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Mathematical Modelling and Performance Analysis of PV Module

Priyadarshini K[1], Vrunda[2], Usha M[3], and Priya[4]
BVB Engineering College, Hubballi, India.
[1]kori95priya@gmail.com, [2]vrundaravikumar@gmail.com, [3]usha.marchade@gmail.com [4]priyagni89@gmail.com

Abstract — **The depletion of non-renewable energy sources demands the use of renewable energy sources. Solar energy is preferred because of its vast and inexhaustible energy supply, which is non-polluting and environmentally clean. This paper emphasizes on the analysis of solar PV module, one of the main prerequisite to get maximum energy from the sun. The paper probes on I-V and P-V characteristics and efficiency of PV module for varying operating temperature and solar insolation obtained using MATLAB/SIMULINK.**

Index Terms — **Solar PV module, I-V characteristics, P-V characteristics**

I. Introduction

With a spurt in the use of non-conventional energy sources, photovoltaic (PV) installations are being increasingly employed in several applications, such as distributed power generation and stand-alone systems. Regardless of the intermittency of sunlight, solar energy is widely available and is free. Recently, photovoltaic system is recognized to be in the forefront in renewable electric power generation. It can generate direct current electricity without environmental impact and contamination when exposed to solar radiation. Being a semiconductor device, the PV system is static, quiet, free of moving parts, and has little operation and maintenance costs [2].

PV module represents the fundamental power conversion unit of a PV generator system. The output characteristics of a PV module depend on the solar insolation, the cell temperature and the output voltage of the PV module. Since PV module has nonlinear characteristics, it is necessary to model it for the design and simulation of maximum power point tracking (MPPT) for PV system applications. However, a major challenge in using a PV source is to tackle its nonlinear output characteristics, which vary with temperature and solar insolation[3].

This paper presents a MATLAB-based simulator, which can be used to enhance the understanding and predict the I-V and P-V characteristics of PV module. It can be used to study the effect of temperature and insolation variation[3].

II. System Discription

A. Characteristics of PV module

The traditional equivalent circuit of a solar cell is represented by a current source in parallel with diode as shown in Fig. 1.1. A mathematical description of the current versus voltage characteristics for the equivalent circuit is represented by coupled non-linear equations, which is generally difficult to solve using analytical methods in real time operations. Hence, it is essential to and the simple model useful for real time application[1].

(i) Simplified Single diode model

It was proposed that SSDM shown in Fig. 1.1 is sufficient for representing three different types of PV cells when the effect of temperature on parameterization is taken into account. The shunt resistor is removed from the model as its value is very large[1].

(ii) Further Simplified Single diode model

The series resistor of SSDM is neglected to form FSSDM. The significance is that there will be large variation in the output characteristics[1].

Selection of appropriate diode model[1]

The selected diode model is 'Simplified Single Diode model,' justified as follows:

(i) The shunt resistance can be neglected since it is very large and corresponds to open circuit.
(ii) The removal of series resistance leads to large variations in the output characteristics and thus it is included in the diode model.

The photovoltaic panel can be modeled mathematically as given in equations[1]

Module photo-current

$$I_{ph} = [I_{SCr} + K_i(T - 298)] * \lambda/1000 \quad (1)$$

Module reverse saturation current-I_{rs}

$$I_{rs} = I_{SCr}/[\exp\left(\frac{qV_{oc}}{N_s kAT}\right) - 1] \quad (2)$$

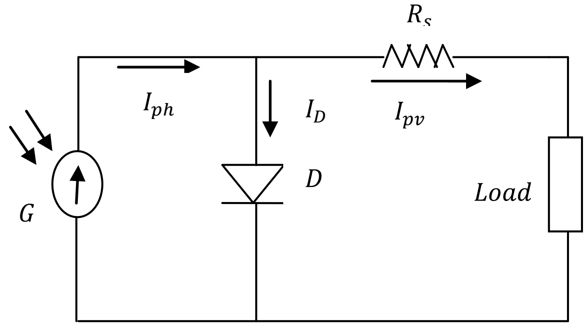

Fig. 1.1: Simplified single diode model

The module saturation current I_o varies with the cell temperature, which is given by

$$I_o = I_{rs}[\frac{T}{T_r}]^3 \exp[\frac{q * E_{g0}}{Bk}\{\frac{1}{T_r} - \frac{1}{T}\}] \quad (3)$$

The current output of PV module is

$$I_{pv} = N_p * I_{ph} - N_p * I_o \left[\exp\left\{q * \frac{(V_{pv}+I_{pv}R_s)}{N_s A k T}\right\} - 1\right] \quad (4)$$

Where $V_{pv} = V_{oc}$, $N_p = 1$ and $N_s = 36$.

A. *Nomenclature:*

- V_{pv} is the output voltage of PV module(V).
- I_{pv} is the output current of PV module(A).
- T_r is the reference temperature = 298K.
- T is the module operating temperature in Kelvin.
- I_{ph} is the light generated current in a PV I_{pv}module(A).
- I_o is the PV module saturation current(A).
- A = B is an ideality factor.
- K is Boltzmann constant = 1.3805*e^{-23}J/K.
- q is the electron charge = 1.6*e^{-19}C.
- R_{se} is the series resistance of the module.
- I_{scr} is the PV module short circuit current at 25℃ and 1000W/m^2.
- K_i is the short circuit current temperature coefficient 0.0017A/℃.
- G is the PV module illumination = 1000W/m^2.
- N_s is the number of cells connected in series.
- N_p is the number of cells connected in parallel.

B. *PV module Specifications:*

Reference module: 36W_p PV module.

- Rated Power = 37.08W_p.
- Voltage at maximum power (V_{max}) = 16.56V.
- Current at maximum power (I_{mp}) = 2.25A.
- Open circuit voltage (V_{oc}) = 21.34V.
- Short circuit current (I_{scr}) = 2.55A.
- Total number of cells connected in series (N_s) = 36.
- Total number of cells in parallel (N_p) = 1.

III. Mathematical Modelling of PV Module and Results

Fig 2.0 shows the mathematical model of a PV Module block developed using MATLAB. It gives an insight on the variation of I-V and P-V characteristics of the PV Module block under reference and varying conditions.

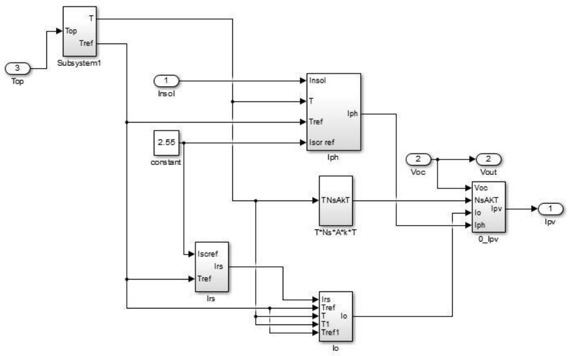

Fig.2.0 MATLAB model of PV Module block

The following are the MATLAB results of PV Module.

Fig 2.1 and 2.2 show the non-linear characteristics of PV Module at constant temperature(313K) and constant solar insolation(1 Sun). Fig 2.3 and 2.4 show that increase in operating temperature at constant solar insolation, increases the output current marginally and the voltage decreases significantly. The output power also decreases marginally because of the increase in the reverse saturation current. Fig 2.7 and 2.8 show that with the increase in solar insolation at constant operating temperature, 313 K, the output current increases considerably and the voltage increases marginally resulting in significant output power increase.

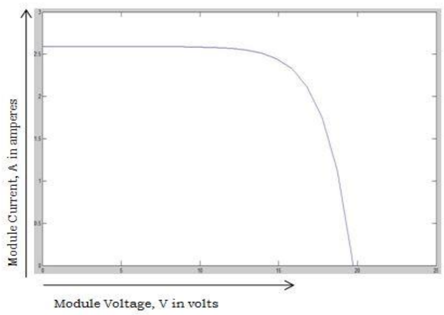

Fig.2.1 I-V characteristics of PV Module

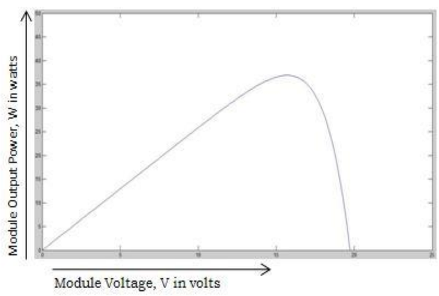

Fig.2.2 P-V characteristics of PV Module

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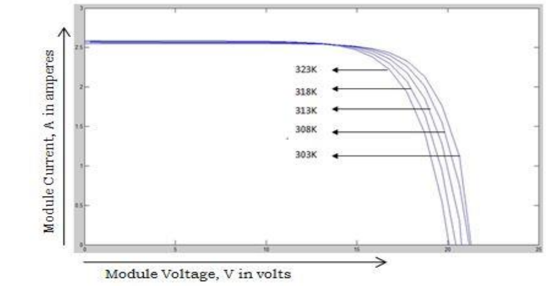


Fig.2.3 I-V characteristics of PV Module for different temperature at 1Sun

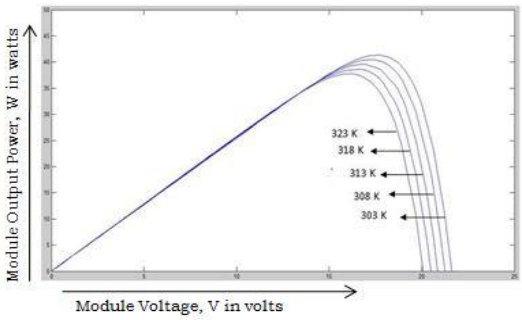
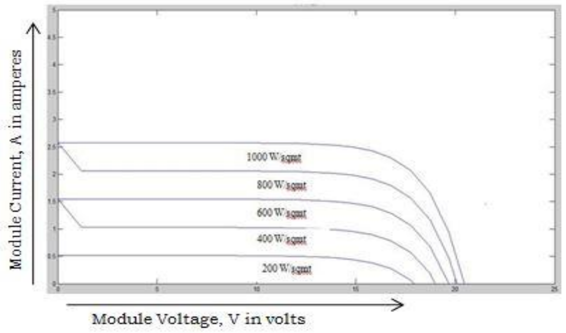


Fig.2.4 P-V characteristics of PV Module for different



temperature at 1Sun

Fig.2.5 I-V characteristics of PV Module for different solar insolation at temperature 313K

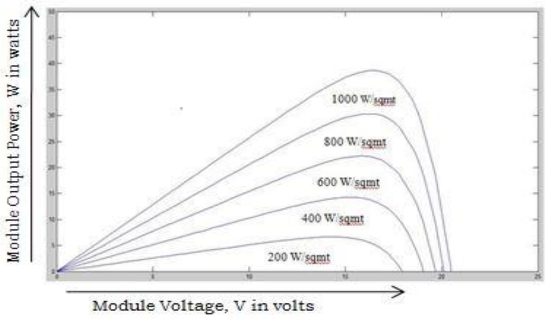


Fig.2.6 P-V characteristics of PV Module for different solar insolation at temperature 313K

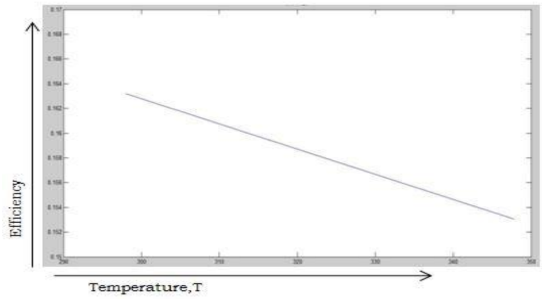


Fig.2.7 Efficiency of PV Module scaled against different temperature at 1Sun

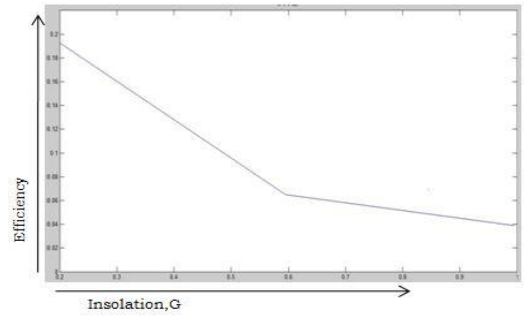


Fig.2.8 Efficiency of PV Module scaled against different solar insolation at 313K

Conclusion

It is necessary to have a mathematical model that accurately represents the electrical characteristics of the PV Module. Thus a reference PV Module is selected, mathematically modeled using MATLAB/Simulink to obtain the I-V and P-V characteristics for constant and varying operating temperatures and solar insolation.

The module output voltage decreases with increase in operating temperature hence the output power decreases. Module current and module output voltage increases with increase in insolation and hence increasing the output power of the PV Module.

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