Parameters Estimation of Photovoltaic Model Using Nonlinear Algorithms

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Abstract: Equivalent circuit model has been proposed to describe the solar cell characteristics and commonly used is single diode model. Sundry methods are currently utilized to determine the values of voltage, current, and power of a photovoltaic cell. A new method is suggested to numerically find these values using the popular methods, Newton Raphson method (NRM); Aitken's extrapolation algorithm (AEM) and Three-step method (TSM) at various values of a load resistance R. Equation based on equivalent circuit of a solar cell so all determinations is implemented in a Matlab in ambient temperature. The obtained results of this new method are given and contrasted with NRM.

Keywords: Newton-Raphson method; Aitken's extrapolation algorithm; Three-Step method; load resistance; equivalent circuit; maximum current.

1. Introduction
Numerical analysis is a science of approximation where numerical methods are used to solve complex and unsolvable problems by analytical methods. There are several types of error, the most important of which are: first Data error (DATA) resulting from solving the problems we get from insufficient practical experiments that we take in close proximity to real values in order to facilitate using. Second Method error: resulting from the replacement of a complex mathematical relationship, for example, another relationship simpler. Third Deductible error: The result of considering that the sum of the endless series, Fourth Computer errors: resulting from the computer itself [1-12]. Numerical analysis is used to solve mathematical equations that are difficult to solve. If we have a fourth or fifth degree equation, it can be solved by conventional methods, but it takes a long time. If the equation of the sixth degree or more is difficult to deal with traditionally, and with the advent of computer it has become extremely important in solving such equations, in order to save effort and time, especially in equations that require a large repetition in order to reach the result or solution [13-21]. PV is structured as a semiconductor p - n junction. The surface of this joint is perpendicular to the direction of the solar radiation. The absorption of these rays leads to the emergence or generation of free carriers within the semiconductor (electrons and holes). The electrons accumulate in the n region and the holes in the p region. As a result, the p and n regions show a photoelectric motor that lasts as long as the free-carrier generation takes place, as long as the photovoltaic cell receives light, and acts as an electric generator when exposed to solar radiation. The main idea is to reproduction electrical energy by means of photovoltaic cells, which form solar cells. Semiconductor materials are the main part to fabricate these cells such as silicon. Many kinds of solar cells are fabricated based on the material used and fabrication technique such as organic and inorganic solar cells [22-30].

This study proposes a method for estimating parameters in single diode model of a solar cell equation based on three different algorithms, Newton-Raphson method; Aitken's extrapolation algorithm;
Three-Step method and explains the performance of these estimation methods. Parameters estimation from equivalent circuit of a solar cell reveals that the parameters estimated are highly accurate, indicating that the estimation algorithm has been constructed correctly. Data acquired from the proposed method were found to be more accurate than the other methods studied in all cases. It is organized as follows: section 2 characterizing the analytical model of a single-diode design of the solar cell; Section 3 establishing the root finding Newton Raphson algorithm (NRM); section 4 the Aitken’s extrapolation algorithm (AEM); section 5 Three step algorithm (TSM); section 6 results and discussion; section 7 conclusions of the acquired results.

2. Solar Cells Equation
The simple equivalent electric circuit of a solar cell shown in Figure 1.

![Figure 1. Single-diode electrical equivalent circuit model of a solar cell.](image)

Using Kiechoff’s current law for the current $I$, the equation of this equivalent circuit is given by

$$ I = I_{ph} - I_D $$

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

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

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 $= 27.5 \pm 26\, mV$ at ($T = 25\, ^\circ\, C$ 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$= 1.6 \times 10^{-19}\, C$.

$$ I_{ph} = I_{source} $$

$$ I_D = I_s \left( e^{\frac{V_{pv}}{V_T}} - 1 \right) $$

Merge Eq. 4 in Eq. 5 we get

$$ (I_{source}) - 10^{-12} \left( e^{\frac{V}{1.2+0.026}} - 1 \right) = \frac{R_L}{V} $$

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. Newton Raphson Method
The following algorithm suggestion for solving Eq. 15 by using NRM (see Figure 3)
INPUT initial approximate solution \( x_0 = 1 \), tolerance \( \varepsilon \), maximum number of iterations \( N \).
OUTPUT approximate solution \( x_{n+1} \)
Step 1: Set \( x = 0 \)
Step 2: while \( i \leq x_0 \)
Step 3: Calculate \( x_{n+1} = x_n - \frac{f(x_n)}{f'(x_n)} \) for \( n = 0, 1, 2, ... \)
Step 4: if \( |x_i - x_{i-1}| < \varepsilon \); then OUTPUT \( x_{n+1} \) and stop.
Step 5: Set \( n = n + 1; i = i + 1 \) and go to Step 2.
Step 6: OUTPUT

4. Aitken’s Extrapolation Algorithm (AEM)
Given: \( x_0, \varepsilon = 10^{-9}, N, f, df \)
Step 1: For \( i = 1 \) to 2
Step 2: Calculate \( \bar{E}_n = \bar{E}_{n+2} = \frac{(\bar{E}_{n+2} - \bar{E}_{n+1})^2}{\bar{E}_{n+2} - 2 \cdot \bar{E}_{n+1} + \bar{E}_n} \) for \( n = 0, 1, 2, ... \)
Step 3: If \( f(x_i) = 0 \) or \( f(x_i) < \varepsilon \), then go to Step 6
Step 4: Set \( \bar{E}_{n+1} = \bar{E}_n \)
Step 5: \( n = n + 1, i = i + 1 \), go back to Step 2.
Step 6: OUTPUT \( x_{n+1} \) and stop iteration.

5. Three Step Method (TSM)
Six-order convergences with three steps are investigated. Let \( f(x) = 0 \) is a nonlinear equation, suppose \( x_0 \) as an initial value, so the iteration results \( x_{n+1} \) can be calculated using the following scheme
\[
y_n = x_n - \frac{f(x_n)}{f'(x_n)}, \quad z_n = x_n - \frac{f(x_n) + f(y_n)}{f'(x_n)},
\]
\[
x_{n+1} = z_n - \frac{f(x_n) \times f(y_n)}{f'(y_n) [f(x_n) + f(y_n)] - f(x_n) \times f(y_n)}
\]
Eq. 7 has a six order convergence called a three step method (TSM); the proposed method.

6. Results and Discussion
Consider the Eq. 6 is modeled in the form single-diode solar cell has obtained the following approximate solutions and the TSM are applied with the first initial value (first value from AEM); while the initial value of the NRM is \( x_0 = 1 \), and Aitken’s extrapolation algorithm (AEM) are \( x_0, x_1 \) (the first and second values from AEM). In Table 1 the NRM, AEM and TSM of the solution results (voltage \( V_{pp} \), current \( I_{pp} \) and power \( P_{pp} \) of the solar cell) are presented and listed in this table when the load resistance \( R = 1 \).
Table 1. The obtained values using NRM, AEM and TSM.

| Iterations | $V_{pv}$-NRM | $I_{pv}$-NRM | $P_{pv}$-NRM |
|------------|--------------|--------------|--------------|
| 1          | 1            | 1            | 1            |
| 2          | 0.971416861  | 0.971416861  | 0.943650719  |
| 3          | 0.946732606  | 0.946732606  | 0.896302627  |
| 4          | 0.929865706  | 0.929865706  | 0.864650231  |
| 5          | 0.923247893  | 0.923247893  | 0.852386673  |
| 6          | 0.922434     | 0.922434     | 0.85084484   |
| 7          | 0.922423136  | 0.922423136  | 0.850864443  |
| 8          | 0.922423135  | 0.922423135  | 0.850864439  |
| 9          | 0.922423135  | 0.922423135  | 0.850864439  |

| Iterations | $V_{pv}$-AEM | $I_{pv}$-AEM | $P_{pv}$-AEM | $V_{pv}$-TSM | $I_{pv}$-TSM | $P_{pv}$-TSM |
|------------|--------------|--------------|--------------|--------------|--------------|--------------|
| 1          | 0.947064814  | 0.947064814  | 0.896931761  | 0.922220699  | 0.922220699  | 0.850491018  |
| 2          | 0.930142469  | 0.930142469  | 0.865165012  | 0.921919557  | 0.921919557  | 0.84993567   |
| 3          | 0.923565731  | 0.923565731  | 0.85297366   | 0.922412266  | 0.922412266  | 0.850844388  |
| 4          | 0.922805568  | 0.922805568  | 0.851570116  | 0.92243132   | 0.92243132   | 0.850864435  |
| 5          | 0.922800229  | 0.922800229  | 0.851560264  | 0.92243135   | 0.92243135   | 0.850864439  |
| 6          | 0.922800256  | 0.922800256  | 0.851560312  | 0.92243135   | 0.92243135   | 0.850864439  |
| 7          | 0.922800255  | 0.922800255  | 0.851560311  | 0.92243135   | 0.92243135   | 0.850864439  |

Figure 3 presents the obtained solutions of the study result. In Table 2 the NRM, AEM and TSM 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 $R = 2$.

Table 2. The obtained values using NRM, AEM and TSM.

| Iterations | $V_{pv}$-NRM | $I_{pv}$-NRM | $P_{pv}$-NRM | $V_{pv}$-AEM | $I_{pv}$-AEM | $P_{pv}$-AEM | $V_{pv}$-TSM | $I_{pv}$-TSM | $P_{pv}$-TSM |
|------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|
| 1          | 1            | 0.5          | 0.5          | 0.94570417   | 0.472875208  | 0.447221925  | 0.917699118  | 0.458849559  | 0.421085836  |
| 2          | 0.971030472  | 0.485515236  | 0.471450089  | 0.945421967  | 0.472710983  | 0.446911348  | 0.917053999  | 0.458517691  | 0.420476946  |
| 3          | 0.926834477  | 0.463417238  | 0.429511073  | 0.918438746  | 0.459219373  | 0.421764865  | 0.917053999  | 0.458517691  | 0.420476946  |
| 4          | 0.917066885  | 0.458533442  | 0.42050836   | 0.917053999  | 0.458517691  | 0.420476946  | 0.917053999  | 0.458517691  | 0.420476946  |
| 5          | 0.917035382  | 0.458517691  | 0.420476946  | 0.917035382  | 0.458517691  | 0.420476946  | 0.917035382  | 0.458517691  | 0.420476946  |
| 6          | 0.917035382  | 0.458517691  | 0.420476946  | 0.917035382  | 0.458517691  | 0.420476946  | 0.917035382  | 0.458517691  | 0.420476946  |

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Figure 4 presents the obtained solutions of the study result.

In Table 3 the NRM, AEM and TSM 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 $R = 3$

| Iterations | $V_{pv}$-NRM | $I_{pv}$-NRM | $P_{pv}$-NRM |
|------------|--------------|--------------|--------------|
|            |              |              |              |

**Figure 3.** Obtained solutions of the study result.  **Figure 4.** Obtained solutions of the study result.
Figure 5 presents the obtained solutions of the study result.

In Table 4 the NRM, AEM and TSM 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 $R = 4$.

| Iterations | $V_{pv}$-NRM | $I_{pv}$-AEM | $P_{pv}$-AEM |
|------------|--------------|--------------|--------------|
| 1          | 0.944437431  | 0.314812477  | 0.297320687  |
| 2          | 0.92381119   | 0.307937063  | 0.284475705  |
| 3          | 0.912938978  | 0.304312993  | 0.277819193  |
| 4          | 0.905043344  | 0.303501445  | 0.276339381  |
| 5          | 0.901403374  | 0.303467791  | 0.276278101  |
| 6          | 0.901403374  | 0.303467791  | 0.276278101  |
| 7          | 0.901403374  | 0.303467791  | 0.276278101  |

$V_{pv}$-TSM $I_{pv}$-TSM $P_{pv}$-TSM

Figure 6 presents the obtained solutions of the study result.
In Table 5 the NRM, AEM and TSM of the solution results (voltage $V_{pp}$, current $I_{pp}$ and power $P_{pp}$ of the solar cell) are presented and listed in this table when the load resistance $R = 5$.

**Table 5.** The obtained values using NRM, AEM and TSM.

| Iterations | $V_{pp}$-NRM | $I_{pp}$-NRM | $P_{pp}$-NRM |
|------------|--------------|--------------|--------------|
| 1          | 1            | 0.2          | 0.2          |
| 2          | 0.96986956   | 0.193973912  | 0.188129393  |

**Figure 5.** Obtained solutions of the study result.

**Figure 6.** Obtained solutions of the study result.
3 0.941324731 0.188264946 0.177218455
4 0.916395843 0.183279169 0.167956268
5 0.898535645 0.179707129 0.161473261
6 0.890477009 0.178095402 0.158589861
7 0.889125763 0.177825153 0.158108925
8 0.889092734 0.177818547 0.158097178
9 0.889092715 0.177818543 0.158097171
10 0.889092715 0.177818543 0.158097171

| Iterations | $V_{pu}$-AEM | $I_{pu}$-AEM | $P_{pu}$-AEM | $V_{pu}$-TSM | $I_{pu}$-TSM | $P_{pu}$-TSM |
|------------|--------------|--------------|--------------|--------------|--------------|--------------|
| 1          | 0.941732458  | 0.188346492  | 0.177372004  | 0.900883039  | 0.180176608  | 0.16231805   |
| 2          | 0.916716819  | 0.183343364  | 0.168073945  | 0.889778347  | 0.177955669  | 0.158341101  |
| 3          | 0.898705719  | 0.179741144  | 0.161534394  | 0.8884201    | 0.17768402   | 0.157858055  |
| 4          | 0.890512633  | 0.178102527  | 0.15860255   | 0.889061297  | 0.177812259  | 0.158085998  |
| 5          | 0.889126783  | 0.177825357  | 0.158109287  | 0.889092694  | 0.177818539  | 0.158097164  |
| 6          | 0.889092735  | 0.177818547  | 0.158097178  |              |              |              |
| 7          | 0.889092715  | 0.177818543  | 0.158097171  |              |              |              |

Figure 7 presents the obtained solutions of the study result.
Figure 7. Obtained solutions of the study result.

The obtained solution plot in the (no. of iteration)-$\epsilon$-plane and the initial-output values proves that the proposed method TSM have a six iterations indicated a fast behavior. Parallel to this feature, it is noticed that the proposed method TSM has a behavior of the solution in the initial value $x_0$ has the smallest error tolerance compared with NRM and AEM. A result of tables 1 to 5 is showing that the suggested method TSM have low absolute errors after relatively view iterations are computed and this in turn is demonstrating their efficiency.

7. Conclusion
This paper presents a new method to calculate the electrical parameter of the solar cell using two different methods; NRM and TSM. Values obtained from the proposed method (TSM) were found to be better compared to (NRM). Additionally, values for single diode solar cell were determined with fast convergence, more capable to determine these parameters and establishing towards the final values.

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