Numerical simulation on the effects of Ambient velocity and Temperature on solar panel efficiency

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Abstract. In desert regions like Thar located in India, the efficiency and capacity of solar panels is affected by many natural factors like wind velocity, surrounding temperature, dust, humidity etc. The main aim of this research is to find the temperature rise observed in solar panels due to surrounding temperature and wind velocity in the Thar Desert. A solar panel model is constructed for this research. The panel is simulated under three different velocities, 2.23m/s, 6.17m/s and 10.10m/s that are prominently observed in different months of a year in the Thar Desert. The surrounding temperatures considered for the simulation are 22.22°C, 30°C and 45°C respectively. Analysis results are obtained using Ansys simulation software. Based on the result, the ambient temperature and wind velocity can be determined to obtain best efficiency of the solar panel constructed in the Thar Desert.

1. Introduction

Due to the ever-growing population, it is very clear that the world will come to a halt in the coming years if the entire population does not use the available resources judiciously. It is very evident that humankind is running out of fossil fuels. We are unable to replenish our non-renewable resources at the rate at which we are consuming them. Climate change, global warming and pollution of our environment are mainly caused by fossil fuels. Renewable resources are the future. They are derived from natural sources and can always be replenished. Hydropower, Tidal energy, wind energy, biomass energy, and solar energy are all a few examples of renewable energy [1]. The reports from the International Renewable Energy Agency states that more than 250 renewable energies have been used in the year 2020. China’s usage of solar energy capacity has increased up to 49 GW and Vietnam up to 11 GW. Japan has also increased its usage to over 5 GW, India and the Republic of Korea have increased their solar energy capacity by 3GW [2].

Solar energy is nothing but the light and heat that is harnessed from the sun with the help of photovoltaic (PV) cells and solar thermal technology. This harnessed energy can be used to generate electricity. Solar energy can be used for cooking, heating, charging, etc. Many industries are now more inclined towards the application of solar energy to produce electricity due to the presence of many heavy-duty machinery. This acts as a very economical option since heavy duty machineries require huge amounts of power to function. The energy generated by solar panels is affected by a lot of factors.

One very important and major factor is environmental issues. This paper mainly focuses on the effects of wind velocity and the surrounding temperature on solar panels, especially in the Thar Desert. Temperature of the PV panels plays an important role in the efficiency of power output
generated. The efficiency of a Photovoltaic cell is highly dependent on the inbuilt temperature. The wind velocity is one of the factors that affects the performance of Photovoltaic cells. It increases the module temperature thereby affecting the performance of the module. The efficiency of a Photovoltaic cell is highly dependent on the inbuilt temperature [3].

Many other studies were done to determine the effect of temperature on heating of the panel due to the solar infrared radiation. The value of solar radiation is always maintained at 1000W/m² and the temperature of the module varies 25°C. The voltage that is generated by the solar radiation is inversely proportional to the temperature growth which has a significant effect on the generated power of the photovoltaic module. As the temperature increases, the current drops. This decrease of the generated current is due to the exposure of the polycrystalline silicon to mainly infrared radiation in the solar spectrum [4].

There were other experiments conducted on a photovoltaic cell module to determine the temperature distribution using finite element thermal analysis. The effect of PV module installation angle, wind direction, and speed on the temperature of the PV module. The proper choice of mounting orientation plays an important role in cooling the PV cell. [5]. The highest temperature of the cells was found to be 64.9 °C which was located at the centre of the module. The temperature of the cell is inverse to its efficiency. Higher the temperature of a cell, lower its efficiency. Since all the cells are connected in series and the performance of the whole module is dependent and limited by the cell that is the least performing, the efficiency of the whole module is likely to be reduced to that of the centre cell [6].

Increase in temperature of the panel leads to a decrease in the performance of the solar panel. The dependency of electrical efficiency and the power output of a photovoltaic module on the surrounding temperature is important [7]. The material used to develop the photovoltaic module influences the electrical performance of the module. In regions of high altitude, the performance of photovoltaic modules was higher due to low surrounding temperature than in regions with higher surrounding temperatures. PV modules that are insensitive to temperature are preferred over the others for high-temperature areas whereas PV modules that are more responsive to temperature should be preferred in regions of low temperature likewise. Depending on the climatic condition of the regions, the type of solar panel and material of the photovoltaic cell should be chosen. Only 5-20% of the solar radiation incident on the panel generates electricity, the rest increases the cell temperature and decreases the overall efficiency of the module [8].

A combination of 3 different photovoltaic systems (Poly-crystalline, Mono-crystalline and Thin-film) can be considered to study their difference in performance based on temperatures [9]. The wind speed data is not collected sometimes since the temperature of the cells is taken into account and it is directly affected by the wind speed. For every one degree rise in the cell temperature above the cell temperature at standard temperature condition resulted in the decrease of energy yield by 0.0984%. Similarly, the temperature coefficient is -0.109% and -0.124% for Mono-crystalline and Poly-crystalline modules [10]. It can be understood that solar energy contributes to a larger extent and proper analysis is required to determine their efficiency.

In this research, the solar panel is simulated to find out the surface temperature under four different conditions that includes a change in surrounding temperature and wind velocity. Under each case, the efficiency of the solar panel is calculated based on the surface temperature obtained after simulating the solar panel.

2. **Effect of wind velocity on cell temperature**

The temperature of the photovoltaic cell is a significant factor that affects the performance of the module. The temperature of the photovoltaic cell is directly affected by the wind velocity. There is a heat equilibrium maintained by giving out the heat that is produced by the solar panel in 3 ways:
Conduction, convection and radiation. The flow of heat is always from a higher temperature region to a lower temperature region.

Conduction occurs when two bodies are in direct contact with each other and when there is a difference in temperature or thermal gradient present [11]. The solar panel design has 5 different layers mentioned in Table – 2. Heat transfer through all these layers occurs via conduction thereby increasing the internal cell temperature. Figure – 1 indicates the flow of heat in the solar panel.

![Figure 1. Heat transfer depiction](image)

Convection is the heat transfer that occurs due to the movement of fluids, liquid and gas from a region of high temperature to low temperature. Convection occurs when the wind strikes the panels, this increases the temperature of the cell. Newton’s law of cooling can be used to calculate the rate of convection heat transfer, which is given by (1) and (2). Symbols and SI unit defined in Table – 2.

$$Q = h \times A \times (T_s - T_f)$$  \hspace{1cm} (1)  

$$h = 5.7 + 3.8 \nu$$  \hspace{1cm} (2)  

From equation (1) and (2) it is observed that temperature of fluid, surface and velocity of air have a great impact on the rate of convection heat transfer.

Radiation is the heat transfer that occurs in the form of electromagnetic waves. This increases the temperature of the photovoltaic cell. Through Stefan-Boltzmann’s law, the emitted energy by the black body is given by (3) [12].

$$P = \sigma + T^4$$  \hspace{1cm} (3)

| Symbol | Definition                      | Unit   |
|--------|---------------------------------|--------|
| Q      | Rate of convection heat transfer| W      |
| h      | Coefficient of convection heat transfer | W/m²°C |
| A      | Area between the two materials in contact | m²    |
| T_s    | Temperature of the surface      | °C     |
| T_f    | Temperature of the fluid        | °C     |
| ν      | Velocity of air                 | m/s    |

Table 1. Definitions and units used in the equations
3. Methodology

Solar Energy is the way of producing electricity using photovoltaic cells which harness radiation emitted by the sun. These solar arrays are simple to install and attach to structures and objects [13]. These are typically installed on the ground and require a significant area of land to generate electricity on the magnitude of MW.

3.1. Design Generation

The aim of this research is to determine the temperature of the solar panel that is affected due to wind velocity and surrounding temperature. Depending upon the temperature results, the efficiency of the solar panel can be predicted in different parts of the year in Thar desert.

The model of the solar panel was done in Solidworks 2020. To simulate the solar panels, ANSYS 2020 R2 Transient Thermal was used. During this process, change in heat flux from with respect to time led to the difference in temperature, which impacts the overall efficiency of the model. For that same reason, there is a need to analyse the transient thermal behaviour of the system to find out the scope of deviation and difference from the normal condition.

3.1.1. Construction of solar panel. The model of the photovoltaic module was made using Solidworks 2020 software. The Solar panel was modelled in Solidworks 2020 software following the standard dimensions as 120 cm X 54 cm X 3 cm as length, breadth and height and consist of 36 solar cells. It consists of six layers of top glass covering, Ethylene Vinyl Acetate layer 1, solar cells, Ethylene Vinyl Acetate layer 2, Black plate and Aluminum metal frame. The properties and dimensions of the six layers are mentioned in Table - 2. Figure – 2 indicates the layers of the solar panel. Figure – 3 indicates a picture of the solar panel design.

| S. No. | Definition                | Thickness (cm) | Specific Heat Capacity (J/kg°C) | Density (kg/m3) | Thermal Conductivity (W/m°C) |
|-------|--------------------------|----------------|---------------------------------|-----------------|-----------------------------|
| 1     | Aluminium Frame          | 2              | 996                             | 2707            | 204                         |
| 2     | Black Plate              | 0.01           | 1250                            | 1200            | 0.2                         |
| 3     | Solar Cell               | 0.04           | 677                             | 2330            | 148                         |
| 4     | EVA 1 and 2              | 0.05           | 2090                            | 960             | 0.35                        |
| 5     | Glass Covering           | 0.3            | 50                              | 3000            | 1.8                         |
3.2. **Software Procedure**

To simulate the solar panels, ANSYS Transient Thermal was used. While simulating the panel, the change in heat flux from time to time led to the formation of the temperature gradient, which impacts the overall performance of the model. Thus, the transient thermal behaviour of the panel was analysed, essentially to find the out-of-scope deviation and difference from the normal condition.

3.2.1. Procedure utilized to analyse the solar panel. ANSYS Transient Thermal utilized to simulate the solar panel. The geometry was designed using Solidworks 2020 software imported into the Design Workbench of ANSYS Transient Thermal. Material properties and aspects for each layer of the solar panel were defined in the Engineering Data module such as, specific heat capacity, thermal conductivity, and density. Figure – 4 indicates the process used in software. In this Geometry section, every layer of the solar panel model was labelled. An automatic mesh was created in the model. “Computational fluid Dynamics” and “Fluent” were chosen in the Physics Preference and the Solver Preference respectively. Individual temperature for each velocity was set as the initial temperature. After this, solar radiation was applied with 1000 W/m² on the model. Different wind velocities were applied on equation (1) (2) to obtain the convection coefficient as shown in Table – 3. Based on Newton’s Law of Cooling, the coefficients of the convective heat transfer can be obtained. After the simulation with boundary conditions, the simulation results of the solar panel model were obtained in the form of many contour plots.
Figure 4. Ansys modules used

Table 3. Material Properties and Sizes of each layer in Solar Panel

| Conditions               | Case - 1 (Ideal condition) | Case - 2 | Case - 3 | Case - 4 |
|-------------------------|----------------------------|----------|----------|----------|
| Aluminium Frame         | 35 °C                      | 22.22 °C | 30 °C    | 45 °C    |
| Black Plate             | 0 m/s                      | 2.23 m/s | 6.17 m/s | 10.10 m/s|

4. Results and Discussions
The four cases were simulated and the results were obtained as contour plots. The results depict the highest and lowest temperature observed on the solar panels when the surrounding temperature and the wind velocity differs from time to time in a year in the Thar Desert.

In case 1, it is observed that the average temperature observed on the panel is 83.6 °C. The minimum temperature is observed on the black plate region and the maximum temperature is observed on the PV cell region. Figure – 5 indicates the simulation results for Case – 1.

Figure 5. Contour plot for case – 1, 0 m/s velocity and 35 °C ambient temperature
In Case – 2, it is observed that the average temperature observed on the panel is 101.3 °C. The minimum temperature is observed on the black plate region and the maximum temperature is observed on the PV cell region. Figure – 6 indicates the simulation results for Case – 2.

![Figure 6. Contour plot for case – 2, 2.23 m/s velocity and 22.22 °C ambient temperature](image)

In Case – 3, it is observed that the average temperature on the panel is 109.5 °C. The minimum temperature is observed on the black plate region and the maximum temperature is observed on the PV cell region. Figure – 7 indicates the simulation results for Case – 3.

![Figure 7. Contour plot for case – 3, 6.17 m/s velocity and 30 °C ambient temperature](image)

In Case – 4, it is observed that the average temperature observed on the panel is 121.45 °C. The minimum temperature is observed on the black plate region and the maximum temperature is observed on the PV cell region. Figure – 8 indicates the simulation results for Case – 4.

From the results it is evident that the highest temperature is observed when the velocity is 10.10 m/s and at 45 °C as in Case – 4. This is during the months of June and July in the Thar desert. During
these months, the solar panel heats up to the maximum and this will result in a decrease in efficiency of the solar panel. This is because the temperature of the solar panel is inversely proportional to the efficiency of the panel. Therefore, there will be less energy generated during the months of June and July.

\[ \text{Figure 8. Contour plot for case – 4, 10.10 m/s velocity and 45 °C ambient temperature} \]

While the temperature of the panel is comparatively stable and less when the wind velocity is 2.23 m/s and 22.22 °C as in Case – 2. Case – 1 is ideal and cannot be considered. Case – 2 conditions can be observed in the months of February-April and September-November. During these months, the efficiency of the solar panel will be maximum compared to the rest of the months. During the months of May and August, the wind velocity and temperature is observed to be 6.67 m/s and 30 °C as in Case – 3. In this condition, the solar panel reaches a temperature of 109.5 °C. This is very less compared to the highest temperature observed during the year. In this part of the month, a reasonable amount of energy can be generated which can be compared to the energy generated during the months of February-April and September-November. The months of January and December are not considered because there won’t be proper sunlight to harvest energy and therefore there won’t be much energy harvested in these months.

It can be observed that Case – 1 follows an ideal condition with uniform increase in temperature. Case – 2 and Case – 3 reach up to a certain limit and the highest temperature peak is observed in case 4. There is a drastic change in temperature in case 4 thereby implementing that the energy generation will be the least in Case – 4 and will be moderate in Case – 2 and Case – 3. The wind velocity is constantly changing and therefore a cooling system can be applied to the solar panel. Cooling systems provide a cooling effect to the panel to bring down the temperature of the same. Air cooling system is the best option out of all solar cooling systems. Figure – 9 indicates the temperature versus time plot where the surface temperature of the solar panel for one hour is plotted.
5. Conclusion
The efficiency of solar panels plays a major role in the process of generation of energy. Constructing solar panels in places like Thar desert may help in generating more energy. It is very important to know about the performance of solar panels and how efficiently they can generate energy during different parts of the year. There will be different conditions observed in different parts of the year. Depending upon the conditions, the efficiency of the solar panel will differ. It is always better to find out the efficiency using software rather than implementing them physically and experimenting on it. It was observed that during the months of February – April and September – November, there will be less temperature observed on the solar panel thereby generating a good amount of energy. Due to global warming, the temperature observed in the desert changes every year and every month. This might affect the results generated above through analysis. There could be other natural calamities such as sand storms which might damage or bring down the solar panel to an adverse condition. Hence all these factors play an important role when it comes to the efficiency of the solar panel. Any change in natural conditions in the desert would change the solar panel’s efficiency, and thus the solar panel could under perform. All these conditions have to be taken into account while constructing solar panels in the Thar desert.
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