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Mathematical Modeling of Photovoltaic Cell

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Abstract: ***Solar energy has been looked upon as a serious source of energy for many years because of the vast amounts of energy that are made freely available, if harnessed by modern technology. It is considered as** 'Renewable Energy'* ***because the technology used to convert the sun's power into electricity does not produce smoke & tapping the sun's energy does not usually destroy the environment. Electricity can be produced directly from photovoltaic (PV) cells. These cells exhibit the "photovoltaic effect" i.e. when sunshine hits the PV cell, the photons of light excite the electrons in the cell and cause them to flow, generating electricity. Each solar cell has a point at which the current (I) and voltage (V) output from the cell result in the maximum power output of the cell. Maximum Power Point Tracking, frequently referred to as MPPT, is an electronic system that operates the Photovoltaic (PV) modules in a manner that allows the modules to produce all the power they are capable of. Various approaches have been proposed to extract the maximum power from mismatched PV array. This paper represents the mathematical modelling of PV cell and also observes the effect of changing radiation on PV cell with constant temperature.***

Keywords: Solar system, Photovoltaic cell, Maximum Power Point Tracking (MPPT), Reconfiguration, I-V and PV characteristics

1. Introduction

Renewable energy uses energy sources that are continually replenished by nature-the sun, the wind, water, the Earth's heat, and plants. Renewable energy technologies turn these fuels into usable forms of energy—most often electricity, but also heat, chemicals, or mechanical power. We often call renewable energy technologies "clean" or "green" because they produce few if any pollutants. World total installed power generation capacity stands at 5.4 Tera Watts per year and it is expected to increase to about 6.22 Tera Watts by 2020. The present installed power generation capacity of India is 229 Giga Watts and expected to increase to about 285GW by 2020. The total installed power generation capacity includes the generation from both non-renewable and renewable energy sources. In India, the conventional sources share 87.55% of the total installed capacity and renewable sources share 12.45%. Due to the fast depletion of fossil fuels and environmental degradation as a result of global warming, researchers and engineers are currently focusing their attention on the development of techniques to harness power from various alternate renewable energy sources such as solar power, wind power and geothermal, tidal power etc. to cover this increasing demand. Solar photovoltaic is an environment friendly renewable source of energy which can help meet the significant part of the increased demand of energy in the country [8]. To obtain the maximum power from PV cells/module, different mechanical and electronic MPPT techniques are used.

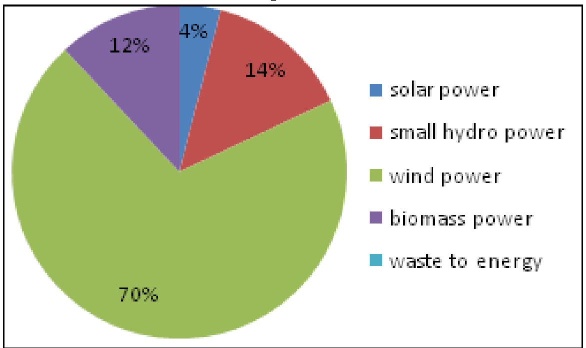

Figure 1: India's Renewable energy Installed capacity.

Because of its location between the Tropic of Cancer and the Equator, India has an average annual temperature that ranges from 25°C - 27.5 °C. This means that India has huge solar potential Due to its geographical location in a tropical region, India is rich in terms of solar radiation and most part of the country receives good radiation for up to 250 to 300 days per year. India receives around 6,000 Trillion kWh per year of solar energy every year. This is far more than its total annual energy requirements. Due to these inherent advantages, the installations of PV array for power generation are expected to grow at a much faster rate in the country. At present the total installed capacity of solar PV generation in India is around 2.079GW. India has launched the Jawaharlal Nehru National Solar Mission (JNNSM) in 2009 according to which a target of 20GW has been fixed for 2020. Fig.1 shows the India's Renewable energy Installed capacity [9].

2. Photovoltaic(PV) Cell

The main part of the solar system is solar cell. Semiconductor solar cells are basically simple devices. Semiconductors are capable to absorb light and convert a percentage of the energy of the absorbed photons to electrical current. A solar cell can be thought of as a semiconductor diode which separates and collects electrons and holes and conducts the generated current in specific direction. The solar cell is delicately designed to efficiently absorb and convert light energy from the sun into electrical energy. Fig.2 shows the physical structure of a basic solar cell [9].

The PV cell physically represent in two way i.e. one diode model and two diode model. A PV cell has a voltage of just 0.5V. To meet the voltage/current demand according to a given application, several solar cells are connected electrically in series or parallel to realize a PV module. Several PV modules are connected in series according to the voltage requirement of the application to make a PV string. Several PV strings are connected in parallel according to the current requirement of the application to make a PV array.

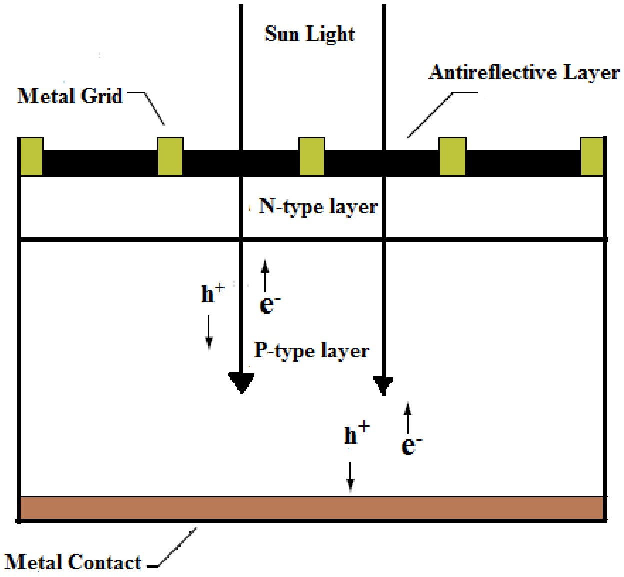

Figure 2: Principle of PV cell.

3. Representation of PV cell

The simplest version of one diode model is shown in Fig. 3. It consists of an ideal current source (representing the current generated by photons falling on the p-n junction) in parallel with a diode. The output of the current source is constant for a particular temperature and radiation condition. The two main parameters of a PV cell are the short circuit current (I_{SC}) and open circuit voltage (V_{OC}). Under short circuit conditions (R_L =0), the photon generated current (I_{ph}) is equal to the short circuit current [1]-[6]. By applying the Kirchhoff law to the node of the circuit reported in Fig.3 the current I produced by the photovoltaic module is obtained.

$$I = I_L - I_D \quad \text{......................... (1)}$$

Where:
I_D = Diode current;
I_L = Photoelectric current related to a given condition of radiation and of temperature.

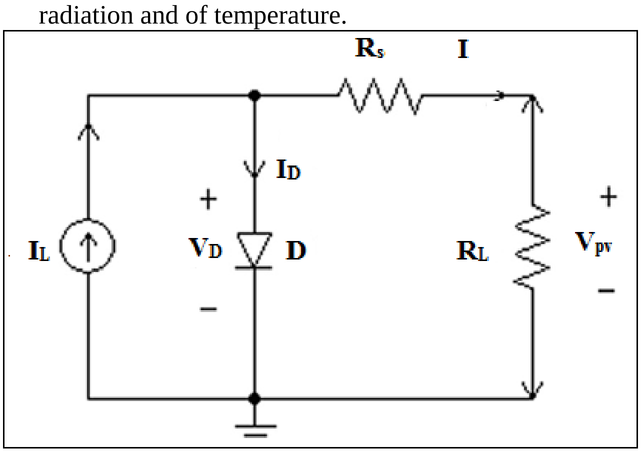

Figure 3: Physical representation of one diode model

I_D diode current is given by the Shockley equation:

$$I_D = I_0\left[exp\frac{q(V+IRs)}{\gamma kTc}) - 1\right] \text{................. (2)}$$

Where:
V = Output voltage [V];
Io = Diode saturation current [A];
γ = form factor which represents an index of the cell failing;
R_S =Series resistance of the cell [Ω];
q = electron charge ($1.602x10^{-19}$ C);
k = Boltzmann constant ($1.381x10^{-23}$ J/K);
T_C = photovoltaic cell temperature [K]

By substituting (2) into (1) the following equation is obtained which represents the I-V module characteristic curve under generic radiation and temperature conditions.

$$I = I_L - I_0\left[\exp\left(\frac{q(V-IRs)}{\gamma kTc}\right) - 1\right] \text{........... (3)}$$

The model proposed in (3) describes the working of a photovoltaic module under the hypothesis of knowing the values of R_S, I_0 and I_L. These values are definable as function of the data usually specified into the datasheet of the modules' manufacturer $I_{SC,REF}$ (short-circuit current under standard condition) $V_{OC,REf}$ (load-less voltage under standard condition). In order to take into account the variation of the diode saturation current and the pv current when temperature and radiation change with respect to standard conditions, the model is completed with the following equations [1]-[3]-[4]:

$$I_0 = I_{0REF}\left(\frac{Tc}{Tcref}\right)^3 \exp\left[\left(\frac{qEg}{k\gamma}\right)\left(\frac{1}{Tcref} - \frac{1}{Tc}\right)\right] \text{........ (4)}$$

Where:
Eg is the energy gap of the material with whom the cell is made (for the silicon it's 1 to 1.2 eV).

The main output current through photovoltaic cell is:

$$I_L = \left(\frac{G}{Gref}\right)\left[Iref + \mu(Tc - Tcref)\right] \text{........... (5)}$$

Where:
G is the radiation [W/m2]
Gref is the radiation under standard conditions [W/m2]
Iref is the photoelectric current under standard
Tcref temperature coefficient of the short-circuit condition.
The cell voltage can be given by:

$$V = \frac{\gamma kTc}{q} ln\left(\frac{IL-I}{Io} + 1\right) - IRs \text{................. (6)}$$

4. Characteristics of pv cell

The basic characteristics as shown in fig.4 which determining the most important parameters of a solar cell are I-V characteristic. From this curve we can read the parameters such as: short circuit current I_{SC} and open circuit voltage V_{OC}. Moreover we can appoint the current I_m and the voltage V_m. These two values define the point of maximum solar cell power on the I-V characteristic. When we have these values we can easily calculated more parameter, such as: the fill factor FF, the maximum power P_{max} or the cell efficiency η [2]-[5]-[7].

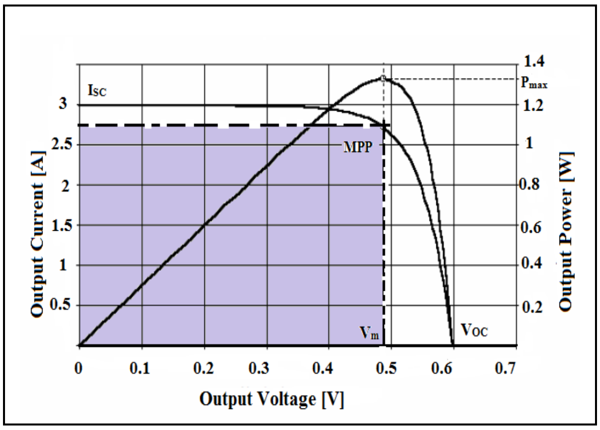

Figure 4: P-V and I-V characteristics of PV cell

5. Modelling of PV cell

By using the equations expressed in the above paragraph the mathematical model has been implemented and the block scheme is reported in Fig. 5[6].

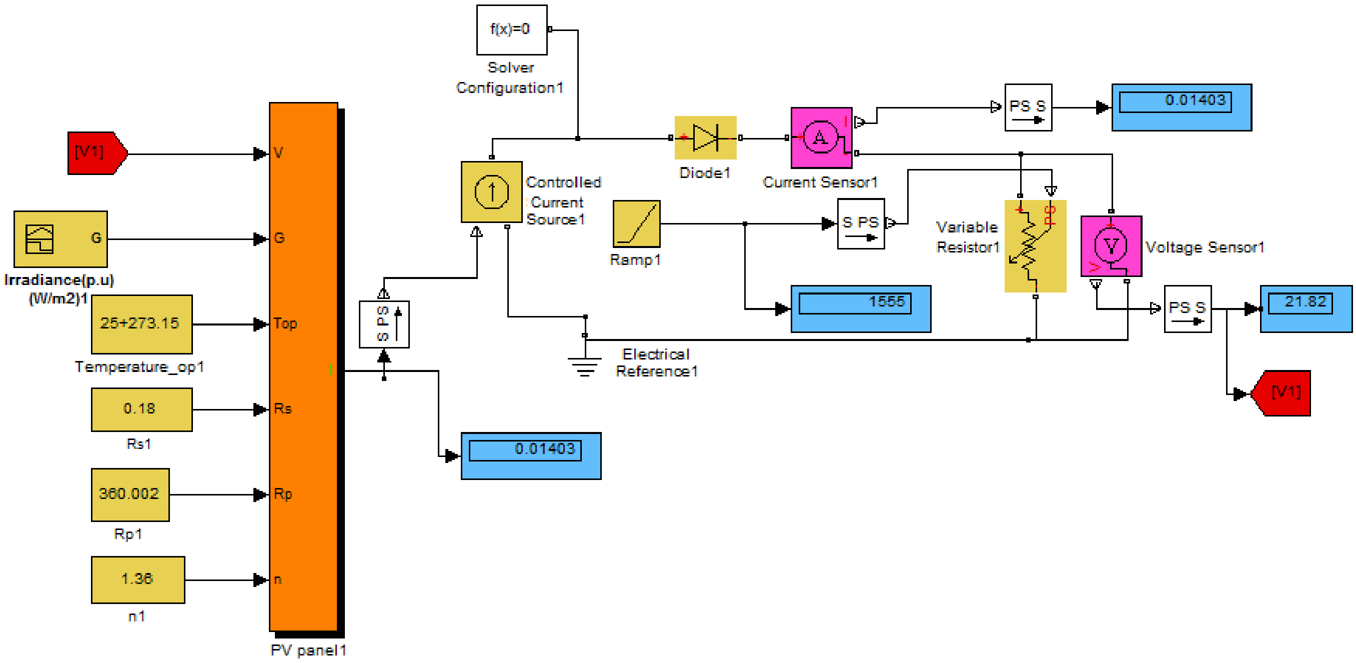

Figure 5: Modelling of PV Cell

6. Simulation Results

The modelling and simulation has been done in Simulink software available with MATLAB. In this work Simulation was carried out, for different values of insolation (G) W/m^2 with constant temperature=25^{o}C. The result is tabulated in Table 1. It is seen that the current is directly proportional to the radiation while voltages remain unaffected. The graphical representation of V-I and P-V characteristics of PV cell when G = 1KW/m^2 and G = 0.8 KW/m^2 are shown in fig. 6 and 7.

Table 1: Voltage, current and power values related to different radiation

Sr. No.	G (KW/m^2)	Voltage (V)	Current (A)	Power (W)
1	1	21.04	3.8	59
2	0.8	21.00	3	48
3	0.6	20.40	2.3	35
4	0.5	20.20	1.9	30
5	0.4	19.89	1.5	25

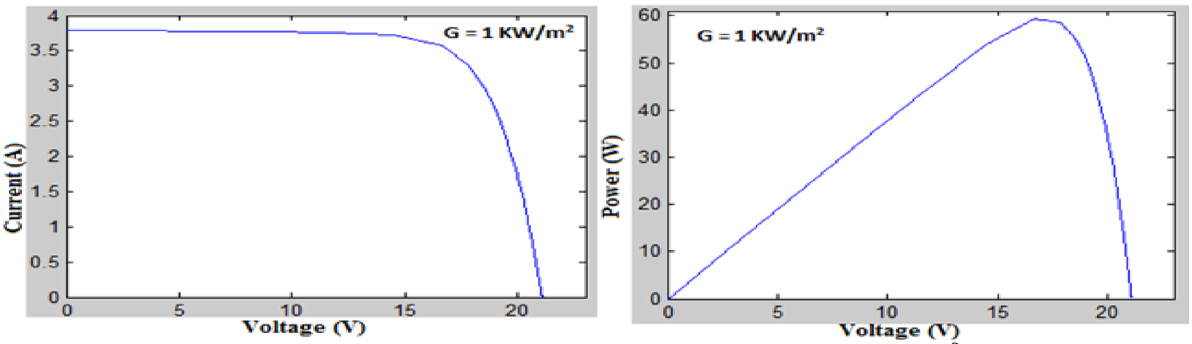

Figure 6: V-I and P-V characteristics of PV cell when G = 1KW/m^2

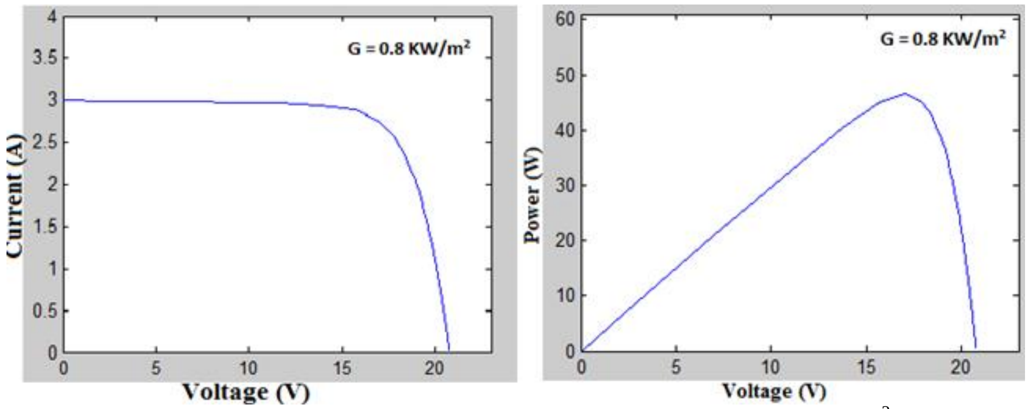

Figure 7: V-I and P-V characteristics of PV cell when G = 0.8KW/m^2

7. Conclusion

In this paper a mathematical model of a PV cell, implemented in Matlab-Simulink environment has been proposed.Finally it is conclude that photovoltaic current vary directly w. r. t variation in solar radiation, whereas PV voltage slightly changes. In order to obtain the large current, connect several PV cells in parallel with each other and to obtain the higher voltage several PV cells are connected in series.

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Author Profile

Subhash Apatekar received the Gold Medal in B.Tech degree in Electrical Engineering from Dr. Babasaheb Ambedkar Technological University in 2013.He now pursuing ME in Electrical Engineering in Solapur University.