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Use of Improved Algorithms for Solving Nonlinear Equation

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ABSTRACT

In this work, two two-step iterative methods are presented for solving nonlinear equations of PV cell in the type single diode style. The absolute error of these numerical methods is discussed too. Many numerical experiments are introduced and compared to other standard method such as Newton's method. The acquired results observe that the efficient, accuracy and fast of the proposed method.

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1. Introduction

In present years, one of the oldest and most basic examples in applied mathematics is that to solve an nonlinear equations have the form of $f(x) = 0$. Generally, this problem has induced several theoretical evolutions involving the fact that solution formularization do not exist. Therefore, the improvement of techniques for finding solutions has been historically an important project. The most popular standard method is Newton's method for solving nonlinear equations. Researchers still attract attention of the fields related to Newton's method. Many numerical methods have been improved to solve nonlinear equations in the type of $f(x) = 0$ using Newton's algorithm in recent years [1-115].

From obtained results, MNRM requires 7 evaluations of the function while the other technique (DM) needs 5 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 MNRM and DM algorithms respectively while; section five and six indicate the numerical problems, discussion and conclusion results respectively.

2. Property of Single-Diode Non-Linear Equation

KCL Kirchhoff's law is employed in order to depict the electrical parameters of PV cell scheme [30-50]

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

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

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

3. Modified Newton-Raphson Method (MNRM)

Step 1: Let a given x_0 (initial value).

Step 2: Compute x from the equation below

$$x_{n+1} = x_n - \frac{f(x_n)}{\acute{f}(x_n)}$$

Step 3: Let $u(x) = \frac{f(x_n)}{\acute{f}(x_n)}$, f(x) goes to zero before $\acute{f}(x_n)$ does

$$x_{n+1} = x_n + \frac{u(x)}{\acute{u}(x)}$$

Step 4: Determine the first derivative of the function

$$\acute{u}(x) = \frac{f(x) \times \acute{f}(x) - f(x) \times \acute{\acute{f}}(x)}{[\acute{f}(x)]^2}$$

Step 5: Calculate the value of x from the following equation

$$x_{n+1} = x_n - \frac{f(x_n) \times \acute{f}(x_n)}{[f(x_n)]^2 - f(x_n) \times \acute{\acute{f}}(x)} \tag{3}$$

The above equation is called Modified Newton-Raphson Method.

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

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

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

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

Step 3: If $|f(a_n)| \geq |f(b_n)|$, $|f(x_n)| < \varepsilon$, $\varepsilon = 10^{-9}$ as a tolerance; stop else go to Step 1.

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.

5. Results and Discussion

Two numerical iterations is suggested to introduce the performance of the Modified Newton-Raphson Method-(MNRM) 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 MNRM algorithm needs 7 iterations while DM technique need 5 iterations to reach to the convergence which proves that DM is faster than MNRM.

Table 1 - The results of MNRM and DM.

Iterations	V_{pv}-MNRM	I_{pv}- MNRM	P_{pv}-MNRM	V_{pv}-DM	I_{pv}-DM	P_{pv}-DM	ε-MNRM	ε-DM
1	0.946728989	0.946728989	0.896295779	0.924879897	0.924879897	0.855402823	0.024305855	0.002456762
2	0.929861208	0.929861208	0.864641866	0.922517430	0.922517430	0.851038409	0.007438073	9.42955E-05
3	0.923246188	0.923246188	0.852383525	0.922423277	0.922423277	0.850864702	0.000823054	1.42489E-07
4	0.922433925	0.922433925	0.850884346	0.922423135	0.922423135	0.850864439	1.07906E-05	3.12639E-13
5	0.922423136	0.922423136	0.850864442	0.922423135	0.922423135	0.850864439	1.79764E-09	0
6	0.922423135	0.922423135	0.850864439				1.11022E-16	
7	0.922423135	0.922423135	0.850864439				0	

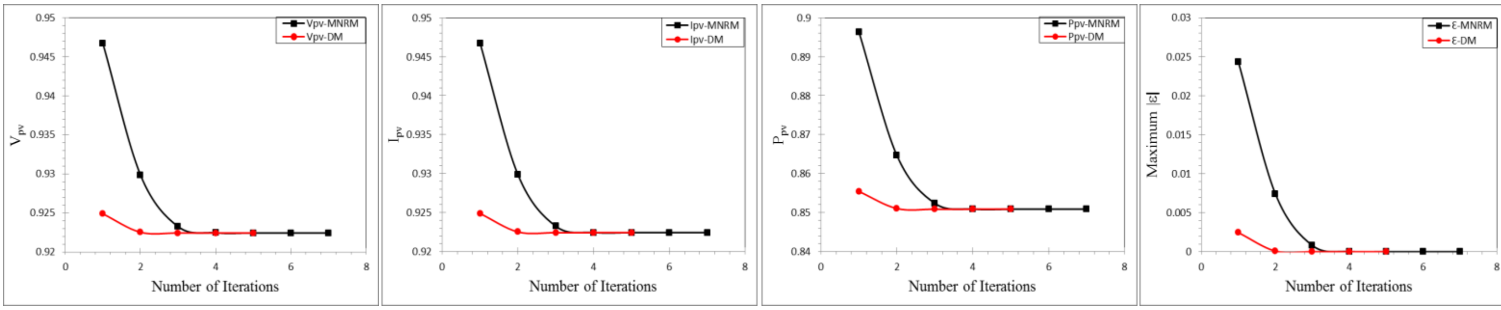

Fig. 1 – The results of MNRM and DM for solving Eq. 2.

Table 2 - The results of MNRM and DM.

Iterations	V_{pv}-MNRM	I_{pv}- MNRM	P_{pv}-MNRM	V_{pv}-DM	I_{pv}-DM	P_{pv}-DM	ε-MNRM	ε-DM
1	0.945414147	0.472707073	0.446903955	0.920703865	0.460351932	0.423847803	0.028378765	0.003668483
2	0.926823333	0.463411667	0.429500746	0.917244136	0.458622068	0.420668403	0.009787951	0.000208754
3	0.918433095	0.459216548	0.421759675	0.917036083	0.458518041	0.420477589	0.001397713	7.00546E-07
4	0.917066480	0.458533240	0.420505464	0.917035382	0.458517691	0.420476946	3.10972E-05	7.49956E-12
5	0.917035397	0.458517699	0.420476960	0.917035382	0.458517691	0.420476946	1.48468E-08	0
6	0.917035382	0.458517691	0.420476946				1.0103E-14	
7	0.917035382	0.458517691	0.420476946				0	

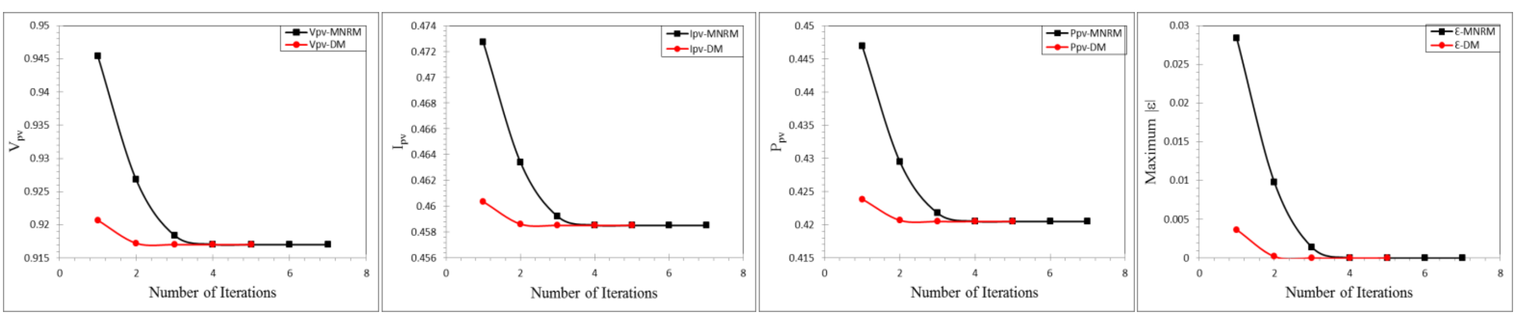

Fig. 2 – The results of MNRM and DM for solving Eq. 2.

Table 3 - The results of MNRM and DM.

Iterations	V_{pv}-MNRM	I_{pv}- MNRM	P_{pv}-MNRM	V_{pv}-DM	I_{pv}-DM	P_{pv}-DM	ε-MNRM	ε-DM
1	0.944071555	0.314690518	0.297090367	0.916040252	0.305346751	0.279709915	0.033668181	0.005636878
2	0.923573490	0.307857830	0.284329330	0.910890252	0.303630084	0.276573684	0.013170115	0.000486878
3	0.912863480	0.304287827	0.277773244	0.910407205	0.303469068	0.276280426	0.002460106	3.83106E-06
4	0.910499475	0.303499825	0.276336431	0.910403374	0.303467791	0.276278101	9.61007E-05	2.27307E-10
5	0.910403518	0.303467839	0.276278188	0.910403374	0.303467791	0.276278101	1.43895E-07	0
6	0.910403374	0.303467791	0.276278101				4.26326E-13	
7	0.910403374	0.303467791	0.276278101				0	

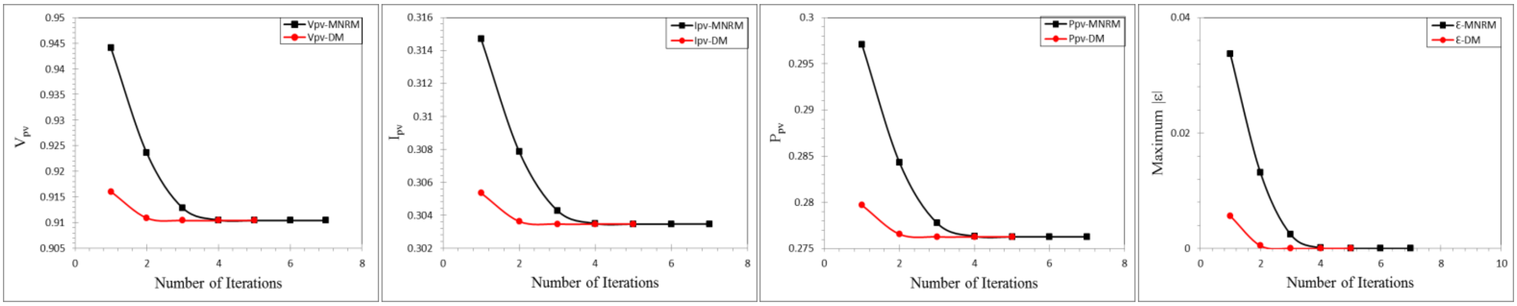

Fig. 3 – The results of MNRM and DM for solving Eq. 2.

Table 4 - The results of MNRM and DM.

Iterations	V_{pv}-MNRM	I_{pv}- MNRM	P_{pv}-MNRM	V_{pv}-DM	I_{pv}-DM	P_{pv}-DM	ε-MNRM	ε-DM
1	0.942700461	0.235675115	0.222171040	0.910792589	0.227698147	0.207385785	0.040959859	0.009051987
2	0.920088564	0.230022141	0.211640741	0.902968073	0.225742018	0.203837835	0.018347962	0.001227471
3	0.906313217	0.226578304	0.205350912	0.901765139	0.225441285	0.203295092	0.004572615	2.45372E-05
4	0.902069876	0.225517469	0.203432515	0.901740612	0.225435153	0.203284033	0.000329274	9.59338E-09
5	0.901742340	0.225435585	0.203284812	0.901740602	0.225435150	0.203284028	1.7381E-06	0
6	0.901740602	0.225435150	0.203284028				3.61988E-12	
7	0.901740602	0.225435150	0.203284028				0	

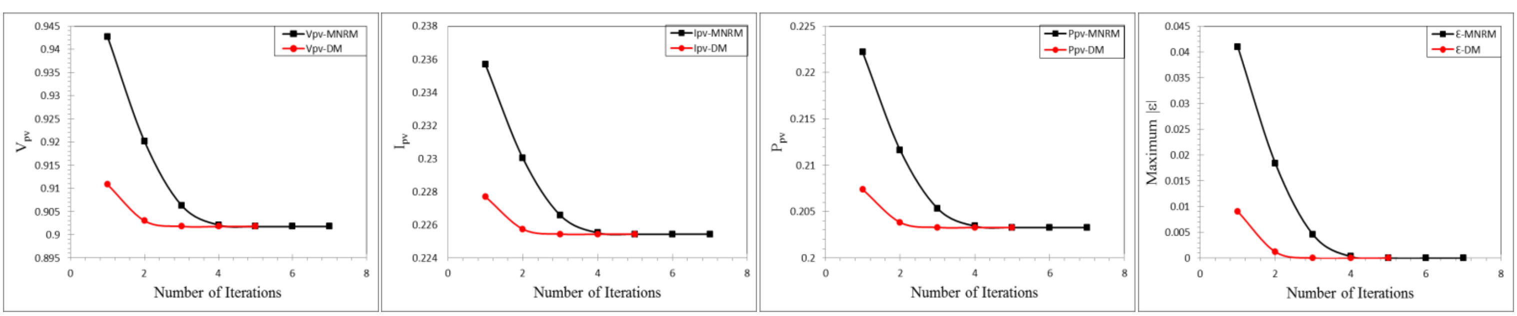

Fig. 4 – The results of MNRM and DM for solving Eq. 2.

Table 5 - The results of MNRM and DM.

Iterations	V_{pv}-MNRM	I_{pv}- MNRM	P_{pv}-MNRM	V_{pv}-DM	I_{pv}-DM	P_{pv}-DM	ε-MNRM	ε-DM
1	0.941300083	0.188260017	0.177209169	0.904838806	0.180967761	0.163746653	0.052207368	0.015746091
2	0.916342096	0.183268419	0.167936567	0.892634615	0.178526923	0.159359311	0.027249381	0.0035419
3	0.898461163	0.179692233	0.161446492	0.889298739	0.177859748	0.158170449	0.009368448	0.000206024
4	0.890439476	0.178087895	0.158576492	0.889093424	0.177818685	0.158097423	0.001346762	7.09617E-07
5	0.889122977	0.177824595	0.158107934	0.889092715	0.177818543	0.158097171	3.02626E-05	5.141E-12
6	0.889092724	0.177818545	0.158097175	0.889092715	0.177818543	0.158097171	9.66595E-09	0
7	0.889092715	0.177818543	0.158097171				1.22791E-13	
8	0.889092715	0.177818543	0.158097171				0	

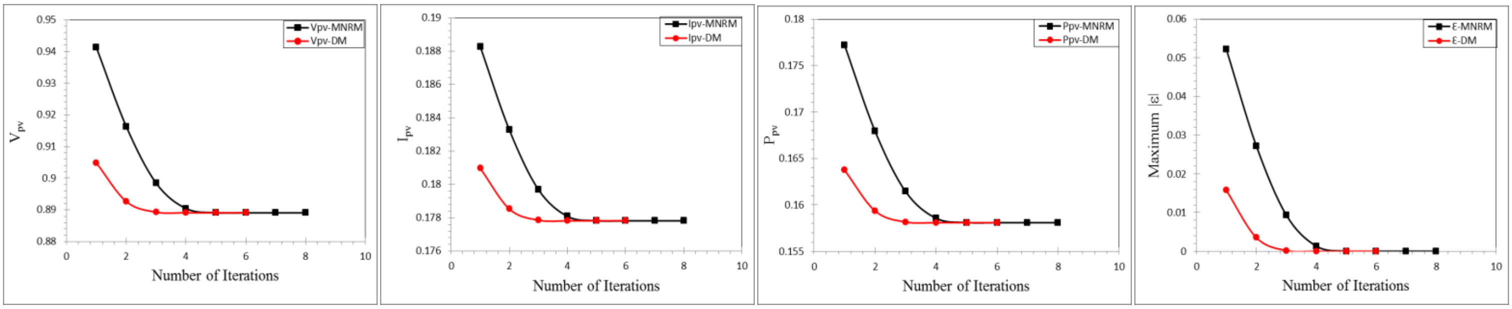

Fig. 5 – The results of MNRM and DM for solving Eq. 2.

6. Conclusion

In this paper, a DM and MNRM iterative methods based on Newton's expression were investigated. These methods were compared in the performance and efficient to the other famous methods. The suggested iterative methods are both convenient and effective with a least iterations. In addition, the suggested method works very well at the initial (starting) point unlike the other method is chosen from both roots. This fact was investigated clearly in the numerical experiments.

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