The Efficiency Estimate of PV Cell under various wind velocities

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Abstract. It is a good chance to harness solar energy for Vietnam to geographic location is near to the equator with the high intense radiation. Photovoltaic (PV) cell is the device to convert directly solar energy into electrical energy. However, its efficiency is strictly impacted by the PV cell surface’s temperature which depends on wind velocity, surrounding temperature, radiation and dust. For a long time, computational modelling has been a good choice for engineers to simulate their products. Currently, some softwares like Ansys Fluent, Comsol Multiphysics are chosen to simulate the thermal performance of product. In this paper, authors used Computational Fluid Dynamic (CFD) – Autodesk to estimates the PV cell temperature, then find out its corresponding efficiency. A 3 dimensions model of PV cell with some layers was created by Inventor software, and then simulated under various wind velocities like 0.5 m/s, 1.5 m/s, 2.5 m/s, 3.5 m/s, 4.5 m/s, 5.5 m/s and 6.5 m/s to find out the PV cell corresponding temperatures. The solar radiation parameter in Ho Chi Minh city in April was established for simulation. With the same surrounding temperature at 30°C, the result shows that the highest PV cell surface’s temperature of 84.8°C with wind velocity of 0.5 m/s will drop to 49.81°C with the wind velocity of 3.5 m/s. When the wind velocity is continue increased, the drop of temperature is trivial. The PV cell efficiency at wind velocity of 6.5 m/s is only 2.75% higher than that of wind velocity of 3.5 m/s. Therefore, when choosing cooling PV cell by air, the air velocity should be chosen at 3.5 m/s to save energy.

Keywords: Solar Energy, PV cell, CFD.

1. Introduction
Viet Nam locates near the equator with the high intense radiation. Therefore, harnessing this free energy is the good way to save energy. Most of applications in solar energy is in the hot water supply. It can be exploited nearly every area of Viet Nam [1]. Besides, PV power is one of the viable energy to replace the traditional fossil fuels which strongly affect the environment. The PV cell is manufactured by following the Standard Test Condition (STC) which indicates that the solar radiation is 1000 W/m², panel temperature is 25°C and light spectrum with an air mass is 1.5. With this condition, the PV cell generates its maximum power named Watt-peak [2]. However, the local weather will affect these parameters and make its efficiency reduced. PV cell temperature is one of the major reasons which reduce PV cell’s
efficiency [3-4]. When the PV cell temperature rises, the rate of photon also rises. However, the reverse saturation current will be increased considerably and lead to the reduction of ban gap which makes the open circuit voltage \( (V_{oc}) \) affected [5]. With the PV cell temperature gain, its power output is gone down as a result of the negative temperature coefficient (-0.5%/°C rising in temperature). Therefore, PV cell has the high efficiency at the low temperature with the correct tilt angle. Radiation, surrounding temperature and wind velocity play an important role to the PV cell temperature. In term of wind velocity, some researchers study on this relationship between this one and PV cell temperature [6]. Latifa Sabri and Mohammad Benzirar made the experiment by changing the wind velocity through the PV cell, and they realized that when increasing wind velocity, PV cell temperature is also gone down, result in the enhanced electrical power. Khelifa [7] studied the PV cell performance by simulating the heat transfer between PV cells and cooling by using ANSYS Fluent software. The results shown that the lower PV cell temperature, the higher power will be gained [8].

In this paper, authors simulated the cooling the PV cell with 2 DC fans with air speed of 3.07 m/s, the surrounding temperature at 36.5°C and solar radiation of 1175 W/m², at 1.30pm by ANSYS software. The results shown that the highest PV cell can reaches 53.6°C in this condition. In [9], Jia Yang conducted the experiment about the impact of wind velocity to the PV cell temperature when he changed the wind velocity from 2 to 8 m/s. Consequently, he claimed that the increased velocity he made, the higher power out he had. S. Armstrong and W.G. Hurley in [10] analyzed the heat that transfer from the PV cell to the air with the velocity of 0.77m/s, 2.14 m/s and 5.76 m/s. The velocity of 5.6 m/s was the best value to have more heat transfer from PV cell to the air [11]. Authors simulated the PV cell temperature with different wind velocities of 0 m/s, 0.43 m/s, 2.5m/s and 6.95 m/s under the outdoor temperature at 35°C and the solar radiation of 1000W/m² by using ANSYS software; and obtained the record of maximum PV cell temperature at 60.885°C with 6.95 m/s compare to 91.651°C with 0m/s.

Moreover, authors estimated the PV cell temperature under Ho Chi Minh city solar radiation, with wind velocities of 0.5m/s, 1.5m/s, 2.5m/s, 3.5m/s, 4.5m/s, 5.5m/s and 6.5m/s by Computational Fluid Dynamic-Autodesk, then calculated the efficiency of PV cell in order to find out the most compatible wind velocity.

The rest of this paper is organized as follow: Model for simulation is in Section 2. Section 3 is Evaluation of Experimental Results. Section 4 concludes the paper.

### 2. Model for simulation.

The model in [12] was the PV cell which included 6x10 pieces of polycrystalline cells series (156mmx156mm per each piece) with parameters listed as in Table 1.

| Table 1. PV cell parameters |
|-----------------------------|
| Peak Power                  | 240 Wp  |
| Max. Power Voltage (Vmp)    | 30.18V  |
| Max. Power Current (Imp)    | 7.96A   |
| Open Circuit Voltage (Voc)  | 36.72V  |
| Short Circuit Current (Isc) | 8.99 A  |
| Cell Efficiency             | 16.5%   |
| Maximum System Voltage      | DC 1000V|
| Temp. Coeff. Of Isc         | +0.045%/K|
| Temp. Coeff. Of Voc         | -0.34% /K|
| Temp. Coeff. Of Pmax        | 240 Wp  |
For simulation, authors created the PV cell model (1560mm x 936mm) by Inventor software including 5 layers as: a/ Glass, b/ Encapsulated by Ethylene vinyl acetate (EVA), c/ PV cell, d/ EVA, e/ Back sheet by Tedlar. These material properties were used from [10] and listed as in Table 2.

| Layer     | Thickness $t$, (mm) | Thermal conductivity, (W/m.K) | Density $\delta$, (kg/m$^3$) | Specific heat Capacity $c$, (J/kg.$^\circ$C) |
|-----------|---------------------|-------------------------------|------------------------------|------------------------------------------|
| Glass     | 3                   | 1.8                           | 3000                         | 500                                      |
| PV cell   | 0.225               | 148                           | 2330                         | 677                                      |
| EVA       | 0.5                 | 0.35                          | 960                          | 2090                                     |
| Tedlar    | 0.1                 | 0.2                           | 1200                         | 1250                                     |

Subsequently, the model was imported to CFD-Autodesk 2018 in order to conduct the simulation. The following steps were carried out as following: 
✓ Material assignment followed Table 2. Besides the PV cell layers, the air volume surround the PV cell was also made by CFD in order to simulate wind velocity.
✓ After finishing material assignment, the model was automatically meshed and some surfaces which were not meshed were modified manually.
✓ After meshing, the number of nodes were 577,176, the number of elements were 2,541,599, and the mesh was depicted as in Figure 1.
✓ Assign the boundary condition.

When the sunlight strike to the PV cell surface, it heats this surface and convert partly into electricity. Most of them become the heat that made the surface temperature increased. The heat loss is taken place by these types: radiation to surrounding air from the surface and the back of the PV cell, convection to surrounding air. The convection heat loss depends on the wind velocity with the Newton’s law of cooling.
\[ Q = h \cdot F \cdot (t_s - t_f) \]  

(1)

\[ h = 5.7 + 3.8v \]  

(2)

where: \( Q \) is known as heat loss by convective (W), \( h \) is the coefficient of convective heat transfer (W/m².K), \( v \) represents the velocity of fluid (m/s), \( t_s \) and \( t_f \) (°C) is temperature of the surface and temperature of the outside fluid, respectively.

The boundary conditions for determining in this simulation were: the variety of wind velocities were 0.5m/s, 1.5m/s, 2.5m/s, 3.5 m/s, 4.5m/s, 5.5m/s, 6.5m/s. Air temperature was at 30°C. Air volume surround the PV cell model with air emissive \( \varepsilon = 0.3 \), the covering glass with the transmittance \( \tau = 0.91 \) and glass emissive \( \varepsilon = 0.9 \); the PV cell with the absorbance \( \alpha = 0.9 \). The radiation was set at 01:00 pm on April 10th, 2020 with latitude of 10.769°, longitude of 106.662° in Ho Chi Minh City. Turbulence model: k-epsilon. The simulation was solved during in 3380s.

3. Evaluation of Experimental Results

With the air temperature at 30°C (the average temperature at Ho Chi Minh city in April yearly), solar radiation at 01:00 pm in April 10th, 2020 whose radiation is highest in a year was chosen, and the wind velocities was changed with values: 0.5m/s, 1.5m/s, 2.5m/s, 3.5 m/s, 4.5m/s, 5.5m/s, 6.5m/s.

According to [13], with the PV cell area \( A_c \) (m²), solar radiation \( G_T \) (W/m²), and max power voltage (\( V_{mp} \)), max power current (\( I_{mp} \)), then the maximum power point efficiency (\( \eta_{mp} \)) of a module is given by:

\[ \eta_{mp} = \frac{I_{mp} \cdot V_{mp}}{A_c \cdot G_T} \]  

(3)

The dependence of the maximum power point efficiency (\( \eta_{mp} \)) to PV cell temperature (\( t_c \)) is expressed by this equation:

\[ \eta_{mp} = \eta_{mp,STC} \cdot [1 + \alpha_p \cdot (t_c - t_{c,STC})] \]  

(4)

where:

- \( \eta_{mp,STC} \): the maximum power point efficiency under standard test condition.
- \( \alpha_p \): the temperature co-efficient of power, (%/°C)
- \( t_{c,STC} \): the cell temperature under standard test condition, (25°C)

3.1 PV panel layers average temperature distribution.

Solar radiation goes through the glass covering the PV cell, strikes on the PV cell surface and convert partly this energy into electricity. Most of them become heat and raise the PV cell temperature, and the temperature of PV cell is displayed in Figure 2.
Figure 2. PV panel layers average temperature distribution.

With the lowest velocity of 0.5 m/s, PV panel layers average temperature are highest with the glass surface temperature of 84.7°C, PV cell average temperature of 84.83°C, and the back of PV panel average temperature of 84.14°C, because the heat convection considerably depends on the velocity, so a few of heat is drawn. At the maximum velocity of 6.5 m/s, the PV panel layers average temperature are lowest with the glass surface average temperature of 44.3°C, the PV cell average temperature of 44.67°C and the back sheet average temperature of 44.043°C. At velocity of 3.5 m/s, the usual wind velocity of Ho Chi Minh city in April, the temperature is 49.56°C, 49.91°C, 49.28°C correspond to the glass surface average temperature, the PV cell average temperature, the back sheet average temperature, respectively.

When the wind velocity rises from 1.5 m/s to 3.5 m/s, the PV panel average temperature drop dramatically. However, the trend of this drop is slow with the velocity range from 3.5 m/s to 6.5 m/s. For instance, the rate of average temperature drop is about 6%, 4%, 1% with the range from 3.5 m/s to 4.5 m/s, 4.5 m/s to 5.5 m/s, 5.5 m/s to 6.5 m/s, respectively. Among layers, the outside layers have the lowest temperature because it directly contacts with outdoor air. In contrast, the PV cell layers is higher than them because the heat must conduct through other layers to the outside air.

Figure 3 expresses the temperature distribution visually on the surface of the PV cell which is needed to estimate the efficiency of electrical power.
Figure 3. PV cell temperature distribution under wind velocities of 0.5 m/s (a), 1.5m/s (b), 2.5m/s (c), 3.5m/s(d), 4.5m/s (e), 5.5 m/s (f), 6.5 m/s (g).
In this simulation, temperature is lowest from the left and rises gradually to right due to the wind flow direction is from left to right. Therefore, the temperature distribution is not equal on the PV cell surface. Under the lowest wind velocity of 0.5 m/s in Figure 3(a), the red area (high temperature) is the biggest. When wind velocity is increased, the red area is decreased, become smaller and gradually to be replaced by the blue and the green areas which indicate the lower temperature.

3.2 Estimate the efficiency of PV cell power.

With parameters in Table 1, the average PV cell temperature in Figure 2 and the formula (4), authors estimate, and display values as shown in Figure 4.

![Figure 4. Efficiency of PV cell under various wind velocity.](image)

Obviously, at the wind velocity of 0.5 m/s, the efficiency is the lowest value of 11.86%, and decrease by 28.12 % compare to the PV cell efficiency at Standard Test Condition. The PV cell efficiency increase accompany with the increase of wind velocity. When wind velocity reaches to 3.5m/s, the PV cell efficiency is 14.57%. However, when the wind velocity is continue raising, the increase in efficiency is inconsiderable. For instance, at the maximum wind velocity of 6.5m/s, the efficiency is only 2.75% higher than that of 3.5m/s. Therefore, if designing the cooling system for the PV cell by fan, wind velocity of 3.5m/s is the most suitable choice for saving energy and ensuring that the efficiency is not low.

4. Conclusion

This paper shows the results of PV cell efficiency under different wind velocities. The higher wind velocity, the lower PV cell temperature will it have. In fact, the PV cell efficiency also goes up to 14.57% at wind velocity of 3.5m/s compare with 11.86% at wind velocity of 0.5m/s. However, from the wind velocity of 3.5 m/s to 6.5m/s, the temperature reduction is very small (approximately 2.75%). Therefore, these efficiencies increase inconsiderably. For that reason, the wind velocity of 3.5 m/s is the best choice to choose for cooling system for the PV cell by fan in order to save energy.
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