Modeling and Simulation of Photovoltaic Cell Using Matlab/Simulink

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Abstract- This paper presents modeling of Photovoltaic (PV) module using MATLAB/Simulink. The model is developed on the basis of mathematical model of the PV module. The PV module of VIKRAM SOLAR PANEL PV- ELDORA 230 is selected for the experimental and technical data to analyze the developed model. The objective of this paper is to develop a model to simulate the behavior of a photovoltaic cell. Both models are implemented in MATLAB/Simulink. To demonstrate the validity of the model the *IV* and *PV* curves results were compared with those provided by the manufacturer.

Index Terms- Photovoltaic (PV), PV cells, Modeling, Simulation, MATLAB/Simulink, IV curves.

I. INTRODUCTION

The entire world is facing a challenge to overcome the hurdle of energy crisis. The diminishing deposits of non renewable energy resources such as coal, natural gas, fossil fuels etc. have added to this worry. It is thus fairly evident that a need exist for developing alternative energy sources. The immediate need would be to vitiate the problems caused by depletion of oil and natural gas, while the long term need would be to develop means that can replace coal and fossil fuels. Rapid population growth and industrialization, demands for an increased amount of electrical energy[1]. Solar energy is a renewable, inexhaustible and ultimate source of energy. If used in a proper way, it has a capacity to fulfill numerous energy needs of the world. Solar cells convert solar energy into electrical energy. This phenomenon occurs in materials which have the property of capture photon and emit electrons. The main material used in the photovoltaic industry is silicon [2]. But there are many lines of research to find materials to replace or supplement to silicon to improve conversion efficiency, as for example [3, 4].

The main aim of this paper is to provide a reader with the fundamental knowledge on design and building the blocks of PV module based on the mathematical equations using MATLAB/ Simulink. The principle and operation of the PV cell and the fundamental characteristics of PV cell are discussed in chapter II. In chapter III mathematical model of the ideal PV cell and also the practical PV cell values are shown from VIKRAM SOLAR PANEL- ELDORA 230 .In chapter IV the different types of models are shown which are analyzed during this work. The simulation model developed using MATLAB/Simulink and the results obtained are presented and discussed in chapter 5.

II. OPERATION AND CHARACTERISTICS OF PV OR SOLAR CELLS

2.1 Principle of Operation of Solar Cell:

Solar cell is basically a p-n junction fabricated in a thin wafer or layer of semiconductor. The electromagnetic radiation of solar energy can be directly converted to electricity through photovoltaic effect. Being exposed to the sunlight, photons with energy greater than the band-gap energy of the semiconductor are absorbed and create some electron-hole pairs proportional to the incident irradiation. Under the influence of the internal electric fields of the p-n junction, these carriers are swept apart and create a photocurrent which is directly proportional to solar insolation [5]. The ideal solar cell, theoretically, can be modeled as a current source in anti-parallel with a diode (Fig.2.1 (a)). The direct current, generated when the cell is exposed to light, varies linearly with solar radiation. An improvement of the model includes the effects of a shunt resistance and another in series [6].
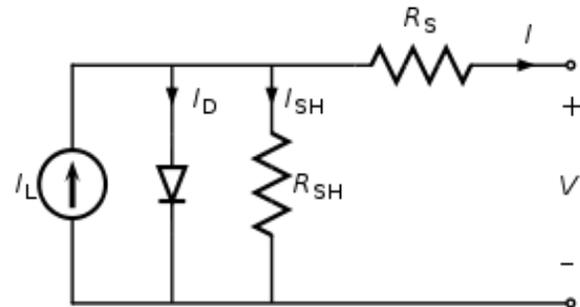

Fig. 2.1(a) Equivalent circuit for PV model

According to [6] and based Fig. 2.1(a) photovoltaic panel its characteristic equation :

$$\checkmark \quad I = I_{ph} - I_d - I_{sh} \qquad ....(1)$$

Being I_{ph}, I_d and I_{sh}:

$$\checkmark \quad I_{ph} = \frac{Ir.Isc}{Ir0} \qquad ....(2)$$

$$\checkmark \quad I_d = I_s.\left(e^{\frac{(V+I.Rs)}{(n.Vt.Ns)}} -1\right) \qquad ....(3)$$

$$\checkmark \quad I_s = I_{sc}.\left(e^{\frac{Voc}{n.Vt}} -1\right) \qquad ....(4)$$

$$\checkmark \quad V_t = \frac{kT}{q} \qquad ....(5)$$

This expression describes the electrical behavior and determines the relationship between voltage and current supplied by a photovoltaic module. It is a non-linear mathematical equation whose parameters are, N_s is number of cells in series, I_{ph} is the current produced by the photoelectric effect, I_S is the

reverse saturation current. R_S and R_{sh} are inherent resistances in series and parallel associated with the cell. Q is the electron charge, K Boltzmann's constant and a, the ideality factor modified.

2.2 Characteristics of Solar Cell:

PV system naturally exhibits a nonlinear I-V and P-V characteristics which vary with the radiant intensity and cell temperature. Fig.2.1 (b) and Fig.2.1(c) respectively shows the equivalent circuit models of cell.
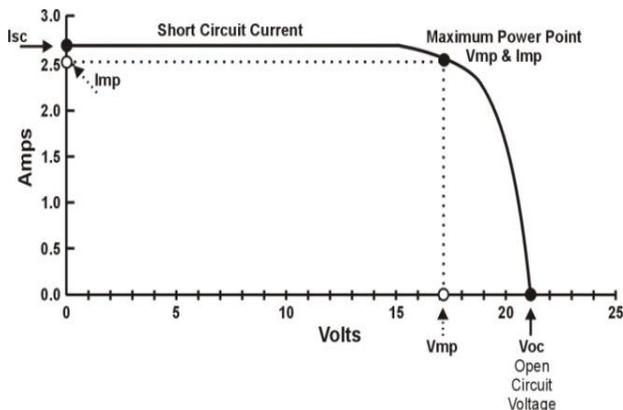

Fig. 2.1(b) I-V curve

The curve drawn (Fig. 2.1(b) and Fig.2.1(c)) shows how the voltage and current varies with Irradiation and Temperature of PV module. We can find out maximum power by finding out the V_{max} and I_{max}. There are different methods of finding out Maximum power of PV module i.e. P_{max} and these are known as MPP Techniques i.e Maximum Power Point Technique at that point we get V_{max} and I_{max}.
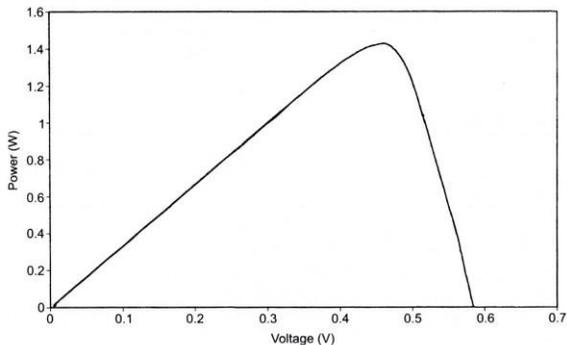

Fig. 2.1(b) P-V curve

The fundamental parameters related to solar cell are short circuit current (I_{sc}), open circuit voltage (V_{oc}), maximum power point (MPP)[6].

Short Circuit Current is the current corresponds to the short circuit condition when the impedance is low and it is calculated when the voltage equals to zero.

$$I\ (at\ V=0) = I_{sc} \qquad .....(6)$$

Open Circuit Voltage is the voltage when the open circuit occurs and there is no current passing through the cell. The Open circuit voltage is calculated when the voltage equals to zero.

$$V\ (at\ I=0) = V_{oc} \qquad ......(7)$$

Maximum Power Point is the operating point at which the power is maximum across the load.

$$P_m = V_m I_m \qquad ......(8)$$

where, V_m is the maximum voltage and I_m is the maximum current.

Efficiency of solar cell is the ratio between the maximum power and the incident light power.

$$\eta = \frac{Pm}{Pin} \qquad ....(9)$$

P_{in} is taken as the product of the solar irradiation of the incident light $(G=\lambda/1000)$, measured in W/m^2, with the surface area (A_c) of the solar cell in m^2.

III.   PHOTOVOLTAIC PANEL TO BE DEVELOPED

In order to apply these concepts to developments of a solar cell model, the VIKRAM SOLAR PANEL PV- ELDORA 230 module has been chosen for modeling. This module has 50 series connected polycrystalline cells. The key specifications are shown in Table 1.

Table1. Key specifications of the VIKRAM SOLAR PV Panel

Model	ELDORA 230
Cell type	Polycrystalline
Maximum Power[W]	(-0/+5w)(pump) 235w
Open circuit voltage V_{oc}[V]	36.65
Short Circuit Current[I_{sc}]	8.35
Current, Max power I_{mpp} [A]	8.08
Voltage , Max power V_{mpp}[V]	29.10
Normal operating cell temperature	45

The performance of solar cell is normally evaluated under the standard test condition (STC), where an average solar spectrum at AM 1.5 is used, the irradiance is normalized to 1000W/m^2, and the cell temperature is defined as 25 ºC.

IV.   TYPES OF MODELS

The two models presented in this paper are part of a more complete study of models of cell or photovoltaic panels. The models that are analyzed and compared differ depending on if they are modeled with MATLAB/Simulink or with the support of some of their toolboxes. Below is a brief summary of each of the simulation forms analyzed in this work.

A. Matlab Programming

This model is made only in Matlab, based on mathematical equations that define the photovoltaic cell. From the work of Walker [7], Gonzalez [8] and Ahikiro [9] a function in Matlab [10] has been developed which calculates the current module from data of voltage, solar radiation and temperature. Setting the constant temperature or radiation, curves *IV* and *PV* will be obtained. From another script also calculates the maximum power point.

B. Matlab Tools

This section has taken into account two ways to represent the *IV* and *PV* curves. In the first form of representation, the graphic interface for curve fitting Cftool (Curve Fitting Toolbox) has been used. The International Journal on "Technical and Physical Problems of Engineering" (IJTPE), Iss. 10, Vol. 4, No. 1, Mar. 2012 47 starting point of this model is the manufacturer's datasheet, in which the *IV* and *PV* curves of the panel are represented. In this curve at least three coordinates (*V*, *I*) are known, (0, I_{SC}), (V_{mpp}, I_{mpp}) and (V_{OC}, 0). Manually more coordinates can be approximated to facilitate the representation. With these coordinates, the tool will provide an equation of a similar curve to the original one. In the second form, the model consists of two Matlab programs. The first serves for the presentation and data capture and calculations are made in the second one. These calculations are based on three functions of MATLAB: fsolve, fzero and lsqnonlin. In this case the data used were obtained experimentally from the panels analyzed. Data can be exchanged from one form of representation to another.

C. Basic Model in Simulink

This model is made based on [11,12]. It is a model like the one shown in section D, also based on mathematical Equation (1) but made with elements of Simulink. It is a basic model in which the values of *Rs* (0.001 Ω) and *Rsh* (1000 Ω) are assumed to be known.

D. Simulink Model with Tags

This is the usual way to model a PV cell that has been developed among other authors, by Villava [12]. It starts from the same equations as in section A, but it is developed in Simulink. Based on this kind of programming could also simulate the basic model of the previous section in this way. The model developed with tags, presented in this paper (Figures 4),

model in Section C is the basic model based on Equation (1). Therefore the results have to be the same. Fig. 4. Types of tags
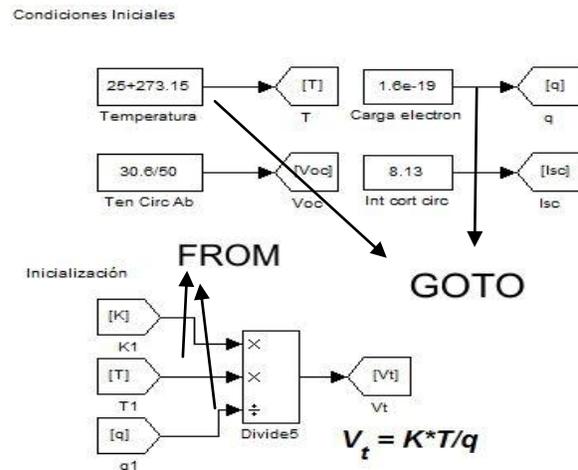

Fig. 4

E. Model of Physical Component

This model is made from physical elements using Simscape. With those elements, electrical equivalent circuit diagram of the cell is performed.

F. Model of Advanced Component Library

This is the simplest model. It works with an element of SimElectronics, that is a toolbox dependent of Simscape. The element to model, Solar Cell, appears in the Source Library. Only, it is needed to enter the parameters that define the cell, provided by the manufacturer's data sheet.

G. Model According with Look Table Function

This model is created from experimental data of the panel that is going to be simulated. It is based on the element Look Table (2D). Lookup Tables library in Simulink which generates a vector of data, from the experimental data of irradiance, voltage and current. Then use the surface fitting tool.

V. MODEL BASED ON SIMULINK WITH TAGS

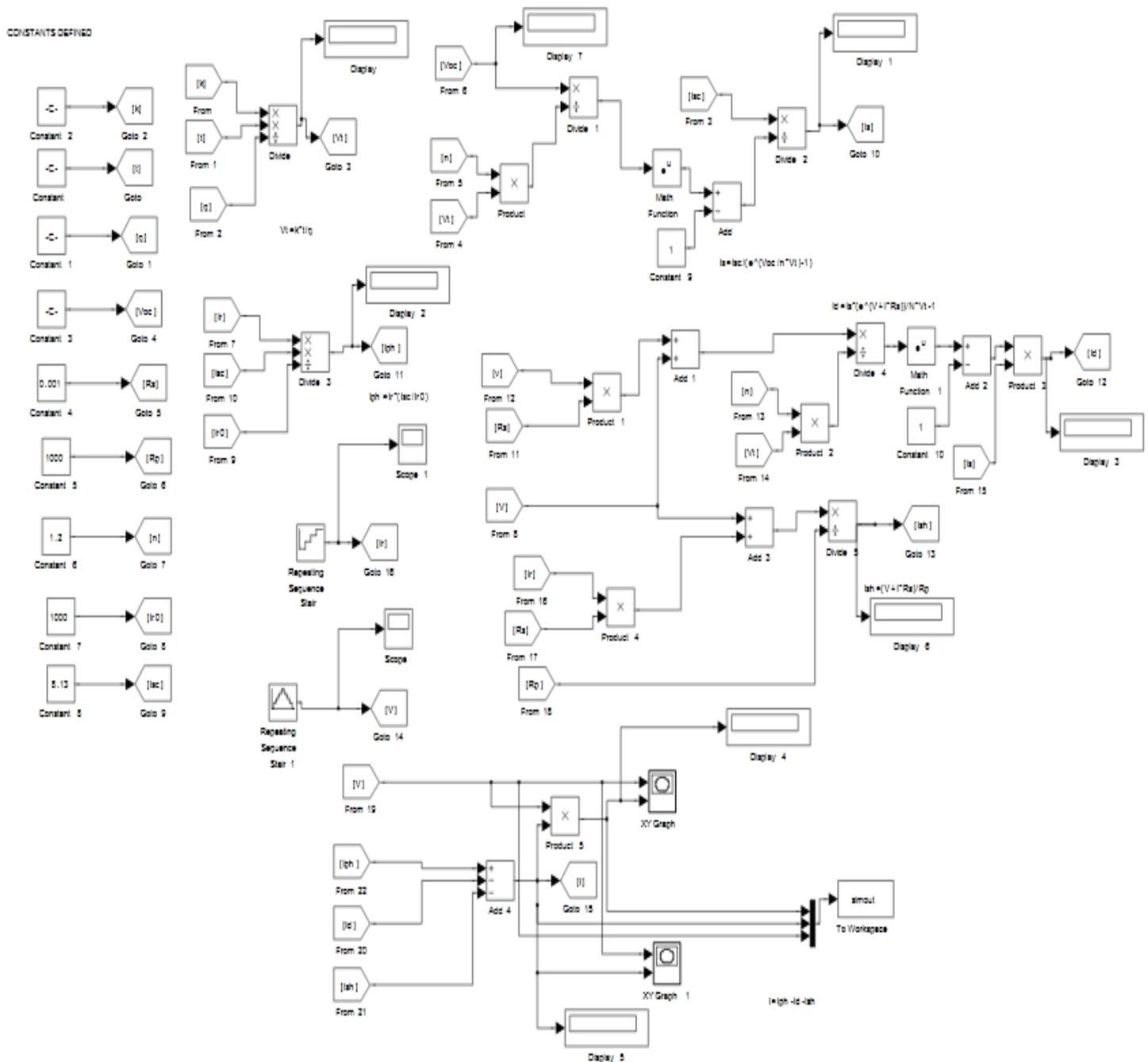In this model two types of tags (Figure 4) were worked with:

Figure 5.1. Simulink model with tags

From: Outputs the data type (or types) of the signal connected to the corresponding Goto block. Library: Signal Routing.

• Goto: Pass block input To/From blocks. Input can be of any type. Library: Signal Routing.

From/Goto combinations can be quite powerful in Simulink. These blocks are useful tools to structure a complex design which would otherwise have many crossing signal lines, a stylistic choice that can make a model harder to decipher. But,

From/Goto blocks can only be used with a local scope. They are basically nonfunctional, simply hiding a signal line from view. The model developed (Figure 5.1) is based on the equivalent circuit of solar cell (Fig.2.1) and its characteristic equation, Equation (1). Where current (I) obtained in the solar panel is defined by the following expression:
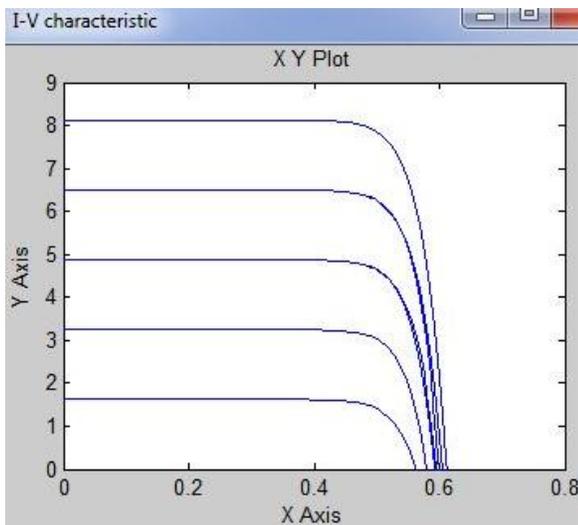
$$I = I_{ph} - I_d - I_{sh}$$

Figure 5.2 IV Curve results

The model developed is shown in Figure 5. In this model the irradiance (I_r) is a vector of value [200 400 600 800 1000]. It will be represented an *IV* characteristic curve for each irradiance value in the same graph, as shown in Figure 5.2. The same goes for the *PV* curve in Figure 5.3. If 50 cells are put in series a full panel simulation is obtained.
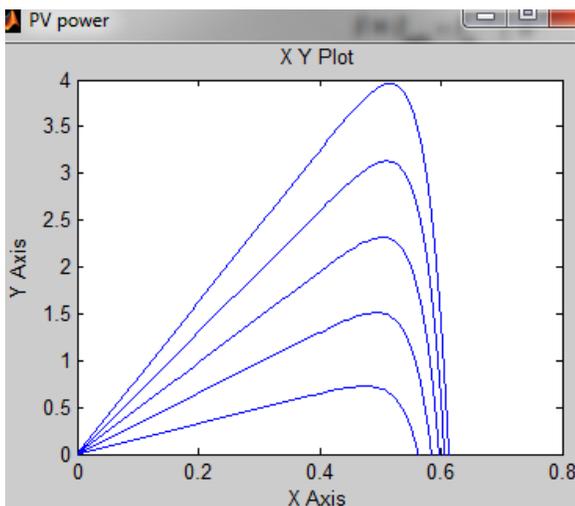

Figure 5.3 PV curves Result

VI. CONCLUSION

Since the field tests can be expensive and depend primarily on weather conditions it is very convenient to have simulation models to perform at any time. For this reason, in this paper, for the development of photovoltaic arrays the methods of modeling in MATLAB/SIMULINK have been analyzed. During analysis one of the method is selected and a model is developed on that. This model has been designed in Simulink with Tags. The blocks with tags makes the model more user-friendly. Such a generalized PV model is easy to use for the implementation on Matlab/Simulink modeling and simulation platform.

Results presented in the paper clearly demonstrates, *IV* and *PV* characteristic curve similar to the graph that presents the manufacturer's data sheet of the solar panel. More similar the curve obtained, better the model will be.

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