Published by :
http://www.ijert.org

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 12, December - 2017

Mathematical Modeling of a Solar Cell and its Performance Analysis under Uniform and Non-Uniform Insolation

M. Vinay Kumar
Department of Electrical & Electronics Engineering,
GMR Institute of Technology, Rajam

U. Salma
Department of Electrical & Electronics Engineering,
Git
Gitam University, Visakapatnam

Abstract **- Solar photovoltaic (PV)based electric power generation is gainingmuch importance due to huge availability of solar energy, developments inPV cell materials and energy transformation technology. Global warming effects and fast depletion of fossil fuelsis directly encouraging thistransformation process.The electric power produced by solar PV module depends on theinsolation and temperature.This paper presents a mathematicalmodel for a solar photovoltaic PVcell in order to evaluate its electrical characteristics with respect to weather conditions such as uniform insolation, change in insolationand change in temperature. The solar PV cell is modeledthrough mathematical equations and is representedby an equivalent circuit having a photocurrent source, a diode, a series resistor and a shunt resistor. As the performance of a solar PV array getsaffected by PV array insolation and temperature, it isimportant to understand the relation between these effects and its dependence on the output electric power of PV array. The main purpose of this paper is to consider the effects of sunlight insolation and celltemperature, then output current and voltage (I-V) characteristics, output powerand voltage (P-V) characteristics of PV model are simulated with help of Matlab simulation. This model is designed with a user-friendly icon and adialog box like Simulink block libraries and it has beendeveloped using Matlab/Simulinksoftware package.**

Keywords - Solar Cell Model, Solar Array Model, Solar Insolation, Maximum Power Point Tracker, Matlab, SIMULINK

I. INTRODUCTION

With increasing alarms about skyrocketing oil prices, depletion of fossil fuel, global warming and destruction to environment and ecosystem, the alternative solution for the above mentioned concerns is to be overcome, the only solution is theusage of alternative energy resources with high efficiency and low emission of gases.

The alternative energy resources are renewable energy sources are also called asnon-conventional energy sources,these arecontinuously renewed by natural biological process. These include solarenergy, wind energy, ocean energy, tidal energy,geo thermal energy, hydropower,bio-energy - bio-fuelsetc., are few examples ofrenewable energy sources. A renewable energy system transformsthe energy found in sunlight, wind, sea-waves, falling-water, geothermal heat, or biomass into required forms, such as in the form of electrical energy or heat energy.

In spite of the intermittency of sunlight, solar energy is broadly available and it is completely free of cost. A photovoltaic (PV) system converts solar energy into electrical energy. PV system is generally utilized in the forefront for electric power generation. It can generate direct current electricity without environmental pollution when exposed to solar radiation. PV systems are gaining more attention as renewable energy source as it does not pollute, has no fuel cost, doesn't contain any moving parts, hence no operating noise, requires less maintenance costs.etc.,

The basic element of a PV system is a PV cell. A PV array consists of several cells connected in series and/or parallelfor having a higher current/ voltage rating of the PV array.

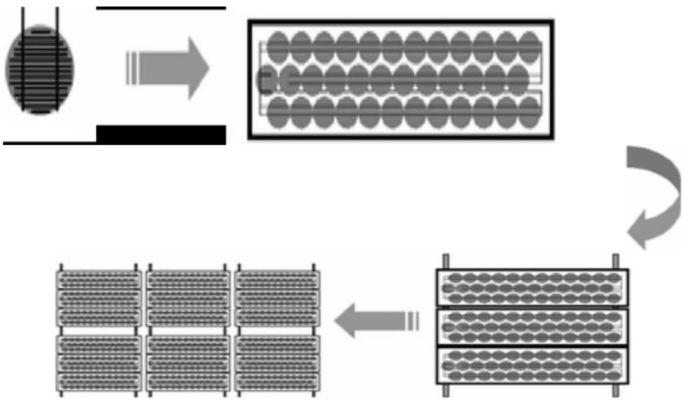


Fig.1.Photovoltaic cell, module, panels and arrays

Model for a PV cell or a PV module based on the Shockley diode equation is presented [1], [2]. PV system sometimes may operate in conditions which results in non-uniform irradiance of PV arrays due to bird dropping, debris, dust, leaves, clouds, shadows etc., if number of PV cells are mismatched due to non-uniform irradiance, such cells will limit the output current of normal PV cells [7]-[10]. These operating conditions leads to reduction in output power, generation of hot spot and finally causes damage to the cell. To protect the PV cells a bypass diode is connected in parallel. To obtain maximum output from a PV system, it is very important to have the knowledge of PV cell characteristics under non-uniform irradiance [11]-[13].

The productivity of a PV array system depends on the working conditions. The current, output voltage and power of PV array fluctuate according to solarirradiation level, temperature and load current.These PV systems used as distributed generators (DG) and canbe located at the places where the demand of electric energy ascends,therebyavoiding losses of transmission and also contributing in reductions tothe CO_2 emission.This paper presents Matlab-Simulink based PV module model, which can be series-paralleled to achieve require current-voltage rating of PV array.

.

II. PHOTOVOLTAIC MODELING

An ideal PV cell is modeled with a current source connected diode in anti-parallel.For a non-ideal PV cell, series resistance and a shunt resistance are connected. The value of series resistance is very small and that of a shunt resistance is very large.PV systemdisplays a nonlinear I-V and P-V characteristicswhich fluctuate with the radiant intensity and operating cell temperature.

A. Mathematical model of aPhotovoltaic Cell

Solar PV cell is a basic component of a PV system,it comprises of p-type and n-type semiconductors and ismanufactured as a p-n junction on a thin wafer of semiconductor. The output of each PV cell is around 0.5V to 0.7V. When theyare connected in series,net output voltage increasesand when connected in parallel,net output currentincreases.

There are many equivalent circuits for a PV cell, a single diode, a two diode model are mostly used. A single diode model being simple and accurate is taken up in this paper.The basic circuit of a single diode model for asolar PV cell [3]-[6]is shown in Fig.2.

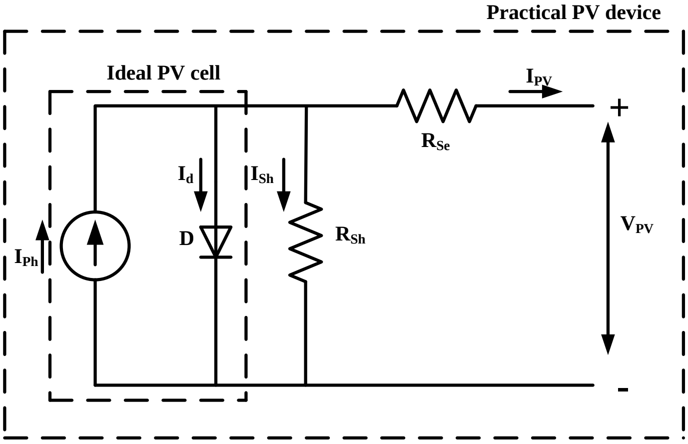


Fig.2. Equivalent circuit of a single solar cell

The symbols for the above circuit are as follows:

I_{ph}: photo current
I_{pv}: output current
I_d : diode current
I_{sh}: shunt current
I_o : reverse saturation current
I_{or}: reverse saturation current at reference temperature
I_{scr}: short circuit current
T_r: reference temperature
T: cell operating temperature
E_{go} : band gap energy
q :charge of a electron = $1.6 * 10^{-19}$coloumbs
K :Boltzman's constant = $1.3805 * 10^{-23}$ J/K
K_i : temperature coefficient of short cuit current
K_v : temperature coefficient of open circuit voltage
V_t : thermal voltage
V_{PV} :output voltage
V_{oc} : open circuit voltage
V_t : thermal voltage
R_{Se}: series resistance
R_{Sh}: shunt resistance
N_{Se}: number of cells in series
N_{Sh}: number of cells in parallel
S_r:solar reference irradiation
S:solar cell operating irradiation
a: ideality factor

The mathematical equations of asolar cell are given below.
Using Kirchoff's first law

$$I_{PV} = I_{Ph} - I_d - I_{sh} \quad (1)$$

$$I_{Ph} = [I_{scr} + K_i(T - T_r)]\left(S/S_r\right)$$

$$I_d = I_o\left[\exp\left(\frac{V_{PV} + I_{PV}R_{Se}}{aV_t}\right) - 1\right]$$

$$I_o = I_{rs}\left(\frac{T}{T_r}\right)^3 \left(\exp \frac{qE_{go}}{\frac{1}{T_r} - \frac{1}{T}}\right)$$

$$I_{rs} = \left(\frac{I_{scr}}{\exp\left(qV_{oc}/AKT\right) - 1}\right)$$

$$I_{sh} = \left(\frac{V_{PV} + I_{PV}R_{Se}}{R_{Sh}}\right)$$

The load current I_{pv} is given as

$$I_{PV} = I_{Ph} - I_o\left[\exp\left(\frac{V_{PV} + I_{PV}R_{Se}}{aV_t}\right) - 1\right] - \left(\frac{V_{PV} + I_{PV}R_{Se}}{R_{Sh}}\right) \quad (2)$$

$$V_t = \left(\frac{KT}{q}\right)$$

Photovoltaic cell characteristic curves, I-V, P-V curves are obtained by simulationequation (2).

B. Mathematical model of a Photovoltaic Module

A number of *Photovoltaic cells* are connected in series- parallel to form an array, number of such arrays are further connected to form panels or modules. The solar PV system converts irradiation is directly to electrical energy through photovoltaic effect. The Fig. 3 shows uniform insolation on a photovoltaic system.

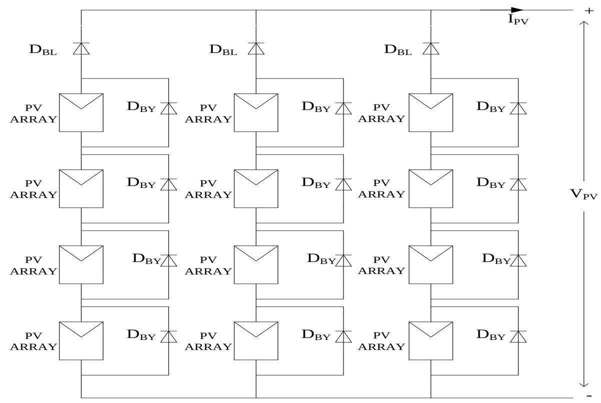


Fig.3. Uniform insolation for a photovoltaic system

The blocking diodes and bypass diodes are generally used in PV systems in series/parallel with PV arrays. A blocking diode allows flow of current from a PV panel to the battery for charging, ie., storing energy during day time, but does not allow the current to flow back from the battery to the PV panel during night times, hence preventing them from discharging.By pass diodes are connected in parallel with PV panels for a multi string PV panel system. These bypasses the path of the current from the shaded panel and provides an alternate path for the current flow and hence maintaining continuity of power supply. Based on single PV cell circuit module, the voltage andcurrent relationship of a PV module can be represented as (3).

$$I_{PV} = N_{Sh} I_{Ph} - N_{Sh} I_o \left[\exp\left(\frac{V_{PV}/N_{Se} + I_{PV} R_{Se}/N_{Sh}}{aV_t} \right) - 1 \right] - \left(\frac{V_{PV}/N_{Se} + I_{PV} R_{Se}/N_{Sh}}{R_{Sh}} \right) \quad (3)$$

C. *Photovoltaic Cell/module under Non-Uniform insolation*

Under uniform insolation, Eq. (3) is able to precisely model the performance of PV module. But for non- uniform insolation, ie.,.under partial shading condition Eq. (3) cannot simulate this weather condition. The Fig. 4 shows non uniform insolation on a photovoltaic system. This non uniform insolation may occur due to various factors like bird droppings, passing of aeroplane, clouds,etc., The shaded PV arrays signify that solar insolation on them is less or nil as compared to the shaded PV array, hence their output power is either low or zero. To maintain the continuity of power production all the PV panels have bypass diode connected in parallel with PV panels, and in such case these types of panels are eliminated and the flow of current follows the bypass diode, hence maintaining continuous power production. The bypass diodes also prevents the flow of current from uniform insolated PV panel which are at higher potential to the less insolated or shaded PV panel which is at a lower potential. Hence, even under non uniform insolation condition the bypass diode helps in operating the whole solar PV system and produce electricity at a lower rate.

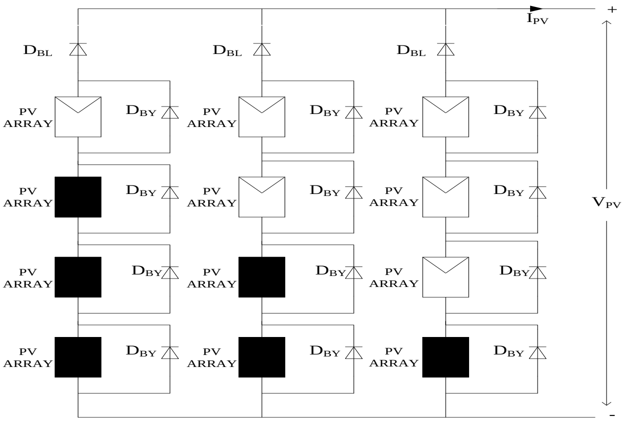


Fig.4. Non-Uniform insolation for a photovoltaic system

Asthe effects of non-uniform insolation on a solar module cannot be obtained from mathematical model ie., Eq. (3),the solarphoto current is used which is denoted by a current source and the effectscan be simulated by changing the values of current source.

III. PV MODULE MODEL IN MATLAB-SIMULINK

A 175W PV module BP 4175B has been chosen for modeling inMatlab-Simulink environment. Theconcerned Electrical characteristics specifications are shown intableI.

Table.IElectrical characteristics

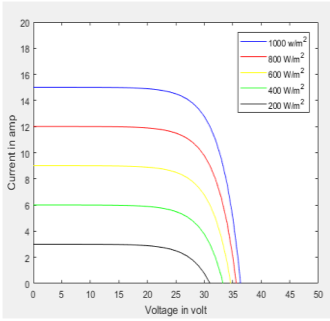
Parameter	Value
Maximum Power	400 W
Voltage at maximum power	32.5 V
Current at maximum power	13.94 A
Short-circuit current	15.5 A
Open-circuit voltage	38.6 V
Temperature coefficient of open-circuit voltage	0.065 %/^{0}C
Temperature coefficient of short-circuit current	-0.5 %/^{0}C

IV. SIMULATION RESULTS

This section presents the simulation resultsof the PV cell at different weather conditions like constant temperature at different insolations and constant insolation at different temperatures. Also the simulation results of the PV cell at non-uniform insolation are presented.

A. *Illustration- I (uniform insolation)*

For a single PV module, the I–V, P-V characteristics at uniform insolationsare presented below. The I–V, P-V curves at a constant temperature of 25°C but at different insolation levels are shown in Fig. 5& Fig. 6 respectively. The solar insolationsare 1000W/m^2, 800W/m^2, 600W/m^2, 400W/m^2, and 200W/m^2 respectively.



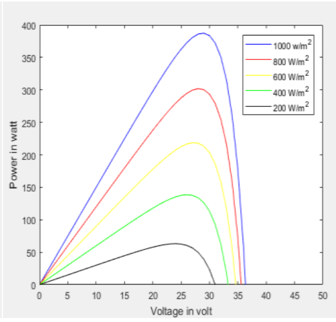
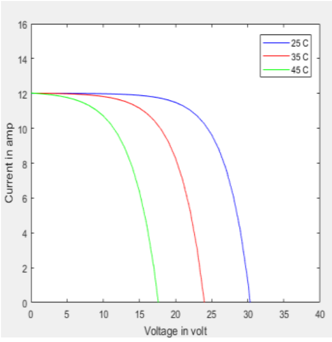


Fig.5. I-V Characteristics at constantFig. 6. P-V Characteristics at constant temperature& various insolation levelstemperature &various insolation levels

The I–V, P-V curves at a constant insolation of 800 W/m^{2}and at different temperatures are shown in Fig. 7& Fig. 8 respectively.The temperatures are 25^{0}C (298^0 K), 35^{0}C (308^0 K) and 45^{0}C (318^0 K) respectively.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 12, December - 2017



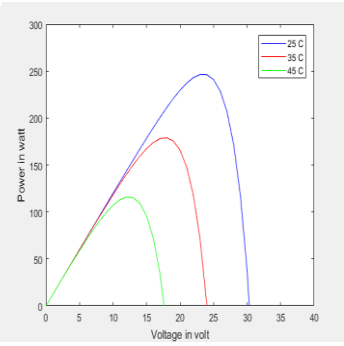


Fig. 7. I-V Characteristics at constant Fig. 8. P-V Characteristics at constant insolation& various temperaturesinsolation & various temperatures

The I–V, P-V curves at non-unifrom insolation at two differentinsolation of 800 W/$m^2$and 500 W/m^2 at a constant temperature of 40^0C(313^0 K) is shown in Fig. 9& Fig. 10 respectively

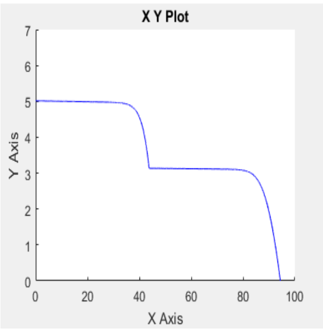


Fig.6.I-V Characteristics of a Partial shading PV system

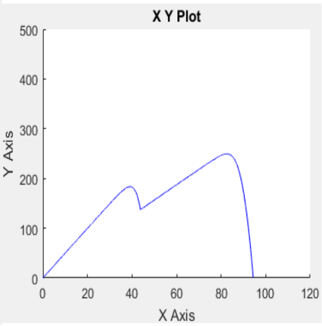


Fig. 6. P-V Characteristics of a Partial shading PV system

V. CONCLUSION

A PV module model simulation using MATLAB-Simulink software is presented in this paper. Using this model I-V andP-V characteristics can be studied with different weather conditions of insolation and temperature, i.e., under uniform and insolationnon-uniform insolation. When PV modules are exposed tonon-uniform insolation, multiple peaks in I-V, P-V characteristics are formed. If the PV system has to operate at maximum efficiency, it needs to track the power at global peak and hence should be able to discriminate between local peak and global peak.

The conclusion drawn from the simulation results are as follows

i. During uniform insolation of a PV modules, there exists only one peak for each I-V and P-V characteristics

ii. During non-uniform insolation of a PV modules, there exists multiple peaks for both I-V and P-V characteristics

iii. The number of power peaks are directly proportional to number of insolation levels on PV modules, during non-uniform insolation of a PV modules.

iv. During non-uniform insolation of a PV modules, the output power produced is more for the same series string.

The simulation not only just gives I-V and P-V characteristics, i.e., the behavior of PV array, but also its study helps in developing electronic circuit for maximum power point tracker for tracking maximum power from P-V characteristics where the system needs to operate, hence new MPPT strategies can be developed. The presented results will help in designing best configuration of PV array to produce maximum output power.

REFERENCES

[1] Francisco M. González-Longatt, “Model of Photovoltaic Module inMatlab™”, II CIBELEC 2005, pp. 1–5, 2005.
[2] Aauschenbach, H. S., “Solar cell array design handbook”, LittonEducational Publishing Inc, USA, 1980
[3] Vu Minh Phap; N. Yamamura; M. Ishida; Nguyen Thuy Nga, “Impact of solar irradiation on PV cell emulating system in series connection mode”, 2017 International Conference on High Voltage Engineering and Power Systems (ICHVEPS), pp. 268 – 271
[4] A. S. Martyanov; D. V. Korobatov; E. V. Solomin, “Simulation model of public street lighting provided by a photovoltaic converter and battery storage”, 2017 International Conference on Industrial Engineering, Applications and Manufacturing (ICIEAM), pp.1 – 5
[5] Rahul S. Sharma; P. K. Katti, “Perturb & observation MPPT algorithm for solar photovoltaic system”, 2017 International Conference on Circuit ,Power and Computing Technologies (ICCPCT), pp.1 – 6
[6] Eduardo M. G. Rodrigues; RaduGodina; EdrisPouresmaeil; João P. S. Catalão, “Simulation study of a photovoltaic cell with increasing levels of model complexity”, 2017 IEEE International Conference on Environment and Electrical Engineering and 2017 IEEE Industrial and Commercial Power Systems Europe (EEEIC / I&CPS Europe), pp. 1 - 5
[7] Tarun Kumar; Bhavnesh Kumar; S K Jha, “MATLAB/Simulink model to study solar cell characteristics under partial shading”, 2017 International conference of Electronics, Communication and Aerospace Technology (ICECA), pp. 642-646
[8] Xiangyun Qing; Hao Sun; Xiangsai Feng; C. Y. Chung, “Submodule-Based Modeling and Simulation of a Series-Parallel Photovoltaic Array Under Mismatch Conditions”, IEEE Journal of Photovoltaics, 2017, pp. 1731 - 1739
[9] K. Tadjine; D. Rekioua, “Photovoltaic panels characteristics under shadows”, 2016 International Renewable and Sustainable Energy Conference (IRSEC), pp. 873 - 878
[10] Gourab Das; M. De; K. K. Mandal; S. Mandal, “ Investigation on modeling, simulation and sensitivity analysis of solar photovoltaic array and utilization of shading effects”, 2017 3rd International Conference on Computational Intelligence & Communication Technology (CICT), pp.1 - 6
[11] Hadi M. El-Helw; Ahmed Magdy; Mostafa I. Marei, “A Hybrid Maximum Power Point Tracking Technique for Partially Shaded Photovoltaic Arrays”, IEEE Access, Year: 2017, Volume: 5, pp. 11900 – 11908 G. M. Masters, Renewable and Efficient Electric Power Systems.NewYork: Wiley-IEEE Press, 2004.
[12] H. Patel and V. Agarwal, “MATLAB-based modeling to study the effectsof partial shading on PV array characteristics,” IEEE Trans. EnergyConvers., vol. 23, no. 1, pp. 302–310, Mar. 2008.
[13] N. D. Kaushika and A. K. Rai, “An investigation of mismatch losses insolar photovoltaic cell networks,” Energy, vol. 32, no. 5, pp. 755–759,May 2007.