ANALYSIS OF MATHEMATICAL MODELLING OF PV MODULE

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Abstract : The study of photovoltaic systems in an efficient manner requires a precise knowledge of the (I-V) and (P-V) characteristic curves of photovoltaic modules. The output characteristics of PV cell depend on the irradiance and the temperature values of the site where the panel is placed. This paper focuses on a MATLAB/SIMULINK model of a photovoltaic cell. This model is based on mathematical equations and is described through an equivalent circuit including a photocurrent source, a diode, a series resistor and a shunt resistor. The developed model allows the prediction of PV cell behaviour under different physical and environmental parameters.

IndexTerms - **PV module, Single diode, MATLAB, Significant points**

I.INTRODUCTION:

The solar radiation is one of the most promising renewable energy sources and can be directly converted into electricity using the photovoltaic (PV) devices, solar cells.

Typically, a PV cell generates a voltage around 0.5 to 0.8 volts depending on the semiconductor and the built-up technology. This voltage is low enough as it cannot be of use. Therefore, to get benefit from this technology, tens of PV cells (involving 36 to 72 cells) are connected in series to form a PV module.

These modules can be interconnected in series and/or parallel to form a PV panel. In case these modules are connected in series, their voltages are added with the same current. Nevertheless, when they are connected in parallel, their currents are added while the voltage is the same.

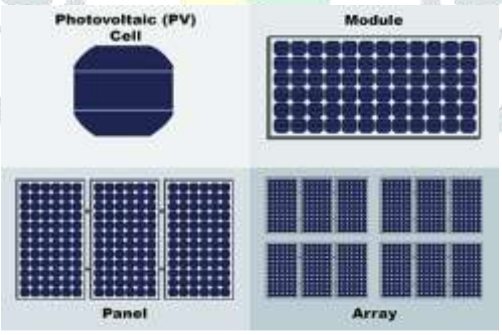

Fig1: Photovoltaic cell, module, panel and array

Three major families of PV cells are monocrystalline technology, polycrystalline technology and thin film technologies. The monocrystalline and polycrystalline technologies are based on microelectronic manufacturing technology and their efficiency is in general between 10% and 15% for monocrystalline and between 9% and 12% for polycrystalline. For thin film cells, the efficiency is 10% for Silicon, 12% for CuInSe and 9% for CdTe.

A PV module consists of number of solar cells connected in series and parallel as per the requirement. When solar light falls on PV cell, light energy is converted to electrical energy without any moving parts. The transmitted light is absorbed within the semiconductor, by using this light energy to excite the free electrons from the low energy status to an unoccupied higher energy level. These excess electron hole pairs contribute to the flow of current.

When the light falls on n type material, the electrons start to flow through n type region, negative junction, positive junction and then to ‘p’ type material.

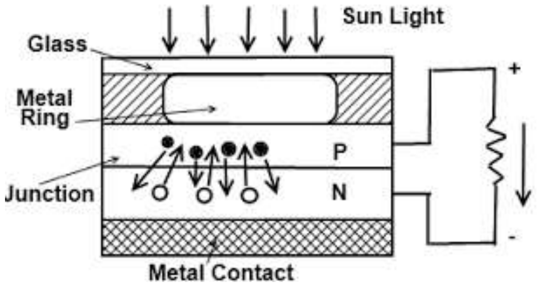

Fig 2: Solar Radiation to electrical energy

II.PROPOSED TOPOLOGY

This paper focuses on a MATLAB/SIMULINK model of a photovoltaic cell. This model is based on mathematical equations and is described through an equivalent circuit including a photocurrent source, a diode, a series resistor and a shunt resistor. Also various operating points of PV cell were discussed.

When V_{ak} and I_{ak} are positive , power flow into diode ie) diode sinks and not generates power. So to generate the power current direction should be reversed by introducing a current source. This current source is photon current and it is depends on solar radiation intensity. I_p is proportional to solar intensity.

When I_p =0, the characteristics is as shown in fig.

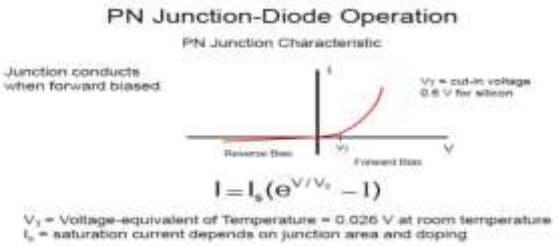

Fig3: PV junction characteristics

As I_p increases the characteristics comes down.ie) more incident power shifts characteristics to IV quadrant.

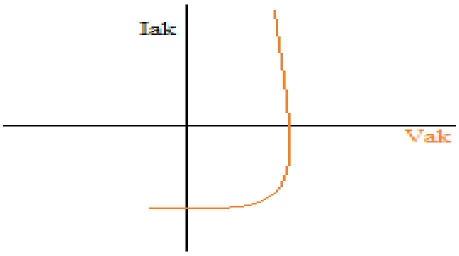

Fig4:.IV quadrant operation

Therefore PV cell is operating in generation mode.

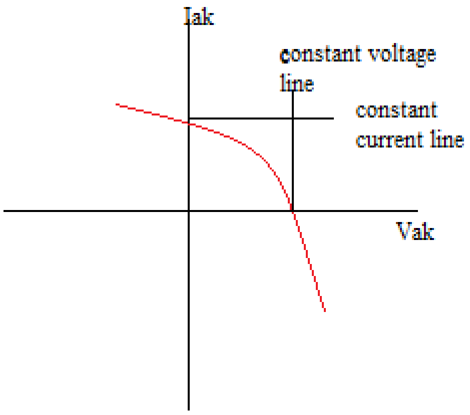

Fig5: Generating mode operation

The ‘I-V’ characteristics flipped as shown in Fig5. The slope of constant current line gives the existence of R_{sh}. The slope of constant voltage line gives the existence of R_{se}.

A. MODEL OF PV CELL

A general mathematical description of I-V output characteristics for a PV cell has been researched and analysed for the past four decades. Such an equivalent based circuit model is mainly used for the Maximum power point tracking techniques (MPPT). The equivalent circuit of the general model which consists of a photon current, a diode, a parallel resistor expressing a leakage current, and a series resistor describing an internal resistance to the flow of current is shown in Fig6.

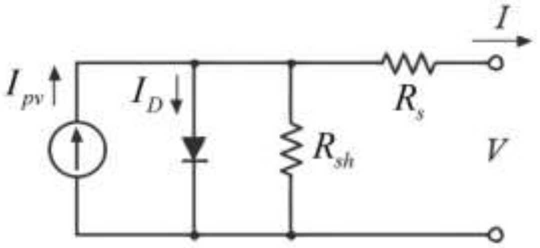

Fig6: Model of PV cell

$$Ipv = Id + IRsh + I \quad (1)$$

$$I=I_{pv}-I_d-IR_{sh} \quad (2)$$

$$I= I_{pv}-I_d-(V+IR_s/R_{sh}) \quad (3)$$

The diode current from pn junction theory is given by

$$I_d=I_o(e^{V+IRs/nVT} – 1) \quad (4)$$

V_T=Equivalent voltage of temperature = KT/q =T/11600

$V+IR_s$ = Drop across diode

n = Ideality factor =2 for silicon cell

I_o = Reverse saturation current, depends on material and temperature

T= Cell temperature in Celsius

K= Boltzmann's constant, 1.38 * 10-19 J/K

q = Charge of electron, 1.6 * 10^{-23} C

$I_o = KT^m e^{-V_{GO}/nV_T}$ (5)

$^{V}{}_{GO}$ = Equivalent band gap energy in electron –holes in ev,1.6 – 1.21 ev for silicon

m = 1.5 for silicon

PV model equation is given by,

$Ip = Iph - Is\,[e\,\{q * (V+I*R_s) / (A*K*T)\} - 1] - (V+I*R_s)/R_{sh}$ (6)

B.SIGNIFICANT POINTS OF PV CELL

There are three significant points in i-v characteristics of PV cell.

i) Short circuit point
ii) Open circuit point
iii) Peak power operating point

1. Short circuit point:

When output terminal is short circuited ,this condition can be obtained.

When $V_T = 0 \rightarrow I = I_{sc}$

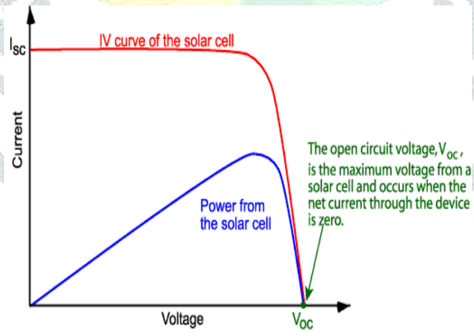

Fig7: I-V characteristics of PV cell

Substituting in equation

$I_{pv} = I_{ph} - Is\,[e\,\{q * (V+I*R_s) / (A*K*T)\} - 1] - (V+I*R_s)/R_{sh}\,;\ \ R_s << R_{sh}$ (7)

$=I_{sc} = I_{pv} \infty$ solar power (insolation);

2. Open circuit point:

When $I = 0 \rightarrow V = V_{oc}$

Substituting in equation

$0 = Ip - I_{o*}(e^{Voc+0.Rs/nVT} - 1) - 0;\ R_s << R_{sh}$

$Ip= I_o*(e^{Voc/nVT} – 1)$

$= I_o*e^{Voc/nVT} – I_o$

Taking logarithm,

$\ln Ip = I_o*V_{oc}/nV_T – \ln I_o$

$\ln(Ip+ I_o)/ I_o = V_{oc}/nV_T$

$V_{oc} = n V_T* \ln(Ip+ I_o)/ I_o$ (8)

From this equation, the Ip changes linearly whereas the V_{oc} changes logarithmically

Fig8: Change in Voc and Isc curve

3. Peak power operating point:

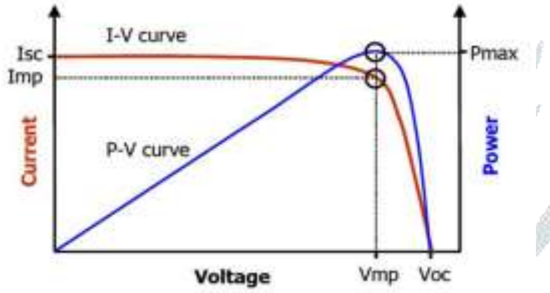

Fig9: P-V characteristics curve

When $I_{sc} =0\rightarrow V_{oc} =0\rightarrow P=0$

When $I_{sc} =0\rightarrow V =V_{oc}\rightarrow P=0$

Therefore to get some power, current and voltage should have some values. This is given by

p-v curve ,p=vi

The peak point is Pmax and corresponding $I =I_{mp}$;$V=V_{mp}$. Therefore I_{mp} and V_{mp} meeting point in I-V curve is peak power operating point. PV cell should behave in this manner ,so that it operates in this point.

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

$Iph = \{Isc + Ki * (T-25)\} * \lambda$ (9)

Where Iph is a light generated photon current, Is is a cell saturation of dark current,

Ki Short circuit current temperature coefficient at Isc

λ Solar irradiation in Watts/m2

Isc Short circuit current at 25° C

Tnom Reference temperature in Celsius

Is Cell saturation current at Tnom

Rsh Shunt resistance in Ω

Rs Series resistance in Ω

The diode current or saturation current varies with the cell temperature which is given by

$$Is = Irs * (T/Tr)3 * [e \{ V_{G}o * (T - Tr) / (A * Vt * Tr) \}] \quad (10)$$

Where Irs=Reverse saturation current at reference temperature

C.I-V equation of PV module:

Since a PV cell produces very low power, the cells should be arranged in series-parallel configuration on a module to produce enough power. As mentioned earlier, PV array is a group of PV modules which are connected in series and parallel circuit configurations to generate the required current and voltage.

In general for a PV cell Ns=Np=1. For a PV module Np=1,Ns=no.of series connected cells. For a PV array Np=Ns=no.of series and parallel connected cells.

$$Ipv = Np*Iph - Np*Is [e\{ q* (V/Ns + I*Rs/Np)\} / A* K*T - 1] - (V*Np/Ns + I*Rs) /Rsh \quad (11)$$

Where

Np= number of parallel cells

Ns= number of series cells

The reference values are taken from the PV module manufacturers datasheet for specified operating condition such as STC(standard test conditions) for which the irradiance is 1000W/m2. The reverse saturation current(Irs) is given by,

$$Irs = Iscr/ [e(q*Voc/Ns*K*A*T)-1] \quad (12)$$

Where Iscr = short circuit current

Table1: Parameters of PV Module

Specifications	Values
Typical peak power (Pp)	240W
Voltage at peak power (Vmp)	30.18 V
Current at peak power (Imp)	7.96
Short-circuit current (ISC)	8.99A
Open-circuit voltage (Voc)	36.72V
Cell efficiency	16.50%

Module efficiency	14.66%
Temperature coefficient of open-circuit voltage	73 mV/ºC
Temperature coefficient of short-circuit current (ki)	3 mA/ºC
Approximate effect of temperature on power	0.38 W/ºC
Number of series cells in the array	6X10 Polycrystalline cells

All these data are under the condition of incident solar power 1KW/m^2 at 25°C

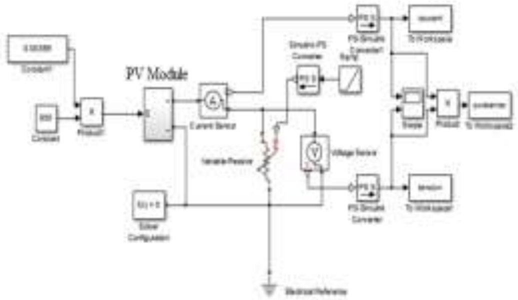

Fig10: Simulink model of PV module

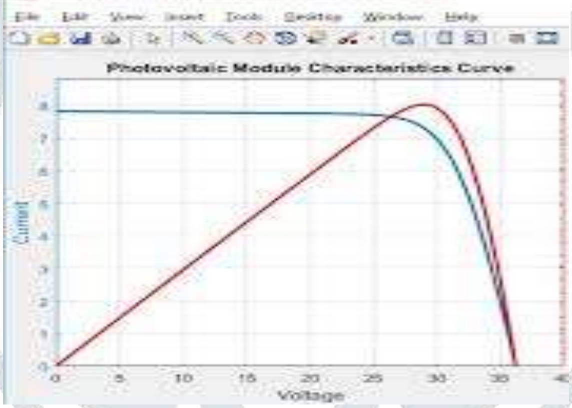

Fig12: PV characteristics

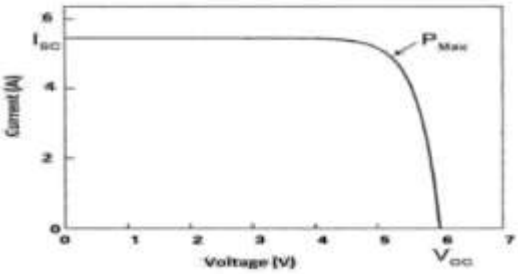

Fig12: VI characteristics

III. CONCLUSION

A mathematical model can be built using MATLAB/Simulink for PV array using appropriate equations. We can conclude that the proposed model can predict the behaviour of any solar PV cell, module and array under climate and physical parameters changes. It is very difficult to change the parameters of the given module in the case of physical modeling. But by analysing the circuit with the help of mathematical model it is very convenient to verify required parameters just by changing values. Similarly the I_V and P-V characteristics are observed for different irradiations and different temperatures.

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