Mathematical Modelling and Performance Analysis of PV Module

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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 and thus it is included in the diode model.

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

Module photo-current

\[ I_{ph} = [I_{SCR} + K_i(T - 298)] \times \lambda /1000 \] (1)

Module reverse saturation current-\(I_{rs}\)

\[ I_{rs} = I_{SCR}/[\exp (\frac{q(V_{oc} - h \cdot \lambda)}{kA \cdot T}) - 1] \] (2)

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 thus it is included in the diode model.

II. SYSTEM DESCRIPTION

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].

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

Module reverse saturation current

\[ I_{rs} = I_{SCR}/[\exp (\frac{q(V_{oc} - h \cdot \lambda)}{kA \cdot T}) - 1] \] (2)

The module saturation current \(I_s\) varies with the cell temperature, which is given by

\[ I_s = I_{rs} \cdot \left[ \frac{1}{T_r} \right]^{3} \exp \left[ \frac{q \cdot V_{oc}}{kA \cdot T} \left( \frac{1}{T} - \frac{1}{T_r} \right) \right] \] (3)

Fig. 1.1: Simplified single diode model

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The current output of PV module is

$$I_{pv} = N_p \cdot I_{ph} - N_p \cdot I_o \left[ \exp \left( \frac{q \cdot \left( \frac{V_{pv} + I_{pv} \cdot R_s}{N_s \cdot A \cdot k \cdot T} \right)}{N_s} \right) - 1 \right]$$  \hspace{1cm} (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 = 298 K.
- $T$ is the module operating temperature in Kelvin.
- $I_{ph}$ is the light generated current in a PV module (A).
- $I_o$ is the PV module saturation current (A).
- $A = B$ is an ideality factor.
- $K$ is Boltzmann constant = $1.3805 \times 10^{-23}$ J/K.
- $q$ is the electron charge = $1.6 \times 10^{-19}$ C.
- $R_s$ is the series resistance of the module.
- $I_{scr}$ is the PV module short circuit current at 25°C and 1000 W/m$^2$.
- $K_i$ is the short circuit current temperature coefficient 0.0017 A/°C.
- $G$ is the PV module illumination = 1000 W/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: 36Wp, PV module.
- Rated Power = 37.08 Wp.
- Voltage at maximum power ($V_{max}$) = 16.56 V.
- Current at maximum power ($I_{mp}$) = 2.25 A.
- Open circuit voltage ($V_{oc}$) = 21.34 V.
- Short circuit current ($I_{scr}$) = 2.55 A.
- 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.
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.

REFERENCES