Characteristics of Solar PV Array Implemented in Matlab Software

Gourab Das, M. De, S. Mandal and K.K. Mandal

Abstract In recent time due to diminishing fossil fuel reserves and increasing social pressure in terms of environmental pollution, complex power system has no other option except to seek for another possibility of alternative energy to eliminate the environmental pollution. Solar energy accounts for the most of the renewable energy on earth. PV module is a particular procedure to accomplish the generation of electric power from solar radiation using semiconductor devices which exhibit photovoltaic effects. The concepts of a PV module and its characteristics have been studied. The P–V and V–I curves have been obtained at changing solar irradiation levels and temperatures.

Keywords Photovoltaic (PV) · Direct current (DC) · Current over voltage (V–I) · Power over voltage (P–V)

1 Introduction

The alarming rate of fossil fuel shortage, oil prices hike, global warming, and potential ill effects in environment, besides, gives the support by Government as well private agencies to develop environment friendly energy resources have put forward renewable power generation as an lucrative domain for research in this field. PV cell power is a sustainable energy technology that has seen extensive growth rate from the 1980s. Both the scaling down in cost and the progress in use have been substantial in solar power generation technology. Renewable energy systems and its subsequent implementation have nowadays become a suitable technical option to produce clean and affordable electric power. To produce a computer model of performance characteristics of different types of crystalline silicon photovoltaic

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modules/strings/arrays, novel theoretical approach has been the major focused area in recent literature [1]. In the recently developed model, the performance of the PV module at any solar irradiance and cell temperature can be simulated. The yield characteristic of solar PV module depends upon solar irradiation, cell temperature, and the output voltage [2]. An optimization-based approach for total cross-tied connected modules in a photovoltaic array is presented [3]. MATLAB coding-programmed modeling and simulation of PV module are presented by focusing on the effects of partial shading on the output of the photovoltaic (PV) systems [4]. Nowadays, PV array has been widely used in the electrical power system which is capable of generating DC electricity without environmental impact [5]. The PV module has been implemented by one-diode or two-diode models [6]. PV array has nonlinear characteristics and it is effective to design in maximum power point tracking. The PV module has semiconductor static device and there is no moving parts, so its maintenance cost is less. Simulation program of PV module has been implemented by series–parallel combination using some simulation parameter constant temperature and varying solar irradiance [7]. A solar module is modeled by attaching a number of cells in series to get a usable voltage which can be utilized in practice [8]. The C-language programming-based PV string simulation strategy was proposed [9] to simulate the effects of partial shading condition and develop new maximum power point tracking (new MPPT) algorithm for power conversion methods. The behavior of hybrid system hiring sustainable energy sources and changeable time is investigated [10] while providing a continuous steady supply. The work focused on modeling of a PV–wind hybrid system in Matlab/Simulink and the obtained model is useful for simulation of a grid-connected hybrid PV–wind system. The main aim of this research work is focused on the investigations on the modeling and simulation of solar energy sources.

1.1 Extraterrestrial Irradiation of Solar

In the core of the Sun originates innermost temperature 10^7 K by the nuclear fusion process and internal radiation flux has dissimilar spectral distribution. This inner radiation assimilates in the external submissive layers which are heated about 5800 K and it is source of radiation with a comparatively uninterrupted spectral distribution. The radiant flux varies throughout the year. So in this paper a different radiant flux (W/m^2) has been considered in Table 1.

1.2 Radiation Components of Solar Beam

Solar radiation fall on atmosphere from the direction of the Sun is the solar ethereal beam radiation. Underneath the atmosphere at the earth's uppermost layer, the radiation will be noticeable by the direction of the Sun disk (like a thin circular

Table 1 Simulation parameters for constant temperature and varying solar radiance

Simulation parameters	Values
Varying solar radiance intensities (S)	200, 400, 500, 800, 1000 W/m^2
Temperature of cell (T)	25 + 273
Reference temperature (Tref)	40 + 273
Short-circuit temperature coefficient (k_i)	0.0023 mA/°C
Boltzmann's constant (k)	1.38065×10^{-23}
Reverse saturation current (I_{rr})	21×10^{-10}A
Cell saturation current (Iscr)	0.75 mA
Area of the module (A)	0.40 m^2
Current temperature coefficient (α)	0.473 mA/°C
Voltage temperature coefficient (β)	636 V/°C
No. of cells connected in parallel (Np)	4
No. of cells connected in series (Ns)	100

object) in the direct beam and also other form of direction is diffuse radiation. The proportion between the beam radiance and the total radiance thus varies from about 0.9 on clear day to zero on complete foggy day (Figs. 1 and 2).

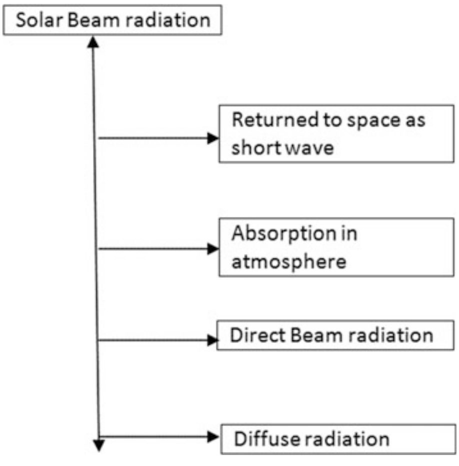


Fig. 1 Effects occurring as ethereal solar radiation is incident upon the atmosphere

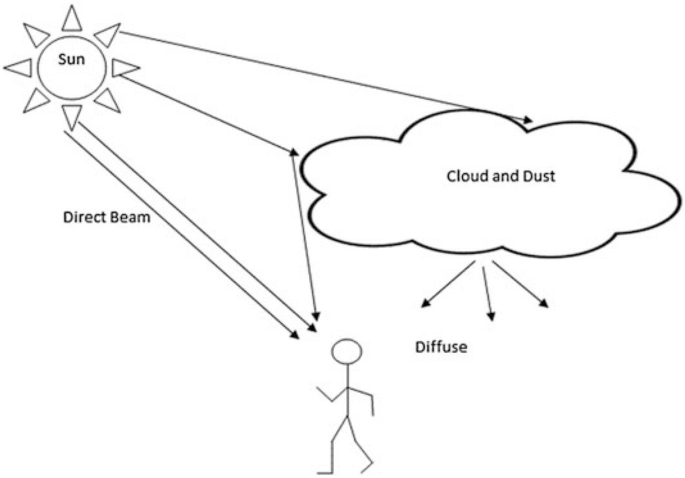


Fig. 2 Pictorial representation of direct beam and diffuse radiation

2 Photovoltaic Model and Its Governing Equation

The popularly known characteristics of a standard silicon p–n junction are shown in Fig. 3.

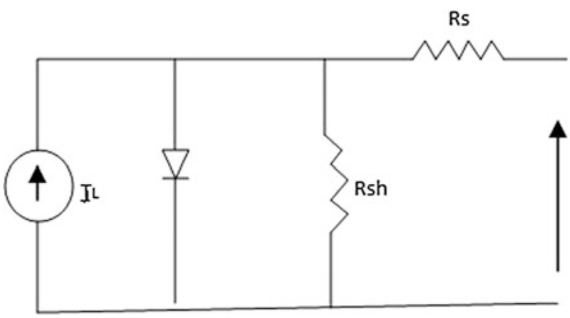
Mathematically, this can be given by

$$I = I_0\{\exp(V/V_T) - 1\}, \tag{1}$$

where I is the solar cell current, I_0 is the current in reverse saturation, V is the solar cell voltage, V_T is known as voltage equivalent of temperature, and at room temperature of 20 °C its approximate value is 26 mV which is equal to KT/Q where K is the Boltzmann's constant, T is the temperature in °K, and Q is the charges of electron.

When the p–n junction is illuminated by radiant flux, the characteristics get improved in shape and shift downward as photon-induced component is added with reverse leakage current.

Fig. 3 Equivalent circuit of solar PV cell



Equation (1) is the diode equation which is modified as follows:

$$I = -I_{SC} + I_0\{\exp(V/V_T) - 1\}. \tag{2}$$

When the junction is short circuited at its terminal V becomes zero and a finite amount current $I = -I_{SC}$ flows through the external path, appearing from p-side. I_{SC} is short-circuit current and its magnitude depends on solar insulation.

Now, a voltage source is installed in external path of p-side, as the magnitude value of the voltage is continually increased from zero and starts decreasing the current. Mathematically, representation of the open-circuit voltage Voc can be given by

$$Voc = V_T \ln\{(I_{sc}/I_0) + 1\}. \tag{3}$$

Typically, $I_{SC} = 2\,\text{A}$, $I_0 = 1\,\text{mA}$, $V_{OC} = 0.55\,\text{A}$ (at room temperature). Mathematically, the I–V characteristic of solar cell may be written (as per standard sign convention) as

$$I = I_{SC} - I_0\{\exp(V/V_T) - 1\}. \tag{4}$$

Solar energy is a best alternative for electric power generation and electromagnetic solar radiation which is exactly converted into electrical energy by solar PV module. Basically, solar module is made up of string of solar cell [8] and solar cell is an ordinary p–n junction diode of semiconductor. The PV module is composed of silicon cells. In open-circuit condition, the silicon cells have operating voltage of 0.7 V. The current ratings depend on the area of the particular cell. The current ratings of the module are proportional to the area of the solar cell, to obtain the higher power output. The solar photovoltaic modules are connected in series and parallel combinations to form solar PV array.

3 Equivalent Circuit

The I–V characteristic given in Eq. (4) is determined for ideal condition, considering internal series resistance of cell is zero and the shunt resistance is infinite. In actual practice, both have finite values, which would alter the characteristics. The ideal and practical equivalent circuits of the solar cell are shown in Fig. 3.

In practice I_{SC} is no longer equal to light generated by current I_V but is less by shunt current through shunt resistance, R_{sh}. The P–V current equation of solar P–V cell can be modified as follows:

$$I = I_L - I_0\{\exp(V + IR_S)/V_T - 1\} - (V + IR_S)/R_{sh} \tag{5}$$

V is P–V voltage, I_L is the photoelectric current (Figs. 4, 5 and 6).

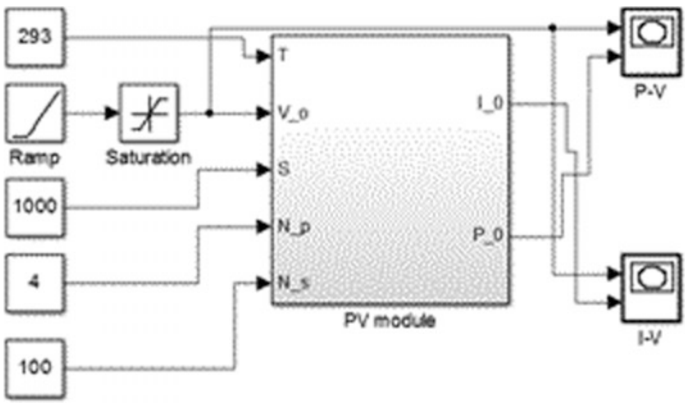


Fig. 4 Simulation model of PV cell

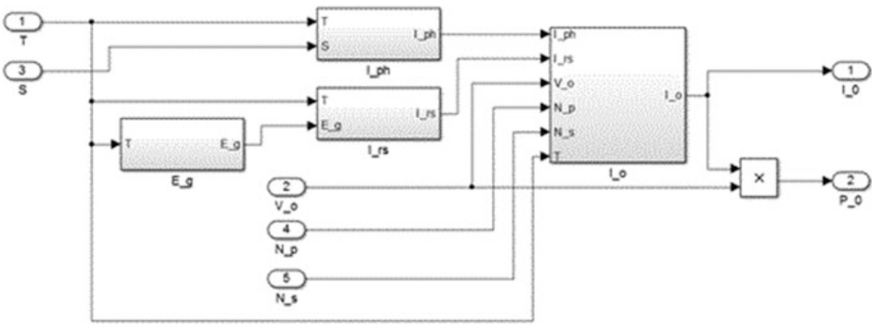


Fig. 5 Operational functional sub-block of PV model

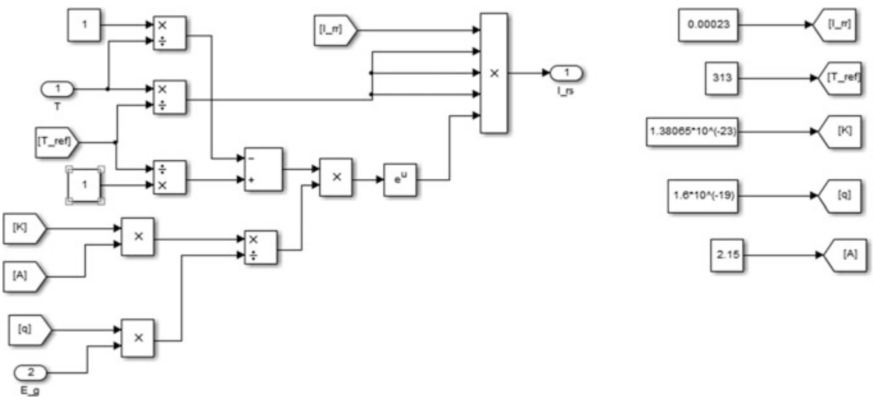


Fig. 6 Operational functional sub-block of PV model

For typical high-quality, one-square-inch silicon cell, series resistance, R_s = 0.05–0.10 Ω, shunt resistance, R_{sh} = 200–300 Ω.

T temperature of the module in Kelvin
I P–V current
I_L I_{SC}.

4 Simulation Model of PV Array with Its P–V and V–I Characteristics

The simulated PV model with four PV modules connected in series and its output of P–V and V–I characteristics are shown in Fig. 1. The programming-based code simplifies the simulation block and increases its efficiency and readability. The PV simulation model has been implemented through different stages. In Simulink model all the stages (functional blocks and sub-blocks) are interrelated. Simulation parameters are listed in Table 1. Simulation program of PV module has been implemented by series–parallel combination using some simulation parameter constant temperature and varying solar irradiance [7] and its output of V–I and P–V characteristics as shown in Figs. 7 and 8.

The plot of electrical characteristics of a PV module is represented at a particular temperature and solar irradiance. This is plotted on a graph with voltage on the axis of abscissas and current on the axis of ordinates, while maintaining irradiance and temperature levels constant. I–V curve presents an unlimited number of current–voltage operating points; the distinct operating point has been determined by the electric load associated to a PV system.

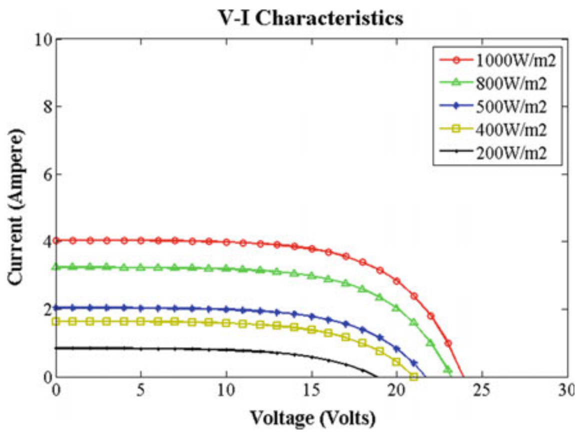


Fig. 7 V–I characteristic of PV cell

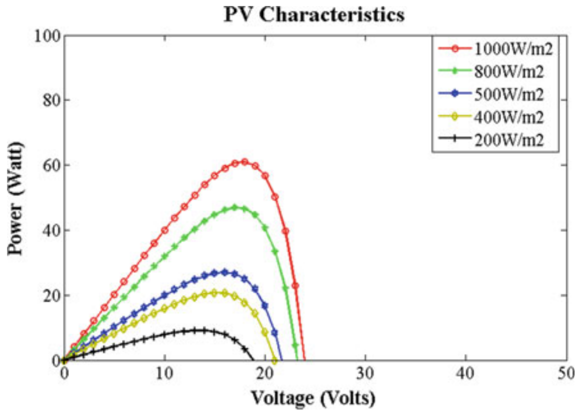
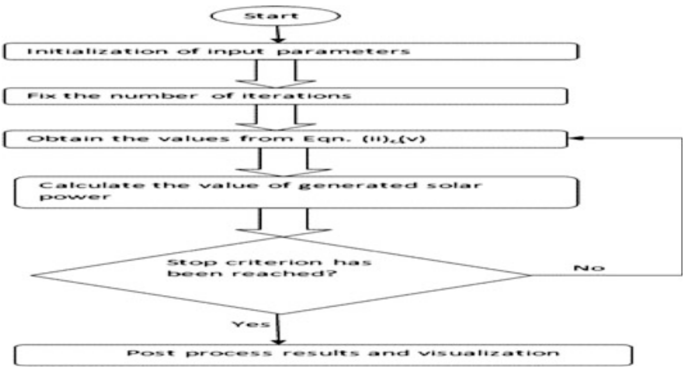


Fig. 8 V–P characteristic of PV cell

5 Matlab Coding Output of PV Array with Its P–V and V–I Characteristics



See Figs. 7, 8 and Table 1.

6 Conclusion

In summary, this paper dealt with PV module characteristics under two different approaches. An analytical model presented under consider of Matlab Simulink method with different solar irradiations and varying temperatures. Also this analytical method should implement through Matlab coding with different irradiances and temperatures. This result is obtained in the form of two fundamental graphs V–I and P–V characteristics.

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