Solar PV Modelling and Parameter Extraction Using Iterative Algorithms

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Abstract. In the present work, improvement of Newton's method with high order convergence has been suggested. This improvement is based on Two-Point Bracketing method. The proposed method Inverse Quadratic Interpolation method requires two steps per iteration. By means of the numerical equation of the one diode model of PV equivalent circuit, included five values of R from 1 to 5 ohms (load resistance of the circuit). The results obtained explain that the new suggested technique is easy to use, more accurate and efficient than other numerical methods are presented here.

Keywords: Inverse Quadratic Interpolation method; Two-Point Bracketing method; equivalent circuit; zeroes; single diode.

1. Introduction
Linear equations represent a stable system. Nonlinear equations represent systems of instability or chaos and relate to most systems in nature. They are difficult-to-solve equations, and they lead to complex phenomena and changes, beginning with a small change, but leading to a significant difference in the system at a large level. Nonlinear equations seek to identify the system in this chaos, and enter the theory of chaos in many areas such as recognition of the state of the atmosphere and changes that occur in the solar system in addition to the state of the economy, and these equations receive the attention of engineers, physicists, and mathematicians. The algorithms employed in order to solve non-linear experiments in the many field like physics [1-30].

In this paper, we applied two numerical iterative techniques, Inverse Quadratic Interpolation method (IQIM) and Two-Point Bracketing (TPBM) formulas with the 1 to 5 ohms of R (load resistance) in order to find a root of one diode model of PV circuit which is non-linear function based on Eq. 3. The suggested algorithm IQIM requires five evaluations of the function while the other technique (TPBM) needs 7 evaluation of the function. The following steps are investigate the procedure of this work: section two, three and four demonstrating the analytical model and the root finding of IQIM and TPBM algorithms respectively while; section five and six indicate the numerical problems, discussion and conclusion results respectively.
2. Model of One Diode

KCL Kirchhoff’s law is employed in order to depict the electrical parameters of PV cell scheme [31-49]

\[ I = I_{ph} - I_D \]  where: \[ I_D = I_0 \left( \frac{-V_{pv}}{e^{\frac{V_{pv}}{kT}} - 1} \right) \]  and \[ I = I_{ph} - I_0 \left( \frac{-V_{pv}}{e^{\frac{V_{pv}}{kT}} - 1} \right) \] . \[ V_T = \frac{kT}{q} = 27.5 \text{ mV} \] , \[ k = \frac{1.38 \times 10^{-23}\text{J/K}}{=\text{Boltzmann constant}}, I_0 = \text{reverse saturation current of the diode} = 10^{-12} \text{A}, I_{ph} = \text{the photocurrent}, m \text{ values is between 1 to 2 indicate the recombination factor}, T = p - n \text{ junction temperature}, q = 1.6 \times 10^{-19} \text{C=} \text{electron charge}.

\[ I_{ph} = I_{source} \] , \[ I_D = I_s \left( \frac{V_{ph}}{e^{\frac{V_{ph}}{kT}} - 1} \right) \]  \[ I_{pv} = \frac{V_{pv}}{R} \] , \[ P_{pv} = I_{pv} \times V_{pv} \]  \[ (I_{source}) = 10^{-12} \left( \frac{V}{e^{1.2 + 0.026} - 1} \right) = V / R \]

3. Two Point Bracketing Algorithm (TPBM)

Two-Point Bracketing is a root-finding algorithm, a numerical method for solving nonlinear equations in the form of \( f(x) = 0 \). This method starts with two \( x \) as initial values, initially found by trial-and-error, at which the function \( f(x) \) has opposite signs. Suppose the current bracketing interval is \([a_b, b_k]\), then the new solution convergent to \( c_k \) is obtained by

\[ c_k = \frac{a_k + b_k}{2} \]  \[ \text{Thus } c_k \text{ is between } a_k \text{ and } b_k \].

The tolerance \( \varepsilon = 10^{-6} \); in order to guess the zero of the functions, the following expression has been used

\[ \sigma = |x_{n+1} - x_n| < \varepsilon, |f(x_n)| < \varepsilon \]

4. Inverse Quadratic Interpolation Method (IQIM)

The zero finding technique is Inverse quadratic interpolation for solving equations of the form \( y = w(x) = 0 \). Quadratic interpolation has been used for the approximation the inverse of \( w. IQIM \) required three initial values \( x_0, x_1, x_2 \) and realized by the recurrence relation

\[ x_{n+1} = \frac{w_{n-1}w_n}{w_{n-2}w_n} x_{n-2} + \frac{w_{n-2}w_n}{(w_{n-1} - w_{n-2})(w_{n-1} - w_n)} x_{n-1} + \frac{w_{n-2}w_n}{(w_{n-1} - w_{n-2})(w_n - w_{n-1})} x_n \]

This method can be proved using secant method and the order of convergence is 1.8.

5. Results and Discussion

Now, we appointed two numerical experiments suggested in this paper to solve non-linear functions and compare with each other. The execution of the Two-Point Bracketing method (TPBM) got in the present work for solving non-linear function with the initial estimate \( x_0 = 1 \) and we compare it with Inverse Quadratic Interpolation algorithm (IQIM) with three initial estimate \( x_0, x_1 \) and \( x_3 \). The convergence criteria have been used here 10-9, which means that the distance between two consecutive iterates. We applied Eq. 3 with five experiments based on \( R \) (1 to 5) ohm, which is the load resistance. All accounting are carried out with the algorithm precision introduced in Tables and
Figures 1 to 5. The results indicate that IQIM algorithm needs 5 iterations while TPBM technique need 6 iterations to reach to the convergence which reveals that IQIM is faster than TPBM.

Table 1. The efficiency of the TPBM and IQIM techniques with the value of tolerance.

| Iterations | $\psi$-TPBM | $FP$-TPBM | $\psi$-IQIM | $FP$-IQIM |
|------------|-------------|------------|-------------|------------|
| 1          | 0.959074734| 0.91982434 | 0.922954788| 0.851845541|
| 2          | 0.938299156| 0.88040531 | 0.92243119  | 0.850879300|
| 3          | 0.926556800| 0.85850750 | 0.922423138| 0.850864445|
| 4          | 0.922840947| 0.85163541 | 0.922423135| 0.850864439|
| 5          | 0.922428568| 0.85087446 | 0.922423135| 0.850864439|
| 6          | 0.922423135| 0.85086444 | 0.922423135| 0.85086444 |
| 7          | 0.922423135| 0.85086444 | 0.922423135| 0.85086444 |

Table 2. The efficiency of the TPBM and IQIM techniques with the value of tolerance.

| Iterations | $\psi$-TPBM | $FP$-TPBM | $\psi$-IQIM | $FP$-IQIM |
|------------|-------------|------------|-------------|------------|
| 1          | 0.958226219| 0.45909874 | 0.917952981| 0.45897649 |
| 2          | 0.936128222| 0.43816802 | 0.917057361| 0.45852868 |
| 3          | 0.922636611| 0.42562915 | 0.917035404| 0.45851770 |
| 4          | 0.917752815| 0.42135115 | 0.917035382| 0.45851769 |
| 5          | 0.917051142| 0.42049139 | 0.917035382| 0.45851769 |
### Table 3. The efficiency of the TPBM and IQIM techniques with the value of tolerance.

| Iterations | $V_{pv}$-TPBM | $I_{pv}$-TPBM | $P_{pv}$-TPBM | $V_{pv}$-IQIM | $I_{pv}$-IQIM | $P_{pv}$-IQIM |
|------------|----------------|----------------|----------------|----------------|----------------|----------------|
| 1          | 0.957364012    | 0.319121337    | 0.305515284    | 0.912063454    | 0.304021151    | 0.277286582    |
| 2          | 0.93389237     | 0.311279746    | 0.29068524     | 0.910468531    | 0.30348951     | 0.276317648    |
| 3          | 0.918236042    | 0.306078681    | 0.281052476    | 0.910403541    | 0.30347847     | 0.276278202    |
| 4          | 0.911689551    | 0.30348132     | 0.276307856    | 0.910403374    | 0.303467791    | 0.276287101    |
| 5          | 0.910452397    | 0.30348132     | 0.276307856    | 0.910403374    | 0.30347847     | 0.276278201    |
| 6          | 0.910403453    | 0.30347818     | 0.276278149    | 0.910403374    | 0.303467791    | 0.276278101    |
| 7          | 0.910403374    | 0.303467791    | 0.276278101    | 0.910403374    | 0.303467791    | 0.276278101    |

### Table 4. The efficiency of the TPBM and IQIM techniques with the value of tolerance.

| Iterations | $ε$-TPBM | $ε$-IQIM |
|------------|----------|----------|
| 1          | 0.046960638 | 0.00166008 |
| 2          | 0.023435863 | 6.51565E-05 |
Figure 3. The number of iterations between TPBM and IQIM algorithms.

Table 4. The efficiency of the TPBM and IQIM techniques with the value of tolerance.

| Iterations | $V_{pv}$-TPBM | $I_{pv}$-TPBM | $P_{pv}$-TPBM | $V_{pv}$-IQIM | $I_{pv}$-IQIM | $P_{pv}$-IQIM |
|------------|---------------|---------------|---------------|---------------|---------------|---------------|
| 1          | 0.956487771   | 0.239121943   | 0.228717214   | 0.904961087   | 0.226240272   | 0.204738642   |
| 2          | 0.931420865   | 0.232855216   | 0.216886207   | 0.901959808   | 0.225489952   | 0.203382874   |
| 3          | 0.913234752   | 0.228308688   | 0.208499428   | 0.901742228   | 0.225435557   | 0.203284761   |
| 4          | 0.9042121     | 0.226053025   | 0.204399881   | 0.901740602   | 0.225435151   | 0.203284028   |
| 5          | 0.901910105   | 0.225477526   | 0.20360459    | 0.901740602   | 0.22543515   | 0.203284028   |
| 6          | 0.901741552   | 0.225435388   | 0.203284457   |               |               |               |
| 7          | 0.901740602   | 0.225435151   | 0.203284028   |               |               |               |

| Iterations | $\varepsilon$-TPBM | $\varepsilon$-IQIM |
|------------|---------------------|---------------------|
| 1          | 0.054747169         | 0.003220485         |
| 2          | 0.029680263         | 0.000219206         |
| 3          | 0.01149415          | 1.62595E-06         |
| 4          | 0.002471498         | 1.49680E-10         |
| 5          | 0.000169503         | 0                   |
| 6          | 9.50442E-07         | 0                   |
| 7          | 0                   | 0                   |
Figure 4. The number of iterations between TPBM and IQIM algorithms.

Table 5. The efficiency of the TPBM and IQIM techniques with the value of tolerance.

| Iterations | $V_{pu}$-TPBM       | $I_{pu}$-TPBM       | $P_{pu}$-TPBM       | $V_{pu}$-IQIM       | $I_{pu}$-IQIM       | $P_{pu}$-IQIM       |
|------------|---------------------|---------------------|---------------------|---------------------|---------------------|---------------------|
| 1          | 0.955597145         | 0.191119429         | 0.182633181         | 0.896134809         | 0.179226962         | 0.160611519         |
| 2          | 0.928860287         | 0.185772057         | 0.172556287         | 0.890013457         | 0.17802691         | 0.158424791         |
| 3          | 0.907465744         | 0.18193149          | 0.164988155         | 0.889116273         | 0.177823255         | 0.15810555          |
| 4          | 0.894506327         | 0.178901265         | 0.160028314         | 0.88909274          | 0.177818548         | 0.15809718          |
| 5          | 0.889801386         | 0.177960277         | 0.158349301         | 0.889092715         | 0.177818543         | 0.158097171         |
| 6          | 0.889109249         | 0.17782185          | 0.158103051         | 0.889092715         | 0.177818543         | 0.158097171         |
| 7          | 0.889092724         | 0.177818545         | 0.158097174         | 0.889092715         | 0.177818543         | 0.158097171         |

| Iterations | $\epsilon$-TPBM     | $\epsilon$-IQIM     |
|------------|---------------------|---------------------|
| 1          | 0.066504431         | 0.007042094         |
| 2          | 0.039767572         | 0.000920742         |
| 3          | 0.018373029         | 2.35586E-05         |
| 4          | 0.005413612         | 2.35618E-08         |
| 5          | 0.000708671         | 0                 |
| 6          | 1.65338E-05         | 0                 |
| 7          | 9.59537E-09         | 0                 |
| 8          | 0                   | 0                 |
Figure 5. The number of iterations between TPBM and IQIM algorithms.

The computational results in Figures and Tables from 1 to 5 with R values varies from 1 to 5 ohms respectively, observe that TPBM algorithm comparable with IQIM algorithm for all the cases gives better results in terms of the function evaluation. The algorithm IQIM established in this paper has less number of computational functions than RFM, then the computing time is reduced and the IQIM technique is faster.

6. Conclusion
In this paper, based on Newton's and two-point bracketing algorithms, we obtain further modification of the algorithm to acquire higher order convergence iterative algorithm. Many examples reveal that the suggested algorithm in this article is more efficient accurate and easy to use because it takes (5) lesser iterations compared with other algorithm (7) and realizes better than common and classical Newton's algorithm and some other methods.

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