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Determination of PV Model Parameters Using Bisection and Secant Methods

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ABSTRACT

The mathematical modeling of solar cell device is used to demonstrate the equivalent circuit of single-diode solar cell model operating under environmental conditions. In this work, bisection (BM) and secant (SM) Methods currently exists to demonstrate the non-linear electrical behavior of this device. The proposed method is tested in order to solve non-linear equation of PV cell with various values of load resistance are characterized. Comparisons between these numerical examples have been compared. The main idea of the present work is to calculate the PV parameters numerically using different methods with the comparison between them. The results showed that secant method is the best because it has least iteration to obtain the optimal values of the PV parameters.

MSC. 41A25; 41A35; 41A36

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1. Introduction

Numerical analysis is a guided application that focuses our efforts on searching for computational systems and thus selecting the best computational system according to the speed and accuracy criteria. It is clear that speed is characteristic and that the achievement of accuracy will consume many of our energies, but it reveals a major trend is the existence of error because the information is rarely set as it usually comes through measurements of some kind. The mathematical system makes another error. Thus, the output information contains an error resulting from

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each of these sources. it is a variety of targeted applications that are important because theories contribute to the search for better computational systems [1-7]. Solar energy has been used to generate electricity in many applications including power plants, water desalination, running of traffic lights, street lighting. The methods of numerical analysis have been used to find the parameters of solar cells by many researchers using these methods to find approximate solutions to complex problems that require a long solution to find results by common methods [8-13]. Recently, many organic and inorganic materials have been used in the preparation of solar cells, which play a major role in improving the parameters of solar cells as well as raising the efficiency to a great value [14-48]. For more application of the approximate solutions, see [49-63].

In this paper, two numerical methods BM and SM are discussed and applied on the nonlinear function of PV cell that have one diode and the obtained results are achieved by means of Matlab software. Comparisons between these methods are presented.

2. Equation of Non-linear Solar Cell

Figure 1 shows the equivalent circuit for PV cell

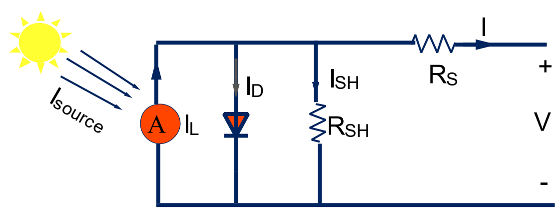

Fig. 1 - An electrical circuit of PV cell.

Kirchhoff's current law (KCL) deals with conversation of current entering and leaving a junction, as indicate in the following equation

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

$$\mathrm{I_D} = \mathrm{I_0} \times (e^{(-V_D/nV_T)} - 1) \tag{2}$$

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

where:

$\mathrm{I_{ph}}$: the photon current (A); $\mathrm{V_T} = \mathrm{KT/q} = 26$ mV: thermic voltage at room temperature and Air-Mass = 1.5, m: the value of the recombination factor is between $(1 < \mathrm{m} < 2)$, q: the electron charge= 1.6×10^{-19} C, k: Boltzmann constant= 1.38×10^{-23}J/K;

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

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

Put Eq. 4 in Eq. 5, yields

$$\mathrm{I_{source}} - 10^{-12}\left(e^{(-V\times q/m\times k\times T)} - 1\right) = \mathrm{V/R} \tag{6}$$

where:

The value of the reverse saturation current ($\mathrm{I_s} = 10^{-12}$) A.

3. Bisection Method

In applied mathematics, the Bisection method is one of the root finding algorithms, in which a period is frequently repeated and a sub-period on which the root is located to improve processing. Although it is very simple and flexible, the method of half-way is relatively slow. If $\mathrm{f(x)} = 0$ is continuous and defined in the period $[a, b]$

where $f(a) \times f(b) < 0$ is different in signal, then at least one of the roots of $f(x)$ is located in the period $[a, b]$. In this case we follow the following algorithm to solve this function

We find the mean values of a, b where the function is defined and let it be x_1 where $x_1 = (a + b) / 2$ (7)

If $f(x_1) = 0$, then x_1 is the root of f(x) and a solution. If the preceding condition is not met, we do the following

If $f(x_1) \times f(b) < 0$, we set $a = x_1$ to approach the solution.

If $f(x_1) \times f(a) < 0$, we put $b = x_1$ to approach the solution.

Repeat steps 1 and 2 until we reach a value where $f(x_i) = 0$ or $f(x_i) \geq P$, where P represents the required resolution in the solution.

The point x_{i+1} can be considered an approximate root of equation $f(x) = 0$ if the condition is met $|x_{i+1} - x_i|$ (8)

where: ε is a very small number.

4. Secant Method

Secant technique requires two initial values to begin. This method can be used for the cases that did not need the first derivative of the function under test, the advantages of secant method over other root finding methods are

- It is rate of convergence is faster than bisection method.
- This method offers rapid convergence and did not require first derivative of the function under examination. The convergence is between linear and quadratic functions.

For a given x_0 and x_1

x_0 is first point of guess interval, x_1 is first point of guess interval

ε is allowed error in calculation satisfy the equation $|x_{i+1} - x_i| < \varepsilon$, where ε is a very small number

f(x) is inter function

Find $x_2, x_3, x_4, \ldots, x_n$ using the following expressions, which indicate the iteration process

$$x_2 = x_1 - f(x_1) \times [(x_1 - x_0)/(f(x_1) - f(x_0)] \tag{9}$$

$$x_3 = x_3 - f(x_2) \times [(x_2 - x_1)/(f(x_2) - f(x_1)] \tag{10}$$

$$\vdots$$

$$x_n = x_{n-1} - f(x_{n-1}) \times [(x_{n-1} - x_{n-2})/(f(x_{n-1}) - f(x_{n-2})] \tag{11}$$

Secant method 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.

The algorithm of the secant method can be describe as following steps

Input x_0, x_1 and ε

Compute $f(x_0)$ and $f(x_1)$

Compute $x_2 = x_1 - f(x_1) \times \frac{x_1 - x_0}{f(x_1) - f(x_0)}$

Test for accuracy of x_2

If $|x_{i+1} - x_i| > \varepsilon$, set $x_0 = x_1$ and $x_1 = x_2$

Goto step 2

Display the required root as x_2

5. Results and Discussion

For Eq. 6, the bisection and secant methods were applied to single variable function using the Matlab ver. 14 software. The results are presented in Table 1 to 6 and Bisection method are applied with the two initial values $x_0 = 0.75$ and $x_1 = 1$. The bisection method (BM) with the input (x_0, x_1) and output x_2 values are applied. Table 1 shows the iteration values obtained using BM, the function in Eq. 6 at the interval [1, 5] depending on the load resistance value converges to 0.916666667 at the 29 second iterations with error level of 0.000000000.

Table 1 - Iteration values for BM with $x_0 = 0.75, x_1 = 1$ and $R = 1$.

Iterations	X_0-BM	x_1-BM	x_2-BM	ε-BM
1	0.75	1	0.875	0.041666667
2	0.875	1	0.9375	0.020833333
3	0.875	0.9375	0.90625	0.010416667
4	0.90625	0.9375	0.921875	0.005208333
5	0.90625	0.921875	0.9140625	0.002604167
6	0.9140625	0.921875	0.91796875	0.001302083
7	0.9140625	0.91796875	0.916015625	0.000651042
8	0.916015625	0.91796875	0.916992188	0.000325521
9	0.916015625	0.916992188	0.916503906	0.00016276
10	0.916503906	0.916992188	0.916748047	$8.13804E^{-05}$
11	0.916503906	0.916748047	0.916625977	$4.06899E^{-05}$
12	0.916625977	0.916748047	0.916687012	$2.03452E^{-05}$
13	0.916625977	0.916687012	0.916656494	$1.01724E^{-05}$
14	0.916656494	0.916687012	0.916671753	$5.08642E^{-06}$
15	0.916656494	0.916671753	0.916664124	$2.54298E^{-06}$
16	0.916664124	0.916671753	0.916667938	$1.27172E^{-06}$
17	0.916664124	0.916667938	0.916666031	$6.35628E^{-07}$
18	0.916666031	0.916667938	0.916666985	$3.18047E^{-07}$
19	0.916666031	0.916666985	0.916666508	$1.5879E^{-07}$
20	0.916666508	0.916666985	0.916666746	$7.96281E^{-08}$
21	0.916666508	0.916666746	0.916666627	$3.95812E^{-08}$
22	0.916666627	0.916666746	0.916666687	$2.00234E^{-08}$
23	0.916666627	0.916666687	0.916666657	$9.77889E^{-09}$
24	0.916666657	0.916666687	0.916666672	$5.12227E^{-09}$
25	0.916666657	0.916666672	0.916666664	$2.32831E^{-09}$
26	0.916666664	0.916666672	0.916666668	$1.39698E^{-09}$
27	0.916666664	0.916666668	0.916666666	$4.65661E^{-10}$
28	0.916666666	0.916666668	0.916666667	$4.65661E^{-10}$
29	0.916666666	0.916666667	0.916666667	0.000000000

Figure 2 shows the result of V_{pv}, I_{pv} and P_{pv} using BM.

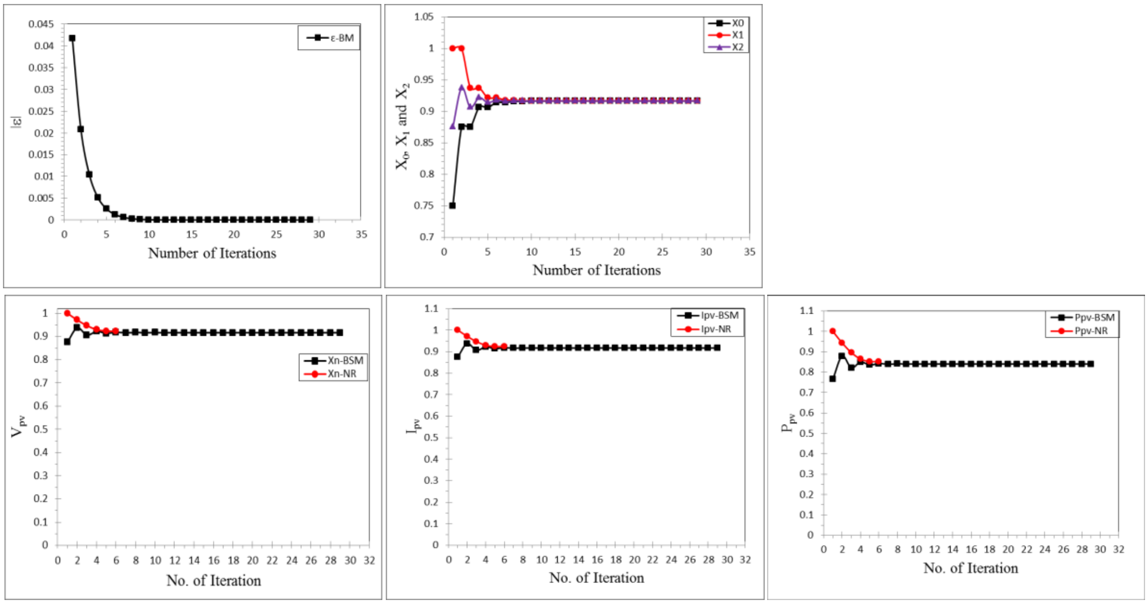

Fig. 2 – Applying BM on Eq. 6.

Table 2 revealed that with $\mathrm{R} = 1$, the function of Eq. 6 converges to 0.926966435 at the 24 second iterations with error level of 0.000000000.

Table 2 - Iteration values for SM with $x_0 = 0.75$, $x_1 = 1$ and $R = 1$.

Iterations	X_0-BM	x_1-BM	x_2-BM	ε-BM
1	0.75	1	1.229943902	0.302977467
2	1	1.229943902	1.460020525	0.53305409
3	1.229943902	1.460020525	1.229799516	0.302833081
4	1.460020525	1.229799516	1.229655707	0.302689272
5	1.229799516	1.229655707	1.198529262	0.271562827
6	1.229655707	1.198529262	1.180349361	0.253382926
7	1.198529262	1.180349361	1.157367591	0.230401156
8	1.180349361	1.157367591	1.136272043	0.209305608
9	1.157367591	1.136272043	1.114463807	0.187497373
10	1.136272043	1.114463807	1.092948986	0.165982551
11	1.114463807	1.092948986	1.071385768	0.144419333
12	1.092948986	1.071385768	1.049946683	0.122980248
13	1.071385768	1.049946683	1.028669416	0.101702981
14	1.049946683	1.028669416	1.007743748	0.080777314
15	1.028669416	1.007743748	0.987490106	0.060523671
16	1.007743748	0.987490106	0.968513994	0.041547559
17	0.987490106	0.968513994	0.951831374	0.024864939
18	0.968513994	0.951831374	0.938868709	0.011902274
19	0.951831374	0.938868709	0.930887202	0.003920767
20	0.938868709	0.930887202	0.927653982	0.000687548
21	0.930887202	0.927653982	0.927008582	4.21471 e-05
22	0.927653982	0.927008582	0.926966898	4.62584 e-07
23	0.927008582	0.926966898	0.926966435	3.12371 e-10
24	0.926966898	0.926966435	0.926966435	0.000000000

Figure 3 shows the result of V_{pv}, I_{pv} and P_{pv} using SM.

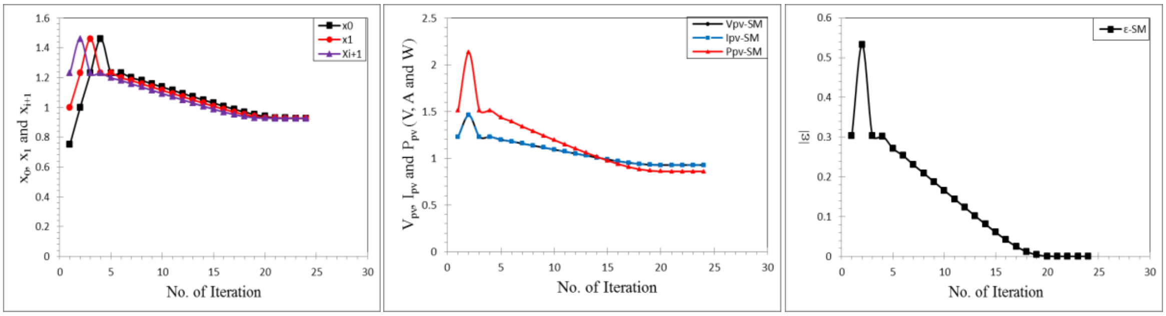

Fig. 3 - Applying SM on Eq. 6 with R = 1.

Table 3 indicated that with R = 2, the function of Eq. 6 converges to 0.926966435 at the 25 second iterations with error level of 0.000000000.

Table 3 - Iteration values for SM with $x_0 = 0.75$, $x_1 = 1$ and R = 2.

Iterations	X_0-BM	x_1-BM	x_2-BM	ε-BM
1	0.75	1	1.233906933	0.306940498
2	1	1.233906933	1.467934322	0.540967888
3	1.233906933	1.467934322	1.233777543	0.306811108
4	1.467934322	1.233777543	1.233648619	0.306682184
5	1.233777543	1.233648619	1.202514365	0.27554793
6	1.233648619	1.202514365	1.184336508	0.257370073
7	1.202514365	1.184336508	1.161352537	0.234386102
8	1.184336508	1.161352537	1.140255166	0.213288731
9	1.161352537	1.140255166	1.118444803	0.191478368
10	1.140255166	1.118444803	1.096905209	0.169938774
11	1.118444803	1.096905209	1.075338905	0.14837247
12	1.096905209	1.075338905	1.05387584	0.126909405
13	1.075338905	1.05387584	1.032557848	0.105591413
14	1.05387584	1.032557848	1.01154953	0.084583095
15	1.032557848	1.01154953	0.991137118	0.064170683
16	1.01154953	0.991137118	0.971864036	0.044897601
17	0.991137118	0.971864036	0.954662475	0.02769604
18	0.971864036	0.954662475	0.940902506	0.013936071
19	0.954662475	0.940902506	0.931959768	0.004993333
20	0.940902506	0.931959768	0.927975254	0.001008819
21	0.931959768	0.927975254	0.927044608	$7.81736e^{-05}$
22	0.927975254	0.927044608	0.926967691	$1.2565e^{-06}$
23	0.927044608	0.926967691	0.926966436	$1.57345e^{-09}$
24	0.926967691	0.926966436	0.926966435	$3.16414e^{-14}$
25	0.926966436	0.926966435	0.926966435	0.000000000

Figure 4 shows the result of V_{pv}, I_{pv} and P_{pv} using SM

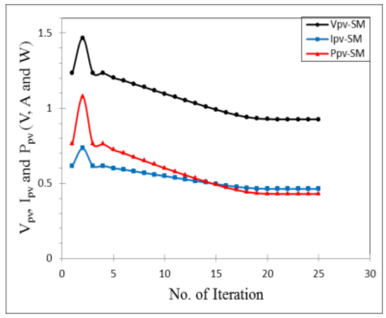

Fig. 4 - Applying SM on Eq. 6 with R = 2.

Table 4 presented that with R = 3, the function of Eq. 6 converges to 0.926966435 at the 25 second iterations with error level of 0.000000000.

Table 4 - Iteration values for SM with $x_0 = 0.75, x_1 = 1$ and $R = 3$.

Iterations	X_0-BM	x_1-BM	x_2-BM	ε-BM
1	0.75	1	1.237902148	0.310935713
2	1	1.237902148	1.475913475	0.54894704
3	1.237902148	1.475913475	1.237786337	0.310819902
4	1.475913475	1.237786337	1.237670899	0.310704464
5	1.237786337	1.237670899	1.206529598	0.279563163
6	1.237670899	1.206529598	1.188353633	0.261387198
7	1.206529598	1.188353633	1.165367766	0.238401331
8	1.188353633	1.165367766	1.144268928	0.217302494
9	1.165367766	1.144268928	1.122454336	0.195487901
10	1.144268928	1.122454336	1.100905523	0.173939088
11	1.122454336	1.100905523	1.079331536	0.152365101
12	1.100905523	1.079331536	1.057849044	0.130882609
13	1.079331536	1.057849044	1.036494063	0.109527628
14	1.057849044	1.036494063	1.015412285	0.08844585
15	1.036494063	1.015412285	0.994857538	0.067891103
16	1.015412285	0.994857538	0.975316296	0.048349861
17	0.994857538	0.975316296	0.957638563	0.030672128
18	0.975316296	0.957638563	0.943124392	0.016157957
19	0.957638563	0.943124392	0.933219572	0.006253137
20	0.943124392	0.933219572	0.928405135	0.0014387
21	0.933219572	0.928405135	0.927104795	0.00013836
22	0.928405135	0.927104795	0.926969598	$3.16321e^{-06}$
23	0.927104795	0.926969598	0.926966442	$7.0085e^{-09}$
24	0.926969598	0.926966442	0.926966435	$3.55382e^{-13}$
25	0.926966442	0.926966435	0.926966435	0.000000000

Figure 5 shows the result of V_{pv}, I_{pv} and P_{pv} using SM.

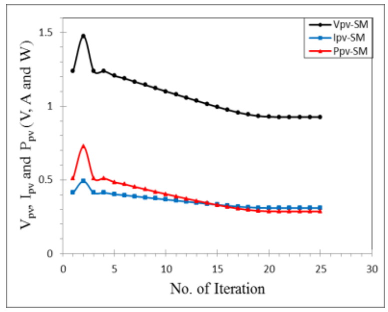

Fig. 5 - Applying SM on Eq. 6 with R = 3.

From Table 5, we noticed that with R = 4, the function of Eq. 6 converges to 0.926966435 at the 25 second iterations with error level of 0.000000000.

Table 5 - Iteration values for SM with $x_0 = 0.75$, $x_1 = 1$ and $R = 4$.

Iterations	X_0-BM	x_1-BM	x_2-BM	ε-BM
1	0.75	1	1.241929941	0.314963506
2	1	1.237902148	1.483958707	0.556992272
3	1.237902148	1.475913475	1.241826409	0.314859974
4	1.475913475	1.237786337	1.241723175	0.31475674
5	1.237786337	1.237670899	1.210575524	0.283609089
6	1.237670899	1.206529598	1.192401304	0.26543487
7	1.206529598	1.188353633	1.169413805	0.24244737
8	1.188353633	1.165367766	1.148313799	0.221347364
9	1.165367766	1.144268928	1.126495719	0.199529284
10	1.144268928	1.122454336	1.104939853	0.177973418
11	1.122454336	1.100905523	1.083358624	0.156392189
12	1.100905523	1.079331536	1.06185907	0.134892635
13	1.079331536	1.057849044	1.040471192	0.113504758
14	1.057849044	1.036494063	1.019324112	0.092357677
15	1.036494063	1.015412285	0.998642318	0.071675883
16	1.015412285	0.994857538	0.97886001	0.051893575
17	0.994857538	0.975316296	0.96074811	0.033781675
18	0.975316296	0.957638563	0.94552724	0.018560805
19	0.957638563	0.943124392	0.934673769	0.007707334
20	0.943124392	0.933219572	0.928963719	0.001997284
21	0.933219572	0.928405135	0.927200663	0.000234228
22	0.928405135	0.927104795	0.926973843	$7.40804E^{-06}$
23	0.927104795	0.926969598	0.926966463	$2.77713E^{-08}$
24	0.926969598	0.926966442	0.926966435	$3.29692E^{-12}$
25	0.926966442	0.926966435	0.926966435	0.000000000

Figure 6 shows the result of V_{pv}, I_{pv} and P_{pv} using SM.

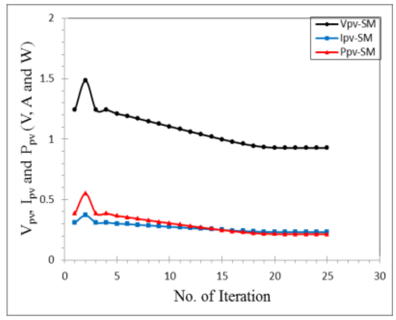

Fig. 6 - Applying SM on Eq. 6 with R = 4.

In Table 6, one can see that with R = 5, the function of Eq. 6 converges to 0.926966435 at the 25 second iterations with error level of 0.000000000.

Table 6 - Iteration values for SM with $x_0 = 0.75$, $x_1 = 1$ and $R = 5$.

Iterations	X_0-BM	x_1-BM	x_2-BM	ε-BM
1	0.75	1	1.245990712	0.319024277
2	1	1.245990712	1.492070755	0.56510432
3	1.245990712	1.492070755	1.245898269	0.318931834
4	1.492070755	1.245898269	1.245806065	0.31883963
5	1.245898269	1.245806065	1.214652696	0.287686261
6	1.245806065	1.214652696	1.196480084	0.269513649
7	1.214652696	1.196480084	1.173491181	0.246524747
8	1.196480084	1.173491181	1.152390257	0.225423822
9	1.173491181	1.152390257	1.130567567	0.203601132
10	1.152390257	1.130567567	1.109030978	0.182064543
11	1.130567567	1.109030978	1.087361887	0.160395452
12	1.109030978	1.087361887	1.065878733	0.138912298
13	1.087361887	1.065878733	1.044449857	0.117483422
14	1.065878733	1.044449857	1.02324989	0.096283455
15	1.044449857	1.02324989	1.0024541	0.075487665
16	1.02324989	1.0024541	0.982458109	0.055491674
17	1.0024541	0.982458109	0.963955077	0.036988642
18	0.982458109	0.963955077	0.948082376	0.021115941
19	0.963955077	0.948082376	0.936312849	0.009346414
20	0.948082376	0.936312849	0.929664222	0.002697787
21	0.936312849	0.929664222	0.927345376	0.000378941
22	0.929664222	0.927345376	0.92698255	$1.61152e^{-05}$
23	0.927345376	0.92698255	0.926966533	$9.76576e^{-08}$
24	0.92698255	0.926966533	0.926966435	$2.52185e^{-11}$
25	0.926966533	0.926966435	0.926966435	0.000000000

Figure 7 shows the result of V_{pv}, I_{pv} and P_{pv} using SM.

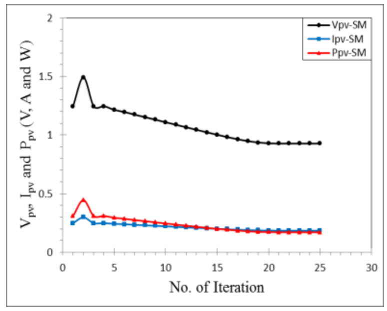

Fig. 7 - Applying SM on Eq. 6 with R = 5.

Comparison the results of these two numerical methods (BM) and (SM) under demonstration, we noticed that the rate of convergence of the methods is in the following order: SM is larger than BM. Comparing the SM and BM, one can see that SM converge faster than BM theoretically order 4. SM requires the evaluation of the function only, and be faster practically as indicated in our study, so depending on these results the SM is faster than BM in terms of the rate of convergence.

7. Conclusion

This research, give numerical solutions of a single-diode for PV cells in terms of BM and SM, based on the obtained results and discussion. One can conclude that the proposed method SM is the most effective than BM and has a converging rate required only a single function evaluation per iteration, simplicity and accurate approximate solution is achieved using a number of iterations. In addition, we can conclude that through the convergence of BM is certain and too slow, so it is very difficult to use this method with the system of equations. The proposed method (SM) is simplicity and accurate approximate solution is achieved using a numbers of iterations.

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