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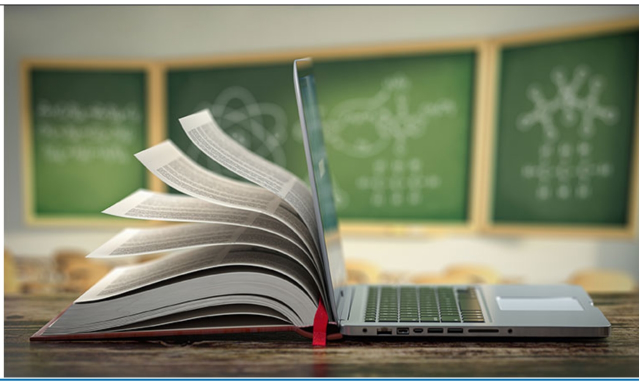

Parameters Extraction of a Single-Diode Model of Photovoltaic Cell Using False Position Iterative Method

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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 trigonometric 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.

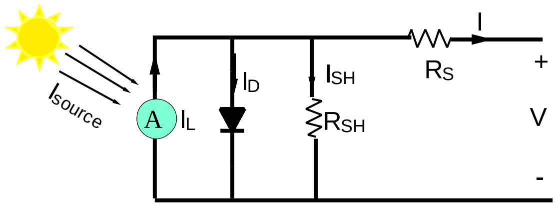

Figure 1. Solar cell's scheme

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

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

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

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

where:

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

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

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

Substitute Eq. 4 in Eq. 5 yields

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

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

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_l is first point of guess interval, x_u 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 and $f(x)$is inter function, then

Find x_2, x_3, x_4, …, x_n using the following expressions

$$x_r = x_u - \frac{f(x_u) \times (x_l - x_u)}{f(x_l) - f(x_u)}$$

$$x_3 = x_3 - \frac{f(x_2) \times (x_2 - x_1)}{f(x_2) - f(x_1)}$$

$$\vdots$$

$$x_n = x_{n-1} - \frac{f(x_{n-1}) \times (x_{n-1} - x_{n-2})}{f(x_{n-1}) - f(x_{n-2})}$$

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_l, x_u and ε

Compute $f(x_l)$ and $f(x_u)$

Compute $x_r = x_u - \frac{f(x_u)\times(x_l - x_u)}{f(x_l) - f(x_u)}$

Test for accuracy of x_2

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

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$\sigma = |x_{i+1} - x_i| < \varepsilon, |f(x_n)| < \varepsilon$(9)

where:ε: the absolute value of the function is a very small number. For convergence criteria, it was required that σ the distance between two consecutive iterates was less than 10^{-9}, the number of iterations represents by $n$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$x_l = 0.9$and$x_u = 1.$

In Table 1, 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 $R = 1$ (load resistance).

Table 1. The voltage values of the solar cell with σ and εvalues using FPM.

Iterations	X_0-FPM	x_1-FPM	x_{n+1}-FPM	ε-FPM	σ-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	0.09743045	0.026095166
5	1.032901166	1.024396885	0.99830172	0.071335285	0.018181131
6	1.024396885	0.99830172	0.980120588	0.053154154	0.019347249
7	0.99830172	0.980120588	0.960773339	0.033806904	0.015906857
8	0.980120588	0.960773339	0.944866482	0.017900047	0.012248262

9	0.960773339	0.944866482	0.932618221	0.005651786	0.009212433
10	0.944866482	0.932618221	0.923405787	0.003560648	0.003242295
11	0.932618221	0.923405787	0.926648083	0.000318352	0.000336896
12	0.923405787	0.926648083	0.926984979	1.85438E-05	1.86386E-05
13	0.926648083	0.926984979	0.92696634	9.47584E-08	9.47303E-08
14	0.926984979	0.92696634	0.926966435	2.81574E-11	2.81574E-11
15	0.92696634	0.926966435	0.926966435	0.000000000	

Figure 3 shows the results using FPM technique.

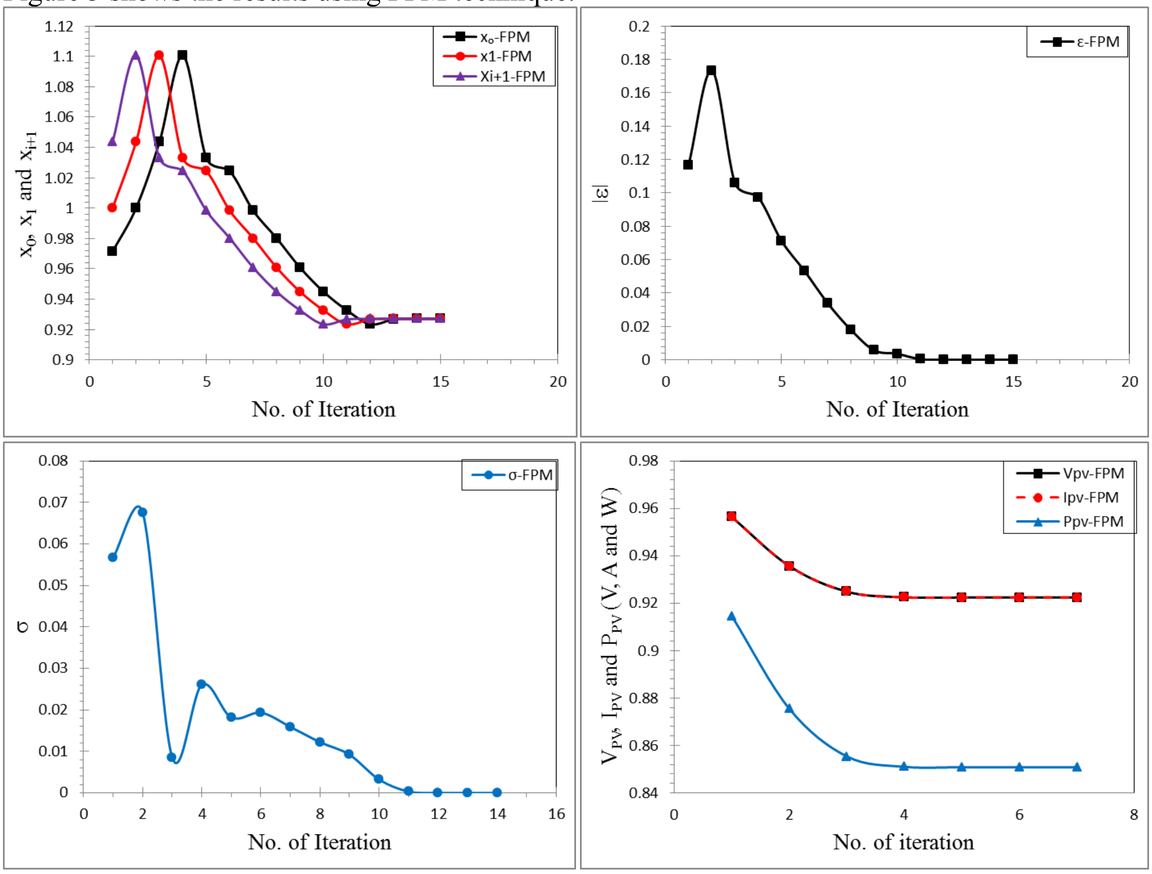

Figure 2. The results by using FPM method.

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 σ and εvalues using FPM.

Iterations	X_0-FPM	x_1-FPM	x_{n+1}-FPM	ε-FPM	σ-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

9	0.960613101	0.943874536	0.930328088	0.003361653	0.015382671
10	0.943874536	0.930328088	0.914945417	0.012021018	0.011345868
11	0.930328088	0.914945417	0.926291285	0.00067515	0.000814109
12	0.914945417	0.926291285	0.927105394	0.00013896	0.000140467
13	0.926291285	0.927105394	0.926964927	1.5078E-06	1.50444E-06
14	0.927105394	0.926964927	0.926966432	3.35535E-09	3.35535E-09
15	0.926964927	0.926966432	0.926966435	0	

Figure 3 shows the results using FPM technique.

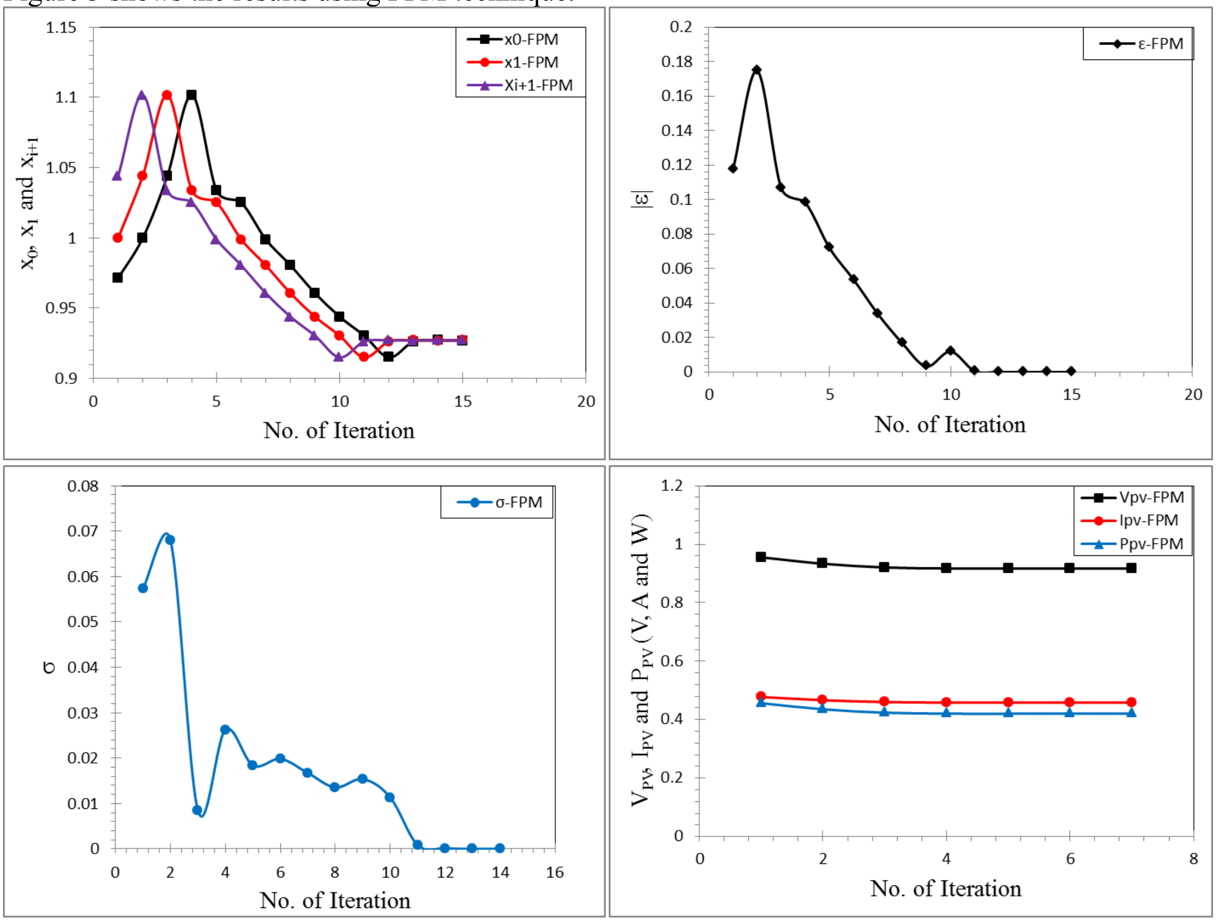

Figure 3. The results by using FPM method.

In Table 3, 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 $R = 3$ (load resistance).

Table 3. Thevoltage'svalues of the solar cell with σ and εvalues using FPM.

Iterations	X_0-FPM	x_1-FPM	x_{n+1}-FPM	ε-FPM	σ-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	0.107338	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

8	0.98082	0.960482362	0.942908	0.015942	0.014925
9	0.960482	0.942908456	0.927984	0.001017	0.028416
10	0.942908	0.927983642	0.899568	0.027399	0.026891
11	0.927984	0.899567834	0.926459	0.000508	0.000764
12	0.899568	0.926458849	0.927222	0.000256	0.000258
13	0.926459	0.927222411	0.926964	2.08E-06	2.08E-06
14	0.927222	0.92696435	0.926966	8.54E-09	8.54E-09
15	0.926964	0.926966426	0.926966	0	

Figure 4 shows the results using FPM technique.

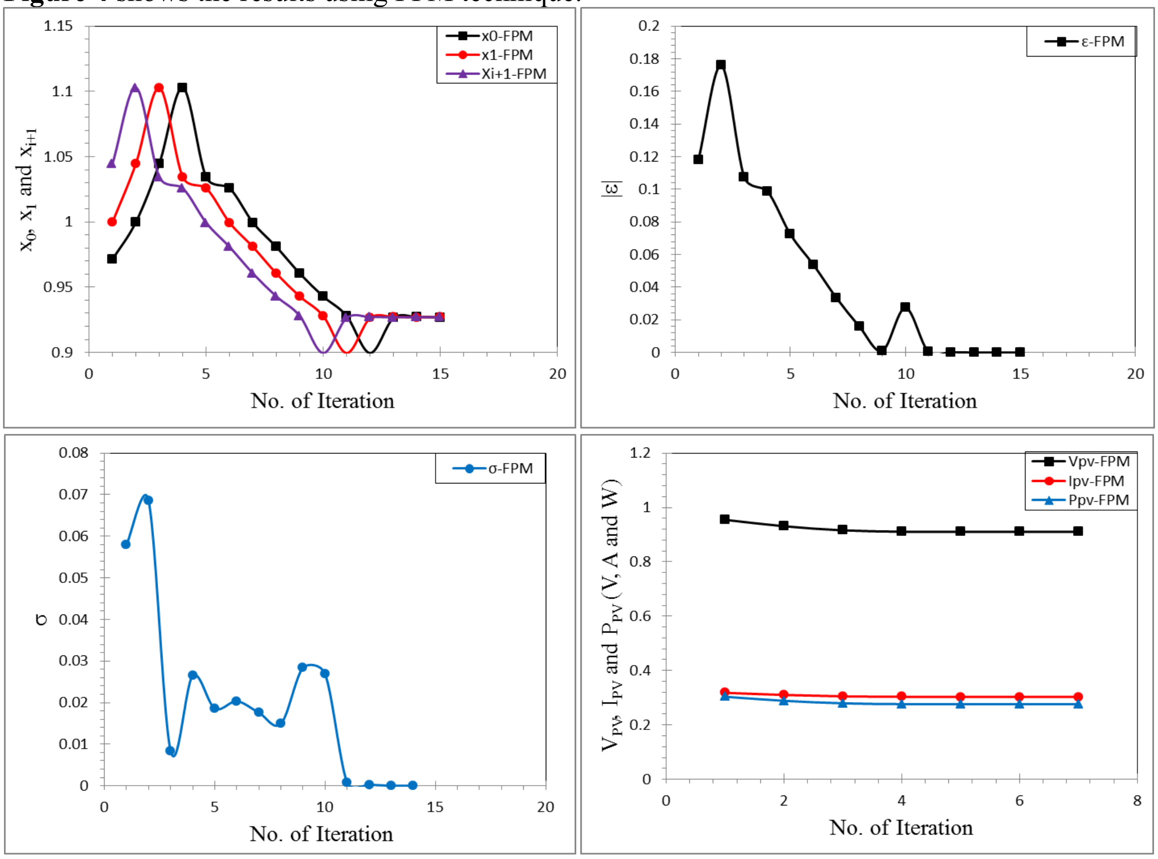

Figure 4. The results by using FPM method.

In Table 4, 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 $R = 4$ (load resistance).

Table 4. The voltage's values of the solar cell with σ and εvalues using FPM.

Iterations	X_0-FPM	x_1-FPM	x_{n+1}-FPM	ε-FPM	σ-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

8	0.981196	0.960381	0.941971	0.015004	0.016382
9	0.960381	0.941971	0.925589	0.001378	0.067548
10	0.941971	0.925589	0.858041	0.068925	0.070992
11	0.925589	0.858041	0.929034	0.002067	0.005072
12	0.858041	0.929034	0.923961	0.003005	0.002905
13	0.929034	0.923961	0.926866	1E-04	0.000105
14	0.923961	0.926866	0.926971	4.9E-06	4.9E-06
15	0.926866	0.926971	0.926966	0	

Figure 5 shows the results using FPM technique.

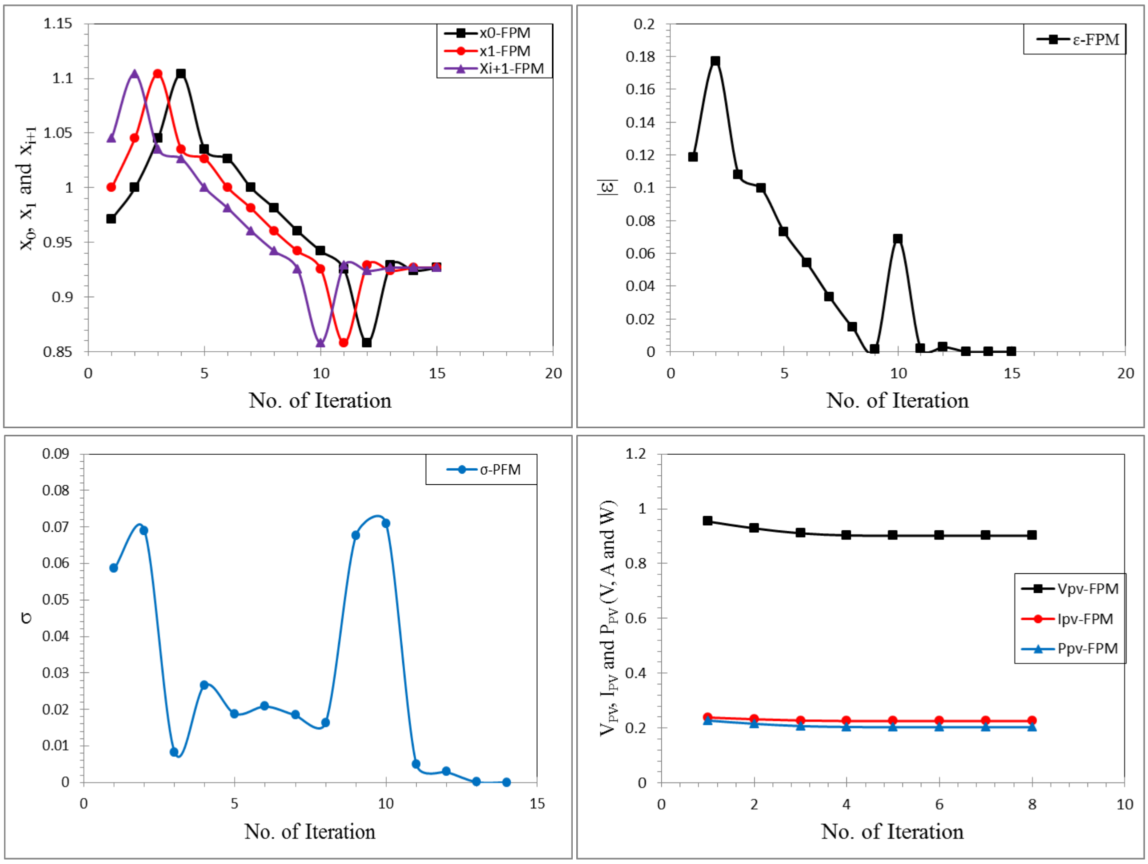

Figure 5. The results by using FPM method.

In Table 5, 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 $R = 5$ (load resistance).

Table 5. The voltage's values of the solar cell with σ and εvalues using FPM.

Iterations	X_0-FPM	x_1-FPM	x_{n+1}-FPM	ε-FPM	σ-FPM
1	0.971417	1	1.04606006	0.119093607	0.059218795
2	1	1.046060063	1.10527886	0.178312402	0.069566765
3	1.04606	1.105278858	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

7	1.000596	0.981588897	0.96030946	0.033343006	0.019246199
8	0.981589	0.960309462	0.94106326	0.014096806	0.017915457
9	0.960309	0.941063262	0.92314781	0.00381865	0.012483412
10	0.941063	0.923147806	0.91066439	0.016302063	0.009779298
11	0.923148	0.910664393	0.92044369	0.006522764	0.008450926
12	0.910664	0.920443691	0.92889462	0.001928162	0.002134459
13	0.920444	0.928894618	0.92676016	0.000206297	0.000199961
14	0.928895	0.926760159	0.92696012	6.33607E-06	6.33607E-06
15	0.92676	0.92696012	0.92696646	0	

Figure 6 shows the results using FPM technique.

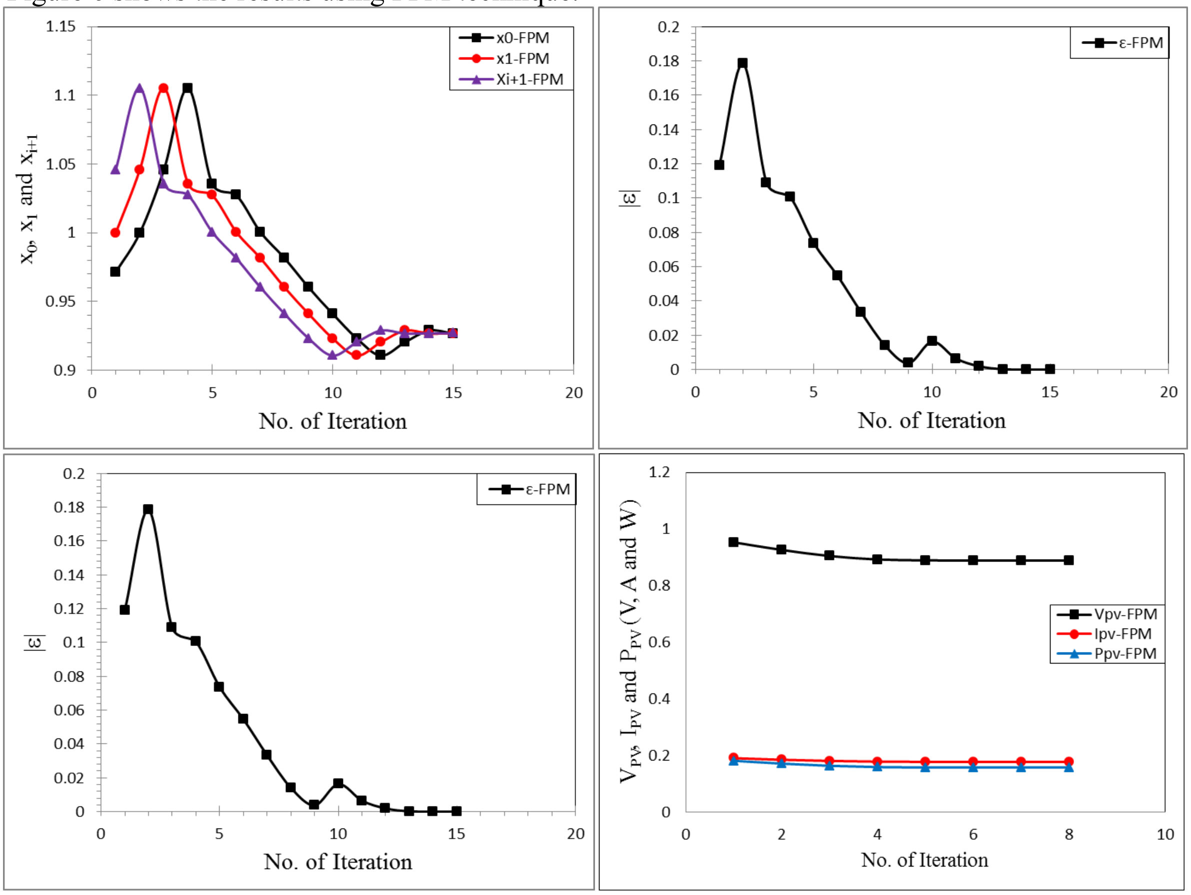

Figure 6. The results by using FPM method.

The plot of the number of iteration with ε plane and initial-output values proves that the proposed (FPM) method has a 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 $x_l \approx 0.9$ and $x_u = 1$ 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.

6. References

[1] Rasheed M and Barillé R 2017 Room temperature deposition of ZnO and Al: ZnO ultrathin films on glass and PET substrates by DC sputtering technique, *Opt. Quantum Electron.* **49** 5 1-14.
[2] Rasheed M and RégisBarillé R 2017 Optical constants of DC sputtering derived ITO, TiO_2 and TiO_2: Nb thin films characterized by spectrophotometry and spectroscopic ellipsometry for optoelectronic devices *J. Non-Crystalline Solids* **476** 1-14.
[3] Rasheed M and Barillé R 2017 Comparison the optical properties for Bi_2O_3 and NiO ultrathin films deposited on different substrates by DC sputtering technique for transparent electronics *J. Alloys Comp.* **728** 1186-1198.
[4] Saidani T, Zaabat M, Aida MS, Barille R, Rasheed M and Almohamed R 2017 Influence of precursor source on sol–gel deposited ZnO thin films properties *J. Mat. Sci. Mat. Electron.* **28** 13 9252-9257.
[5] Guergouria K, Boumezoued A, Barille R, Rechemc D, Rasheed Mand Zaabata M 2019 ZnOnanopowders doped with bismuth oxide, from synthesis to electrical application, *J. Alloys Comp.* **791** 550-558.
[6] Bouras D, Mecif A, Barillé R, Harabi A, Rasheed M, Mahdjoub A and Zaabat M 2018 Cu: ZnO deposited on porous ceramic substrates by a simple thermal method for photocatalytic application *Ceramics Int.* **44** 17 21546-21555.
[7] Dkhilalli F, Borchani SM, Rasheed M, Barille R, Guidara R and Megdiche M 2018 Structural, dielectric, and optical properties of the zinc tungstate ZnWO4 compound *J. Mat. Sci. Mat. Electron* **29** 8 6297-6307.
[8] Dkhilalli F, Borchani SM, Rasheed M, Barille R, Shihab S, Guidara K and Megdiche M, Characterizations and morphology of sodium tungstate particles *Royal Soc. Open Science*, **5** 8 1-12.
[9] Chaichan MT and Kazem HA 2018 *Generating electricity using photovoltaic Solar plants in Iraq* (pp. 47-82). Springer.
[10] Rasheed MS 2014 On Solving Hyperbolic Trajectory Using New Predictor-Corrector Quadrature Algorithms *Baghdad Sci. J.* **11** 186-192.
[11] Saidi W, Hfaidh N, Rasheed M, Girtan M, Megriche A and EL Maaoui M 2016 Effect of B_2O_3 addition on optical and structural properties of TiO_2 as a new blocking layer for multiple dye sensitive solar cell application (DSSC) *RSC Adv*. **6** 73 68819-68826.
[12] Aukstuolis A, M. Girtan M, Mousdis GA, Mallet R, Socol M, Rasheed M, Stanculescu A 2017 Measurement of charge carrier mobility in perovskite nanowire films by photo-CELIV method *Proc. Romanian Acad Ser. a-Math. Phys. Techn. Sci. Inform. Sci.* **18** 1 34-41.
[13] Dkhilalli F, Megdiche S, Guidara K, Rasheed M, Barillé R and Megdiche M 2018 AC conductivity evolution in bulk and grain boundary response of sodium tungstate Na_2WO_4, Ionics, **24** 1 169-180.
[14] Enneffati M Louati B, Guidara K, Rasheed M and Barillé R 2018 Crystal structure characterization and AC electrical conduction behavior of sodium cadmium orthophosphate *J. Mat. Sci. Mat. Electron.* **29** 1 171-179.
[15] Kadri E, Krichen M, Mohammed R, Zouari A and Khirouni K 2016 Electrical transport mechanisms in amorphous silicon/crystalline silicon germanium heterojunction solar cell: impact of passivation layer in conversion efficiency*, Opt. Quantum Electron.* **48** 12 1-15.
[16] Kadri E, Messaoudi O, Krichen M, Dhahri K, Rasheed M, Dhahri E, Zouari A, Khirouni K, Barillé R 2017 Optical and electrical properties of SiGe/Si solar cell heterostructures: Ellipsometric study *J. Alloys Comp.* **721** 779-783.
[17] Kadri E, Dhahri K, Zaafouri A, Krichen M, Rasheed M, Khirouni K and Barillé R 2017 Ac conductivity and dielectric behavior of a−Si:H/c− $Si_{1-y}Ge_y$/p−Si thin films synthesized by molecular beam epitaxial method *J. Alloys Comp*. **705** 708-713.

[18] Azaza NB, Elleuch S, Rasheed M, Gindre D, Abid S, Barille R, Abid Y and Ammar H 2019 3-(p-nitrophenyl) Coumarin derivatives: Synthesis, linear and nonlinear optical properties *Opt. Mat.* **96** 109328.
[19] Enneffati M, Rasheed M, Louati B, Guidara K and Barillé R 2019 Morphology, UV–visible and ellipsometric studies of sodium lithium orthovanadate, *Opt. Quantum Electron.* **51** 299.
[20] RASHEED M and SHIHAB S 2019 Parameters Estimation for Mathematical Model of Solar Cell, *Electron. Sci. Technol. Appl.* (2019).
[21] RASHEED M and SHIHAB S 2019 Modeling and Simulation of Solar Cell Mathematical Model Parameters Determination Based on Different Methods *Insight Math.* **1** 1.
[22] Hamimid M, Feliachi M and Mimoune SM 2010 Modified Jiles–Atherton model and parameters identification using false position method *Phys. B: Conden. Matt.* **405** 8 1947-1950.
[23] Ageev AL and Antonova TV 2013 New methods for the localization of discontinuities of the first kind for functions of bounded variation *J. Inv.Ill-Posed Probl.* **21** 2 2013 177-191.