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Research Article

Analysis of Mathematical Modeling of PV Cell with Numerical Algorithm

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Abstract: In this paper, we exhibit two multi steps iterative algorithms for solving nonlinear equation. These two techniques are free from second derivative and per iteration; they only need six evaluations of the single-diode model function for solar cell of it is first derivative. Numerical examples investigate that both of the two techniques are more accurate, efficient and easy to use and more practical than of the two step methods. The absolute error values for all the algorithms have been demonstrated and compared.

***Keywords*:** two-point bracketing algorithm, classic chord algorithm, zeroes, three step method, solar cell

1. Introduction

Numerical analysis is the field of computer science and mathematics that implements, analyzes, and creates, techniques for solving numerically the examples of applied mathematics. Nowadays, based on a single diode model of solar cell several researchers have advanced many iterative techniques for solving nonlinear equations of it. These techniques can be assorted as one-step; two-step and three-step techniques. These techniques have been approached using Newton's method. At the present, many researchers has been displayed that these techniques can be employ to refinement some iterative techniques so as to solve nonlinear problems in the variant fields such as engineering and science [1-18]. We proposed and analyzed some iterative techniques without using second derivatives in order to solve the nonlinear equations of the solar cell (single diode) model using different values of the load resistance. There are many modes progressed on the progression the convergence of Newton's method, in order to attain lesser iterations than it [19-71].

In this paper, a numerical iterative method Two-Point Bracketing algorithm based on Newton's and Classic Chord methods have been performed and demonstrated for solving the zeroes of nonlinear equations. It is described as the following steps: section 2 depicting the analytical sample of a single-diode design of the solar cell; section 3 demonstrate the root finding of Classic Chord method; while in section 4 Two-Point Bracketing algorithm has been described; section 5 results and discussion; section 6 conclusions of the accomplished results.

2. Characteristics of single-diode solar cells equation

In order to develop a clear describe of solar cells, the electrical model of the photovoltaic cell must first be

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clarified. The common model of a photovoltaic cell its representation as an ideal current source with a diode connects in parallel as shown in Figure 1.

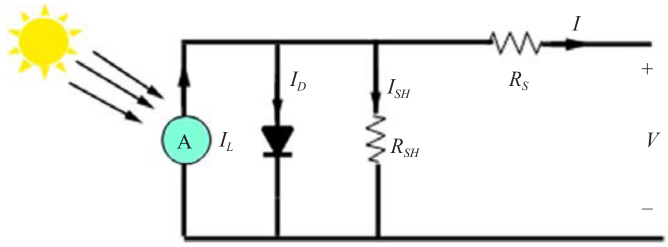


Figure 1. Circuit of a single-diode model

The demonstration of the *PV* cell is illustrated by the nonlinear equations below based on Kiechoff's current law has been applied of the circuit

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

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

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

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 ≅ 26 mV at (T = 25 °C Air-Mass = 1.5); m is the recombination factor closeness to an ideal diode (1 < m < 2), k is Boltzmann constant = 1.38 × 10^{-23} J/K; T is *p-n* junction temperature (K); q is the electron charge = 1.6 × 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

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

$$I_{pv} = \frac{V_{pv}}{R};\ P_{pv} = I_{pv} \times V_{pv} \tag{7}$$

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

The current supplied by the solar cell is influenced by several factors, the most important of which are the temperature, the amount of light falling and the load resistance attached to the cell. According to Eq. 6 one can calculate V of the cell numerically based on the first derivative of this equation.

3. Classic chord method (CCM)

For a given x_0, compute the approximate solution x_{n+1} by the iterative scheme

Step 1: $x_{n+1} = x_n - mf(x_n)$ where $0 < m'f(x_n) < 2$;

Step 2: $x_{n+1} = x_n - m_n f(x_n)$ m change at each iteration;

Step 3: $Z_{n+1} = x_{n+1} - \dfrac{x_{n+1} - x_n}{f(x_{n+1}) - f(x_n)} f(x_{n+1})$.

4. Two-point bracketing method (TPBM)

Step 1: for a given $[a_k, b_k]$.

Step 2: compute c_k as follows $C_k = \dfrac{a_k + b_k}{2}$, c_k is between a_k and b_k.

By assuming that $\varepsilon = 10^{-9}$ as a tolerance; the following criteria is used for calculating the zeros

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

The model problem is to calculate the voltage and the power of the solar cell numerically, this idea is achieved by applying Kiechoff's current law on the circuit of a single-diode model and the obtained results are Eqns. 6 and 7.

5. Results and discussion

Consider the Eq. 6 we start with $x_0 = 1$; the results obtained by classic chord method (CCM) and proposed method (TPBM) is shown in Tables. In Table 1 numerical results of Eqs. 6 and 7 for CCM and TPBM. The results are listed in this table when the load resistance $R = 1$; and Figure 2 exhibits the obtained solutions of the study result.

Table 1. Comparison with CCM and TPBM

Iterations	V_{pv}-CCM	I_{pv}-CCM	P_{pv}-CCM
1	0.956342897	0.956342897	0.914591738
2	0.935676402	0.935676402	0.875490329
3	0.924881651	0.924881651	0.855406068
4	0.922517679	0.922517679	0.851038869
5	0.922423278	0.922423278	0.850864704
6	0.922423135	0.922423135	0.850864439
7	0.922423135	0.922423135	0.850864439

Table 1. (cont.)

Iterations	V_{pv}-TPBM	I_{pv}-TPBM	P_{pv}-TPBM	ε-CCM	ε-TPBM
1	0.94600965	0.94600965	0.894934257	0.033919763	0.023586515
2	0.930279026	0.930279026	0.865419067	0.013253267	0.007855892
3	0.923699665	0.923699665	0.853221071	0.002458516	0.001276531
4	0.922470479	0.922470479	0.850951784	$9.45447E^{-05}$	$4.73443E^{-05}$
5	0.922423206	0.922423206	0.850864572	$1.43773E^{-07}$	$7.18866E^{-08}$
6	0.922423135	0.922423135	0.850864439	$3.33178E^{-13}$	0
7				0	

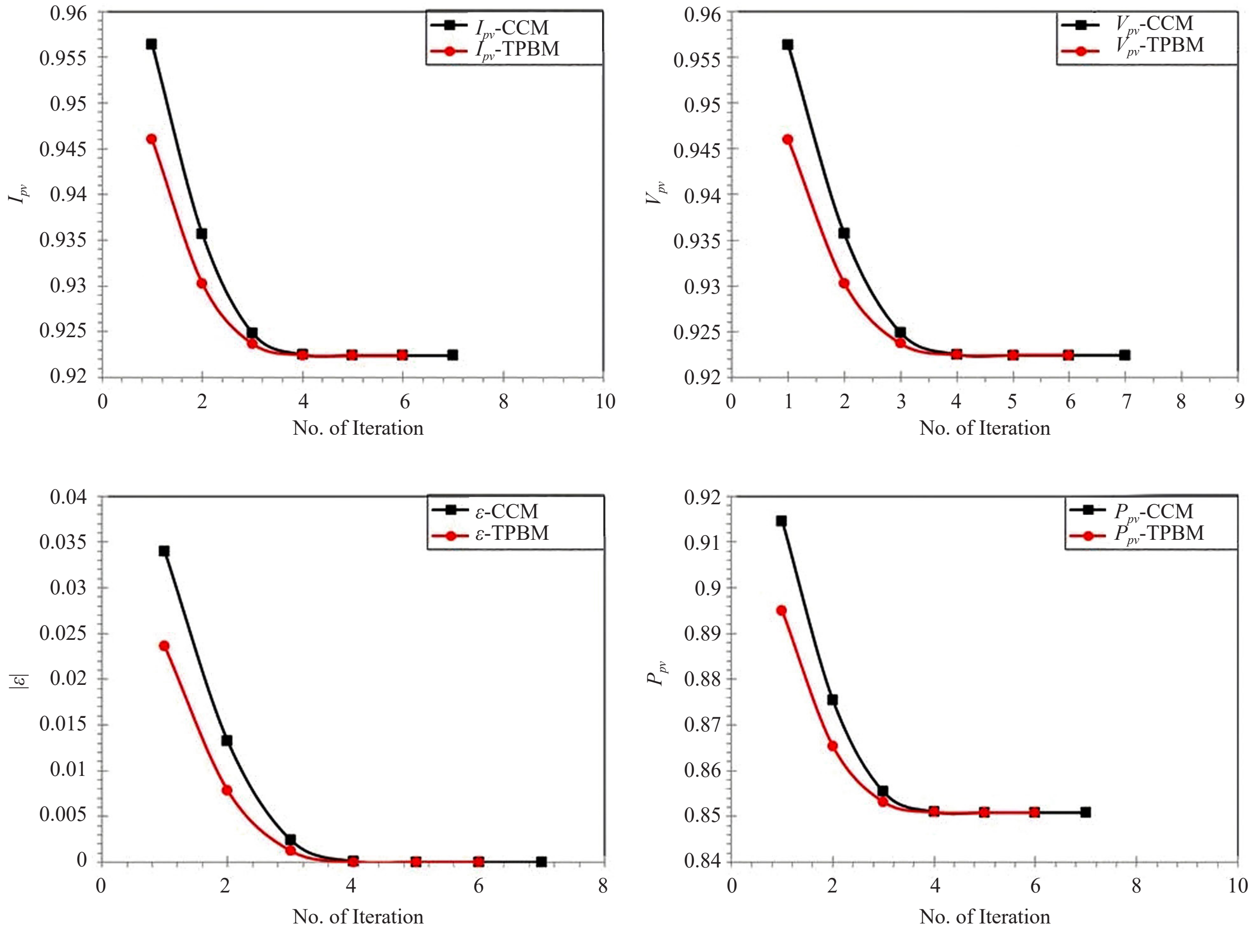


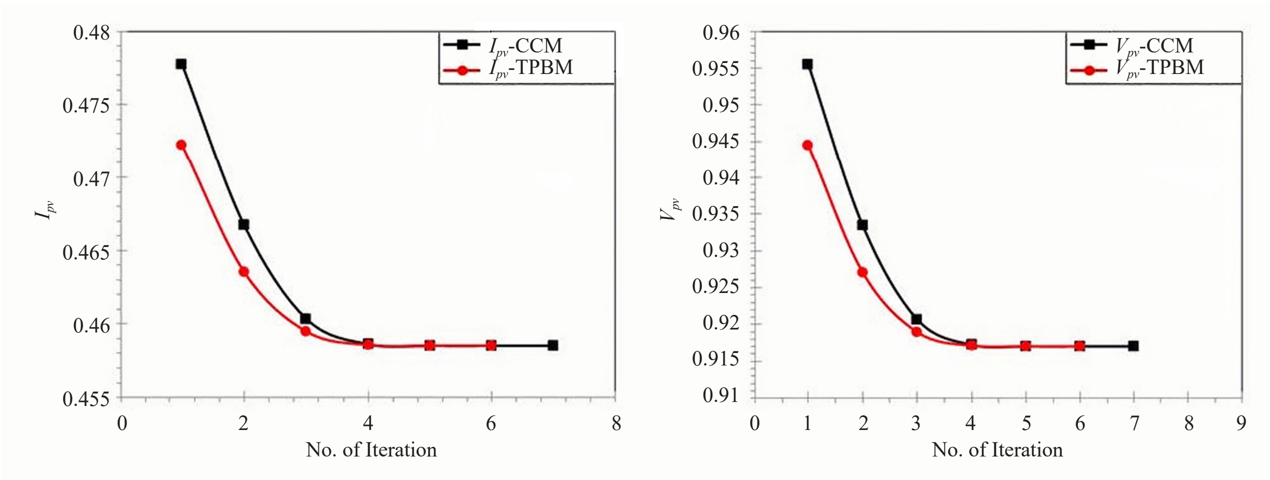
Figure 2. Comparison of numerical and absolute error for Eqs. 6 and 7

In Table 2 numerical results of Eqs. 6 and 7 for CCM and TPBM. The results are listed in this table when the load resistance $R = 2$; and Figure 3 exhibits the obtained solutions of the study result.

Table 2. Comparison with CCM and TPBM

Iterations	V_{pv}-CCM	I_{pv}-CCM	P_{pv}-CCM
1	0.955509809	0.477754904	0.456499497
2	0.933452268	0.466726134	0.435666569
3	0.920708719	0.46035436	0.423852273
4	0.917245199	0.4586226	0.420669378
5	0.917036095	0.458518047	0.4204776
6	0.917035382	0.458517691	0.420476946
7	0.917035382	0.458517691	0.420476946

Iterations	V_{pv}-TPBM	I_{pv}-TPBM	P_{pv}-TPBM	ε-CCM	ε-TPBM
1	0.944481039	0.472240519	0.446022216	0.038474426	0.027445656
2	0.927080494	0.463540247	0.429739121	0.016416886	0.010045111
3	0.918976959	0.45948848	0.422259326	0.003673337	0.001941577
4	0.917140647	0.458570324	0.420573483	0.000209817	0.000105265
5	0.917035739	0.458517869	0.420477273	7.12519E^{-07}	3.5626E^{-07}
6	0.917035382	0.458517691	0.420476946	8.24774E^{-12}	0
7				0	



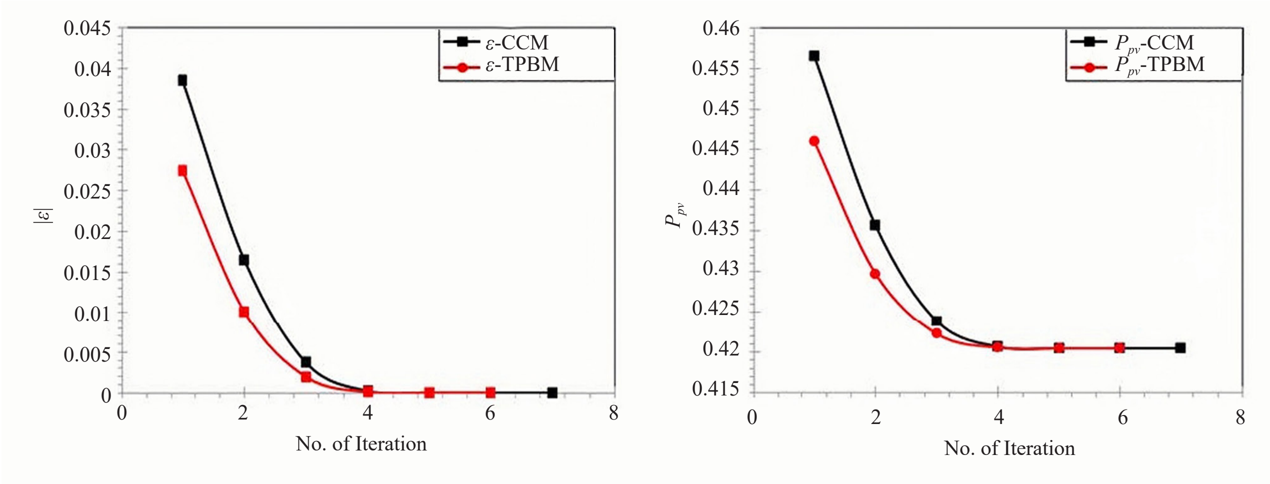


Figure 3. Comparison of numerical and absolute error for Eqs. 6 and 7

In Table 3 numerical results of Eqs. 6 and 7 for CCM and TPBM. The results are listed in this table when the load resistance; R = 3 and Figure 4 exhibits the obtained solutions of the study result.

Table 3. Comparison with CCM and TPBM

Iterations	V_{pv}-CCM	I_{pv}-CCM	P_{pv}-CCM
1	0.954668501	0.318222834	0.303797316
2	0.931130761	0.31037692	0.289001498
3	0.916050375	0.305350125	0.279716096
4	0.91089377	0.303631257	0.27657582
5	0.910407299	0.3034691	0.276280483
6	0.910403374	0.303467791	0.276278101
7	0.910403374	0.303467791	0.276278101

Iterations	V_{pv}-TPBM	I_{pv}-TPBM	P_{pv}-TPBM	ε-CCM	ε-TPBM
1	0.942899631	0.314299877	0.296353238	0.044265127	0.032496257
2	0.923590568	0.307863523	0.284339846	0.020727387	0.013187194
3	0.913472073	0.307863523	0.278143742	0.005647001	0.003068698
4	0.910650534	0.303550178	0.276428132	0.000490396	0.00024716
5	0.910405337	0.303468446	0.276279292	$3.92473E^{-06}$	$1.96237E^{-06}$
6	0.910403374	0.303467791	0.276278101	$2.53289E^{-10}$	0
7				0	

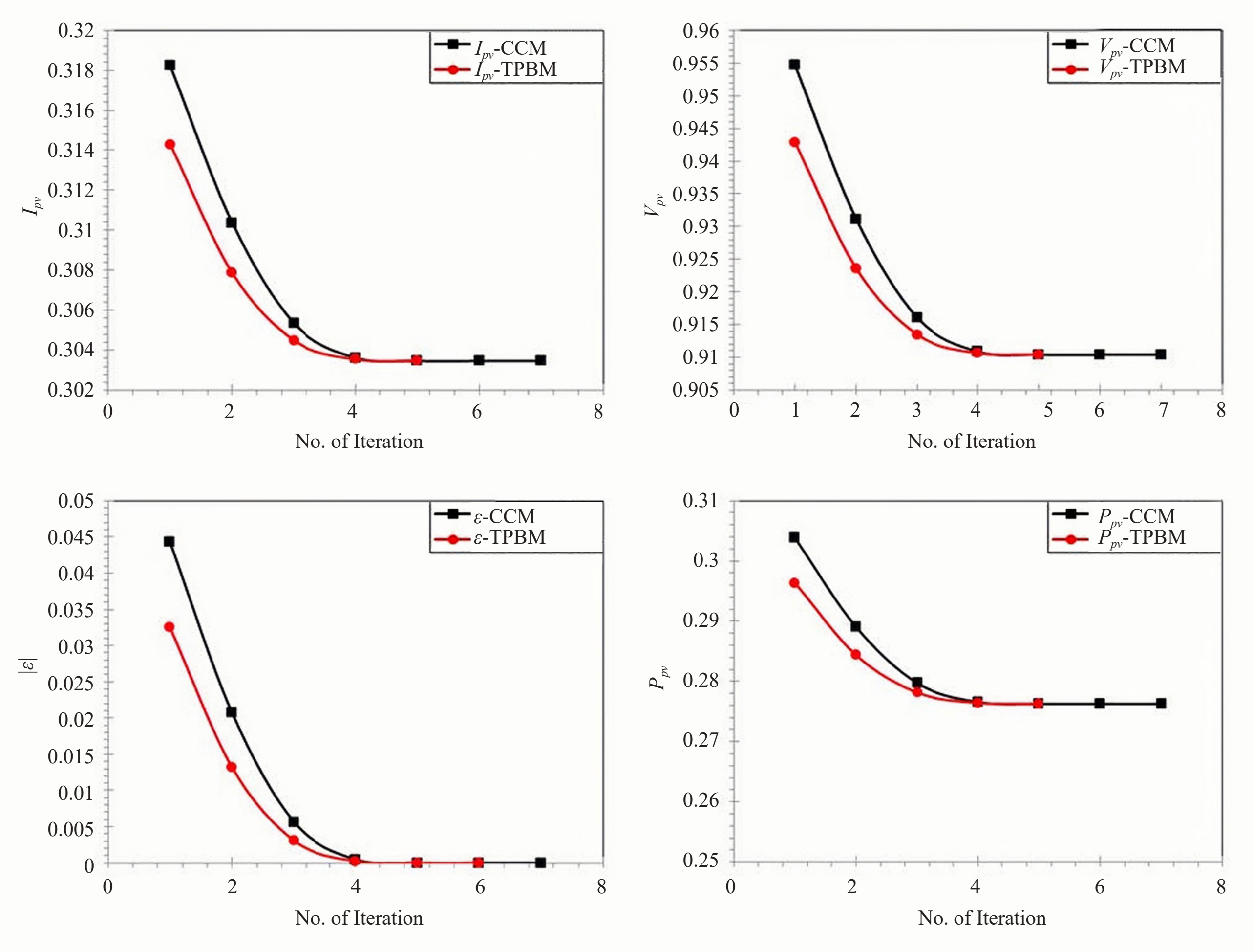


Figure 4. Comparison of numerical and absolute error for Eqs. 6 and 7

In Table 4 numerical results of Eqs. 6 and 7 for CCM and TPBM. The results are listed in this table when the load resistance $R = 4$; and Figure 5 exhibits the obtained solutions of the study result.

Table 4. Comparison with CCM and TPBM

Iterations	V_{pv}-CCM	I_{pv}-CCM	P_{pv}-CCM
1	0.953818908	0.238454727	0.227442627
2	0.928705897	0.232176474	0.215623661
3	0.910811452	0.227702863	0.207394375
4	0.902978861	0.225744715	0.203842706
5	0.901765899	0.225441475	0.203295434
6	0.901740613	0.225435153	0.203284033
7	0.901740602	0.22543515	0.203284028
8	0.901740602	0.22543515	0.203284028

Table 4. (cont.)

Iterations	V_{pv}-TPBM	I_{pv}-TPBM	P_{pv}-TPBM	ε-CCM	ε-TPBM
1	0.941262402	0.235315601	0.221493728	0.052078306	0.0395218
2	0.919758674	0.229939669	0.211489005	0.026965295	0.018018072
3	0.906895156	0.226723789	0.205614706	0.00907085	0.005154554
4	0.90237238	0.225593095	0.203568978	0.001238259	0.000631778
5	0.901753256	0.225438314	0.203289734	$2.52971E^{-05}$	$1.26539E^{-05}$
6	0.901740607	0.225435152	0.203284031	$1.07408E^{-08}$	$5.37042E^{-09}$
7	0.901740602	0.22543515	0.203284028	$1.9984E^{-15}$	0
8				0	

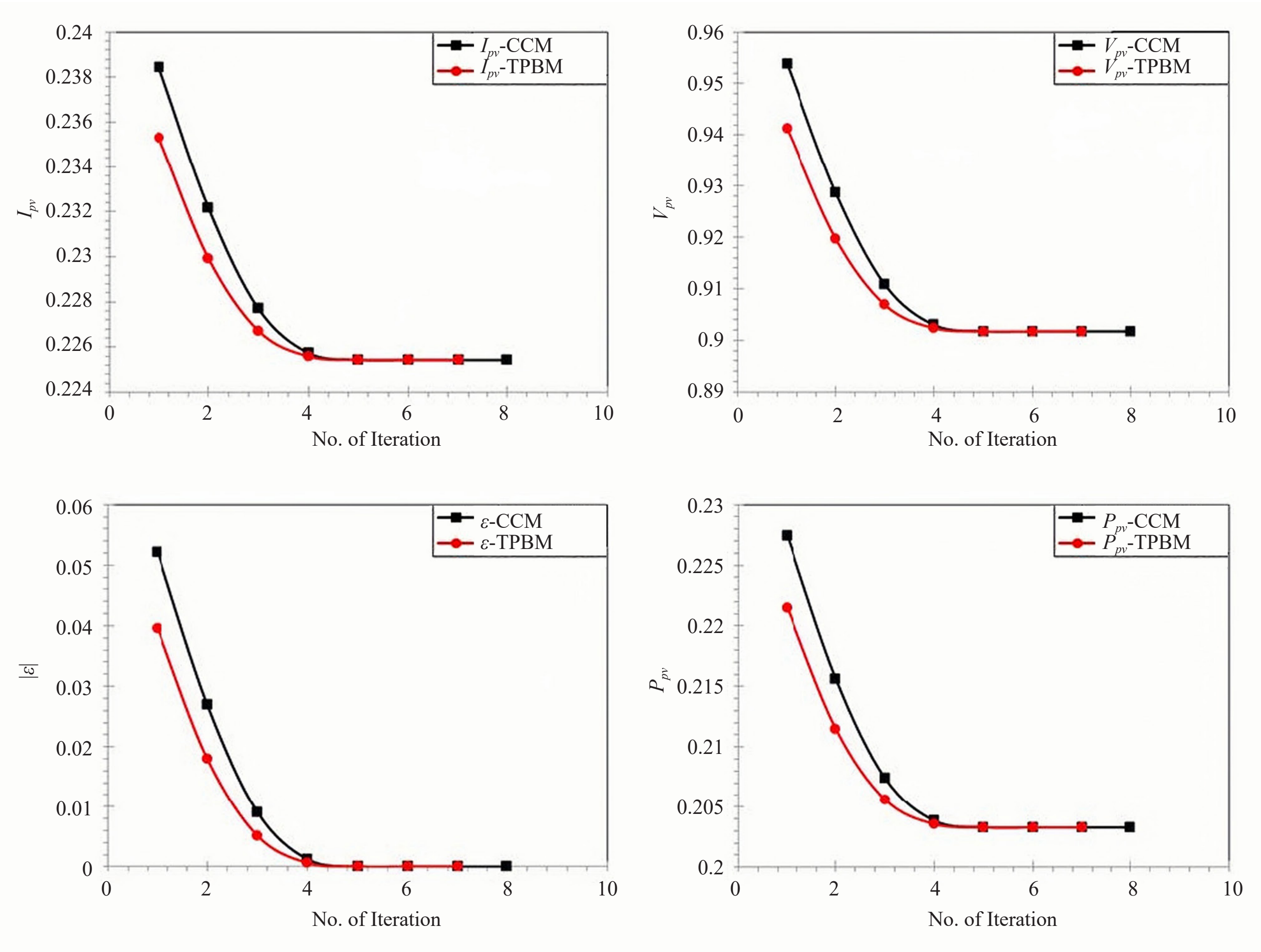


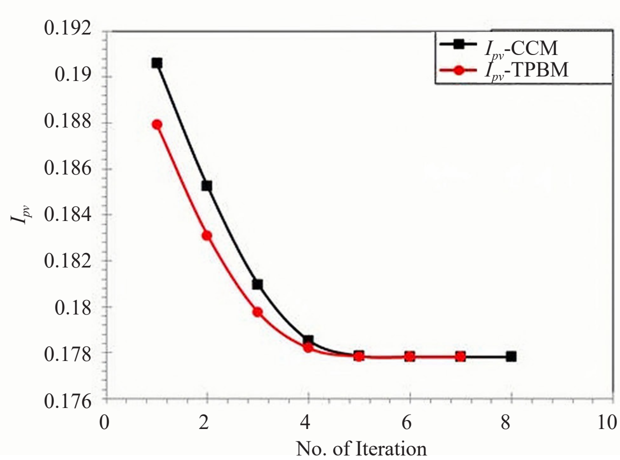
Figure 5. Comparison of numerical and absolute error for Eqs. 6 and 7

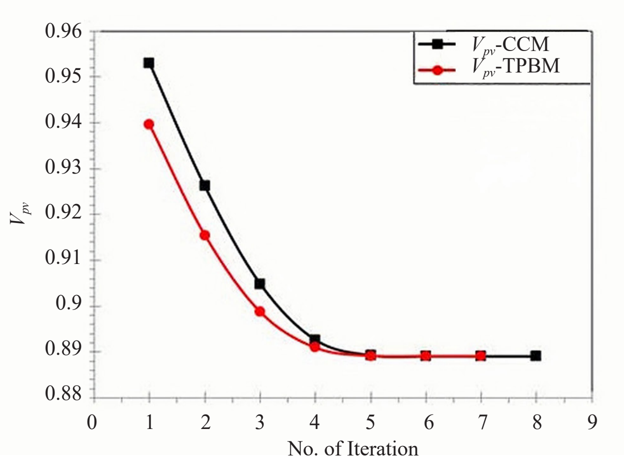
In Table 5 numerical results of Eqs. 6 and 7 for CCM and TPBM. The results are listed in this table when the load resistance R = 5; and Figure 6 exhibits the obtained solutions of the study result.

Table 5. Comparison with CCM and TPBM

Iterations	V_{pv}-CCM	I_{pv}-CCM	P_{pv}-CCM
1	0.952960959	0.190592192	0.181626918
2	0.926171251	0.18523425	0.171558637
3	0.904871952	0.18097439	0.16375865
4	0.89266728	0.178533456	0.159370975
5	0.889306005	0.177861201	0.158173034
6	0.889093511	0.177818702	0.158097454
7	0.889092715	0.177818543	0.158097171
8	0.889092715	0.177818543	0.158097171

Iterations	V_{pv}-TPBM	I_{pv}-TPBM	P_{pv}-TPBM	ε-CCM	ε-TPBM
1	0.939566105	0.187913221	0.176556893	0.063868245	0.05047339
2	0.915521602	0.18310432	0.167635961	0.037078536	0.026428887
3	0.898769616	0.179753923	0.161557365	0.015779238	0.009676902
4	0.890986643	0.178197329	0.15877144	0.003574566	0.001893928
5	0.889199758	0.177839952	0.158135242	0.00021329	0.000107043
6	0.889093113	0.177818623	0.158097313	$7.96312E^{-07}$	$3.98156E^{-07}$
7	0.889092715	0.177818543	0.158097171	$1.11464E^{-11}$	0
8				0	





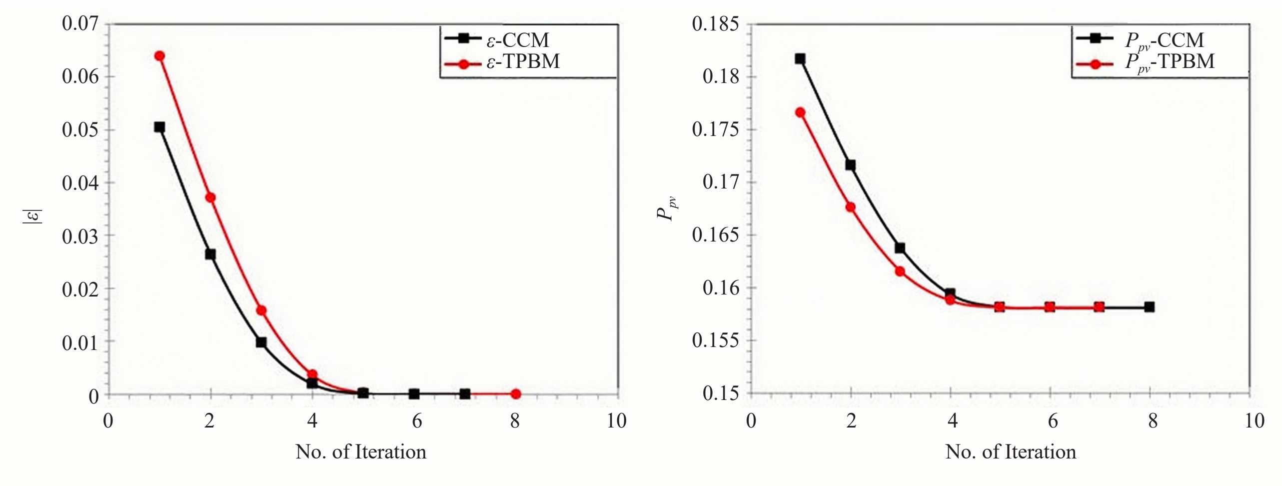


Figure 6. Comparison of numerical and absolute error for Eqs. 6 and 7

Thus from the Tables 1, 2, 3, 4 and 5 the main observations are, first the present algorithm picks a lesser number of iterations than the other method, second the results in the last column of these Tables, shows the absolute error's value is least for of the proposed algorithm. Therefore, the proposed technique is faster than the other method. In addition, only 6 and 7 iterations have been needed when using the proposed methods; "Classical Chord" and "two-point bracketing" respectively, while using Newton method we need nine iterations as indicated in the Tables 1, 2, 3, 4 and 5.

6. Conclusion

In this paper, we exhibit two iterative techniques for solving nonlinear equations of single diode model for solar cell with various values of load resistance. We proved that the acquired results from the proposed method Two-Point Bracketing algorithm are comparable with the Newton's and CCM methods in all cases. Several numerical examples detect that the new proposed method is more accurate, efficient and easy to use with lesser iterations compared with other methods. Numerical computations recorded here have been carried out in MATLAB program the stopping criterion has been taken as $|x_{n+1}-\alpha|+|f(x_{n+1})|<10^{9}$.

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