A voltage Source Simulation Model of a Solar Cell

B Kibirige[1], **O Nemraoui and TP Jili**
University of Zululand, Faculty of Science and Agriculture, Department of Physics and Engineering, Private Bag X 1001, KwaDlangezwa, 3886, RSA

E-mail: kibirige@pan.uzulu.ac.za

Abstract. Most circuit based models of solar cells are presented as a **current source (CS)** in parallel with a diode. It is useful to model the solar cell as a voltage source especially solar cell battery charging models. In this paper a circuit based **voltage source (VS)** simulation model for a solar cell is developed. The model is implemented using Matlab/Simulink software package. Solar irradiance and cell temperature are taken into consideration. Based on previous studies, the model's current and voltage characteristics are calculated and validated against data from experiments. It is compared with a circuit based model implemented in PSpice at constant irradiance and constant junction temperature. The results from all three scenarios show a close fit.

1. Introduction

Most solar cell models are represented as a constant current source in parallel with an ideal diode [1, 2, 3]. Although some researchers model the cell (array) as a voltage source [4] especially for solar battery charging studies, the representation is used without proper validation. This paper is a report on the development of a generalised voltage source model. The model was developed using published data and implemented in the Matlab/Simulink simulation environment. Also a constant voltage source based solar cell equivalent circuit diagram was implemented in P-Spice. IV Characteristic data from experiments carried out on a Silicon solar cell was used to validate the Matlab/Simulink and the PSpice model.

2. Developing the generalised Matlab/Simulink Model

Data from published technical information [5] was studied and used to establish generalised mathematical expressions for a solar cell. The expressions given in equations (1) to (3) were determined using information given in table 1[5].

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[1] To whom any correspondence should be addressed.

Table 1. Variation of a solar cell open-circuit voltage and short-circuit current with illuminance [5].

Illuminance , X (lx)	Open-Circuit voltage, V_{oc} (V)	Short-Circuit Current, I_{sc} (uA)
0.1	0.25	0.0055
1	0.315	0.055
10	0.385	0.55
100	0.445	5.5
1000	0.5	55
10000	0.56	550

$$V_{oc} = 0.026 ln(X) + 0.316 \text{ V} \quad (1)$$

$$I_{sc} = 0.055 \times 10^{-6} X \text{ A} \quad (2)$$

$$I_{sc} = 4 \times 10^{-13} e^{37.16 V_{oc}} \text{ A} \quad (3)$$

These relationships confirm findings from literature [1, 2, 3] that:

- the open circuit voltage varies logarithmically with illuminace,
- the short circuit currents varies linearly with illuminance
- and the short circuit current varies exponentially with the open circuit voltage.

Expressions (1) can also be written as:

$$V_{oc} = 0.026 \ln\left(X e^{0.316/0.026}\right) \quad (4)$$

Implying that:

$$X = \frac{e^{V_{oc}/0.026}}{e^{0.316/0.026}} \quad (5)$$

Therefore equation (2) becomes:

$$I_{sc} = 0.055 \times 10^{-6} \left(\frac{e^{V_{OC}/0.026}}{e^{0.316/0.026}}\right) = \frac{0.055}{e^{0.316/0.026}} \; e^{V_{OC}/0.026} \quad (6)$$

and relating equation (3) to the diode equation [6, 7]:

$$I = I_o\left(e^{V/V_T} + 1\right) \approx I_o e^{V/V_T} \quad (7)$$

And equation (7) is equivalent to equation (6)

$$I_o e^{V/V_T} \equiv \frac{0.055}{e^{0.316/0.026}} \; e^{V_{OC}/0.026} \quad (8)$$

Where V_T is the thermal voltage expressed as: $V_T = \frac{KT}{q}$, K is Boltman's constant, T is the junction temperature and q is the electron charge. I_0 is the reverse saturation current; a current that flows independent of the reverse bias voltage, before the junction diode breakdown voltage. From equation (7), it is noted that $V_T = 0.026$ V; implying a junction temperature of 28 °C. The reverse saturation current, I_0 can therefore be expressed as:

$$I_o = \frac{0.055}{e^{0.316/0.026}} = \frac{I_{sc}}{e^{V_{oc}/V_T}} = \frac{0.055}{e^{V_{G1}/V_T}} \quad (9)$$

2.1. Temperature dependence

It is implicitly implied that the whole system is dependent on temperature since the thermal voltage V_T is a function of the thermal dynamic temperature. However, the saturation current I_o also approximately doubles for every 10 °C increase in the junction temperature [7]. This temperature dependence of I_0 can be expressed as [6, 7]

$$I_o(T) = I_{o1} \times 2^{(T-T_1)/10} \quad (10)$$

3. Voltage Source circuit representation of a Solar Cell

When a solar cell is illuminated under a large reverse bias, the current generated from the device I is given by [6]:

$$I = I_{sc} + I_o \quad (11)$$

The relationship between a bias voltage varying between -1 V and 1 V and the generated current is given in equation (12) [6]:

$$I = I_{sc} + I_o\left(1 - e^{V/nV_T}\right) \quad (12)$$

Where n is the diode equivalence factor included to compensate for surface recombination and carrier generation within the depletion region [6]. A series resistance R_s together with a parallel resistance R_p were included in the circuit model to compensate for ohmic resistances introduced by the system used for the experiments. The current generated from the solar cell became:

$$I = I_{sc} + I_o + I_{R_p} - I_{R_s} \quad (13)$$

These resistances together with n were used as the fitting factors for the model. Equation (14) was the expression developed for the Matlab/Simulink representation of the proposed circuit by considering equations (1) to (13). The current I, generated by the device, was portrayed as a function of the open circuit voltage V_{oc} and the bias voltage V, implying a voltage source equivalent to the open circuit voltage V_{oc}.

$$I = I_o\left(e^{V_{oc}/V_T} + 1 - e^{(V - I_{R_S}R_S)/nV_T}\right) + \frac{V - I_{R_S}R_S}{R_p} \quad (14)$$

The Matlab/Simulink model is given in figure 4. This model includes irradiance/illuminance and temperature dependence expressed in equations (4) and (10).

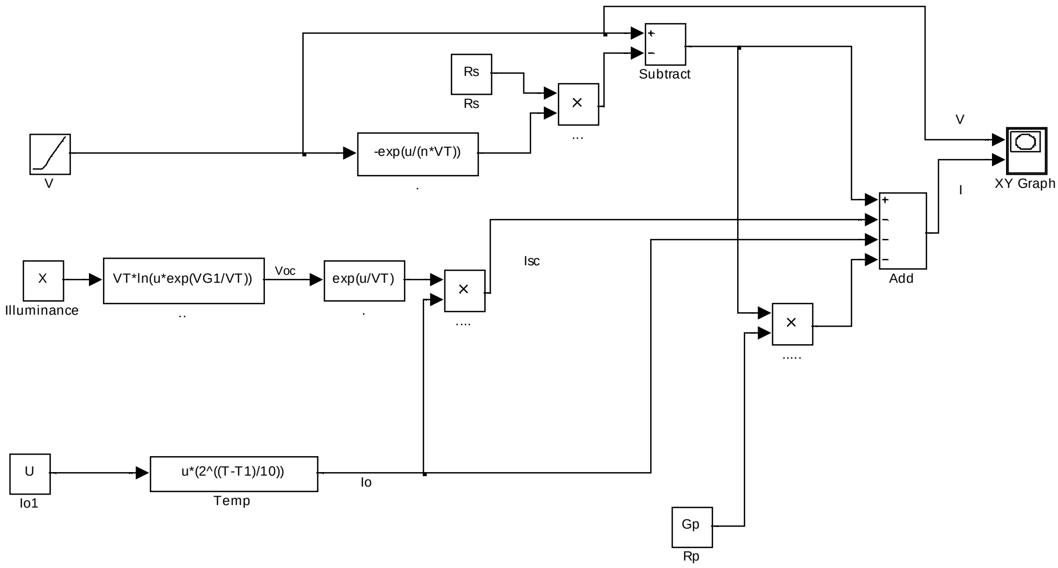

Figure 1. Matlab/Simulink solar cell model with Voc as source to the system.

Equation (13) was modified for the P-Spice model shown in figure 5 and:

$$I = \frac{V_{oc}}{R_i} + I_o + \frac{V - I_{R_S}R_S}{R_p} - I_o e^{\left(\left(V - I_{R_S}R_S\right) - V_{oc}\right)/nV_T} \qquad (15)$$

The series voltage source 0.71 V was added to compensate for the P-Spice- diode forward voltage drop. The short circuit $I_{sc} = \frac{V_{oc}}{R_i}$

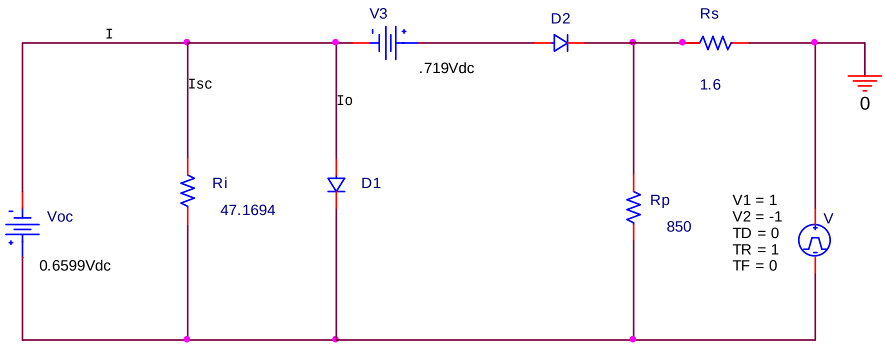

Figure 2: P-Spice _Voltage Source Circuit representation of a Solar Cell

4. Experiment and Simulations

The silicon solar cell was tested to obtain IV characteristics at 1000 W/m^2 irradiation at a temperature of 25 °C. The cell had an area of 0.45 cm^2. The voltage and current measurements were carried out using a four wire system, the Keithley 2400 source meter. And the bias voltage (V) was varied between -1 V and 1 V. The data collected from the experiments and from the simulations is presented in figure 3.

5. Results and discussions

Figure 3 shows the IV characteristic results for the Matlab/Simulink Model, the P-Spice Model and the data harnessed from the experiments. For the considered solar cell, V_{oc} = 0.6500 V, I_{sc} = 0.01399 A, n = 2, R_s = 1.6 Ω, R_p = 850 Ω and R_i = 47.1694 Ω. Results show a good fit between the data from experiments and the data for both the Matlab/Simulink and the P-Spice models.

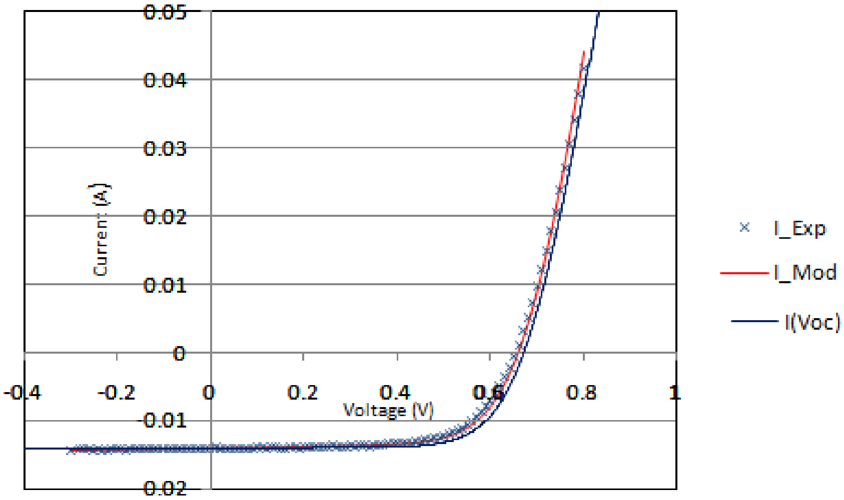

Figure 3. I-V characteristics for data from experiments, (I_Exp); Matlab/Simulink model, (I_Mod) and P-Spice model (I_Voc)

6. Conclusion

Simulation results from both Matlab/Simulink and P-Spice Voltage Source solar cell models compared well with experimental results. Therefore, it can be conclude that a Voltage Source Solar cell model can be used in studies required to optimise solar cell applications.

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