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Simulink Model of Solar Module for PV Power Generation System

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Abstract—*The grid connected photovoltaic (PV) power generation system is expected to be more widespread in distribution system due to increasing fossil fuel cost. There is a need of research activities in creating new control technology, development of high-performance conversion system and study of effects of environmental parameters to make it economic viable and stable in integration with the utility grid. The PV system produces electric power without hampering the environment by directly converting the solar radiation into electric power. However, the solar radiation never remains constant. It keeps on varying throughout the day. The need of the hour is to deliver a constant voltage to the grid irrespective of the variation in temperatures and solar isolation. The user wants to operate the photovoltaic (PV) array at its highest energy conversion output by continuously utilizing the maximum available solar power of the array. 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 photo current source, a diode, a series resister and a shunt resister. The developed model allows the prediction of PV cell behavior under different physical and environmental parameters. Simulation results presented here validate the component models and the chosen cell parameter for further analysis of PV integration with utility grid.*

Keywords*: Mat lab software, Solar cell model, Photo voltaic energy.*

1. INTRODUCTION

The development of new energy sources is continuously enhanced because of the critical situation of the chemical industrial fuels such as oil, gas and others. There is a pressing need to accelerate the development of renewable energy technologies in order to address the global challenges of energy security, climate change and sustainable development. The renewable resources have become a more important contributor to the total energy consumed in the world. In fact, the demand of solar energy has increased by 20% to 25% over the past 25 years. The market for PV system is growing worldwide, in order to get benefit from the application of PV systems, research activities are being conducted to get further improvement in their cost, efficiency and reliability.

Photovoltaic cells convert sunlight directly to electricity. They are basically made up of a PN junction. Figure 1 (a) shows the PN junction and 1 (b) shows the photocurrent generation principle of PV cells. In fact, when sunlight falls on the cell, the photons are absorbed by the semiconductor atoms, freezing electrons from the negative layer. This free electron finds its path through an external circuit towards the positive layer resulting in an electricity current from the positive layer to the negative one.

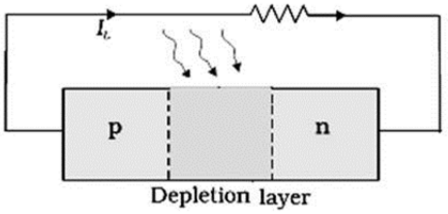


Fig. 1 (a) PN junction

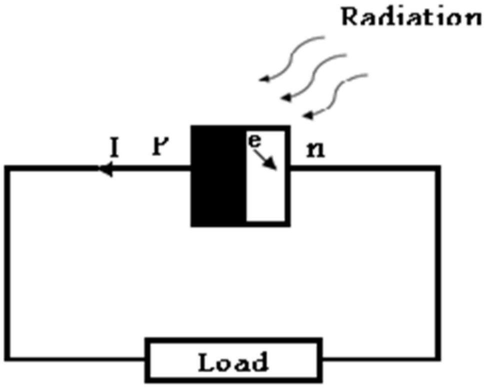


Fig. 1(b) Photocurrent generation principal

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 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 voltage is same.

But there are two major problems with PV generation systems. One is the low conversion efficiency of solar energy into electrical power and the other is the non-linear characteristics of PV array which makes the electrical power generated vary with temperature and solar irradiation.

Three major technologies of PV cells are mono crystalline technology, polycrystalline technology and thin film technologies and their efficiencies are normally between 10% and !5% for mono crystalline cell and between 9% and 12% for polycrystalline. For thin film cells, the efficiency is 10% for a-Si, 12% for CulnSe2 and 9% for CdTe. The paper is focused on Mat lab/SIMULINK Model of mono crystalline solar cell behavior under different varying parameters such as solar irradiation, temperature, series resister, shunt resister, diode saturation and current, etc.

Knowledge of the characteristics of a PV module is a prerequisite for designing and dimensioning a PV power supply system. This is the reason for the development of PV module models useful for electrical measurement. This approach allows the development of new high-performance conversion systems balancing system-components and permitting the evaluation of the entire system in various scenarios.

2. MATHEMATICAL MODEL OF PV CELLS:

The simplest equivalent circuit of a PV cell (Fig. 2) is a current source whose intensity is proportional to the incident radiation, in parallel with a diode D and a shunt resistance *Rsh.* This resistance represents the leakage current to the ground. The internal losses due to current flow and the connection between cells are modeled as a small series resistances Rs.

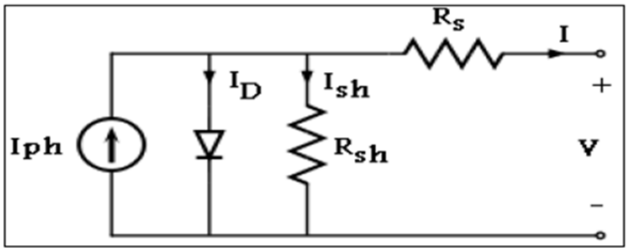


Fig. 2: Equivalent circuit of a PV

The *I-V* characteristic is described by Equation (1), which shows the net current *I* of the cell as a function of the external voltage *V*; *m*is the well-known ideality factor of the junction and its value ranges between 1 and 2.

$$I = Ipv – Io\left(e^{\frac{q(V+Rs.I)}{mkT}} - 1\right) - \frac{V+Rs.I}{Rsh} . \qquad (1)$$

A closed-form exact solution of Equation 1 for the unknown current *I is* not available, hence numerical methods should be used to solve it. In this work the Newton-Raphson iterative method use as is for solving the unknown current.

a. Ideal Solar Cell

The ideal equivalent circuit of a solar cell is a current source in parallel with a single-diode. The configuration of the simulated ideal solar cell with single-diode is shown in Fig.3 (a).

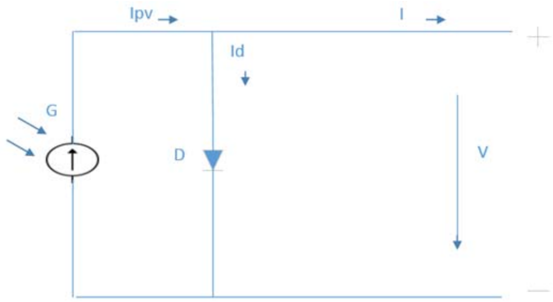


Fig. 3a

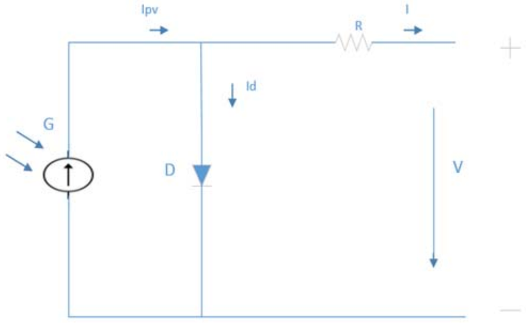


Fig. 3b

Fig. 3: (a &b) Ideal Solar cell with single diode

In Fig. 3. (a) *G* is the solar radiance, Ipv is the photo generated current, *Id* is the diode current, *I* is the output current, and *V* is the terminal voltage. The I-V characteristics of the ideal solar cell with single diode are given by:

$$I = Ipv – Io\left(e^{\frac{q(V+Rs.I)}{mkT}} - 1\right). \ (2)$$

Where, *Io*is the diode reverse bias saturation current, *q* is the electron charge, *m* is the diode ideality factor, *k* is the Boltzman's constant, and T is the cell temperature.

A solar cell can be at least characterized by the short circuit current *Isc* , the open circuit voltage *Voc* , and the diode ideality factor *m*.

For the same irradiance and temperature conditions, the short circuit current *Isc* is the greatest value of the current generated by the solar cell. The short circuit current *Isc* is as given by;

$$\text{Isc=I=Ipv for V=0} \tag{3}$$

For the same irradiance and *p-n* junction temperature conditions, the open circuit voltage *Voc* is the greatest value of the voltage at the cell terminals. The open circuit voltage *Voc* is given by:

$$\text{Voc}=\frac{mkT}{g}\,ln\left(\frac{Isc+Io}{Io}\right) \tag{4}$$

b. Solar Cell with Series Resistance

More accuracy can be introduced to the model by adding a series resistance. The configuration of the simulated solar cell with single-diode and series resistance is shown above in Fig. 2.

The I-V characteristics of the solar cell with single-diode and series resistance are given by

$$\text{I=Ipv–Io}\left(e^{\frac{q(V+Rs.I)}{mkT}}-1\right) \tag{5}$$

For the same irradiance and *p-n* junction temperature conditions, the inclusion of a series resistance in the model implies the use of a current equation to determine theoutput current in function of the terminal voltage.

The short circuit current *Isc* is given by:

$$\text{Isc=I=Ipv–Io}\left(e^{\frac{q(V+Rs.I)}{mkT}}-1\right)\text{ for V=0} \tag{6}$$

Normally the series resistance is small. Hence, the open circuit voltage *Voc* is same as in eq. (4) for I=0.

3. SIMULATION:

The SIMULINK model equation for determining the diode reverse saturation current at the reference temperature which given by:

$$\text{Io }=\frac{Isc,n+Kf\,\Delta\,T}{e^{\left(\frac{Voc,n+Kv\,\Delta\,T}{m\,Vt}\right)-1}} \tag{7}$$

Where ‘n’ in all equations is for nominal condition Ki (usually 25ºC and1000w/m^2), is the current coefficient, Kv is the voltage coefficient, ΔT=T-Tn [being T and Tn the actual and nominal temperature (K)].

The SIMULINK model equation for determining the light generated current of the photovoltaic cell which depends linearly on the influence of temperature and solar radiation as given by

$$\text{Isc=(Isc,n+Ki }\Delta T\text{)}\,\frac{G}{Gn} \tag{8}$$

Fig. 4. shows the SIMULINK model for determining the model current, which isgiven by:

$$\text{Im=IscNpp–IoNpp}\left[e^{\frac{\left(V+I\left(\frac{Nss}{Npp}\right)Rs\right)}{(mVt\,Nss)}}-1\right] \tag{9}$$

Where Im -model current (A), Nss - no. of series connected module, Npp -no. of parallel connected module, Vt- thermal potential of PV array(V).

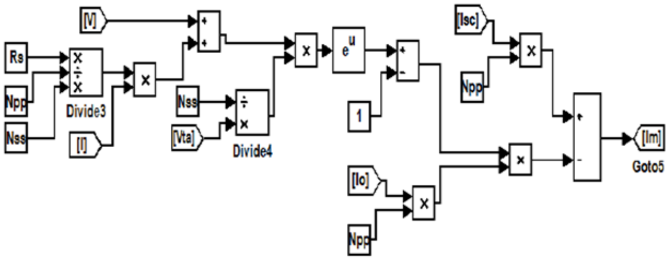
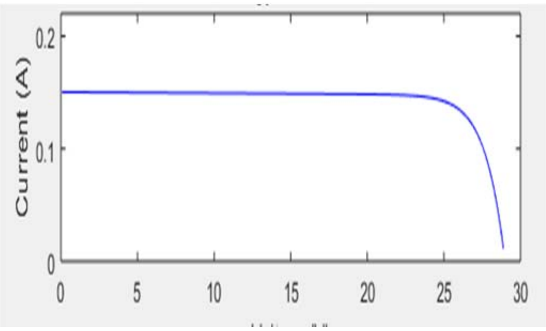
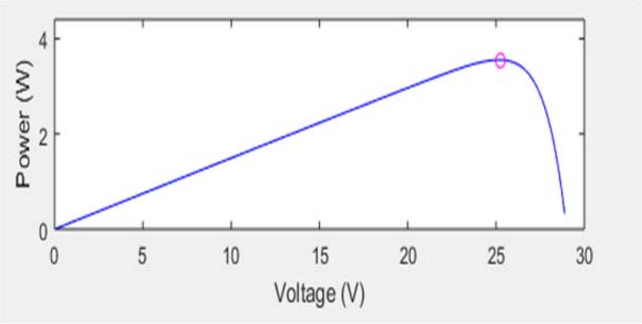


Fig. 4: SIMULINK model for Im.



P-V curve



I-V curve

Fig. 5: P-V& I-V curve of reference PV module at 25℃

4. EXPERIMENTAL RESULTS AND DISCUSSIONS:

In reality, many factors could affect the performance of the solar cells. Those parameters are not constant but changing all the time. A study is carried out on simulation model to predict how the I-V characteristics changes with the environmental parameters such as temperature and irradiance. In this section, a reference P-V curve and a reference I-V curve are presented. Then scenarios of different changing parameters are analyzed**.**

4.1 Effects of Cell Temperature:

Equations (1) in itself do not let to draw the current is I-V curve; the temperature dependence of the photo-current, the open circuit voltage and saturation current is mandatory to complete the model;

$$Ipv(T)=Ipv(Tref)+ \alpha(T-Tref) \quad (10)$$

$$Ipv(Tref)=Isc\ (Tref)\frac{G}{Gref} \quad (11)$$

$$Io(Tref)=\frac{Isc\ (Tref)}{\left((e^{\frac{q.Voc(Tref)}{nkTref}}-1\right)} \quad (12)$$

$$Voc(T)=Voc(Tref)+\beta(T-Tref) \quad (13)$$

Where G is the irradiation in kw/m,∝ the temperature coefficient of the current and $\beta$the temperature coefficient of the voltage. The subscript ref identifies the standard test conditions (STC) defined in the IEC 61215 international; In particular, Tref=25℃ and Gref=1000W/m^2 A set of reference input parameters has been used to generate a reference PV curve and a reference curve for all simulations presented in this paper. The reference PV curve and I-Vcurve are used to be compare with cases in which one of the parameters is different. The reference input parameters are given in a table 1:

Table 1: Parameters of PV Model.

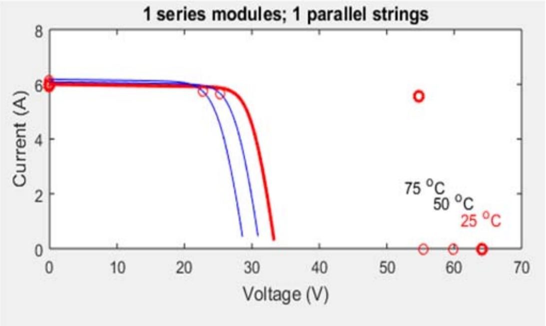
Parameter	Values
Number of cells in a module	50
Reference Solar irradiance	G=1000W/m^2
Open circuit Voltage	Voc (V)= 33.7
Short-circuit current	Isc (A)=6.11
Current at maximum point	Imp (A) =5.19
Voltage at maximum point	Vmp (V) =27.64
Ideality factor	m=1.3
Temperature coefficient of current	Ki=0.000617(A/K)
Temperature coefficient of voltage	Kv=0.273 (V/K)
Series résistance	Rs=0.243 (Ω)
Shunt resistance	Rsh=452 (Ω)

The ideality factor is considered constant and is chosen in Table 2. according to technology of the PV cell.

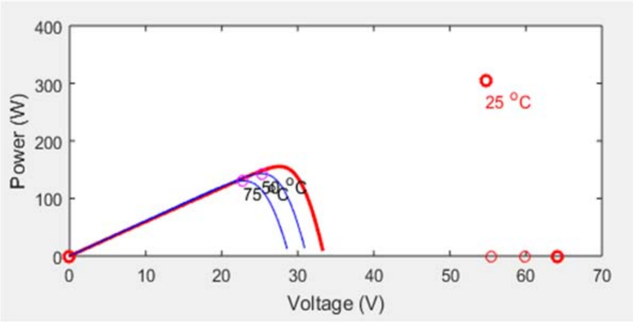
Table 2: Ideality factor (m) of different technology.

Technology	Ideality factor
Si-mono	1.2
Si-poly	1.3
a-Si-H	1.8
a-Si-H tandem	3.3
a-Si-H triple	5
CdTe	1.5
CdTs	1.5
AsGa	1.3

The reference PV and I-V curves are compared with the P-V and I-V Curves with a temperature of 50 and 75 as shown in Fig. 6



I-V curve



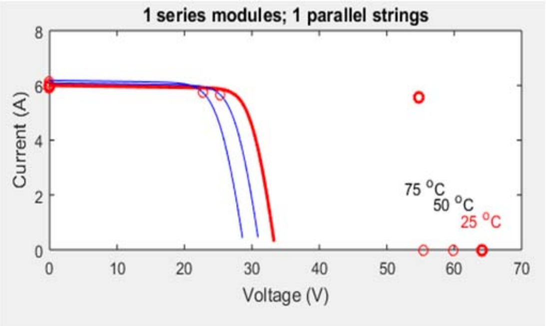
P-V curve

Fig. 6: Effects of changing the temperature

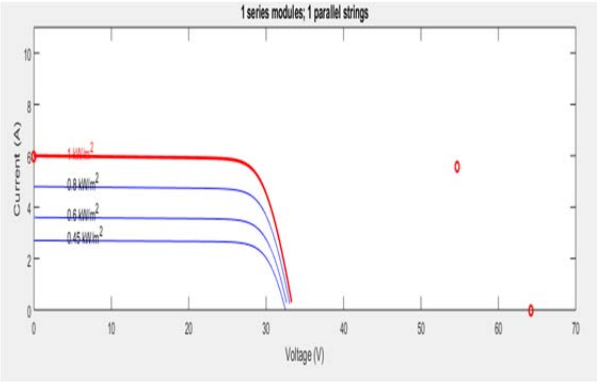
From the comparison, it is seen that an increase in temperature leads to decrease in the open circuit voltage and a slight decrease in the short circuit current. In general, for a given solar radiation when the cell temperature increases. This behavior is validated and presented in Fig. .6

4.2 Effects of Irradiation:

As shown in Fig.7 the reference PV and I-V curves are compared with the P-V and I-V curves with an irradiance of 800 W/m^2,600 W/$m^2$and 450 W/m^2.



P-V curve



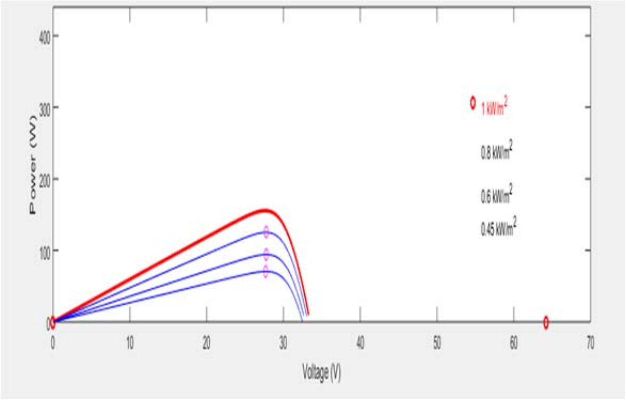
I-V curve

Fig. 7: Effect of changing irradiation

From the comparison, it can be seen that an increase in the irradiance leads to a open circuit voltage and a large increase in the short circuit current. Thus the PV cell current is strongly depending on the solar radiation however the voltage has a 50 mV increase as the solar radiation increased from 450 W/m^2 to 1000 W/m^2.

4.3 Effect of series resistance changes

The reference PV and IV curves are compared with the P-V and I-V curve with a series resistance of 0.400 Ω. The series résistance of the PV Cell is low, and in some cases, it can be neglected. However, to render the model for any PVCell, it is possible to vary this resistance and predict the influence of its variation on the cell outputs. As seen from the Fig. 8 the variation of Rs affects the slope angle of the I-V curves resulting of the maximum power point. It is seen that the series resistance causes an inward bending at the corners of the I-V and P-V



Curves with no changes in Isc or Voc.

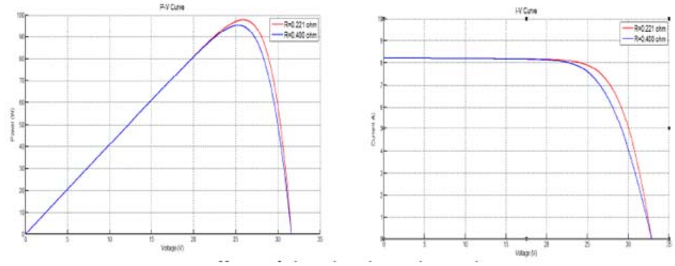


Fig. 8: Effect of changing the series resistor.

5. CONCLUSION

In this paper a solar cell model using Mat lab/ Simulink mathematical operation blocks is introduced. This model is based on the fundamental electrical circuit equations of a solar PV cell considering the effects of physical and environmental parameters such as the irradiance, cell temperature, series resistance, shunt resistance, and number of series cell in terms of the PV and IV curve. The simulation results are discussed demonstrating the feasibility of the proposed model. A MATLAB script permits to verify the panel output under different weather conditions.

The model has excellent accuracy in generating the PV and IV curves. Moreover, this model could be built with any general purpose simulation software.

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