to cool and amount of water required to cool. The experimentations has been conducted by considering six PV modules of each 185 W capacity, water tank of 0.3 m^3 capacity and centrifugal pump of 1 hp input power. The setup has made to spray water on PV panel by using 120 water nozzles. At finally, this research concluded that the PV cell will be efficient, when it starts to cool at Maximum Allowable Temperature (MAT). Because if PV panel temperature reaches beyond MAT, the efficiency and power output will drop by 0.5% of every 1℃ rise in temperature. The experimentation also done for optimizing the amount of water required for cooling. Both cooling rate and heating rate models are validated experimentally[2].

Modelling and experimentation of Concentrated Photovoltaic cells (CPV) were done. In modelling, the two groups of silver backed rectangle reflective mirror locating under solar cell stand were considered. Where, each group contains six mirrors and the light energy falling on it will be focused to solar cell. It has been observed that the solar cell temperature in CPV rises to high because of optical losses and this leads to reducing efficiency. It has been concluded that cooling rate has to be increased in according to the temperature to be decreased[3].

The problem is stated that, most of solar radiations falling on PV panel have been converted into heat energy, which results in increasing of module temperature and lead to low efficiency. A novel micro heat pipe array was used for cooling of PV panel and both air-cooling and water-cooling were investigated and compared their efficiency yielding. The air cooling solar PV panel model has been developed such that, the heat pipe evaporator section was adhered to the back side of PV panel with dimensions of 283 mm of length and 300 mm of width and its condenser section of length 200 mm and width of 300 mm was exposed to air. The water cooling solar panel model has been developed such that, the heat pipe evaporator section was adhered to the back side of PV panel with dimensions of 283 mm of length and 285 mm of width and its condenser section was adhered to a water flume with its length of 40 mm and width of 285 mm. The results are also compared .i.e. air cooling reduce temperature by 4.7℃ and increase output power by 2.6% for a day of maximum ambient temperature of 36℃ , wind speed of 5.32 m/s and daily global radiation of 26.3 MJ, whereas the water cooling system reduce temperature by 8℃ and increased output power by 13.9% for a day of maximum ambient temperature 35℃ , wind speed of 4.72 m/s and daily global radiation of 21.9 MJ[4].

Here, the modelling and analysis of solar PV panel with both water cooling system and air cooling system were done and revealed their advantages and disadvantages. It has been predicted that Water cooling system is more prominent than air cooling system in providing electricity because water has good cooling capacity and the warm water from cooling process may also used for preheating applications like preheated water inside boiler[5].

In this project the problem stated that, as the temperature of photovoltaic cells increases the output efficiency will decreases i.e. for every degree rise in temperature the output power will decreases by 0.45%. Radiation fluctuations at mean of about 300w/m^2 and 550w/m^2 on silicon plate were performed by passing low wind speed of 1 m/s to high wind speeds of 4 m/s and 12 m/s and analyzed for both steady and transient state, where the thermal profile of the cell in response to environmental conditions will be analyzed by steady state and significance of fluctuations will be analyzed by transient state. The response of partial shading with different wind speeds are analyzed and thus observed that reducing in lateral temperature difference at high wind speeds. At finally concluded that mean temperature increases with increasing radiations and drop significantly with increases in wind speed[6].

It has been conducted experiment on the efficiency of solar PV panel which is installed in green roof and compare to the panel installed on a bare roof. In this study, the green roof is a small patch of green surrounded by a concrete roof. Two PV panels of same output power ratings installed in either of roofs and experimentation has been carried out. The problem stated that, increasing temperature of PV will reduce efficiency. So the evapotranspiration rate model for a small green roof has developed and its influence on temperature rise of PV cell has studied. The experimentation has been conducted for 3 days and setup has been described that, PV panel were placed 30 cm above green roof and concrete roof and inclined at 10℃ from the surface and HOBO (temperature and humidity) sensors are placed at 6 cm and 12 cm from canopy. These humidity and temperature data were used to measure the effectiveness of evapotranspiration model. It is found that evapotranspiration rate have a cooling effect to its microclimatic conditions and reduces the ambient temperature around 4℃ by converting sensible sensible heat to latent heat. At finally, it is been concluded that the PV panel installed in green roof produces higher efficiency than the PV panel installed in concrete roof due to evapotranspiration cooling effect. Because the climatic conditions like temperature, humidity has major influence on evapotranspiration process and cools by latent heat[7].

3. Conclusions

A detailed description of the photovoltaic effect and factors influencing on PV panel efficiency has been discussed. The detailed description is based on experiments and observations published on open literature. From the literature survey, it has been concluded that cooling of PV panel is necessary at noon hours and various experimental setups of cooling are discussed. From the cooling it has been concluded that PV panel will be efficient at cooling to the range of 30℃ -35℃ .

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