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Various Numerical Methods for Solving Nonlinear Equation

Mohammed RASHEED [a,*], Ahmed Rashid [b], Taha Rashid [c], Saad Hussin Abed Hamad [d], Noghanian Toroghi Manoochehr [e]

[a] *Applied Science Department, University of Technology, Baghdad, Iraq, e-mail: rasheed.mohammed40@yahoo.com, mohammed.s.rasheed@uotechnology.edu.iq.*

[b] *Al Iraqia University, College of Arts, Baghdad, Iraq, e-mail: dr.ahm.8215@gmail.com, ahmed_rashed@aliraqia.edu.iq.*

[c] *Computer and Microelectronics System, Faculty of Engineering, University of Malaysia (UTM), Skudai 81310, Johor Bahru, Malaysia, and Al Iraqia University, College of Arts, Baghdad, Iraq, e-mail: tsiham95@gmail.com, taha1988@graduate.utm.my.*

[d] *College of Computer Science & Information Technology, Al-Diwaniyah, Iraq, e-mail: shsaadsh2014@gmail.com*

[e] *Computer and Microelectronic Systems, Faculty of Electrical Engineering, University of Technology Malaysia (UTM), Skudai 81310, Johor Bahru, Malaysia, e-mail: noghanianmanoochehr@graduate.utm.my.*

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ABSTRACT

In this work, two iterative methods is proposed and described here for solving nonlinear equation of PV cell device. The type of solar cell is single diode model based on its equivalent circuit with various values of load resistance R. These methods do not require second order of derivative and easy to use. The convergence of the proposed method do not discussed here. In order to found the accuracy and efficiency of the proposed and other method, the absolute error value have been calculated and compared. The advantages of the new proposed method can be investigated by comparing with the Improved Hornor-Newton method; and the results obtained indicate that the propose method is more accurate, efficient and easy to use than the second method.

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*Corresponding author: Mohammed RASHEED

Email addresses: rasheed.mohammed40@yahoo.com , 10606@uotechnology.edu.iq

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1. Introduction

Pure, science and engineering technology are used the iterative methods to solve the nonlinear equations deals with the functions in the form of $f(x) = 0$. All these methods take one or two or three initial values for it's starting point. Some of these methods investigated by two or three or multi steps for it's solutions. It is well know that the decreasing of the number of steps don't indicate the efficiency of these methods; while the decreasing the number of computations are show the accuracy and efficiency of the iterative method and it's order of convergence. Newton's method is a popular and standard method is used for solving the nonlinear equations of different technologies. In recent years; several researchers are employed this method for solving nonlinear equation of PV cell for example Rasheed et al. they analyzed and demonstrated many iterative methods for solving nonlinear equation of solar cell device such as bisection, secant, two bracketing, two step, three step methods [1-115].

The suggested algorithm IHOM requires 8 evaluations of the function while the other technique (DM) needs 6 evaluation of the function. The following steps are investigate the procedure of this work: section two, three and four investigating the modelling and the root finding of IHOM and DM algorithms respectively while; section five and six indicate the numerical problems, discussion and conclusion results respectively.

2. Essential a Non-Linear Equation

KCL Kirchhoff's law is employed in order to depict the electrical parameters of PV cell scheme [11-22]

$$I = I_{ph} - I_{Diode}, I_{Diode} = I_0 \left[\exp\left(\frac{-V_{pv}}{nV_T}\right) - 1\right] \quad (1)$$

where:

I_0 is diode reverse saturation current measured in (A), I_{ph} is light current, n is diode ideality factor (unitless), $k = (1.38 \times 10^{-23} J/K)$ is Boltzmann constant, $q = (1.602 \times 10^{-19}\ C)$ is elementary charge, V_T is thermal voltage given by $V_T = \frac{kT}{q}$, $I_{ph}$is the light generated current in the cell, T is temperature (p-n junction), I_D is the voltage dependent current lost to recombination.

The current I_{pv} and power $P_{pv}$of the cell is given by $I_{pv} = \frac{V_{pv}}{R}$; $P_{pv} = I_{pv} \times V_{pv}$

The final equation from the circuit is given by

$$(I_{source}) - 10^{-12}\left(e^{\frac{-V}{1.2*0.026}} - 1\right) = V / R \quad (2)$$

3. Improved Hornor-Newton Method (IHOM)

The following steps can express this iterative method

Step 1: let initial value x_0

Step 2: describe by the newton's iteration method

$$x_{k+1} = x_k - \frac{f(x_k)}{\acute{f}(x_k)}, \qquad k = 0, 1, 2, 3, \ldots$$

Step 3: compute

$$x_{k+1} = x_k - \frac{b_{k,0}}{c_{k,1}}, \qquad k = 0, 1, 2, 3, \ldots$$

Step 4: Taylor series expansion and the following result will be as follows.

$$x_{k+1} = x_k - \frac{f(x_k)}{\acute{f}(x_k)}\left[1 + \frac{f(x_k) \times \acute{\acute{f}}(x_k)}{2 \times (\acute{f}(x_k)^2)}\right]$$

Step 5: calculate the recursive formula of improved Newton-Horner iteration as the following expressions

$f(x_k) = b_{k,0}$, $\acute{f}(x_k) = c_{k,1}$, and $\acute{f}(x_k) = 2! \times d_{k,2}$

Step 6: the resulting improved Newton-Horner iteration method will be

$x_{k+1} = x_k - \frac{b_{k,0}}{c_{k,1}}\left[1 + \frac{2\times b_{k,0}\times d_{k,2}}{2\times(c_{k,1})^2)}\right]$ or

$$x_{k+1} = x_k - \frac{b_{k,0}}{c_{k,1}}\left[1 + \frac{b_{k,0}\times d_{k,2}}{(c_{k,1})^2)}\right], k = 0, 1, 2, 3, \ldots \quad (3)$$

4. Dekker's Algorithm (DM)

This method obtain when we combine the Bisection and Secant Methods achieved by Dekker in 1969.

Step 1: The first one called linear interpolation secant method using the following formula

$$x_{n+1} = \begin{cases} x_n - \frac{x_n - x_{n-1}}{f(x_n) - f(x_{n-1})} f(x_n) & \text{if } f(x_{n-1}) \neq f(x_n) \\ m & \text{otherwise} \end{cases} \quad (4)$$

Step 2: the second one can be obtained by bisection method

$$m = \frac{a_n + b_n}{2}$$

where: a_n: the "contrapoint" this means that $f(x_n)$ and $f(b_k)$ have opposite signs, so the interval $[a_n, b_n]$ consist of the solution.

For the two algorithms, the tolerance is If$|f(a_n)| \geq |f(b_n)|, |f(x_n)| < \varepsilon, \varepsilon = 10^{-9}$.

5. Results and Discussion

Two numerical iterations is suggested to introduce the performance of the Improved Hornor-Newton Method (IHOM) represented in Eq. 3 acquired in the present paper in order to solve non-linear equation with the initial value $x_0 = 1$ and we compare it with Dekker's Algorithm (DM) represented in Eq. 4 with two initial values x_0 and x_1. For convergence criteria, the distance between two consecutive iterates is based on Eq. 5, less than 10^{-9}. Five examples in Eq. 2 are used for numerical testing with the R values from 1-5 ohm, represents (load resistance) of the circuit. All determinations are carried out with the algorithm precision introduced in Tables and Figures 1 to 5 and the number of function evaluations needed are extracted from the Eq. 2. The numerical examples and the approximate solutions produced by two techniques for solving Eq. 2.

The following Tables and Figs. indicate that IHOM algorithm needs 8 iterations while DM technique need 6 iterations to reach to the convergence which proves that DM is faster than IHOM.

Table 1 - Using numerical technologies to analyze the solutions of Eq. 2.

Iterations	V_{pv}-IHOM	I_{pv}- IHOM	P_{pv}-IHOM	V_{pv}-DM	I_{pv}-DM	P_{pv}-DM	ε-IHOM	ε-DM
1	0.691771569	0.345885784	0.239273952	2.265023621	1.132511811	2.565166003	0.225263813	1.347988239
2	0.866573289	0.433286645	0.375474633	0.924867275	0.462433638	0.427689739	0.050462093	0.007831893
3	0.910009416	0.455004708	0.414058569	0.917079547	0.458539773	0.420517447	0.007025966	4.41643e-05
4	0.916663928	0.458331964	0.420136378	0.917035404	0.458517702	0.420476966	0.000371455	2.19013e-08
5	0.917031761	0.458515880	0.420473625	0.917035382	0.458517691	0.420476946	3.62153e-06	8.81517e-14
6	0.917035381	0.458517690	0.420476945	0.917035382	0.458517691	0.420476946	1.49912e-09	0
7	0.917035382	0.458517691	0.420476946				3.33067e-16	
8	0.917035382	0.458517691	0.420476946				0	

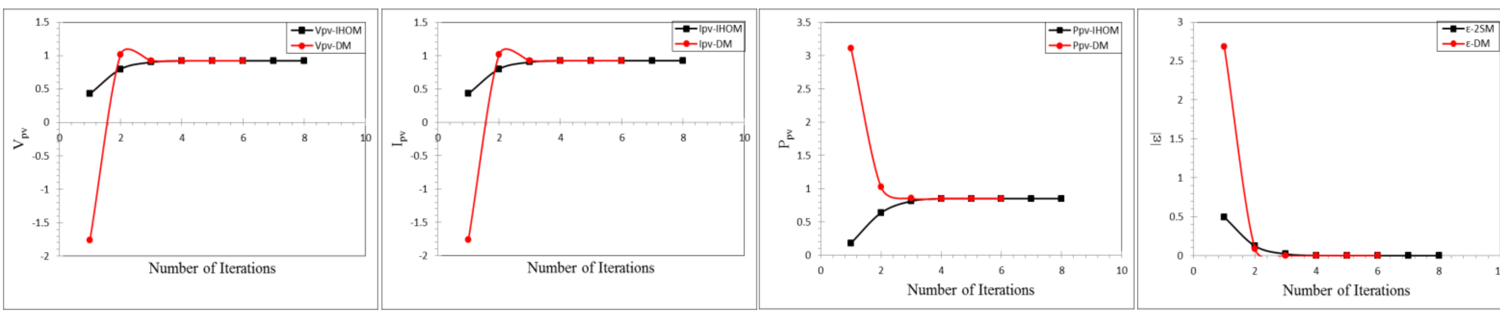

Fig. 1 – New analytical algorithms in nonlinear equation.

Table 2 - Using numerical technologies to analyze the solutions of Eq. 2.

Iterations	V_{pv}-IHOM	I_{pv}- IHOM	P_{pv}-IHOM	V_{pv}-DM	I_{pv}-DM	P_{pv}-DM	ε-IHOM	ε-DM
1	0.691771569	0.345885784	0.239273952	2.265023621	1.132511811	2.565166003	0.225263813	1.347988239
2	0.866573289	0.433286645	0.375474633	0.924867275	0.462433638	0.427689739	0.050462093	0.007831893
3	0.910009416	0.455004708	0.414058569	0.917079547	0.458539773	0.420517447	0.007025966	4.41643e-05
4	0.916663928	0.458331964	0.420136378	0.917035404	0.458517702	0.420476966	0.000371455	2.19013e-08
5	0.917031761	0.458515880	0.420473625	0.917035382	0.458517691	0.420476946	3.62153e-06	8.81517e-14
6	0.917035381	0.458517690	0.420476945	0.917035382	0.458517691	0.420476946	1.49912e-09	0
7	0.917035382	0.458517691	0.420476946				3.33067e-16	
8	0.917035382	0.458517691	0.420476946				0	

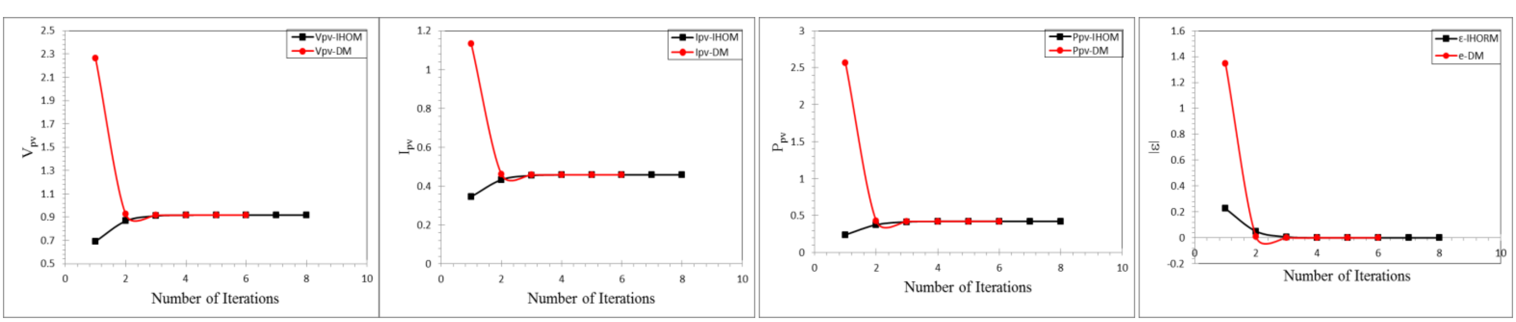

Fig. 2 – New analytical algorithms in nonlinear equation.

Table 3 - Using numerical technologies to analyze the solutions of Eq. 2.

Iterations	V_{pv}-IHOM	I_{pv}- IHOM	P_{pv}-IHOM	V_{pv}-DM	I_{pv}-DM	P_{pv}-DM	ε-IHOM	ε-DM
1	0.779539843	0.259846614	0.202560789	1.029156699	0.343052233	0.353054504	0.130863532	0.118753325
2	0.888363228	0.296121076	0.263063075	0.910311873	0.303437291	0.276222569	0.022040146	9.1501e-05
3	0.910627284	0.303542428	0.276414017	0.910406178	0.303468726	0.276279803	0.00022391	2.80389e-06
4	0.911169131	0.303723044	0.276743062	0.910403885	0.303467962	0.276278411	0.000765757	5.10536e-07
5	0.910444101	0.303481367	0.276302820	0.910403374	0.303467791	0.276278101	4.0727Ee-05	4.60135e-11
6	0.910403443	0.303467814	0.276278143	0.910403374	0.303467791	0.276278101	6.87108e-08	0
7	0.910403374	0.303467791	0.276278101				1.78191e-13	
8	0.910403374	0.303467791	0.276278101				0	

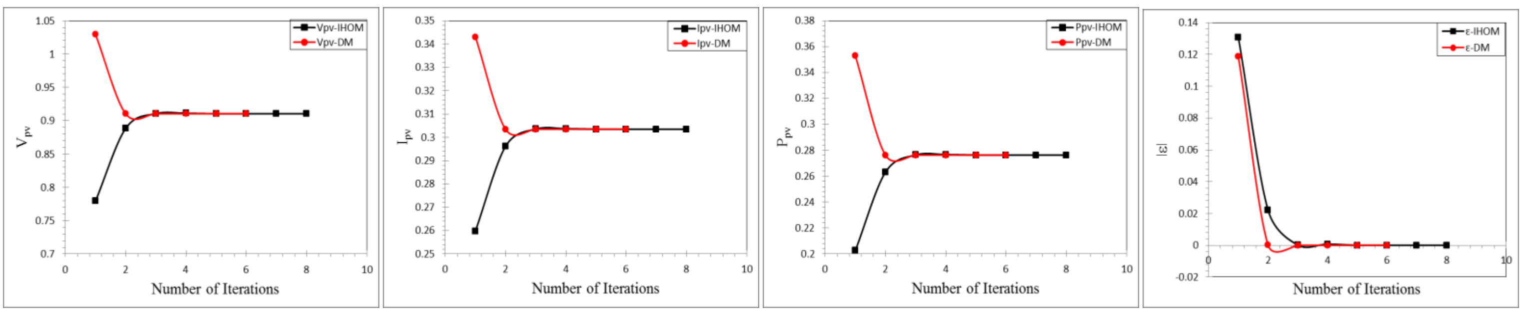

Fig. 3 – New analytical algorithms in nonlinear equation.

Table 4 - Using numerical technologies to analyze the solutions of Eq. 2.

Iterations	V_{pv}-IHOM	I_{pv}- IHOM	P_{pv}-IHOM	V_{pv}-DM	I_{pv}-DM	P_{pv}-DM	ε-IHOM	ε-DM
1	0.823180576	0.205795144	0.169406565	0.908657079	0.227164270	0.206414422	0.078560026	0.006916477
2	0.898446452	0.224611613	0.201801507	0.901355386	0.225338846	0.203110383	0.003294150	0.000385216
3	0.908885890	0.227221472	0.206518390	0.902051101	0.225512775	0.203424047	0.007145288	0.000310499
4	0.904487439	0.226121860	0.204524382	0.901750974	0.225437743	0.203288705	0.002746837	1.03719e-05
5	0.901969560	0.225492390	0.203387272	0.901740607	0.225435152	0.203284031	0.000228958	5.11122e-09
6	0.901741933	0.225435483	0.203284628	0.901740602	0.225435150	0.203284028	1.33094e-06	9.99201e-16
7	0.901740602	0.225435151	0.203284028	0.901740602	0.225435150	0.203284028	4.25894e-11	0
8	0.901740602	0.225435150	0.203284028				0	

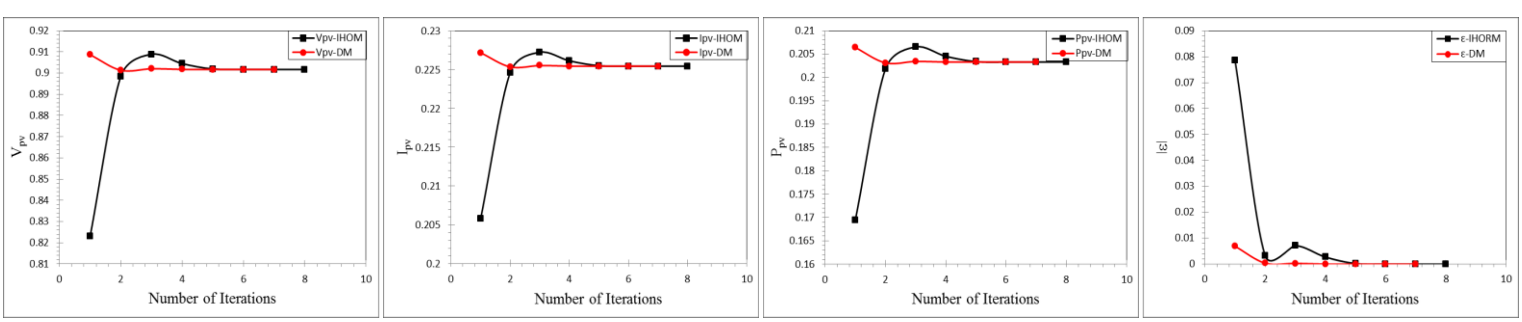

Fig. 4 – New analytical algorithms in nonlinear equation.

Table 5 - Using numerical technologies to analyze the solutions of Eq. 2.

Iterations	V_{pv}-IHOM	I_{pv}- IHOM	P_{pv}-IHOM	V_{pv}-DM	I_{pv}-DM	P_{pv}-DM	ε-IHOM	ε-DM
1	0.849170074	0.169834015	0.144217963	0.877558280	0.175511656	0.154021707	0.039922641	0.011534435
2	0.903825999	0.180765200	0.163380287	0.892676049	0.178535210	0.159374106	0.014733284	0.003583334
3	0.906012953	0.181202591	0.164171894	0.890938034	0.178187607	0.158754116	0.016920239	0.001845319
4	0.896365939	0.179273188	0.160694379	0.889232180	0.177846436	0.158146774	0.007273224	0.000139465
5	0.890248776	0.178049755	0.158508577	0.889093286	0.177818657	0.158097374	0.001156061	5.70849e-07
6	0.889121037	0.177824207	0.158107244	0.889092715	0.177818543	0.158097171	2.83224e-05	8.21831e-12
7	0.889092731	0.177818546	0.158097177	0.889092715	0.177818543	0.158097171	1.651e-08	0
8	0.889092715	0.177818543	0.158097171				5.55112e-15	
9	0.889092715	0.177818543	0.158097171				0	

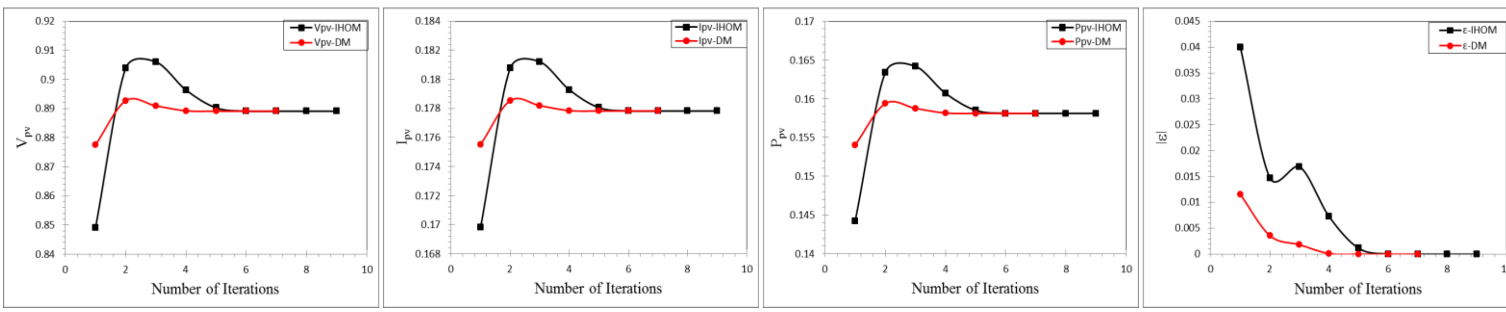

Fig. 5 – New analytical algorithms in nonlinear equation.

6. Conclusion

Two iterative methods is proposed for solving nonlinear equation of PV cell in this paper. The proposed method is free of second derivative of the function with lesser number of evaluations than Improved Hornor-Newton method. Many experiments are introduced here and compared with IHNM. Tables from 1-5; we evaluations reported here have been executed in MATLAB program the stopping criterion has been possessed as $|x_{n+1} - \alpha| + |f(x_{n+1})| < 10^9$.

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