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Modelling of PV Arrays- An effective approach

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Abstract

In this paper a novel technique is proposed for modeling and simulating photovoltaic array. The aim of this paper is to simulate the model of photovoltaic (PV) array and to evaluate the characteristics of it in terms of variations in environmental parameters like irradiation and working temperature. PV array Modeling is a basic need of any research activity on the PV generation system. In this paper the MATLAB Simulink model is proposed, and the results shown of PV array are non linear in nature and has a nearly constant current up to OC voltage, and Pmax in relation to the voltage is selected for particular climatic conditions.

Keywords: Open Circuit voltage (Voc), PV array, Short-circuit current (Isc), MPP.

A. INTRODUCTION

Nowadays, the modelling of photovoltaic devices is intensively researched. The modelling of photovoltaic devices and the simulation of their behaviour form an important part of the current research in the field of solar energy. The main problem of photovoltaic panels is, of course, their dependence on climatic conditions, which greatly change the power output. This paper describes a clear process for creating a PV array [9] through the MATLAB simulation, which is simple and effective in a different of climatic conditions.

If we can harvest only a fraction of the available energy on the earth's surface, we could solve our energy problems. Sunlight can be directly converted into electricity by a PV system while wind energy can be utilized to generate electrical energy which can further be purified by using some efficient electronic load controllers [4,14]. A photovoltaic cell is the fundamental unit of a PV system. The PV cells can be arranged into series /parallel to make PV panels and PV arrays [1-3, 10].

The energy generated by a single module is rarely sufficient for commercial use, so the modules are grouped together to form a photovoltaic array which is capable to supply required load demand. In order to fulfill more output voltage modules need to be arranged in series, and in parallel for more output current [5,7].

The output current and voltage of a PV array may be used directly to supply light loads like DC motors and lighting systems. More power demanding applications need power electronics converters to meet demand with power of PV array. These converters are used for regulation of current and voltage at the load terminals, to optimize flow of power in PV grid. The aim of this paper is to discuss the characteristics and operation of a PV array with the help of fundamental equations.

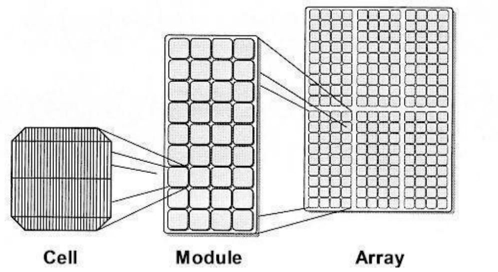


Fig 1: Photovoltaic Hierarchy

The output and efficiency of a photovoltaic system varies with the intensity of solar radiation and working temperature. The assessment of photovoltaic system is normally done by taking a standard solar irradiance as default conditions. This is required to make a comparison of power generated amongst various photovoltaic cells. The parameters of PV system are generally stated in a chart. These chart/sheets provide considerable information regarding the attainment and properties of the photovoltaic arrays in relation to these Standards working Conditions. These SWC are as follows:

$$Solar\ Irradiance(G_n) = 1000\ {}^{W}\!/_{m^2}$$

$$Standard\ Temperature\ (T) = 25^0 Cn$$

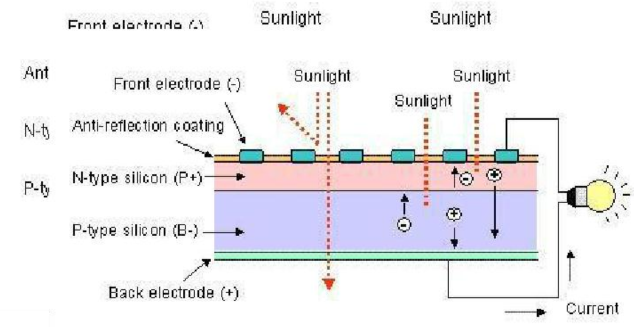
$$Solar\ Spectrum\ Density\ distribution = 1.5 A.M$$

It is important to note that the maximum photon energy should be absorbed by the semiconductor having energy band gap. However, in the present situation it is possible to subjectively arrange a group of materials into various efficiency regions.

Semiconductors materials like GaAs use multi junction tandem, are known to have ultrahigh-efficiency (absorption efficiency more than 30%) and high-efficiency cells (absorption efficiency more than 20%) are usually made by single-crystal silicon materials of high quality in basic cell . Some PV diodes having efficiency of 12% to 20% are made up of Polycrystalline and amorphous thin-film materials and moderate-efficiency cells (efficiency less than 12%) are made up of some new materials like dye-sensitized nanostructure TiO_2, which are of very low cost [3,7].

B. WORKING OF PHOTOVOLTAIC CELL (PV)

A photovoltaic cell (PV) is considerred as a p-n junction diode with sunlight incident on its p– n junction. Photovoltaic cells are made of several classes of semiconductors utilizing different manufacturing process. At present the polycrystalline and monocrystalline silicon diodes are mostly used in various applications. Silicon PV diodes is made of thin silicon layer or electrically connected thin silicon film. Doping is done on one side surface of Si photovoltaic to form *p-n* semiconductor. A thin metallic layer is used for the sun facing side of cell as shown in Figure 2[ ].



A. Fig 2: Working of photovoltaic cell (PV)

Photoelectric effect is the principle of operation of photovoltaic cell, according to which when sun light falls on PV cell, electron will be emitted from the conduction band. In the PV cell, as sunlight incidents to its surface, semiconductor material absorbed some part of the photon energy. If the absorbed energy is more than the band energy of semiconductor, the electron escapes from valence band to the conduction band and hence, pairs of holes electrons are generated in the semiconductor material. These generated electrons now can move freely and by applying electric field they are forced to move in a particular direction, produced current which can be taken out through a metal plate at the bottom and top end of the photovoltaic cell.

The ideal photovoltaic cell is represented in Fig. 3 as equivalent circuit model. The fundamental equation from the theoretical operation of semiconductors that for explaining mathematical description of I-V characteristic of the ideal PV cell the fundamental equation of theoretical operation of semiconductor [3] is:

$$I = I_{PV,cell} - I_{0,cell}\left[\exp\left(\frac{qV}{akT}\right) - 1\right] \quad (1)$$

Where,

IPV,cell = PV generated current,

Id = the Shockley diode ,

I0 = diode reverse saturation current, q = electronic charge,

k = Boltzmann const.,

T= *p-n* junction temperature (K) a = ideality factor of diode.

shows the I-V curve obtained from Eq.(1) is shown in Figure 4.

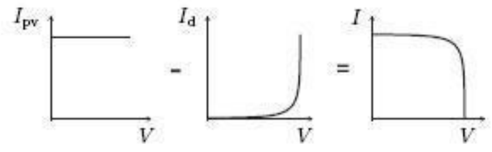


Fig 4: Characteristic I-V curve of the PV cell. The net cell current I is the composition of Ipv and Id.

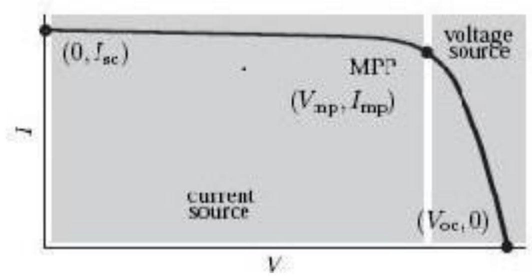


Figure 5: I-V curve

$$I = I_{pv} - I_0\left[\exp\left(\frac{V + R_s I}{V_t a}\right) - 1\right] - \frac{V + R_s I}{R_p}$$

B. PV cell modelling and characteristics

Single diode model [6]

In a photovoltaic (PV) cell characteristic basically there are three important parameters, Voc, Isc and Pmpp. Generally manufacturers provide these parameters in their manual for a particular photovoltaic cell or module. By using these parameters we can build a simple model but more information is required for designing an accurate model [3,8].

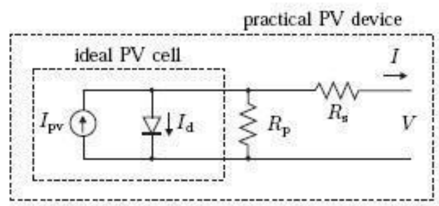


Fig 3: Single-diode model a practical photovoltaic cell

Where

Ipv - *PV current*

Io - *dark saturation current of cell*

V_t - *Thermal voltage (kT/q),*

q - *1.6 x* 10^{-19} *C electron charge.*

T - operating temperature of PV cell

a -ideality factor

Rp -parallel resistor

Rs -Series resistor

Equation (1) represents the basic PV cell, which does not describe the I-V curve of a actual PV array because several photovoltaic cells are interconnected to form PV array and to obtain modified equation (2) some more parameters are included to the basic equation, where Ns cells are connected in series. If the array is composed of Np cells in parallel, the Ipv and I0 may be expressed as:

Ipv=Ipv,cell * Np,

I0=I0,cell * Np.

Figure 5 shows the I-V of PV array, emphasizing various points of operation.

Double diode model

This model is used an extra diode, which is connected across the circuit of single diode model. This extra diode is used for more accurate I-V characteristic which is considered for the variation in flow of current at low current values due to recombination of charge in the depletion region of *p-n* semiconductor junction [10].

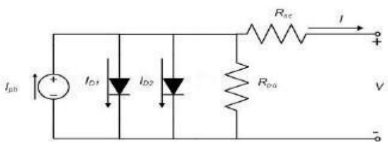


Fig 6: Double diode model

The accuracy of this model is more than the single diode model but there is a difficulty to solve the equation and gives low efficiency, thus single diode model is preferred. The current equation for double diode model is given below [10]:

$$I = I_{pv} - I_{o1}\left[\exp\left(\frac{V+IR_s}{V_t}\right) - 1\right] - I_{o2}\left[\exp\left(\frac{V+IR_s}{aV_t}\right) - 1\right] - \left(\frac{V+IR}{R_p}\right) \quad (3)$$

The series resistance Rs is of low value and highly influences the performance of PV cell when operated as a voltage source and parallel resistance Rp highly influences the performance of PV cell when operated as a current source. In an array Rs is the sum of many series resistances connected individually to form array of PV cells while shunt resistance Rp is of high value and is mainly due to the p-n junction leakage current and varies with the type of production of photovoltaic cell. These parameters are sometimes neglected to simplify the model,

The photo electron generation and hence the current generated by PV array is highly dependent on amount of irradiation. It is difficult to evaluate photo-generated current (Ipv) of the basic PV cell, without the effect of Rs and Rp. Name plate of PV cell specifies only the maximum short circuit current available at the PV system terminals. Generally it is supposed that in PV models Isc is nearly equal to Ipv because in practical PV cell the Rs has low value and Rp is high. The photo generated current (Ipv) depends on the solar irradiation and is also affected by the working temperature [10] as per the equation below:

$$I_{pv} = (I_{pv,n} + K_I \Delta T)\frac{G}{G_n} \quad (4.a)$$

$$I_{pv,n} = \frac{R_p + R_s}{R_p} I_{sc,n} \quad (4.b)$$

Where

$I_{sc,n}$ = SC current value of cell at STC (25^{o}C & 1KW/ m ^{2})
K1= SC temperature co-efficient of cell

ΔT = Change in temperature of cell between reference value and actual value.

G_n = Nominal Solar irradiation in kW /m^2

G = Actual Solar irradiation in kW /m^2

Ipv,n = photo current at standard condition

The saturation current of PV cell I0 and its variation with the temperature may be expressed by [6]:

$$I_o = I_{o,n}\left(\frac{T_n}{T}\right)^3 \exp\left[\frac{qE_g}{ak}\left(\frac{1}{T_n} - \frac{1}{T}\right)\right] \quad (5)$$

where Eg is the band gap energy of the diode , and I0,n is the saturation current [6,10]:

$$I_0 = \frac{I_{sc,n} + K_I \Delta T}{\exp\left(\frac{V_{oc,n} + K_V \Delta T}{aV_t}\right) - 1} \quad (6)$$

Where

$V_{oc,n}$ = Open Circuit voltage of cell, K_V = Voltage/ temperature coefficient.

Vt, = thermal voltage of Ns cells at temperature Tn.

The saturation current I0 of PV cells which are connected to form PV array depend on density and the effective area of the PVcells.

C. MODELLING OF PHOTOVOLTAIC ARRAY

The PV array can be simulated with an equivalent circuit model as in Fig 3. Two simulation strategies are possible. One is simulation of equivalent circuit model functional equations using Script Language of Simulator. Other one is simulation of equivalent circuit model blocks using Simulation Block function Generator [8]. The parameter get from Datasheet is shown below:

Table 1. Taken from the Datasheet[10]

Parameters	Values
Max. Power (Pm)	140W
Voltage at max. power (Vmp)	17V
Current at max. power (Imp)	8.24A
OC voltage (Voc)	21V
SC current (Isc)	10A
coefficient of temp(Ki) of Isc	(0.065 ± 0.015)%/°C
temp coefficient of Voc (Kv)	– (80±10)mV/°C
NOCT	47±2°C

By adjusting the equivalent circuit model from the given data in table 1 is shown in below mentioned table:

Table II: Electrical Characteristics Data Achieved From Table I

Parameters	Values
a	1.3
R_s	0.05Ω
R_p	100Ω
I_o	7.89e-5A
I_{pv}	8.89A

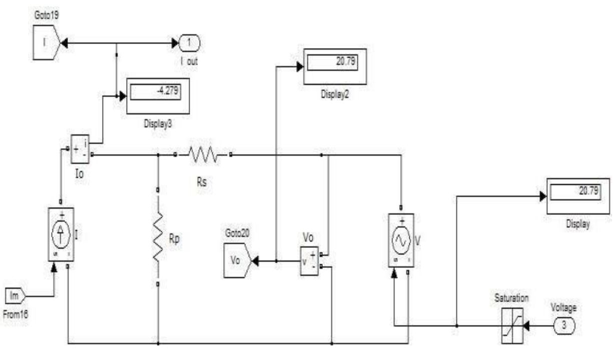


Fig 7: Subsystem implementation of generalized PV model[10]

Where Rs & Rp are obtained by iterative method by Newton - Rraphson method. The circuit model consists of only one current source. By solving the I-V eq. 2 numerical value of current is obtained. The solution of eq. 2 can be implemented by MATLAB SIMULINK [6,8-9] as it has the feature of Sim Power Systems blockset as shown in fig 7. Figs. 9 and 10, [10] Show the P-V curves & I-V curve of the WS140 solar panel respectively simulated with the MATLAB/SIMULINK.

Table 1 is obtained from the specification of the PV panel datasheet and the data from Table 2 is obtained through the simulation process of the model. For a photovoltaic cell with an ideal I-V characteristic, the OC voltage and the SC current are evaluated to VOC = 21 V and ISC = 10 A. that is, the output current and the power of the photovoltaic cell depend on the voltage and the operating temperature of the cell and the solar irradiation / irradiation as well as the increase of the working temperature, the SC current, from the photovoltaic cell increases, while the maximum value of output power decreases. To the extent that the increase in output current is much less than the voltage drop, the net power decreases at high temperatures. On the other hand, with the increase in solar irradiation, the short-circuit current of the photovoltaic module and also the maximum output power increase. The reason is that the no-load voltage depends logarithmically on the solar radiation, but the short-circuit current is directly proportional to the radiation intensity. The temperature reached by the cells when operated in the open circuit at an surrounding temperature of 20°C under irradiation conditions.

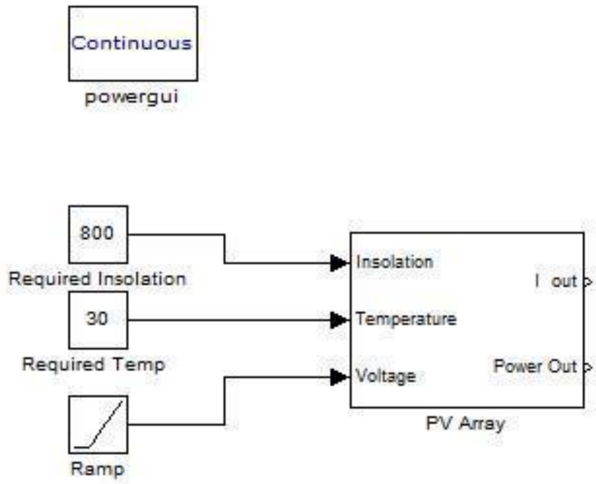


Fig 8: Generalized PV Model

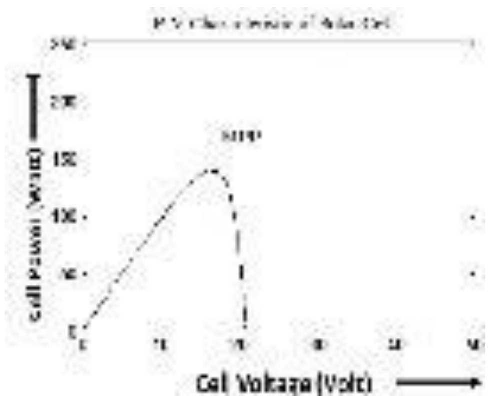


Fig 9: P-V Plot of simulated Solar Module[10]

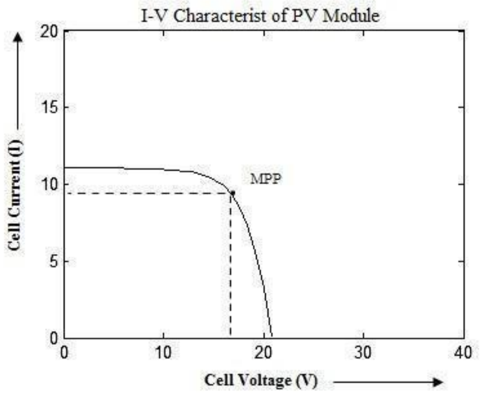


Fig 10: I-V Plot of simulated Solar Module[10]

E. CONCLUSIONS

The aim of this paper is to fact-finding prodigious points of the I-V graph of the PV array by using the mathematical equations. MATLAB Simulink is used to simulate photovoltaic model. The output results display the non-uniform output. The I-V characteristic is almost sustained value of current up to Voc and the P-V graph depicts maximum power picked with reference to the voltage at certain climatic condition. PV cell current varies uniformly with variation in irradiation however; output voltage varies logarithmically as per the mathematical equations. Current rises with increase in temperature up to certain value but because of short circuit Current the voltage declines at 2.2 mV / ^{0}C. The proposed method can be adopted by researchers or companies to develop (MPPT) technique for on grid and/or off grid PV system.

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