Modeling and Simulation of Photovoltaic Arrays using Simple Mathematical Block by Matlab Simulink

Partha Sarothi Sikder*, Nitai Pal**

Abstract— In this paper a simple mathematical model using Matlab Simulink block of a solar photovoltaic system is considered for plotting the nonlinear I-V characteristic of photo voltaic cell. The characteristics is plotted with three given points i,e open circuit voltage of the PV array (V_{oc}), short-circuit current of the PV array (I_{sc}) and the maximum power delivered by the PV array (V_{max}, I_{max}), as given by the manufacturer. The graph also validitated for data provided by the manufacturer. In this paper single diode model of photo voltaic cell is chosen for simplicity and temperature effect on the photo voltaic cell is also considered here. The PV array model shows the change of voltage, power and current for different irradiation. From the PV array characteristic curve, for different temperature and irradiation the maximum voltage (V_{max}) and maximum current (I_{max}) at maximum power point that can be obtained from the PV cell are also shown.

Index Terms—Array, Equivalent Circuit, Maximum Power, Photovoltaic (PV), Simulation, Temperature effect,

1 INTRODUCTION

Development of a country is dependent on availability of good quality and reliable electrical energy. Growth in electric power consumption is an indicator of the industrial, agricultural and commercial development of a country. Rapid development in power sector and adequate power is needed to improve socio-economic condition of a country [1]. Availability of sufficient power at reasonable rates will have multiple effects on the economy of a country through increase in investments and improved productivity of agriculture, industry and business. So, for the countries growth, development and improvement of power sector and increase in generation of electrical energy is of prime importance [2].

India is a developing country and is one of the largest power-generating country with an installed capacity of 249.488 GW (end June 2014) [3]. The power requirement increasing day by day but generation of power is limited and cannot be increased to meet the total demand.

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So till now a huge difference between electrical power demand and power supply exists. So far in India generation of electricity using non-renewable energy sources like Coal, nuclear energy, natural gas, petroleum, and diesel and hydroelectric are some of the traditional sources of energy used worldwide for the generation of electricity [4] which pollute our environment. Problem associated with the major generating sources (Thermal) is the emission of greenhouse gases effecting environment and human being. Engineers and scientist are attempting to focus for the generation of electrical energy which can reduce the emission of the green house gases. So the present scenario is to generate power through renewable energy sources (wind, solar etc.) in a big way to meet the countries partial power requirement.

So far India produces only 12.45% of the total energy generated from renewable energy sources which is mostly dependent on wind energy [3]. The geographical location of India located between the Tropic of Cancer and the Equator. So India has an average annual temperature that ranges from 25°C–27.5 °C [5]. This means that India has huge solar potential which is about 5000 trillion kWh per year incident over most parts of India's land areas and receiving 4-7 kWh per sq. m. per day [6].

Solar cell or photovoltaic cell (PV) directly converts solar energy into electrical energy. When a p-n junction of the semiconductor diode exposed at light it generates electricity. A single PV cell produces a small amount of voltage around 0.5 volts to 0.8 volt which is too small to use as commercial as well as domestic purpose. To obtain large amount of voltage and current a large no of series-parallel connection of PV cell is required which is called PV array or PV cell [7]. A simplified model is to study the various illuminated condition as well as different temperature condition with the module **Lanco Solar LSP 250-260M-60** used in India.

2 MATHEMATICAL MODELS AND EQUIVALENT CIRCUIT OF SOLAR PV ARRAY

The equivalent circuit model and diagram is shown in fig 1. This consists of photon generated current, a diode, a parallel resistor preventing the leakage current, and a series resistor describing an internal resistance of the cell[8]-[15].

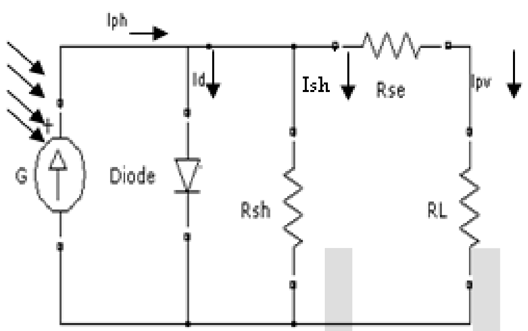

Figure.1. Equivalent circuit of PV module with.

From the equivalent circuit diagram is shown in Fig (1) using Kirchoff's current law equation for current I_{PV} is found as shown in equation (1)[9].

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

Here, I_{ph} represents the photon generated current, I_d represents the voltage-dependent current lost to recombination, and I_{sh} represents the shunt resistance current.

Where

$$I_d = I_s\left[e^{\left\{\frac{q\times(V+I_{PV}\times R_s)}{(A\times K\times T)}\right\}} - 1\right] \quad (2)$$

$$I_{sh} = \left[\frac{\{V+(I_{PV}\times R_s)\}}{R_{sh}}\right] \quad (3)$$

From equation (1)

$$I_{PV} = I_{ph} - I_s\left[e^{\left\{\frac{q\times(V+I_{PV}\times R_s)}{(A\times K\times T)}\right\}} - 1\right] - \left[\frac{\{V+(I_{PV}\times R_s)\}}{R_{sh}}\right]$$

$$= I_{ph} - I_s\left[e^{\left\{\frac{(V+I_{PV}\times R_s)}{(V_t)}\right\}} - 1\right] - \left[\frac{\{V+(I_{PV}\times R_s)\}}{R_{sh}}\right] \quad (4)$$

Where $V_t = \frac{A\times K\times T}{q}$

The light generated current mainly depends both on irradiance and temperature [9]. It is measured at some reference conditions. Thus,

$$I_{ph} = \left\{I_{sc} + K_i \times (T - T_{ref}) \times \frac{\lambda}{\lambda_{ref}}\right\} \quad (5)$$

Where

I_{PV} is a light generated photon current,
I_s is a cell saturation of dark current,
T Cell temperature in Kelvin
T_{ref} Reference temperature in Kelvin
K Boltzmann's constant, 1.38*10^-23 J/K
q is the Charge of electron, 1.6*10^-19 C
K_i Short circuit current temperature coefficient at I_{sc}
λ Solar irradiation in kW/m²
λ_{ref} Solar irradiation in kW/m² at STC, 1 kW/m²
I_{sc} Short circuit current at 25º C
E_g Band gap energy [for silicon 1.1 eV]
A Ideality factor [1.6 for silicon]
I_s Cell saturation current at T_{ref}
R_{sh} Shunt resistance in Ω
R_{se} Series resistance in Ω

Equation (2) is not sufficient to describe the I-V characteristic until more cells are connected in series parallel. If N_s is the no of cell connected in series and N_p is the no of cell connected in parallel then equation 2 becomes

$$I_{PV} = N_p \times I_{ph} - N_p \times I_s\left[e^{\left\{\frac{\left(\frac{V}{N_s}+\frac{I_{PV}\times R_s}{N_s}\right)}{(V_t)}\right\}} - 1\right] - \left(\frac{V\times N_p}{N_s} + \frac{I_{PV}\times R_s}{R_{sh}}\right) \quad (6)$$

At Standard test condition (STC) for which irradiance 1000W/m²

$$I_{rs} = \frac{I_{scr}}{\left[e^{\left\{\frac{q\times V_{oc}}{(N_s\times A\times K\times T)}\right\}} - 1\right]}$$

$$= \frac{I_{scr}}{\left[e^{\left(\frac{V_{oc}}{N_s \times V_t}\right)} - 1\right]} \quad (7)$$

Where $V_t = \frac{A \times K \times I}{q}$ and

I_{scr} is the short circuit current

$$I_s = I_{rs} \times \left(\frac{T}{T_{ref}}\right)^3 \times \left[e^{\left\{\frac{E_g \times (T - T_{ref})}{(V_t \times A \times T_{ref})}\right\}}\right] \quad (8)$$

3 DEVELOPMENT OF SIMULINK OF A SPECIFIC SOLAR PV ARRAY

A polycrystalline solar module **Lanco Solar LSP 250-260M-60** is taken as reference module to carry out the study. This module is used for the utility side applications. The electrical characteristics of this module is given in the Table-1whichis taken from the data sheet of the manufacturer.

Table -1 Electrical specification of Lanco Solar LSP 250-260M-60

Specifications	Variable	Values
Maximum power at STC	P_{max}	255
Optimum operating voltage	V_{mp}	31.15 V
Optimum operating current	I_{mp}	8.03A
Open circuit voltage	V_{oc}	38.04A
Short circuit current	I_{sc}	8.71A
Module efficiency	η	15.2
No. Of series cells	N_s	60
No. Of series cells	N_p	1

Electrical specifications under test conditions (STC) of irradiance 1000 W/m², spectrum of 1.5 air mass and the cell temperature is 25°C is considered [8].

4 BLOCK DIAGRAM USING MATLAB SIMULINK

The various stages of development of Simulink model are shown in Fig.3. Uusing matlab simulink basic mathematical block, different block has been formed and interconnect them for developing the main simulink PV array block.

From equation (5) the photon generated current developed as bellow which required Reference Temperature (T_{ref}), Temperature (T), Insolation (λ), Short Circuit Current (I_{sc}) and K_i .Short circuit current temperature coefficient is considered as input. The simulation blocks for photon generated current is implemented in Fig.2. The value of short circuit current (I_{scr}) of the module is taken from the data sheet of the reference model.

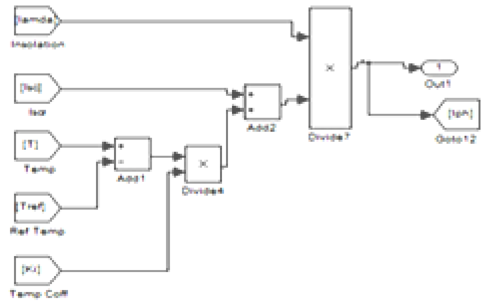

Fig .2. Simulink model for Photon generated current I_{ph}

At different temperature and Irradiation the value of photon generated current is shown in the table 2 where the photon generated current reduces as the irradiation is reduces at constant temperature. At constant irradiance with the increasing temperature increases the value of photon generated current.

Table-2. I_{ph} for different values of irradiance and temperature

Sl. No	Irradiation Kw/m²	Value of I_{ph} (A)			
		25° C	40° C	50° C	80°C
1	1	8.71	9.53	10.0	11.74
2	0.8	6.96	7.62	8.06	9.388
3	0.6	5.22	5.72	6.05	7.041
4	0.4	3.48 4	3.81	4.03	4.694
5	0.2	1.74	1.90	2.01	2.347

The subsystem of reverse saturation current is implemented in Fig. 3 using equation (7).

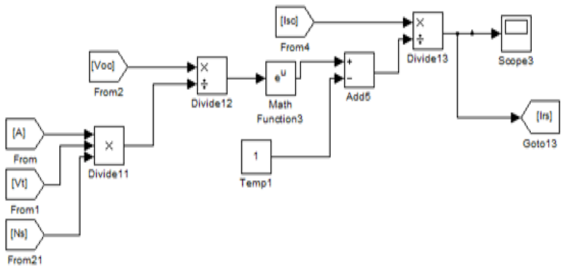

Fig.3 Simulink model for reverse saturation current reverse saturation current I_{rs}

Table 3 shown the Module reverse saturation current with temperature

Table -3 reverse saturation current I_{rs} for various temperature

Sl.No	Temperature ºC	Reverse saturation current I_{rs} (A)
1	25ºC	1.756*10^-6
2	40ºC	3.766*10^-6
3	50ºC	5.792*10^-6
4	80ºC	1.94*10^-5

From the table it is concluded that if the temperature increases the reverse saturation current increases with the temperature. It does not depend on the irradiance of the sun. The simulink module for saturation current is simulated in Fig. 4

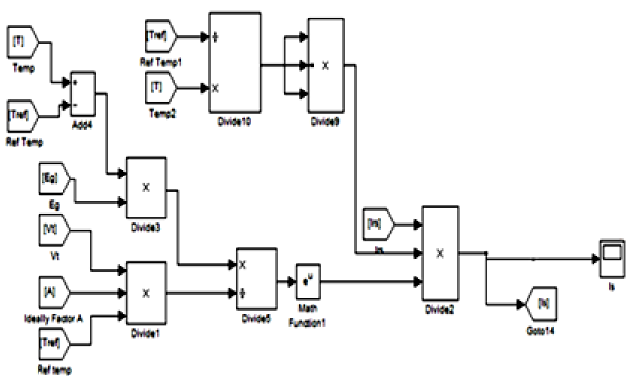

Fig.4. Simulink model for saturation current.

The module saturated current is calculated for various temperatures is given in
Table 4.

Table -4 saturation current I_s for various temperature

S.No	Temperature ºC	Array saturation current I_s (A)
1	25ºC	1.756*10^-6
2	40ºC	1.535*10^-5
3	50ºC	5.847*10^-5
4	80ºC	0.002082

From the table it's concluded that if the temperature is increasing the saturation current also increases with the temperature. The saturation current is constant according to the change of the irradiance of the sun.

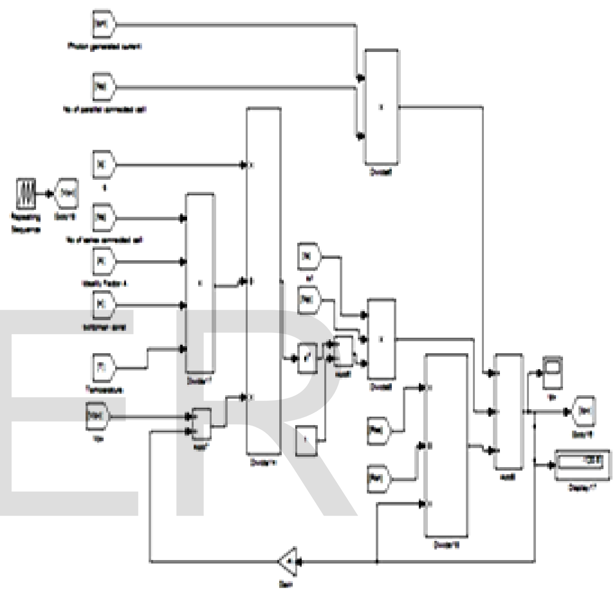

Fig.5. Simulink model module output current I_{PV}.

The final model for PV array is found in Fig .5 which generates the PV array current at a given irradiance and temperature. To plot the I-V curve and P-V curve a little modification is required which is shown in Fig. 6.

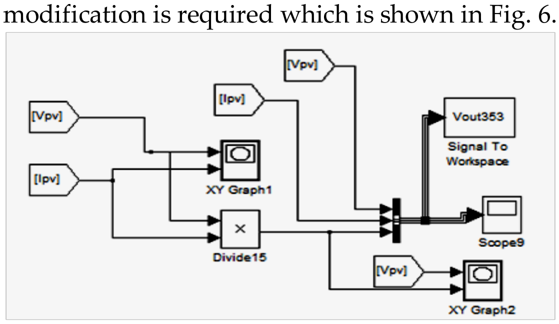

Fig.6. The final model which gives output voltage and current for varying irradiance and temperature

5 SIMULATION RESULT

The PV module taken for modelling is **Lanco Solar LSP 250-260M-60**. The developed model is implemented for the above module and evaluated. The evaluation is done using the equations developed in the previous sections.

The chosen module provides the output power of 250W maximum nominal and has 60 series arrays.

The technical specifications are listed in the table 1.The PV and IV characteristics are modeled and simulated for the chosen module using the developed equations and models. Fig. 7 and Fig. 8 shows the PV and IV characteristics of module under varying irradiance at constant temperature respectively.

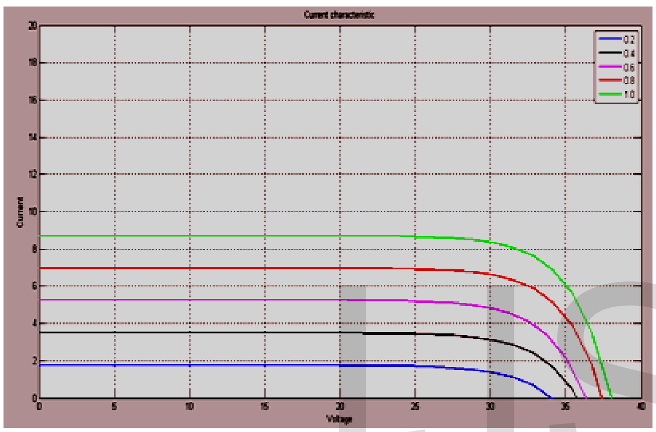

Fig. 7 I-V characteristics under varying irradiance at constant temperature (298K)

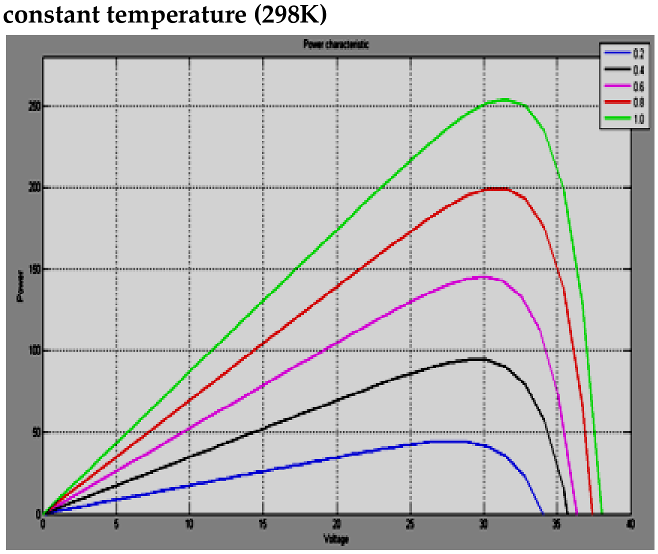

Fig. 8 PV characteristics under varying irradiance at constant temperature (298K)

Table.5 I-V Curves with various temperature levels

I- V Curves	Constant Irradiance level 1 KW/m²			
	Temperature in Kelvin	P_{max} (W)	V_{max} (V)	I_{max} (A)
1	25°C	254.34	31.52	8.06
2	40°C	244.69	27.60	8.86
3	50°C	235.57	26.30	8.95
4	80°C	195.73	19.00	10.30

Table 6. I-V Curves with various Irradiance levels

I- V Curves	Constant Temperature 25°C			
	Irradiance level in KW/m²	P_{max} (W)	V_{max} (V)	I_{max} (A)
1	1	254.34	31.52	8.0694
2	0.8	199.58	31.52	6.3319
3	0.6	146.64	30.21	4.8533
4	0.4	94.41	28.91	3.2657
5	0.2	44.56	27.60	1.6142

From the I-V and P-V curve it is concluded that at constant temperature (298K)the PV module deliver maximum power with adequate operating voltage to the consumer if the irradiance is at the maximum level. The other condition shows how the power delivered by the module as well as the current and voltage which are dependent on irradiance.

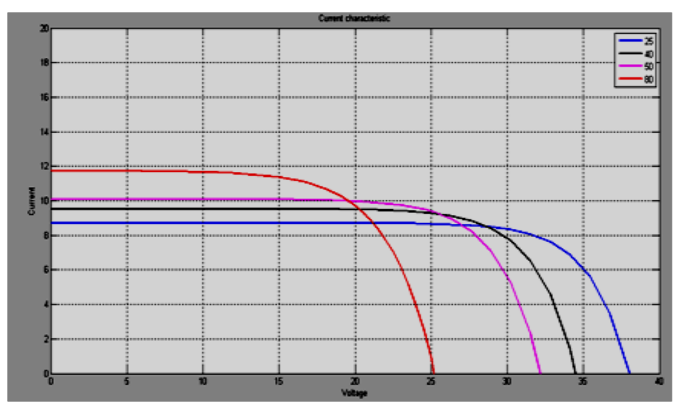

Fig. 9. I-V characteristics under varying temperature at constant irradiance (1KW/m²)

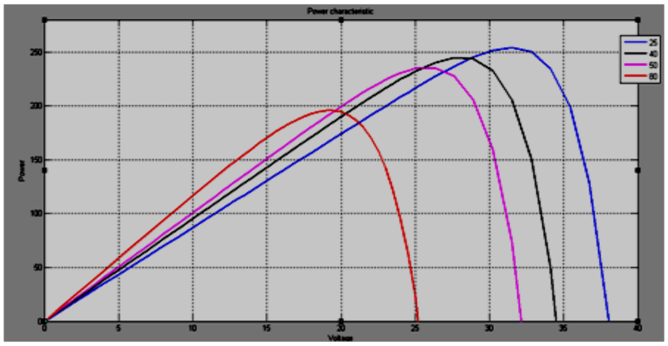

Fig. 10. P-V characteristics under varying temperature at constant irradiance (1KW/m²)

From the characteristics it is observed that at the constant irradiance level (1 KW/m²) the PV module deliver maximum power with adequate operating voltage to the consumer if the operating temperature is the reference temperature. The other condition shows how the power delivered by the module as well as the current and voltage dependent on temperature. At constant irradiance if the operating temperature of the PV array increases then the output power decreases accordingly the voltage also decreases. But the output current gradually increases as the operating temperature of the PV array increases.

CONCLUSION

The following equivalent circuit module models are described. These models have been proposed with different sets of auxiliary equations that describe how the primary parameters of the single diode equation change with array temperature and irradiance. The parameters applicable to the module , are examined here instead of those for arrays or arrays because module models are the basic performance models used for modeling arrays in PV modeling software packages. To draw the I-V and the PV characteristic of the **Lanco Solar LSP 250-260M-60** a simplified simulink module is described here and the result is compared with the data sheet for validation and found to be satisfactory.

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