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A New Technique for Solar Cell Parameters Estimation of The Single-Diode Model

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Abstract. In the current study, an implicit algorithm has been applied to solve the nonlinear equation of a single diode solar cell using several iterations with an initial value of $x_0 = 1$. The proposed algorithm is achieved with the different values of load resistance. The equation based on equivalent circuit of a solar cell and all the determinations are implemented at ambient temperature using MATLAB program. The obtained results of this new method are given, and the absolute errors are investigated.

Keywords: Implicit method; single diode model; parameters; iterations; load resistance.

1. Introduction

Numerical analysis is a science of approximation where numerical methods are used to solve complex and unsolvable problems by analytical methods. In numerical analysis, all aspects of the existing problem are studied numerically, using theoretical development, understanding of numerical methods, and attempting to implement them in the form of computer programs. These programs are characterized by a high level of confidence and effectiveness. Common interests and perspectives among them, which include mathematical methods of numerical analysis is based on the principle of creating, analyzing, and implementing a number of algorithms to arrive at digital solutions to mathematical problems that are built on a range of constant variations and fluctuations, such as quantitative analysis, or numerical methods [1-8]. Photovoltaic have been used in space for a long time in 1958, when Van Gard was launched, with 6 photovoltaic cells on its surface. While other batteries stopped working shortly after the ship was launched, since then, solar photovoltaic cells have been widely used in space and their use has helped to increase the length of spaceflight. For spaceships and high reliability relatively high yield. The main idea is to reproduction electrical energy by means of photovoltaic cells, which form solar cells. Several kinds of solar cells are synthesized based on the material used and fabrication technique such as silicon, organic and inorganic solar cells [9-55]. This study proposes a method for estimating parameters in single diode model of a solar cell equation based on implicit algorithm (IM) and explains the performance of this estimation method. It is organized as follows: Section two characterizing the analytical model of a single-diode design of the solar cell; Section three establishing the root finding Implicit algorithm (IM); Section four results and discussion; Section five conclusions of the acquired results.

2. Characteristics of Single-Diode Solar Cells Equation

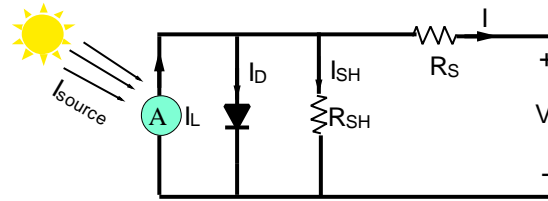A photo voltaic cell (equivalent circuit) is shown in Figure 1.

Figure 1. Single-diode electrical equivalent circuit model of a solar cell.

By applying Kiechoff's current law for the circuit, the equation of this equivalent circuit is given by

$$I = I_{ph} - I_D \tag{1}$$

$$I_D = I_0 \left(e^{\frac{-V_{pv}}{nV_T}} - 1 \right) \tag{2}$$

$$I = I_{ph} - I_0 \left(e^{\frac{-V_{pv}}{mV_T}} - 1 \right) \tag{3}$$

where:

I_{ph} is the photocurrent (A); I_0 is reverse saturation current of the diode (A); I and V_{pv} are the delivered current and voltage, respectively (V); $V_T = \frac{kT}{q} = 0.0259\,V$ is thermic voltage $= 27.5 \cong 26\,mV$ at $(T = 25\,^oC$ Air-Mass $= 1.5)$; m is the recombination factor closeness to an ideal diode $(1 < m < 2)$, k is Boltzmann constant $= 1.38 \times 10^{-23} J/K$; T is $p-n$ junction temperature (K); q is the electron charge $= 1.6 \times 10^{-19}\,C$.

$$I_{ph} = I_{source} \tag{4}$$

$$I_D = I_s * \left(e^{\frac{V_D}{nV_T}} - 1 \right) \tag{5}$$

Merge Eq. 4 in Eq. 5 we get

$$(I_{source}) - 10^{-12} \left(e^{\frac{-V}{1.2*0.026}} - 1 \right) = \frac{V}{R} \tag{6}$$

where: I_s reverse saturation current $= 10^{-12} A$. In parallel, $V_D = V_{pv} = V$

According to Eq. 6 one can calculate V of the cell numerically based on the first derivative of this equation.

3. Implicit Method (IM)

The following algorithm suggestion for solving Eq. 5 by using NRM

Initial approximate solution $x_0 = 1$, tolerance ε,

$$\acute{f}(x_{n+1}) = x_n - \frac{f(x_n)}{\acute{f}(x_n)} \text{ for } n = 0, 1, 2, \dots.$$

$$x_{n+1} = x_n - \frac{2 \times f(x_n)}{\acute{f}(x_{n+1}) + \acute{f}(x_n)}$$

In the implicit formula, the indefinite integral involved in the following equation

$$f(x) = f(x_n) + \int_{x_n}^{x} \acute{f}(\lambda)\, d\lambda \tag{7}$$

Is approximated by the trapezoidal rule to obtain

$$\int_{x_n}^{x} \acute{f}(\lambda)\, d\lambda = \frac{x-x_n}{2}\left[\acute{f}(x_n) + \acute{f}(x)\right] \tag{8}$$

Put Eq. 8 into Eq. 7 yields

$$f(x) = f(x_n) + \frac{x-x_n}{2}\left[\acute{f}(x_n) + \acute{f}(x)\right] \tag{9}$$

Since $f(x) = 0$, therefore Eq. 9 can be written as

$$x = x_n - \frac{2 \times f(x_n)}{\left[\acute{f}(x_n) + \acute{f}(x)\right]} \tag{10}$$

Take the next iterative point, that is put $x = x_{n+1}$ to obtain

$$f(x_{n+1}) = f(x_n) + \frac{1}{2}(x_{n+1} - x_n)(\acute{f}(x_n) + \acute{f}(x_{n+1})) \text{ or}$$

$$x_{n+1} = x_n - \frac{2 \times f(x_n)}{\acute{f}(x_{n+1}) + \acute{f}(x_n)} \tag{11}$$

Eq. 11 is an implicit formula, which requires having the derivative of the function at the $(n+1)^{th}$ iterative step to calculate the $(n+1)^{th}$ iterative itself.

Thus, the resulting formula is

$$x_{n+1} = x_n - \frac{2 \times f(x_n)}{\acute{f}(x_{n+1}^{*}) + \acute{f}(x_n)}$$

where: $\acute{f}(x_{n+1}^{*}) = x_n - \frac{f(x_n)}{\acute{f}(x_n)}, \; n = 0, 1, 2, \ldots$ $\tag{12}$

and x_0 is the starting value

4. Results and Discussion

Consider Eq. 6 is modelled in the form single-diode solar cell has obtained the following approximate solutions and the IM are applied with the first initial value x_0. In Table 1, the IM of the solution results (voltage V_{pv}; current I_{pv} and power P_{pv} of the solar cell) are presented and listed in this table when the load resistance $R = 1$.

Table 1 and Figure 3 Illustrate the obtained approximate results when $R = 1$

Table 1. The obtained values using IM.

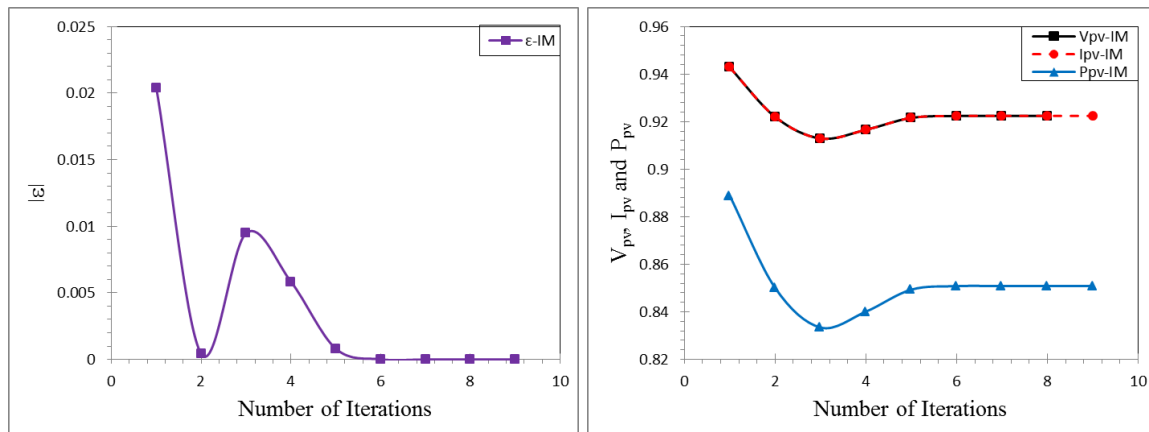| Iterations	V_{pv}-IM	I_{pv}-IM	P_{pv}-IM	ε-IM
1	0.942812862	0.942812862	0.888896093	0.020389728
2	0.922004414	0.922004414	0.85009214	0.00041872
3	0.912933605	0.912933605	0.833447766	0.00948953
4	0.91658633	0.91658633	0.840130499	0.005836805
5	0.921613448	0.921613448	0.849371348	0.000809686
6	0.922412182	0.922412182	0.850844233	1.09529E-05
7	0.922423133	0.922423133	0.850864436	1.91849E-09
8	0.922423135	0.922423135	0.850864439	0.000000000
9	0.922423135	0.922423135	0.850864439	0.000000000

Figure 2. Voltage, current and power of solar cell with the absolute error values.

Table 2 and Figure 3 Illustrate the obtained approximate results when $R = 2$.

Table 2. The obtained values using IM

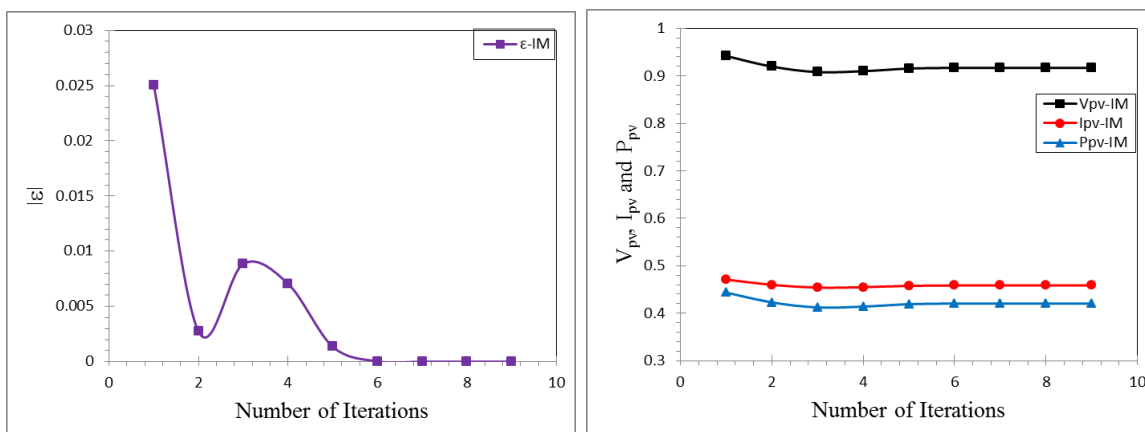| Iterations	V_{pv}-IM	I_{pv}-IM	P_{pv}-IM	ε-IM
1	0.942039802	0.471019901	0.443719494	0.025004419
2	0.919767328	0.459883664	0.422985969	0.002731946
3	0.908172101	0.45408605	0.412388282	0.008863282
4	0.909981837	0.454990918	0.414033472	0.007053546
5	0.915681905	0.457840953	0.419236676	0.001353477
6	0.917003597	0.458501799	0.420447799	3.1785E-05
7	0.917035366	0.458517683	0.420476931	1.62789E-08
8	0.917035382	0.458517691	0.420476946	4.44089E-15
9	0.917035382	0.458517691	0.420476946	0.000000000

Figure 3. Voltage, current and power of solar cell with the absolute error values.

Table 3 and Figure 5 Illustrate the obtained approximate results when $R = 3$.

Table 3. The obtained values using IM.

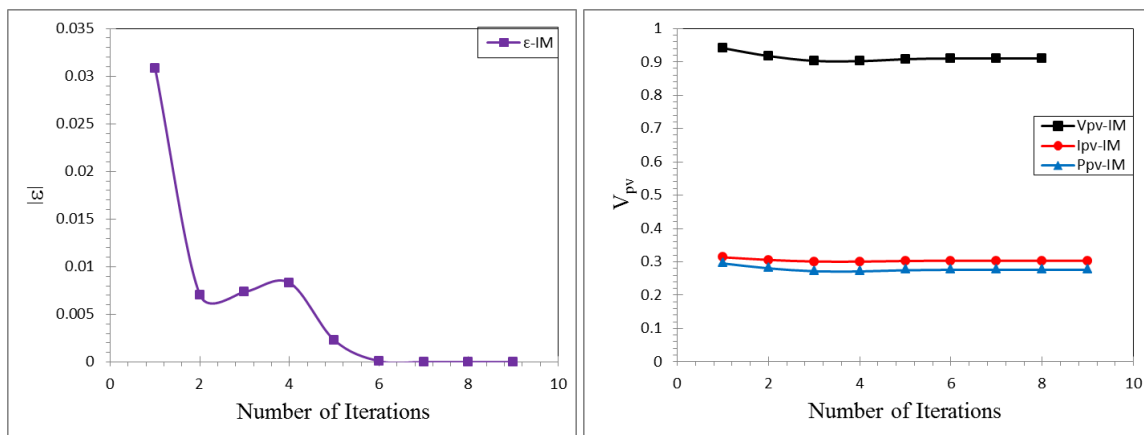| Iterations	V_{pv}-IM	I_{pv}-IM	P_{pv}-IM	ε-IM
1	0.94126616	0.313755387	0.295327328	0.030862786
2	0.917476245	0.305825415	0.280587554	0.007072871
3	0.903018143	0.301006048	0.271813922	0.007385231
4	0.902074754	0.300691585	0.271246287	0.00832862
5	0.90809742	0.30269914	0.274880308	0.002305954
6	0.910304588	0.303434863	0.276218148	9.87862E-05
7	0.910403215	0.303467738	0.276278004	1.59376E-07
8	0.910403374	0.303467791	0.276278101	4.1267E-13
9	0.910403374	0.303467791	0.276278101	0.000000000

Figure 4. Voltage, current and power of solar cell with the absolute error values.

Table 4 and Figure 6 Illustrate the obtained approximate results when $R = 4$.

Table 4. The obtained values using IM.

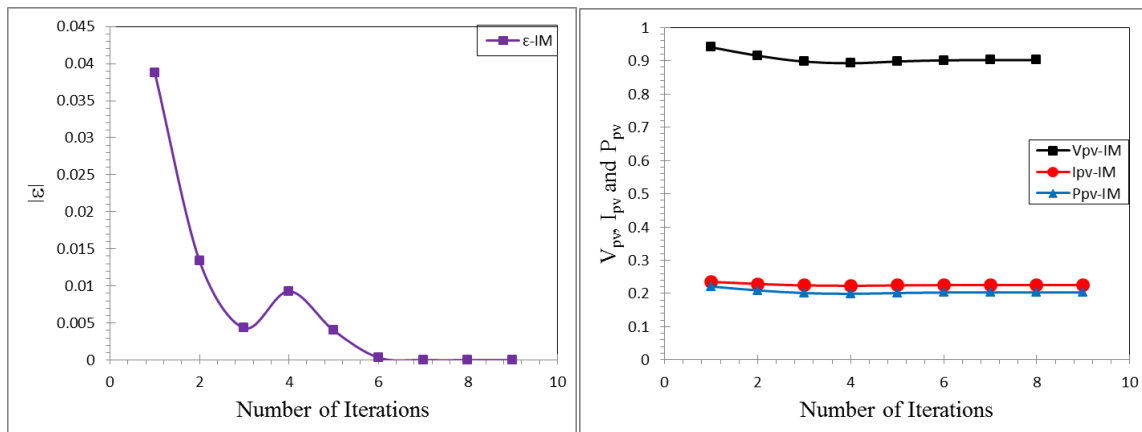| Iterations	V_{pv}-IM	I_{pv}-IM	P_{pv}-IM	ε-IM
1	0.940491937	0.235122984	0.221131271	0.038751335
2	0.9151298	0.22878245	0.209365638	0.013389198
3	0.897428152	0.224357038	0.201344322	0.00431245
4	0.89244529	0.223111323	0.199114649	0.009295312
5	0.897748102	0.224437025	0.201487914	0.0039925
6	0.901401786	0.225350447	0.203131295	0.000338816
7	0.90173867	0.225434667	0.203283157	1.93238E-06
8	0.901740602	0.22543515	0.203284028	6.17006E-11
9	0.901740602	0.22543515	0.203284028	0.000000000

Figure 5. Voltage, current and power of solar cell with the absolute error values.

Table 5 and Figure 6 Illustrate the obtained approximate results when $R = 5$.

Table 5. The obtained values using IM.

| Iterations	V_{pv}-IM	I_{pv}-IM	P_{pv}-IM	ε-IM
1	0.939717132	0.187943426	0.176613658	0.050624417
2	0.912726587	0.182545317	0.166613965	0.023633872
3	0.891352644	0.178270529	0.158901907	0.002259929
4	0.88049295	0.17609859	0.155053567	0.008599764
5	0.882268872	0.176453774	0.155679672	0.006823843
6	0.887741339	0.177548268	0.157616937	0.001351375
7	0.889058854	0.177811771	0.158085129	3.38608E-05
8	0.889092695	0.177818539	0.158097164	1.96857E-08
9	0.889092715	0.177818543	0.158097171	0.000000000
10	0.889092715	0.177818543	0.158097171	0.000000000
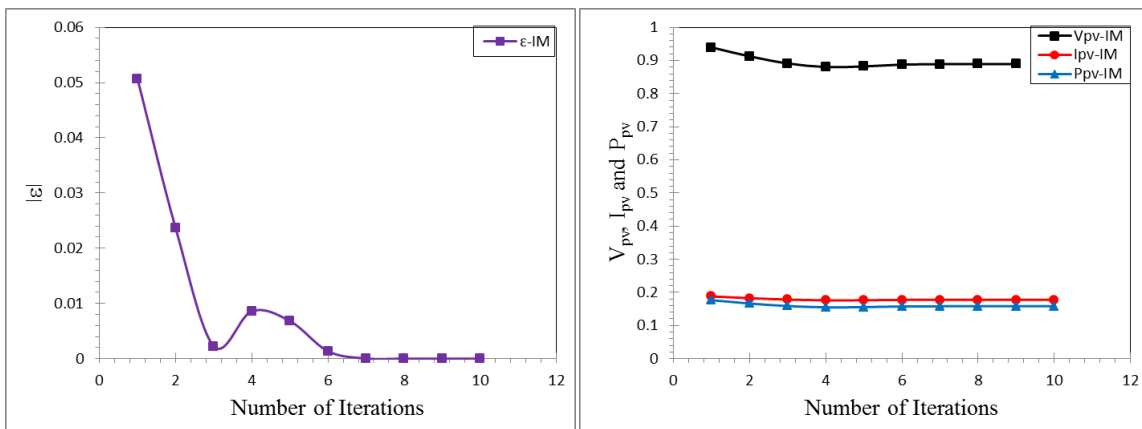
Figure 6. Voltage, current and power of solar cell with the absolute error values.

The obtained solution plot in the (no. of iterations)-ε-plane and the initial-output values prove that the proposed method IM have nine iterations indicated a fast behaviour. Parallel to this feature, it is noticed that the proposed method IM has a behaviour of the solution in the initial value x_0 with small error tolerance. Results from Tables 1-5 are showing that the suggested method IM exhibits low absolute errors after computed iterations which in turn demonstrating its efficiency.

5. Conclusions

This paper presents a new method to calculate the electrical parameter of the solar cell using implicit method. Values acquired from the proposed method IM were found to be sufficient and values for single diode solar cell were determined with fast convergence, more capable to determine these parameters towards establishing the final values.

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