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The Genetic Algorithm is used to extract the parameters of a solar cell from a current-voltage characteristic

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Abstract:

In order to evaluate the performance of a solar cell and to extract the highest amount of output power feasible from the cell, it is essential to determine the characteristics of the solar cell. A computationally based binary-coded genetic algorithm (GA) is proposed in this study for extracting the parameters (I0, Iph, and n) for a single diode solar cell from its current-voltage (I-V) characteristic using the current-voltage characteristic. Utilizing LabVIEW as a programming tool, the technique was developed and tested by applying it to an I-V curve created from the literature and using reported data. It was shown to be effective. Using GA, we were able to acquire values for parameters that were in excellent agreement with previously published values for silicon and plastic solar cells. modify as follows: "After the program's validation, it was used to the extraction of parameters for an experimental I-V characteristic of a 4 x 4 cm2 polycrystalline silicon solar cell measured at less than 900 W/m." The I-V characteristic derived using GA is very similar to the experimental one in all respects.

Introduction

The globe is on the lookout for alternative energy sources to meet today's growing energy demand, and solar photovoltaics (SPV) energy conversion is playing an increasingly important role. It is critical to understand the precise parameters of a solar cell or module in order to run an SPV plant at its greatest capacity. On the other hand, many physical characteristics such as photocurrent (Iph), series resistance (RS), shunt resistance (Rsh), saturation current (I0), and diode ideality factor have a direct impact on the overall performance and conversion efficiency of a solar cell (n). Consequently, precise assessment of such characteristics is constantly necessary, not only for the purposes of cell performance evaluation, but also for the purposes of improving cell design, fabrication process, and quality control [1]. For the extraction of cell parameters, a variety of approaches have been reported in the literature, including polynomial curve fitting [2], Lambert W function [3], particle swarm optimization [4], and pattern search optimization [5.] A binary-coded GA is used in this study to extract cell characteristics from an empirically determined I-V characteristic. The algorithm is computationally based and uses binary codes. In order to retrieve cell parameters, a programme for GA is developed utilising the LabVIEW (laboratory virtual instrument engineering workbench, version 10) programming tool as a development environment. Using the suggested GA, the characteristics of silicon and plastic solar cells are shown to be in excellent agreement with those previously published in the literature [3, 8]. The I-V characteristic of a commercial polycrystalline silicon solar cell derived using GA is also in excellent agreement with the I-V characteristic of an experimental polycrystalline silicon solar cell.

2. THEORY

$$I = I_{ph} - I_0\left[\frac{q(V+IR_s)}{nk_BT} - 1\right] - \frac{V+IR_s}{R_{sh}} \qquad (1)$$

In where I is the output current, Iph is the photocurrent, I0 is the saturation current, Rs is the series resistance, Rsh is the shunt resistance, n is the ideality factor, kB is the Boltzmann constant, and T is the temperature are all given as variables. When it comes to solar cells, the direct extraction of

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parameters from eq. (1) is constrained by the nonlinear I-V relationship and transcendental character of the current equation. Alternative procedures, such as the Newton-Raphson method [6] and the Least Square method [7], have been employed in the past to determine the parameters. Based on data reported in the literature [3, 8], the I-V parameters of silicon and plastic solar cells were calculated in this study. The value of I was determined for the set of different values of V using the Newton-Raphson technique using the GA extracted values of Iph, I0, and n from the synthesised I-V characteristic using the GA extracted values of Iph, I0, and n. As a result, the validity and robustness of the current technique were evaluated using the I-V characteristic. It was necessary to obtain the values of Rs and Rsh from the experimental I-V characteristic of a commercial polycrystalline silicon solar cell in order to derive Iph, I0, and n from the experimental I-V characteristic of the solar cell. The values of Rs and Rsh were obtained by linear regression of selected points on the I-V characteristic near the open circuit and short circuit conditions, respectively. With respect to equation (1), the value of dV/dI under short circuit situation (i.e. I Isc and V 0) yields the value of Rsh. With respect to equation (2),

$$\frac{dV}{dI} = R_{sh} + R_s \approx R_{sh} \qquad (2)$$

And at open circuit condition (i.e. $I = 0$ and $V = V_{oc}$

$$\frac{dV}{dI} = \frac{nk_B T q^{-1}}{I_{sc} + I - V/R_{sh} + nk_B T/(qR_{sh}) + (I + I_{sc})R_s/R_{sh}} +$$

$$+ R_s \approx \frac{nk_B T q^{-1}}{I_{sc} + I - V/R_{sh}} + R_s \qquad (3)$$

3. SOLAR CELL PARAMTERS EXTRACTION

In many ways, Darwin's idea of natural selection and natural evolution served as an inspiration for the Genetic Algorithm. The processes of selection, crossover, and mutation all contribute to the improvement of the fitness of a population in genetic algorithms. In this study, the set of unknown parameters (i.e. solar cell parameters) is defined as X (I0, Iph, and n) for a cell, where X is the number of unknown parameters. These unknown parameters are the members (i.e., individuals) of the population, and they were discovered via the process of continuous evolution through GA. Initially, a huge population (Npop) of sets of solar cell characteristics (i.e., X I0, Iph, and n) is generated via a random sampling procedure. Then, using eq., the computer estimates current using the Newton-Raphson technique for each randomly generated set of solar cell characteristics for each experimental voltage, based on the Newton-Raphson method (1). Then, at each iteration of the genetic algorithm, the estimated currents are compared with the experimental values in order to determine the fitness of the solution. In order to enhance the fitness, the selection operator was used to pick the set of parameters that corresponded to greater fitness, which was then followed by the crossover and mutation operators. As a selection, crossover, and mutation operator, the elimination method, random-point crossover, and single bit flipping were employed in this study, with the elimination method serving as the selection, crossover, and mutation operator. In our examples, the fit-ness function is defined as follows:

$$F(X) = \left\{ \sum_{i=1}^{p} \left[I^{exp}(V_i) - I^{cal}(V_i) \right]^2 \right\} \Big/ p \qquad (4)$$

In this equation, Iexp(Vi) and Ical(Vi) are the experimental and calculated values of current at Vi, respectively, and p is the total number of voltage steps in the I-V characteristic equation. According to eq. (4), a lower value of the fitness function indicates more agreement between the fitted I-V characteristic and the synthetic I-V characteristic and the experimental I-V characteristic.

4. DISCUSSION OF RESULTS AND CONCLUSIONS

The I-V characteristics of a silicon sun cell and a plastic solar cell, respectively, are shown in Figs. 1 and 2, which were calculated and fitted using GA. The values of the reference parameters and the

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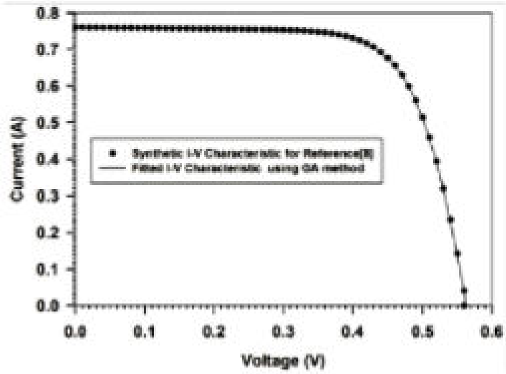
values of the GA-extracted parameters for a silicon solar cell and a plastic solar cell, respectively, are shown in Table 1 and Table 2.



From the Fig. 1 and Fig. 2, it is observed that syn-thetic I-V characteristics exactly overlap on the fitted I-V characteristics obtained using GA. It is also concluded that the parameters extracted by GA are very close to those reported results in references [3, 8] as listed in Table 1 and Table 2 for the silicon solar cell and plastics solar cell respectively.
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3. SOLAR CELL PARAMTERS EXTRACTION

Genetic Algorithm is essentially inspired by Darwin's theory of natural selection and natural evolution. In GA, the fitness of a population is improved by the processes of selection, crossover and mutation. In this work, the set of unknown parameters (i.e. solar cell parameters) are defined as X (I0, Iph and n) for a cell. These un-known parameters are the members (i.e. individuals) of population and were extracted using continuous evolu-tion through GA. Initially, a large population (Npop) of sets of solar cell parameters (i.e. X I0, Iph and n) are created randomly. Then, the program calculates current based on Newton-Raphson method for each randomly generated set of solar cell parameters for each experi-mental voltage using eq.(1).Then, calculated currents are compared with experimental values at every genetic iteration in order to evaluate the fitness of the solution. The set of parameters corresponds to better fitness were selected by selection operator and followed by crossover and mutation operator in order to improve the fitness.
In this work, an elimination method, random-point

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crossover and single bit-flipping were used as a selection, crossover and mutation operator respectively. The fitness function in our cases is defined as,

2
exp
1

Table 1 – Parameters from Ref. [8] and extracted using GA with R_s = 0.0364 Ω and R_{sh} = 53.76 Ω

Silicon solar cell (33 °C)		
Parameters	Ref.[8]	GA extracted values
n	1.4837	1.484
I_0 (μA)	0.3223	0.329
I_{ph} (A)	0.7608	0.761

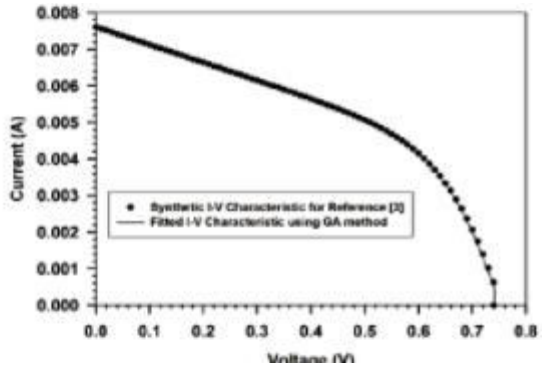

Fig. 2 – Synthetic and fitted I-V characteristic of Plastic solar cell

Table 2 – Parameters from Ref. [3] and extracted using GA with Rs 8.59 and Rsh 197.24

Fig. 2 – Synthetic and fitted I-V characteristic of Plastic solar cell Table 2 – Parameters from Ref. [3] and extracted using GA with Rs 8.59 and Rsh 197.24

As an additional test, GA is used to extract parameters from measured I-V characteristic for a commercial poly crystalline silicon solar cell as shown in Fig. 3. The area of cell is 16 cm^2 and the illuminated I-V characterristic was measured at the light intensity 900 W/m^2 at temperature 35 °C. Table 3 shows the GA-extracted parameters for a poly crystalline silicon solar cell. It is

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Table 3 – GA-extracted parameters for polycrystalline silicon solar cell with fixed parameters Rs = 0.3214 Ohm and Rsh = 61.51 Ohm

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Poly crystalline silicon solar cell (35 °C)	
Parameters	GA extracted values
n	0.894
I_0 (pA)	8.8338
I_{ph} (A)	0.164

It was determined that the measured I-V characteristic is a good match with the fitted I-V characteristic. However, it is found that the fitted I-V characteristic is somewhat out of phase with the measured I-V characteristic around the short-circuit current when the short-circuit current is high. This may be due to the fact that the values of Rs and Rsh were calculated using a linear regression technique, which may have resulted in slightly different values for Rs and Rsh than the actual values for those variables.

5. Conclusion

The ex-traction of cell parameters for synthetic and measured I-V characteristics using a GA-based technique has been shown to be effective. The findings acquired via the use of GA are in excellent agreement with the stated and measured values. Consequently, it is clear that a GA-based software may be a valuable tool for extracting solar cell data, which can then be used to assess the performance of solar PV panels. The linear regression approach was used to predict the series resistance and shunt resistance based on the experimental data. The results were promising. These parameters, on the other hand, may be slightly off from their true values in certain cases. A further refinement in the algorithm is required to extract all solar cell properties, including Rs and Rsh, using genetic evolution in order to overcome this constraint.

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