Comparative Study of Matlab-Simulated and Conventional Si-based Solar Panel

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***Abstract*—Solar cells are promising devices for clean electric energy and have attracted intensive research. Modeling and simulation of photovoltaic solar cells allows the prediction of cell behavior under different physical and environmental parameters. Mathematical model of photovoltaic system is made depending on Shockley diode equation. The aim of this paper is to describe the comparative study between the MATLAB-SIMULINK based modeling of solar panel and conventional Si-based solar panel. Finally nice agreements have been obtained between the simulation and experimental results.**

***Keywords*—Photovoltaic solar panel, Solar cell model, Fill factor, Maximum power point**

I. Introduction

The conventional energy sources exhibit some problems such as pollution, less energy security and the most important is that these sources are limited. Renewable energy sources (such as PV system) are clean and almost have no impact on the environment. That's why these clean sources of energy are getting more popular all over the world. The market for PV systems is growing worldwide. According to earth policy institute, at the end of the year 2013 global solar generated electricity is 124.8 TWh's. The voltage produced by a solar cell is very low generally, 0.5 to 0.8 volts. For this reason the cells need to be connected together to give enough voltage for charging a battery at least of 12 V. Commercial modules use different combination of connections depending on voltage or current requirement [2]. Solar cells are mainly p-n junctions in which drift and diffusion currents exist. For desirable drift current the cell operates in reverse direction. The photon energy greater than the band gap energy of the solar cell material is absorbed resulting emergence of electron-hole pairs [4].The carriers create a current which depends on the incidence of solar irradiation and finds its path through an external electrical load..

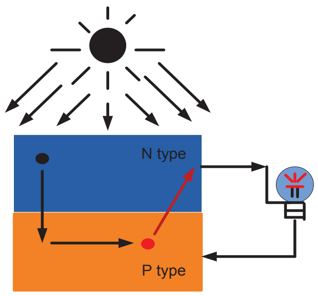

Fig. 1 Basic photovoltaic solar cell structure

II. Mathematical Modeling of Solar Cell

PV cell model is important for simulation and the accuracy of simulation depends on it.The model must include the characteristic curves to emulate the cell in software.We can use the equivalent circuit of Fig. 2 for solar cell modeling [2, 5].

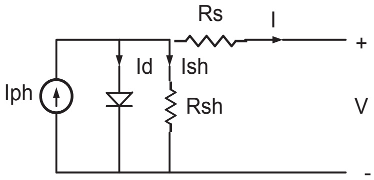

Fig. 2 Solar cell equivalent circuit

The circuit of Fig. 2 shows a solar cell which contains a diode, a current source, a series resistance and a shunt resistance [1,2,5,6]. In view of that, current to the load can be given as:

$$I = I_{ph} - I_O \left(e^{\left(\frac{q\,(V+I\,R_S)}{KT}\right)} - 1 \right) - \frac{V + IR_S}{R_{sh}} \qquad (1)$$

Table1. Solar cell parameters

NAME	SYMBOL	VALUE	UNIT
Reverse saturation	Io	1×10^{-9}	A
Electronic charge	q	1.6×10^{-19}	C
Series resistance	R_s	.001	Ω
Boltzmann constant	K	1.3×10^{-23}	J/K
Photo current	I_{ph}	4	A
Shunt resistance	R_{sh}	1000	Ω
Temperature	T	300	K
Voltage	v	0:0.01:0.6	volt

Temperature and solar irradiation affects the photocurrent of the cell [1, 6, 7].It can be expressed as:

$$I_{ph} = \{I_{SC} + K_I(T - T_r)\}\, G \qquad (2)$$

Now, cells saturation current is given by:

$$I_S = I_{RS}\left(\frac{T}{T_r}\right)^3 e^{\left[\frac{q\,E_G\left(\frac{1}{T_r}-\frac{1}{T}\right)}{AK}\right]} \tag{3}$$

Here,I_{RS} and E_G are reverse saturation current and energy gap respectively. A is ideality factor. Now, I_{RS} at reference temperature is given by,

$$I_{RS} = \frac{I_{SC}}{e^{\left[\frac{q\,V_{OC}}{N_S\,AKT}\right]} - 1} \tag{4}$$

In a module several solar cells need to be connected in different combinations because a single cell produces very small power. A panel or array consists of a number of modules connected in parallel or series or both as per the requirement [6, 7].The electrical circuit for a module withN_S series andN_P parallel cells is shownbelow:

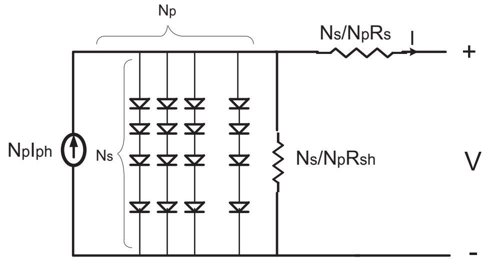

Fig.3 Equivalent circuit models of generalized PV array/panel.

The final equation for current I of the panelis:

$$I = N_P\,I_{Ph} - N_P\,I_S\left(e^{\left[\frac{q\left(\frac{V}{N_S}+\frac{I_{RS}}{N_P}\right)}{AKT}\right]} - 1\right) - \frac{\left(\frac{N_P\,V}{N_S}+I_{RS}\right)}{R_{sh}} \tag{5}$$

For one cell N_S=N_P=1.

III. SIMULINK BASED MODELING OF PV MODULE

As shown in Fig. 5, a generalized PV module is made by SIMULINK based subsystem modeling. In this model 36 cells are connected in series and user friendly masking icon is also shown in Fig. 6The subsystem is made based on the equations (2), (3), (4), (5) [6, 11].

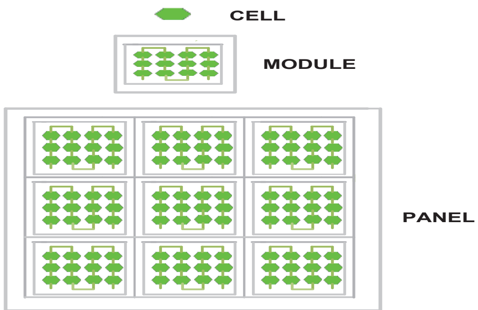

Fig. 4 Photovoltaic hierarchy

By varying the environmental and physical parameters, I~V and P~V curves are obtained from the SIMULINK based modeling(Fig. 7).

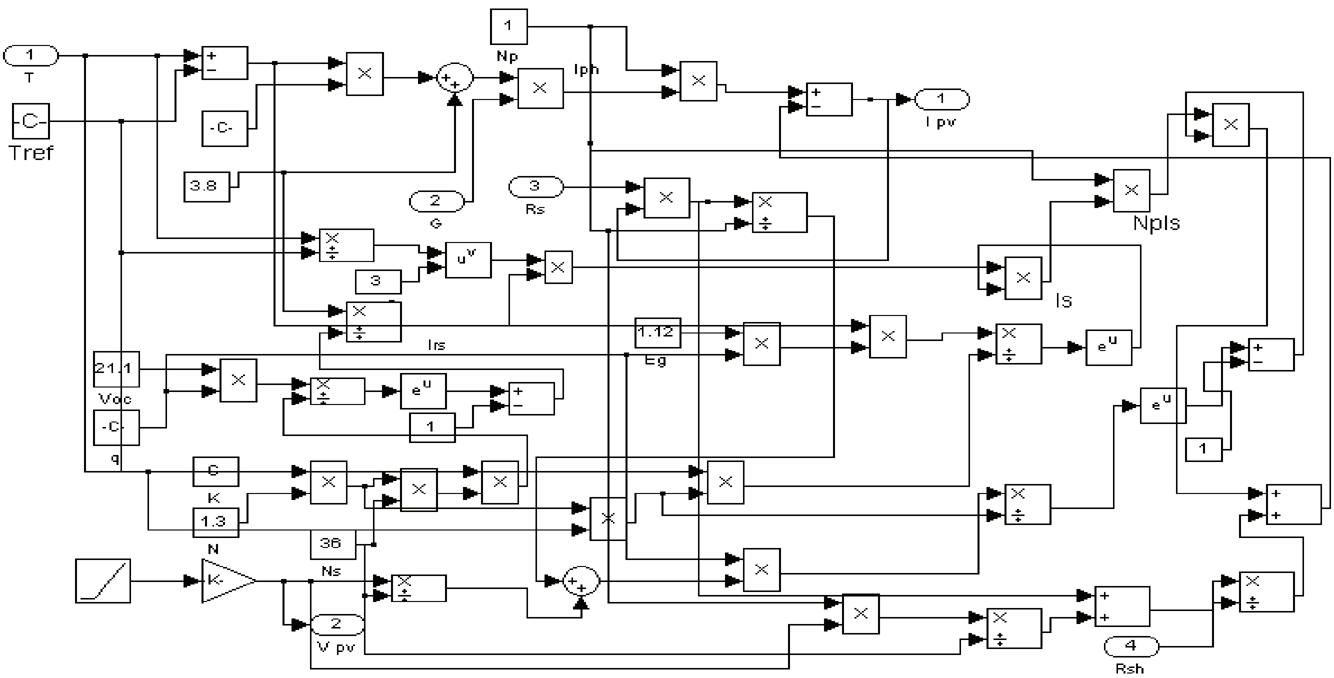

Fig. 5 SIMULINK based subsystem for PV module.

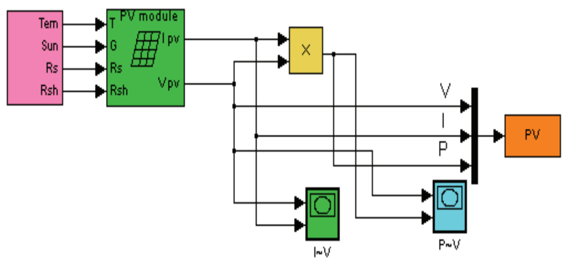

Fig.6 SIMULINK based modeling for PV module

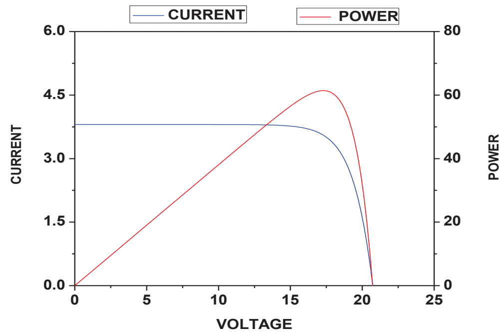

Fig. 7 I~V & P~V curves for PV module

IV. Basic Parameters of Solar Cells

A. Short Circuit Current

It is the current in the circuit when the load is zero in the circuit. It is obtained by short circuiting the output terminals.

B. Open Circuit Voltage

It is obtained by setting I=0 in the equation (1) and by neglecting the series and shunt resistances we obtain as:

$$V_{OC} = \frac{AKT}{q} ln\left(\frac{I_{ph}}{I_o} + 1\right) \qquad (6)$$

C. Fill Factor

Fill Factor is animportant parameter for solar cells. It decreases when the series resistance is high and increases with the output power of the cell [10]. So, for an efficient cell it is desired series resistance to be as small as possible. The maximum value of fill factor can be 1 but is not possible in practice and can be calculated as follows:

$$FF = \frac{P_{max}}{V_{OC} I_{SC}} \qquad (7)$$

D. Maximum Power

During open circuit and short circuit conditions power output is zero. Output power is given by,

$$P_{OUT} = V_{OUT}\, I_{OUT} \qquad (8)$$

The maximum power of the cell is derived from the maximum power point in the I-V curve.

$$P_{max} = V_{max} I_{max} \qquad (9)$$

The maximum possible output can be given as:

$$P_{max} = V_{OC}\, I_{SC}\, FF \qquad (10)$$

E. Solar Cell Efficiency

Efficiency of a solar cell is given by:

$$\eta = \frac{P_{max}}{P_{in}} = \frac{V_{OC} I_{SC}\, FF}{P_{in}} \qquad (11)$$

Solar PV module power conversion efficiency is directly related with the fill factor.So,with the increase in fill factor efficiency is increased and vice versa.

V. Simulink Based Modeling of PV Panel

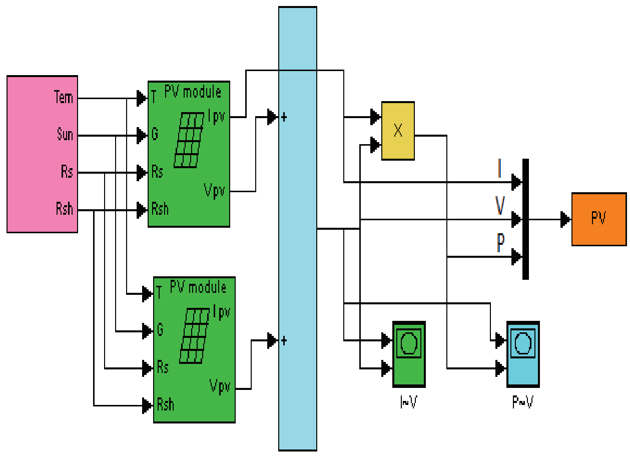

Fig. 8 SIMULINK based PV panel for 2 modules

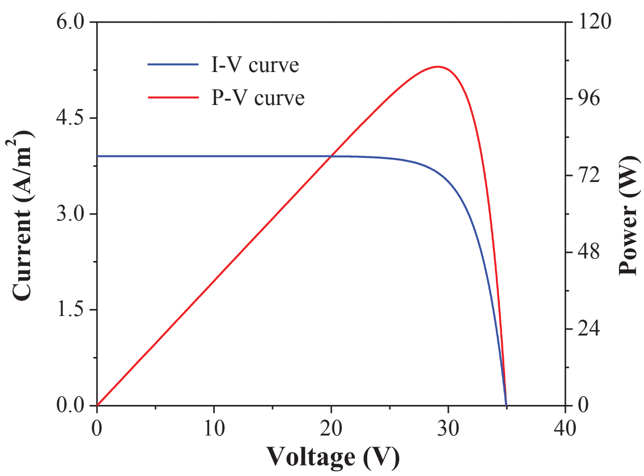

Fig. 9 I~V and P~V curves of PV panel for 2 modules

For standard loads single module power is not sufficient. So several modules are combined which creates a panel to supply the load [6]. The connection of modules in a panel may be in series for higher voltage or parallel for higher current.Figure 8 shows theSIMULINK based PV panel for 2 modules and Fig. 9 showsI~V and P~V curves for 2 modules in series.Now, Fig. 10 shows PV panel for more than 2 modules.Characteristiccurves obtained from the SIMULINK modelingare shown in Fig. 11.

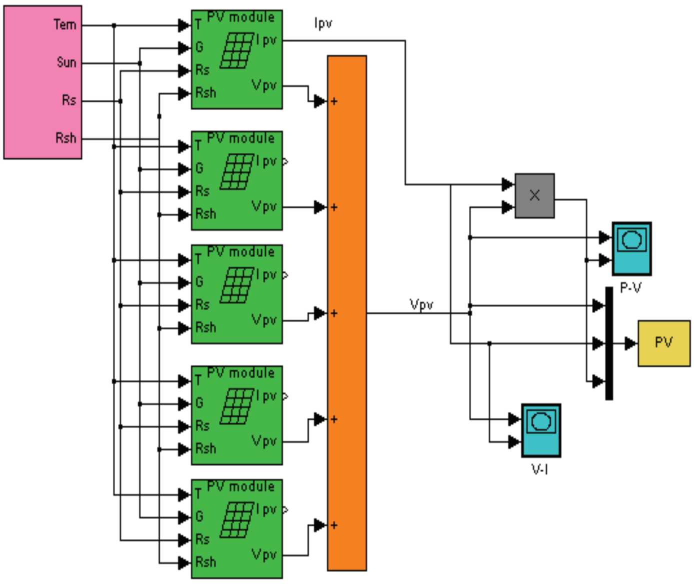

Fig. 10 SIMULINK based PV panel model for more than 2 modules

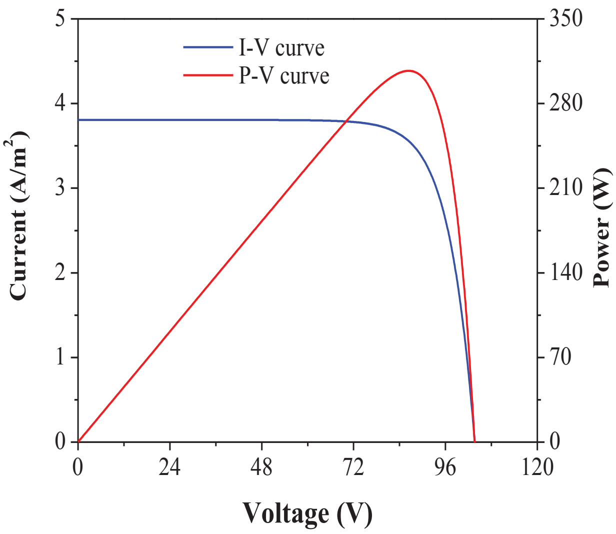

Fig. 11 Characteristic curves of PV panel for more than 2 modules

VI. Comparing Between The Experimental And Simulation Results

For series connected modules the simulation results are compared with the experimental results. For measuring experimental results ET 250 photovoltaic trainer is used in our lab. In our experiments two modules are connected in series for higher voltage. Tilt is set to$23^0$for the PV array, solar radiation is measured 0.75 KW/m^{2}and trainer is taken in south in the experiment (Fig. 12). For different combination of modules external wires can be used.The load was varied using a variable resistor. The variable resistor helps obtain characteristic curves of the panel.Sensors on the solar module detect radiation and temperature [3].

Fig. 12Solar panel setup for experimental results

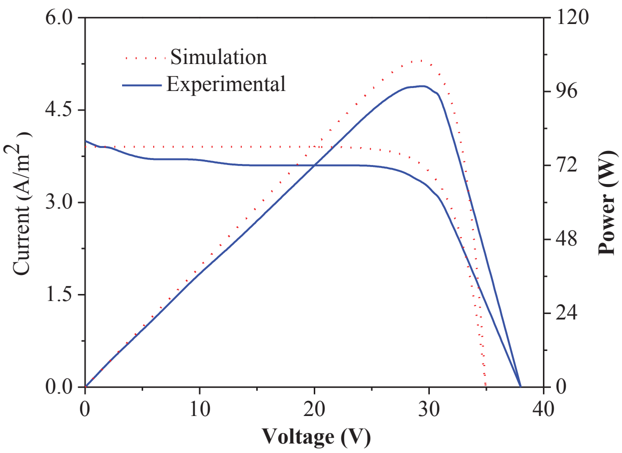

Fig. 13I ~V and P~V curves for series connected modules

Table 2:Performance observation

Parameters	Simulation results	Experimental results
I_{SC} (A/m^2)	3.8	3.8
V_{OC} (V)	35	38
Efficiency (%)	14.39	12.81
Fill Factor (%)	0.804	0.67

SIMULINK based model of photovoltaic panel is evaluated with the experimental results for two series connected modules. From Fig.13 it is shown that for irradiation 0.75 $KW/m^2$and temperature 27^0C, good agreement between the V_{OC} and I_{SC}, but fill factor collapses for the experimental results. Again it is shown that due to the collapsing of fill factor maximum power point is collapsed for the experimental results. Efficiency for experimental and simulation results are 12.81% and 14.39% respectively measured from equations (7) and (11).

Table 3: Standard parameters of each of the Module of ET 250 Photovoltaic trainer

Cells	36 (monocrystalline)
Module area	0.63m²
Max. Power	85Wp
Short-circuit current	5.29A
Open-circuit voltage	21.94V
Slide resistor	0---10 Ohm
Temperature range	0---100°C
Voltage	0---20V
Current	0---20A
Solar Irradiance	0---2000W/m²
LCD digital Displays	0---199.9mv DC

VII. Conclusion

MATLAB-SIMULINK is a smart tool for predicting the physical and environmental parameter changes of PV cell, module and array. In this paper,Matlab-SIMULINK based and the conventional Si-based photovoltaic solar panel were successfully simulated and compared with conventional solar panel. Good agreement was achieved between the simulation and experimental results for series connected modules. This study can be extended by grid connected PV system for future research.

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