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Improved Photovoltaic MATLAB Modeling Accuracy by Adding Wind Speed Effect

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Abstract

Photovoltaic (PV) are generally modeled using mathematical equations that describe the PV system behavior. Most of the modeling approach is very simple in terms of that PV module temperature is calculated from nominal constant cell temperature such as ambient temperature and incoming solar irradiance. In this paper, we newly present MATLAB model particularly embedding the effect of wind speed to describe more accurate cell temperature. For analyses and validate purpose of the proposed model, solar power is obtained and compared with and without wind speed from the 50Wp PV module provided by vendor datasheet. In the simulation result, we found that power output of the module is increased to 0.37% in terms of cell temperature a degreed down when we consider the wind speed in the model. This result is well corresponded with the well-known fact that normal PV is 0.4% power changed by cell temperature a degree difference. Therefore it shows that our modeling method with wind speed is more appropriate than the methods without the wind speed effect.

Keywords: Photovoltaic (PV) Module, Irradiance, Wind Speed, MATLAB/Simulink, Power-Voltage Curve, Current-Voltage Curve

1. Introduction

A solar photovoltaic (PV) system uses a solar cell to convert solar energy into electricity based on photoelectric effect. The basic PV system is a cell that are classified namely mono-crystalline (or single crystalline), poly-crystalline, amorphous, organic cell and Nano-PV cells. Currently PV technology has been used in many applications such as solar power plants, home use, satellite, and communication powering, and nowadays aircraft and electric vehicle applications[1,2].

The output of the solar module is in direct current (DC) form, and so conversion device is necessary to convert this power into alternating current (AC). The solar PV energy conversion is low efficient process due to major losses involved in the physical process of conversion within the PV cell. In this process, the two major important factors determining energy outputs of PV are incoming solar irradiance and cell temperature.

In most of the PV products, the PV cell performances given in the module are defined under standard test conditions (STC) i.e. irradiance 1000 W/m^2, and the cell temperature 25°C. Temperature has a substantial effect on the power output of the solar panel: increasing the temperature by one degree results in a 0.4% decrease in power output for silicon solar panels.

Solar energy obtained from a solar PV cell is fluctuating in nature affected by external conditions like solar irradiance and cell temperature. The amount of power extracted from PV system is a function of the PV module voltage and current. In these regards, many different studies have been conducted in the literature to obtain the characteristics of PV model[3-10].

In this research, we studied existing model in MATLAB[3-5] and developed a single diode model in Simulink which takes solar irradiance, cell temperature, and wind speed into account. In most of the cases of PV

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installations, actual measurements of cell temperature are not considered but they usually take STC values. And these standard conditions are not actual cases in every scenario and rarely met PV outdoor installation scenario. Therefore it is essential to consider the physical relation between the PV cell temperature, incoming irradiance and relevant meteorological parameters such as the wind speed which is the most important parameters affecting cell temperature and humidity.

In this paper, the PV cell temperature is calculated as a function of ambient temperature, incoming solar irradiance, and wind speed. And the calculated cell temperature is used in PV model to characterize power-voltage (P-V) and current-voltage (I-V) curves. We compare these modeling results to determine the accuracy of PV power output in terms of modeling with and without the wind speed.

This paper is organized as follows, mathematical description of solar PV cell and proposed model are presented in Section 2. Section 3 describes wind effect design. Experimental setup, measured values and work results are described in Section 4. Finally conclusions are stated in Section 5.

2. Numerical Background and Mathematical Description of Solar PV Cell

Solar cell is an electronics device which consists of a layer of semiconductor materials in the form of P-N junction fabricated in a thin wafer. When photons from the solar energy hit the solar cell generate current proportional to the solar insulation[11]. The magnitude of the current is directly proportional to the solar radiation and also depends on cell temperature on the area.

Solar cells are very sensitive to temperature. Increasing the temperature reduces the band gap of a semiconductor, thereby effecting most of the semiconductor material parameters. The open circuit voltage decreases significantly with increasing PV module temperature (values are up to -0.45%/K for crystalline silicon) whereas the short circuit current increases only slightly (values range between 0.04 and 0.09%/K).

PV cell modelling needs an equivalent circuit with exponential characteristics and can be achieved from a diode. This model accepts the solar irradiance and the temperature as input parameters and produces current output. With this types of mathematical modelling, single diode is less complex and most commonly used. Hence, for the most analytical and design purposes single diode model as shown in Fig. 1 is used. The equation of the single diode model is

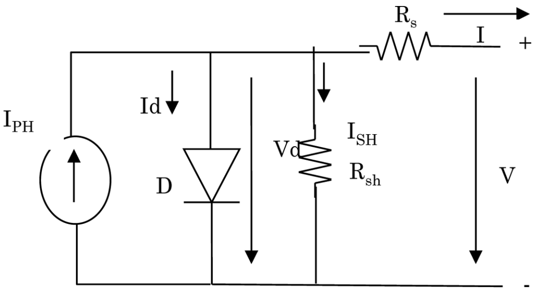

Fig. 1. Single diode solar cell model.

$$I = I_{PH} - I_d \left[e^{\frac{q(V+IR_{se})}{AKT}} - 1 \right] - \frac{(V+IR_{SE})}{R_{SH}} \tag{1}$$

where,

$$I_{PH} = I_{SC} \times \frac{I_{RR}}{1000} \times [1+(T_{CELL} - T_{REF}) \times K] \tag{2}$$

where I_{PH} the photo is a generated current by a solar cell, I_d is the diode saturation current and I_{SH} is shunt resistance current. R_{SH} and R_{SE} are the shunt resistance and series resistance respectively. A is the shape factor, k is the Boltzmann constant. q is the electron charge. V is the terminal voltage of the cells.

PV cell temperature is considered as equivalent to the ambient temperature in many studies in the literature. In this paper, the PV cell temperature is calculated as a function of irradiance variation, the ambient temperature[12] and wind speed. Wind speed eventually has a significant effect on cell temperature and thus this effect is taken into account for calculating the cell temperature for more accurate modeling.

3. Wind Effect Design Model

We found that in many references PV cell temperature is applied by the ambient one. But in this proposed model, PV cell temperature is calculated as a function of the ambient temperature, irradiance and wind speed[13,14].

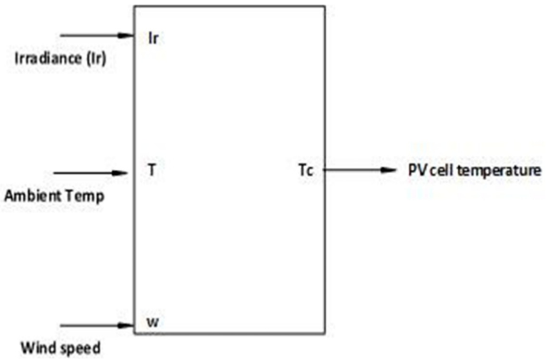

Fig. 2. Block diagram for PV cell temperature.

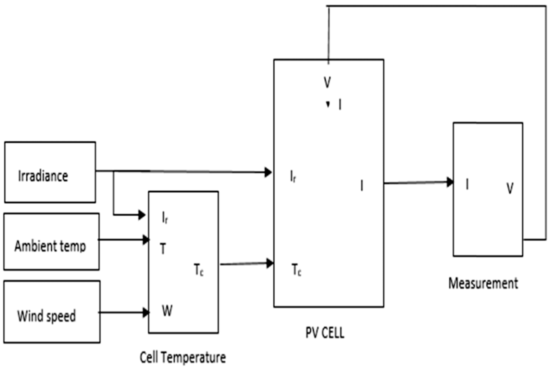

Fig. 3. Block diagram for PV model.

$$T_C = 1.14\times(T-T_S)-k\times w+0.0175\times(I_r-300)+30 \quad (3)$$

where T_C is the PV cell temperature, T and T_S are the ambient and STC temperature respectively. I_r is the solar irradiance. k is the coefficient depending on the PV cell material[14]. We take k = 1.509 for monocrystalline cell. And W is the wind speed in m/s.

From Eq. 2 and 3, the photo generated current by solar cell is

$$I_{ph} = \frac{I_{SC}\times I_{rr}}{1000}\,[1+[\{1.14\times(T_a-T_{ref})\} +0.0175\times I_{rr}-1.509\times w_s+24.75]\times k] \quad (4)$$

According to above Eq., PV solar model has been developed using MATLAB/Simulink tool.

Firstly the cell temperature of PV is calculated as a function of ambient temperature, solar irradiance, and wind speed. The PV cell temperature is shown in Fig. 2.

Then cell temperature is inputted and the current is outputted based on its operating voltage. The model has developed using the mathematical equations which are translated to MATLAB/Simulink blocks based on single diode model[3-5]. The PV module block diagrams is shown in Fig. 3.

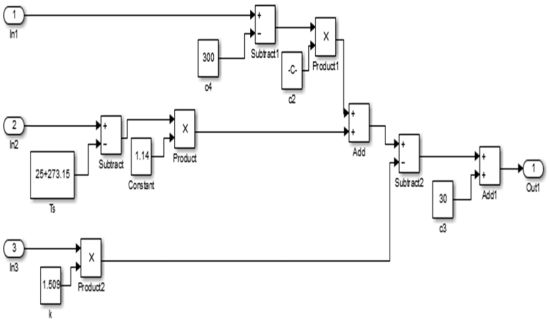

Fig. 4. Sub block diagram for PV cell temperature calculation.

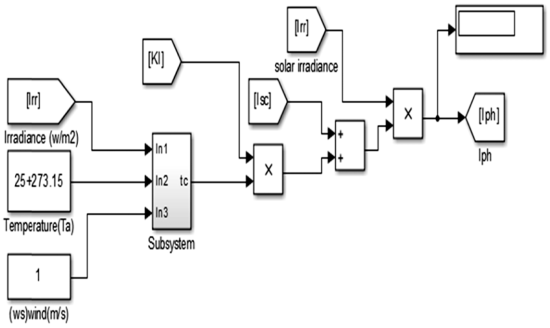

Fig. 5. Sub block diagram for PV model.

In Fig. 3, we can see the cell temperature calculated in Fig. 2 is fed to PV cell model which has also irradiance as an input. In this PV cell model, the current is calculated and used to obtain the power cell output.

In Fig. 4 and 5, for PV cell temperature and PV model, MATLAB/Simulink sub block are presented respectively. Fig 4. sub block shows the calculation process for Eq. 3, and Fig 5. sub block represents of Eq. 4.

4. Experimentation and Results

A 50Wp capacity monocrystalline solar PV module (Waree WS-50) has been chosen for modelling and analysis. The datasheet parameters of PV panels used in this study are given in Table 1[15].

Table 1. Technical specs of solar module WS-50

Paeameter at STC	Variables	Specs.
Types of cell	Mono crystalline Silicon Cells	
Max Power in watts	Pm	50
Open circuit voltage in volts	Voc	21
Short circuit current in amps	Isc	3.17
Voltage at Max.Power	Vmp	17
Current at Max.Power	Imp	2.94
Temprature coefficients of voltage per kelven (V/K)		-0.123
Temprature coefficients of current per kelven (mA/k)		4.4
NOTC in degree celsius		47

For the experimental setup, first we run our simulation model in STC condition without wind effects, after then we take the real scenario data of incident radiation on the surface of the solar panel value (1,000 W/m^2 solar irradiance), outdoor temperature 25°C and wind speed (1 m/s and 1.2 m/s) to calculate the PV Cell temperature. And plot all these values in MATLAB. In Fig. 6, solar cell temperature with different irradiance, outdoor temperature and the wind speed are shown.

In Fig. 6, we simply take wind speed (1 to 10 m/s), solar irradiance (500 to 1000 W/m^2) and outdoor temperature (5 to 28°C). As a result, we can see PV cell temperature changes in time. It means that, to calculate more accurate PV power, PV cell temperature cannot be considered as the fixed parameter.

The cell temperature is calculated as a function of irradiance, ambient temperature, wind speed and used as input parameters in MATLAB/Simulink models. The I-V and P-V characteristics of the solar cell at STC condition in addition of 1 m/s wind speed and cell temperature have been obtained experimentally.

Firstly, to validate the results obtained from the simulation model, an experimental set up has been arranged to obtain P-V and I-V characteristics of the solar cell at STC and compare with the previous work[16]. Fig. 7 and 8 illustrate the P-V and I-V characteristics of the Sim-

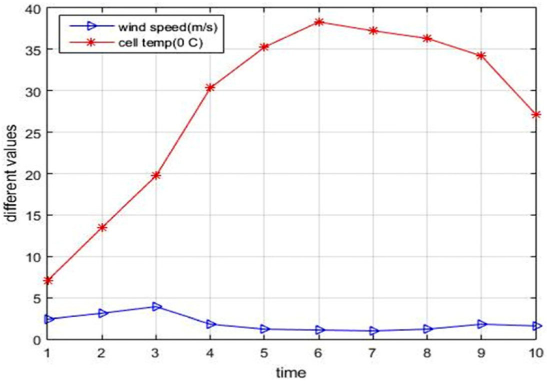

Fig. 6. Calculated cell temperature.

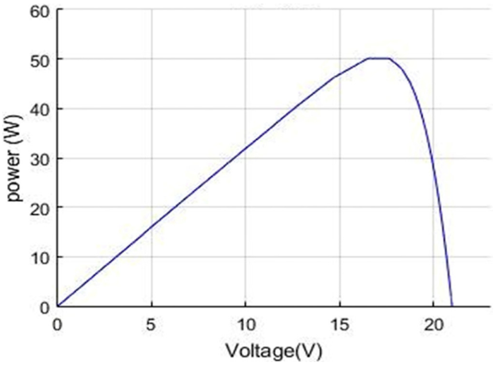

Fig. 7. P-V at STC condition.

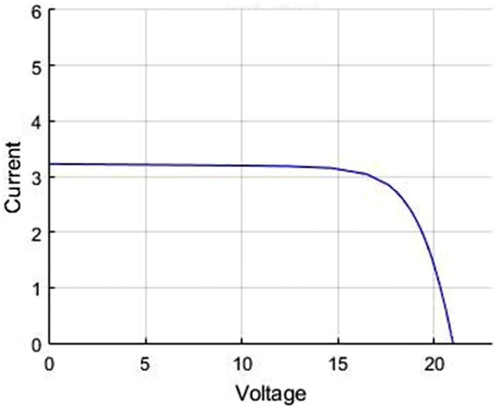

Fig. 8. I-V at STC condition.

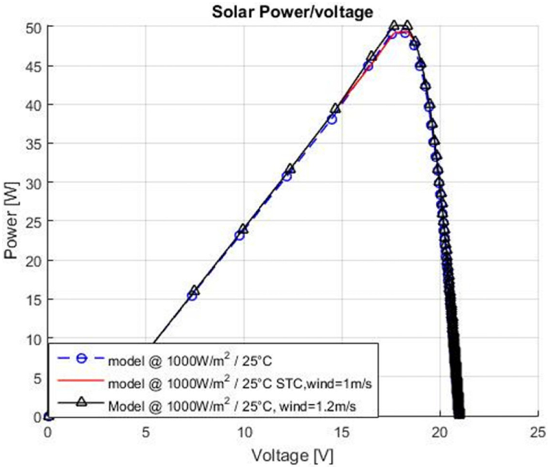

Fig. 9. P-V curves for STC only and STC with two different wind speeds (Entire range is shown).

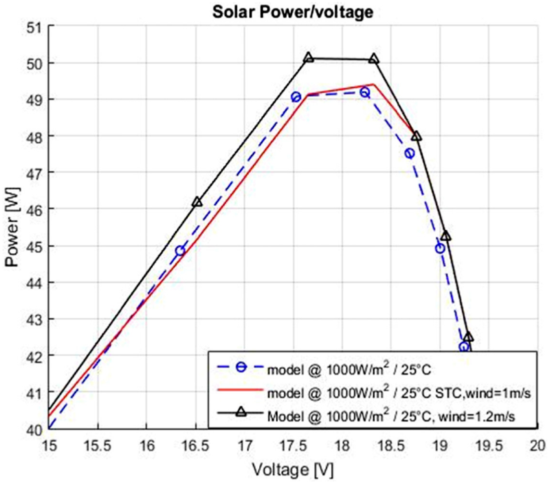

Fig. 10. P-V curves for STC only and two different wind speeds (Limited range is shown to enlarge).

ulink model for solar irradiance 1,000 W/m^2 and 25°C. The experimental results are almost matching with the previous work[16] and manufacturer's data sheet.

Fig. 9 shows the P-V outputs for the entire voltage range in terms of three cases such as STC state without wind speed, STC with wind speed 1m/s, and STC with wind speed 1.2 m/s. In Fig. 10 we just extend the power output results from Fig. 9 to show more clearly about the power output differences for each three case.

From Fig. 10, we can see the differences of power outputs. STC only modeling has the least output values, and STC with wind speed 1.2m/s clearly outperformed the STC only case. This results present the importance of wind speed modeling for accurate simulation of PV systems. But most of the PV modeling approaches are not considering the wind effect, and they commonly use irradiation and ambient temperature only.

Table 2. Experimental results of the module

Wind speed	Cell temp	U_{OC} (V)	P_m (W)
STC only	T=25°C	21	49.19
1 m/s	T=23.2585°C	21.2	49.41
1.2m/s	T=22.9567°C	21.32	50.11

Averaged values from the measurement of PV Simulink model are shown in Table 2. For the these outputs, the parameters of the WS-50 module is set to ambient temperature 25°C and irradiance 1,000 W/m^2.

The experimental results show that, from the Table 2, the module maximum output power is approximately +0.37% increased per temperature one degree down. According to the theory, the power output of a crystalline solar cell decreases only 0.4% when the cell temperature is raised by one degree Celsius[13].

5. Conclusion

In this paper, a mathematical model of PV simulation is developed in terms of specially considering wind speed. Thus we use 3 parameters to calculate PV power such as incoming solar irradiance, cell temperature and wind speed. As the wind speed increases, the cell temperature will be dropped and better PV cell efficiency has been resulted.

The temperature dependency of PV cell performance is greatly related and we prove that the maximum output power increases equal to +0.37% per degree. This result is well agreed with the well-known fact that the power of normal PV module is changed 0.4% if the cell temperature is changed one degree difference. Therefore we can conclude that the proposed model including wind speed using MATLAB/Simulink is performed well.

Acknowledgements

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