

ESTIMATION OF THE PARAMETERS OF SOLAR CELLS FROM CURRENT-VOLTAGE CHARACTERISTICS USING GENETIC ALGORITHM

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ABSTRACT

This paper presents a method for calculating the light generated current, the series resistance, shunt resistance and the two components of the reverse saturation current usually encountered in the double diode representation of the solar cell from the experimental values of the current-voltage characteristics of the cell using genetic algorithm. The theory is able to regenerate the above mentioned parameters to very good accuracy when applied to cell data that was generated from pre-defined parameters. The method is applied to various types of space quality solar cells and sub cells. All parameters except the light generated current are seen to be nearly the same in the case of a cell whose characteristics under illumination and in dark were analyzed. The light generated current is nearly equal to the short-circuit current in all cases. The parameters obtained by this method and another method are nearly equal wherever applicable. The parameters are also shown to represent the current-voltage characteristics well.

KEYWORDS

Solar cell, current-voltage characteristics, reverse saturation current, series resistance, shunt resistance, particle radiation, genetic algorithm

1. INTRODUCTION

It is important to have the full characteristics of the solar cells and thus the solar array because of several reasons. Space solar arrays are optimized for end of life conditions (EOL). Since space systems require high reliability, the margins used are usually high and thus even at the end of life the solar array does not operate at maximum power point. The space array continuously undergoes irradiation by charged particles in geosynchronous orbit, low earth orbit or medium earth orbit due to trapped protons and electrons. Solar flare protons affect even the satellites that are situated away from the earth. Since the current from the array depends on where the array operates at each point in its life time, it is necessary to have a proper estimate of the full characteristics of the solar array. Sometimes, certain off-optimality for small periods is allowed in the design of the solar array so that it operates at points between the maximum power point and the open-circuit voltage. This is another reason why the

knowledge of the full I-V characteristics of the cell is necessary for optimum design and analysis of the performance. Full I-V characteristics of solar cells are obtained from limited data by several means. Usually, the solar cell parameters like diffusion and recombination currents, light generated current, series resistance and shunt resistance are obtained from the measurements of several points on the I-V curve and then using these parameters the entire I-V curve is plotted using equations representing appropriate models. The knowledge of these parameters in itself is highly important for studying solar cells and for the design and manufacture of the solar cells. The effect of various environments like charged particle environment and the impact of solar array arcing have been seen to impact some or all of these parameters.

Diffusion current is characterized by an ideality factor equal to one and it varies with forward bias V_j and temperature T following the expression given by [1]

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$$I_d = I_{01} [\exp(qV_j/nkT) - 1] \quad (1)$$

with $I_{01} \propto T^3 \exp(-E_g(T)/kT)$, I_{01} is the saturation current and E_g is the energy gap of the material, k is the Boltzmann constant, q is the electronic charge and n is the ideality factor which is equal to 1.

Recombination current in the space charge region (SCR) varies following the relation [1]

$$I_{rec} = I_{02} [\exp(qV_j/nkT) - 1] \quad (2)$$

with $I_{02} \propto T^{3/2} \exp(-E_g/2kT)$, n is the ideality factor which is equal to 2.

The full illuminated I-V characteristics of the solar cell using the equation (1) and (2) can be represented as

$$I = I_L - I_d - I_{rec} - (V_j)/R_{sh} \quad (3)$$

where I_L is the light generated current. Using the above equation and $V_j = V + IR_s$, the double diode equation for the solar cell is obtained and is given by

$$I(V) = I_L - I_{01} \{ \exp [(V + IR_s)K/T] - 1 \} - I_{02} \{ \exp [(V + IR_s)K/2T] - 1 \} - (V + IR_s)/R_{sh} \quad (4)$$

where R_s is the series resistance and R_{sh} is the shunt resistance of the solar cell and K is equal to q/k .

This double diode model has been in use for obtaining solar array currents at different voltages and intensities and aspect angles by people working in the area of solar arrays especially those in space industry. The accuracy of this model is found to lie within 1 to 2% for space quality silicon and gallium arsenide solar cells. Although this model is very attractive, the actual calculation of the two components of the reverse saturation current as well as the series resistance and shunt resistance is not easy. It is also not possible to directly apply a least squares method because of the non linear nature of the problem. This problem is compounded by the fact that we have to solve implicit equations also.

This problem has been attacked from different angles by different authors. S. Mottet[2] has given a least-square solution of the problem. Since the solar cell equation is implicit, the solution is not straightforward, but uses iteration procedure for estimating the series resistance. Sharma et. al. [3] have employed an analytical solution to the problem. However, the equations in this method are complicated and in practice, the analytical solution is not straight forward and the use of software is usually required. Another limitation of this method is that the light generated current is assumed to be equal to the short-circuit current and shunt resistance is totally neglected. Recently, Suresh Puthanveetil [4] has suggested a spread sheet solution to the problem. Even though the light generated current appears as an output, here again shunt resistance is totally neglected.

Genetic Algorithms belong to the group of evolutionary computation methods. These are adaptive search algorithms used to tackle optimization problems. These algorithms are heuristic in nature and the search is conducted by creation of generations of solutions. The search is refined by information gained from previous generations. The fitness of each solution is computed and the final solution is based on the principle of the survival of the fittest as in Darwin's theory of evolution.

In the present paper, we employ Genetic Algorithm to solve the problem and to arrive at the parameters defined above. There are several advantages to Genetic Algorithm. One is that a full search of the solution space is not required. Another advantage is that this software can be easily adapted for a more general equation of the form

$$I(V)=I_L-I_01\{\exp [(V+IR_s)K/mT]-1\}-I_02\{\exp [(V+IR_s)K/2nT]-1\}-(V+IR_s)/R_{sh} \quad (5)$$

where m and n are new parameters which may sometimes be necessary for more accuracy. Similarly, the dark cell I-V measurement can be used directly without altering the software to estimate all parameters except the light generated current. In fact to the best of our knowledge the first use of genetic algorithm for solar cells was made by Okumura et al., [5] to obtain the parameters of solar cell under dark condition employing a single diode model of the form

$$I(V)=I_01\{\exp [(V+IR_s)K/mT]-1\}-(V+IR_s)/R_{sh} \quad (6)$$

2. ALGORITHM

The algorithm can be broken down into the following steps

- i. Generation of initial population is done by random number generation. The number of initial population is chosen as 1000 in our case, but this number can be varied depending on the choice of the user. Each parameter like the light generated current, series resistance and so on are represented by a 16 bit binary number (The number of bits can be increased for more accuracy). This binary number is converted to decimal number and the value for each of these parameters is calculated by dividing the range of (the difference between upper and lower limits) of the variables which are chosen initially in a logarithmic fashion.
- ii. The fitness of the first and other generations are calculated by comparing the I-V curve generated from the solution to the experimental values by least squares. The one where the sum of the least squares is minimum is ranked as one, the next one as two and so on.
- iii. The next generation is created by choosing the parents and creating offsprings. Here we have allowed only the first 30% of the population (arranged rank wise) to create off-springs. The off-springs are created by crossing over of the bits of the father and mother after a certain bit which is randomly chosen. We have also used the principle of elitism by retaining the first five ranks in the next generation without change.
- iv. A small percentage of the bits are randomly altered (to effect mutation) so as to increase diversity.
- v. The ranking, selection of parents, reproduction, selection of elites and mutation are repeated for each generation.
- vi. A total of 100 generations is created and the first rank of the last generation is chosen as the fittest solution.

3. RESULTS AND ANALYSIS

The first analysis we have carried out with this software is with imaginary Silicon 2 ohm-cm solar cell with the following parameters which are given in Table 1.

Table 1. Input parameters for obtaining the current-voltage characteristics of a simulated solar cell

Parameter	Value
I _L	1.00 amp
I ₀₁	1×10^{-10} amp
I ₀₂	5×10^{-7} amp
R _s	0.025 ohm
R _{sh}	1000 ohm

Using these parameters we have calculated the I- V characteristics of the solar cell. Using these current and voltage values as input, we have run the genetic code to get back the parameters and the results are given in Table 2.

Table 2. Output parameters of the simulated solar cell of Table 1. obtained through genetic algorithm

Parameter	Value
I _L	0.9999 amp
I ₀₁	1.1184×10^{-10} amp
I ₀₂	4.958×10^{-7} amp
R _s	0.02488 ohm
R _{sh}	980 ohm

From this table we understand the most of the parameters can be known very accurately if the input current and voltage values are measured properly. There is some inaccuracy as far as I₀₁ is concerned which here is about 12%. Shunt resistance inaccuracy is about 2% and all other errors are minimal. This gives an indication of the accuracy of this method of estimating the parameters given in Tables 1 and 2.

Next, we have used the developed software to analyze 10 ohm Si solar cells of nominal dimension 2cm x 4cm before and after radiation to a fluence level of 3×10^{13} electrons/cm². The cell types are both BSR type cells. Figure.1 gives the I-V characteristics of unirradiated BSR cell at 28°C. The I-V characteristics of the same cell irradiated to a fluence of 3×10^{13} 1 MeV electrons/cm² at 28°C are given in Figure.2. The experimental data is represented by discrete points and the data according to our theory is presented as a continuous line in both the cases. This continuous line is generated using the parameters evaluated using genetic algorithm. In both of the above, one can notice the close match that exists between theory and experiment. It is to be noted that the experimental data were obtained by using the standard facilities and methods used in space industry.

The results of the parameters evaluated are tabulated below:

Table 3. Output parameters of a silicon solar cell before and after electron irradiation obtained through genetic algorithm

Parameter	Value before irradiation	Value after irradiation
IL	0.31819 amp	0.31012 amp
I01	8.86168×10^{-11} amp	1.2437×10^{-10} amp
I02	6.4422×10^{-7} amp	9.46299×10^{-7} amp
Rs	0.0561 ohm	0.0539 ohm
Rsh	531.8 ohm	632.4 ohm

It is seen that the light generated current decreases, I01 and I02 both increase as expected. There is no remarkable change in series resistance and we believe that the apparent increase in shunt resistance also is due to the limitations of the model or method rather than a real increase in shunt resistance.

Further, we have compared the dark and illuminated characteristics of a silicon solar cell and the result is given in Table below.

Table 4. Output parameters of a silicon solar cell in dark and under illumination obtained through genetic algorithm

Parameter	Value for cell not illuminated	Value for illuminated cell
IL	1e-20 amp	1.0690 amp
I01	1.4329×10^{-10} amp	1.3395×10^{-10} amp
I02	3.1619×10^{-7} amp	4.869×10^{-7} amp
Rs	0.025148 ohm	0.023355 ohm
Rsh	447.2 ohm	945.2 ohm

There is a good match between the two values of I01 and Rs. Both the values of I02 are comparable, but not quite identical. The differences can be due to measurement inaccuracy and the limitations of the model.

We have also used the developed software to analyze the following types of solar cells and the results are given below.

- i. GaInP solar cells
- ii. (In)GaAs solar cells
- iii. Ge solar cells

Table 5. Output parameters of a GaInP solar cell in under illumination obtained through genetic algorithm

Parameter	Value
Isc(measured value)	0.50798 amp
Voc(measured value)	1.3961V
IL	0.508875 amp
I01	1.9989×10^{-25} amp
I02	9.87147×10^{-13} amp
Rs	0.043591 ohm
Rsh	192.7 ohm

Table 6. Output parameters of an (In)GaAs solar cell in under illumination obtained through genetic algorithm

Parameter	Value
Isc(measured value)	0.55074 amp
Voc(measured value)	1.0305V
I _L	0.5505 amp
I ₀₁	2.359×10^{-18} amp
I ₀₂	3.5898×10^{-10} amp
R _s	0.053179 ohm
R _{sh}	9999 ohm

Table 7. Output parameters of a Ge solar cell in under illumination obtained through genetic algorithm

Parameter	Value
Isc(measured value)	0.84733amp
Voc(measured value)	0.2474V
I _L	0.85929 amp
I ₀₁	2.766×10^{-3} amp
I ₀₂	4.4109×10^{-3} amp
R _s	0.02306 ohm
R _{sh}	199.98 ohm

The three cells mentioned above comprise the sub-cells of triple junction solar cells usually used in the space industry. In all the cases, it is seen that the light generated current is nearly equal to the short circuit current as expected.

Next, we have compared the results of the parameters generated by the method of Puthanveettil to the method employing genetic algorithm. It can be seen that there is very good agreement between the parameters estimated by both methods wherever applicable.

Table 8. Output parameters of a silicon solar cell under illumination obtained through the spread sheet method and through genetic algorithm

Parameter	Puthanveettil	Genetic algorithm
I _L	0.3180 amp	0.3182 amp
I ₀₁	8.106×10^{-11} amp	8.862×10^{-11} amp
I ₀₂	7.034×10^{-7} amp	6.442×10^{-7} amp
R _s	0.0626 ohm	0.0561 ohm
R _{sh}	infinite	531.8 ohm

The last question which we addressed is the utility of genetic algorithm on the reproduction of the current voltage characteristics of the solar cells. In all the cells which we have carried out the study, the results show a very good match between the measure values and the values estimated from the parameters like I₀₁ and I₀₂ which we have obtained using genetic algorithm. An example is given in Figure 1 for a silicon BSR solar cell.

4. CONCLUSION

A method of calculating the solar cell parameters like the two different components of the reverse saturation current and the series resistance, the shunt resistance and the light generated current was developed using genetic algorithm applied to the experimental current voltage characteristics of the cell. The data obtained were physical and the variations seen in the parameters due to irradiation were as expected in the silicon solar cell. Similarly, the parameters except the light generated current did not vary much when the illuminated and dark cell characteristics of the same silicon cell were analyzed using genetic algorithm. The algorithm was used to analyze other types of cells and there was very close match between values generated by genetic algorithm and by another method proposed by Puthanveetil. The algorithm was applied to get back the solar cell parameters from the characteristics of an ideal cell which was generated using the solar cell equation from the solar cell parameters and the reproduction of values was seen to be very good. There was close match between the current-voltage characteristics generated from the parameters obtained by genetic algorithm and the original experimental values. All these point to the adequacy of genetic algorithm to obtain the solar cell parameters.

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