Parameters Extraction of a Single-Diode Model of Photovoltaic Cell Using False Position Iterative Method

Mohammed Rasheed\textsuperscript{1}, SuhaShihab\textsuperscript{2}, Osama Alabdali\textsuperscript{1}, Hassan Hadi Hussein\textsuperscript{1}

\textsuperscript{1} Applied Sciences Department, University of Technology, Baghdad, Iraq.
\textsuperscript{2} College of Education for Pure Sciences, University Of Anbar, Al-Anbar, Iraq.

E-mail: 10606@uotechnology.edu.iq

Abstract. In the present work, the nonlinear equation for a single-diode design of a photovoltaic cells is introduced. The mathematical model based on False Position Method (FPM) was used to determine the parameters of the voltage of the solar cell device based on the electrical equivalent circuit. The False Position Method currently presents to demonstrate the non-linear electrical behavior of this device. The proposed method is tested to solve the nonlinear example and the obtained results are used.

Keywords: False position method, iterations, absolute error, load resistance, mathematical model, nonlinear equation

1. Introduction

One of the purpose often practiced in applied mathematics and requires tired arithmetic is the solving of transcendental and algebraic equations (transcendental function). Any equation contains different forces of (\(x\)) or trigonometrical or exponential functions or logarithmic or so-called (transcendental function)-nonlinear equation. In order to find the roots of such equations, there is no theoretical method or direct law for this point. The approximate numerical analysis is needed to obtain the results or the roots of these equations, and the results are uncontrolled and approximated compared to the theoretical results. The method of numerical results generally based on the accuracy of the error reached (degree of accuracy). However, the adopted numerical techniques is the best solution to find the approximate results, especially for nonlinear equations and difficult solved by theoretical techniques. However, there are many numerical techniques to solve these equations. The roots determined in numerical techniques can be calculated roughly by drawing or approximate the calculation when one see a difference in the function's value from negative to positive or vice versa. On the other hand, there is a cut of the function of the \(x\) -axis. Depending on the root's nature, found and numerical techniques adopted many natural choices and the most important of these methods: simple iterative method, Bisection Method, Newton Raphson and False Position Method [1-8]. Solar energy has been utilized to generate electricity in several applications including running of traffic lights, water desalination, street lighting, power plants, and the operation of many electronic apparatus for example calculators, clocks, vehicles, space stations and the operation of satellites [9]. There are many types of photovoltaic cell depending on the components and the materials preparation [10-16] including organic and inorganic solar cells [17-19].
The present work focuses on the proposed and characterized a new technique to give the roots in real case of a non-linear expression of the solar cell (single diode model). It describes according to the following points: in section two describes the characterizing of numerical model of an electric circuit based on photovoltaic cell; in section three establishing the root FPM are included while the discussion and conclusions of the results are listed in sections four and five. The acquired computations are implemented with Matlab program.

2. Properties of Photovoltaic Cell Equation (Single-Diode)

The design of solar cell's circuit scheme for single diode model is shown in Figure 1.

![Figure 1. Solar cell's scheme](image)

Applying Kirchhoff's current law on this equivalent circuit, yields

\[ I = I_{ph} - I_D \]  

(1)

\[ I_D = I_0 \left( \frac{-V_{pp}}{e^{\frac{V}{kT}} - 1} \right) \]  

(2)

\[ I = I_{ph} - I_0 \left( \frac{-V_{pp}}{e^{\frac{V}{kT}} - 1} \right) \]  

(3)

where:

- \( I_{ph} \): the photocurrent (A);
- \( I_0 \): reverse saturation current of the diode in (A);
- \( V_{pp} \) and \( I \) are the delivered voltage and current respectively in (V); the thermic voltage is \( 26mV \), according the equation (3)
- \( V_T = \frac{kT}{q} = 0.0259 V \) at room temperature with air-mass = 1.5;
- \( m(1 < m < 2), k \): Boltzmann constant = \( 1.38 \times 10^{-23} J/K \);
- \( T \): junction's temperature (K);
- \( q \): electron charge equal to \( 1.6 \times 10^{-19} C \) [20].

\[ I_{ph} = I_{source} \]  

(4)

\[ I_D = I_S \times \left( \frac{V_{pp}}{e^{\frac{V}{kT}} - 1} \right) \]  

(5)

Substitute Eq. 4 in Eq. 5 yields

\[ (I_{source}) - 10^{-12} \left( \frac{-V}{e^{\frac{V}{kT}} - 1} \right) = \frac{V}{R} \]  

(6)

where: \( I_S \) reverse saturation current= \( 10^{-12} A \)

Based on Eq. 6, the first derivative of it is needed in order to determine the \( V \) of the diode [21].

3. False Position Method (FPM)

The FPM is the most effective approach to find the root of a nonlinear function. It is a generalized from the Newton-Raphson method and does not require obtaining the derivative of the function. It has a super linear convergence.
For a given \( x_0 \) and \( x_1 \), \( x_1 \) is first point of guess interval, \( x_2 \) is first point of guess interval, \( \varepsilon \) is allowed error in calculation satisfy the equation \( |x_{i+1} - x_i| < \varepsilon \) where \( \varepsilon \) is a very small number and \( f(x) \) is inter function, then
Find \( x_2, x_3, x_4, \ldots, x_n \) using the following expressions
\[
\begin{align*}
x_n &= x_{n-1} - \frac{f(x_{n-1}) \times (x_{n-1} - x_{n-2})}{f(x_{n-1}) - f(x_{n-2})} \\
x_n &= x_{n-1} - \frac{f(x_{n-1}) \times (x_{n-1} - x_{n-2})}{f(x_{n-1}) - f(x_{n-2})}
\end{align*}
\]
Advantages of FPM over other root finding methods are:
Its rate of convergence is faster than bisection method.
FPM is not needed to find the derivative of the function as in Newton-Raphson method and other methods [22].
The algorithm of the FPM can be describe as the following steps
Input \( x_1, x_2 \) and \( \varepsilon \)
Compute \( f(x_1) \) and \( f(x_2) \)
Compute \( x_3 = x_{n-1} - \frac{f(x_{n-1}) \times (x_{n-1} - x_{n-2})}{f(x_{n-1}) - f(x_{n-2})} \)
Test for accuracy of \( x_2 \)
If \( |x_{i+1} - x_i| > \varepsilon \), set \( x_i = x_{n-1} \) and \( x_i = x_2 \)
Go to step 2
Display the required root as \( x_2 \)
The approximate root of equation \( f(x) = 0 \) is the point \( x_{i+1} \) is considered according to the equation \( \sigma = |x_{i+1} - x_i| < \varepsilon \) \( |f(x_{n+1})| < \varepsilon \)
\( |n| \) and the solute value of the function represented by \( f(x_n) \) [23].

4. Results and Discussion
Suppose the equation of the solar cell (single-diode) has obtained the following approximate solutions, and the Bisection method are applied with the two initial values \( x_1 = 0.96 \) and \( x_2 = 1 \).
In Table 1, the False position method (FPM) with the input \( (x_1, x_2) \) and output \( x_2 \) values of the solution results and the absolute error function are obtained in the condition of \( R = 1 \) (load resistance).

| Iterations | \( X_0 \)-FPM | \( x_1 \)-FPM | \( x_{n+1} \)-FPM | \( \varepsilon \)-FPM | \( \sigma \)-FPM |
|------------|---------------|---------------|-----------------|-------------------|----------------|
| 1          | 0.971416861   | 1             | 1.043657103     | 0.116690668       | 0.056758036 |
| 2          | 1             | 1.043657103   | 1.100415139     | 0.173448704       | 0.067513973 |
| 3          | 1.043657103   | 1.100415139   | 1.032901166     | 0.105934731       | 0.008504281 |
| 4          | 1.100415139   | 1.032901166   | 1.024396885     | 0.097430405       | 0.02695166  |
| 5          | 1.032901166   | 1.024396885   | 0.99830172      | 0.071335285       | 0.018181131 |
| 6          | 1.024396885   | 0.99830172    | 0.98012058      | 0.053154154       | 0.019347249 |
| 7          | 0.98012058    | 0.960773339   | 0.944866482     | 0.017900047       | 0.012248262 |
| 8          | 0.98012058    | 0.960773339   | 0.944866482     | 0.017900047       | 0.012248262 |
Figure 2. The results by using FPM method.

In Table 2 the False position method (FPM) with the input \( (x_l, x_u) \) and output \( x_2 \) values of the solution results and the absolute error function are obtained in the condition of \( R = 2 \) (load resistance).

Table 2. The voltage's values of the solar cell with \( \sigma \) and \( \varepsilon \) values using FPM.

| Iterations | \( x_0 \)-FPM | \( x_1 \)-FPM | \( x_2 \)-FPM | \( \varepsilon \)-FPM | \( \sigma \)-FPM |
|------------|---------------|---------------|---------------|-----------------|----------------|
| 1          | 0.971416861   | 1             | 1.044256778   | 0.117290343     | 0.057376293    |
| 2          | 1             | 1.044256778   | 1.101633071   | 0.174666637     | 0.068030557    |
| 3          | 1.044256778   | 1.101633071   | 1.033602514   | 0.106636079     | 0.008450977    |
| 4          | 1.101633071   | 1.033602514   | 1.025151536   | 0.098185102     | 0.026289396    |
| 5          | 1.033602514   | 1.025151536   | 0.998862141   | 0.071895706     | 0.018400919    |
| 6          | 1.025151536   | 0.998862141   | 0.980461222   | 0.053494787     | 0.019848121    |
| 7          | 0.998862141   | 0.980461222   | 0.960613101   | 0.033646666     | 0.016738565    |
| 8          | 0.980461222   | 0.960613101   | 0.943874536   | 0.016908101     | 0.013546447    |
In Table 3, the False position method (FPM) with the input \((x_0, x_1, x_{20})\) and output \(x_2\) values of the solution results and the absolute error function are obtained in the condition of \(R = 3\) (load resistance).

| Iterations | \(X_0\)-FPM | \(X_1\)-FPM | \(x_{20}\)-FPM | \(\varepsilon\)-FPM | \(\sigma\)-FPM |
|------------|-------------|-------------|--------------|----------------|-----------|
| 1          | 0.971417    | 1           | 1.044857     | 0.117891       | 0.057992  |
| 2          | 1           | 1.044857162 | 1.10285      | 0.175883       | 0.068545  |
| 3          | 1.044857    | 1.102849636 | 1.034305     | 0.107383       | 0.008396  |
| 4          | 1.10285     | 1.034304827 | 1.025908     | 0.098942       | 0.026477  |
| 5          | 1.034305    | 1.025908432 | 0.999432     | 0.072465       | 0.018612  |
| 6          | 1.025908    | 0.999431612 | 0.98082      | 0.053853       | 0.020337  |
| 7          | 0.999432    | 0.9808198   | 0.960482     | 0.033516       | 0.017574  |

Figure 3 shows the results using FPM technique.
Figure 4 shows the results using FPM technique.

In Table 4, the False position method (FPM) with the input \((x_0, x_{ul})\) and output \(x_n\) values of the solution results and the absolute error function are obtained in the condition of \(R = 4\) (load resistance).

Table 4. The voltage's values of the solar cell with \(\sigma\) and \(\varepsilon\) values using FPM.

| Iterations | \(X_0\) FPM | \(x_1\) FPM | \(x_n+1\) FPM | \(\varepsilon\) FPM | \(\sigma\) FPM |
|------------|-------------|-------------|---------------|----------------|-------------|
| 1          | 0.971417    | 1           | 1.045458      | 0.118492       | 0.058607    |
| 2          | 1           | 1.045458    | 1.104065      | 0.177098       | 0.069057    |
| 3          | 1.045458    | 1.104065    | 1.035008      | 0.108042       | 0.008341    |
| 4          | 1.104065    | 1.035008    | 1.026667      | 0.099701       | 0.026658    |
| 5          | 1.035008    | 1.026667    | 1.00001       | 0.073043       | 0.018814    |
| 6          | 1.026667    | 1.00001     | 0.981196      | 0.054229       | 0.020815    |
| 7          | 1.00001     | 0.981196    | 0.960381      | 0.033415       | 0.018411    |
Figure 5 shows the results using FPM technique.

In Table 5, the False position method (FPM) with the input \( (x_0, x_u) \) and output \( x_r \) values of the solution results and the absolute error function are obtained in the condition of \( R = 5 \) (load resistance).

Table 5. The voltage's values of the solar cell with \( \sigma \) and \( \epsilon \) values using FPM.

| Iterations | \( x_0 \)-FPM | \( x_1 \)-FPM | \( x_{r+1} \)-FPM | \( \epsilon \)-FPM | \( \sigma \)-FPM |
|------------|---------------|---------------|-----------------|-----------------|----------------|
| 1          | 0.971417      | 1             | 1.04606006      | 0.119093607     | 0.059218795    |
| 2          | 1             | 1.046060063   | 1.10527886      | 0.178312402     | 0.069566765    |
| 3          | 1.04606       | 1.10527858    | 1.03571209      | 0.108745637     | 0.008283741    |
| 4          | 1.105279      | 1.035712093   | 1.02742835      | 0.100461897     | 0.026832002    |
| 5          | 1.035712      | 1.027428352   | 1.00059635      | 0.073629895     | 0.019007453    |
| 6          | 1.027428      | 1.00059635    | 0.9815889       | 0.054622441     | 0.021279435    |
Figure 6 shows the results using FPM technique.

The plot of the number of iteration with ε plane and initial-output values proves that the proposed (FPM) method has thirty iterations indicated a slow behavior. In addition, it is noticed that the suggested technique (FPM) has a behavior of the result in initial values $\mathcal{X}_1 \approx 0.9$ and $\mathcal{X}_\mu = 1$ has tolerance as the smallest error.

In Tables (1-5), the proposed FPM technique is faster than other methods, and it has a less error after view the calculated iterations that depending on the efficiency investigating.

5. Conclusion

In the present work, numerical results of a single-diode (solar cell) in mathematical numerical formula were obtained. The basic advantages of the proposed (FPM) method are accurate approximate solution and a numbers of iterations produce simplicity.
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