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Multistep Iterative Algorithms for Solving Nonlinear Equation

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A B S T R A C T

We present two new iterative methods, called the Secant and Dekker's Algorithms for solving nonlinear equations in this paper. These equations based on different values of load resistance R of a single diode scheme. We examined the effectiveness of these iterative methods by approximating the simple zeros of afford nonlinear equations. The approximate solutions of the numerical methods are accurate, stable, consistent and easy to use.

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1. Introduction

We shall present two iterative methods called Secant Algorithm and Dekker's Algorithm; root finding algorithms in order to find a simple zeros of a nonlinear equation in the kind of $f(x) = 0$ in the present work. It is popular that the algorithms in order to find the zeros of these equations have several application fields in engineering and science. We shall employ the most popular algorithm, called secant method because of it's simplicity and need a starting point or estimate and free from second derivative of the function $f(x)$. Many researchers are determined the roots of nonlinear equations of a solar cell in the field of science and engineering for example Rasheed et al. [1-115].

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

2. Formula and Property for Single-Diode Model

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

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

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. Secant Algorithm (SM)

Advantages of secant method over other root finding methods are

It is rate of convergence is faster than bisection method.

Secant method is no need to find the derivative of the function as in Newton-Raphson method.

Step 1: Suppose starting values x_0 and x_1

Step 2: Find $x_2, x_3, x_4, \ldots, x_n$ using the following expressions

$$x_2 = x_1 - f(x_1) \times \frac{x_1 - x_0}{f(x_1) - f(x_0)}$$
$$x_3 = x_3 - f(x_2) \times \frac{x_2 - x_1}{f(x_2) - f(x_1)} \quad (3)$$
$$\vdots$$
$$x_n = x_{n-1} - f(x_{n-1}) \times \frac{x_{n-1} - x_{n-2}}{f(x_{n-1}) - f(x_{n-2})}$$

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

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

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 Dekker's Algorithm (DM) represented in Eq. 4 acquired in the present paper in order to solve non-linear equation with the initial value $x_0 = 1$ and we compare it with Secant Algorithm (SM) represented in Eq. 3 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 SM algorithm needs 7 iterations while DM technique need 5 iterations to reach to the convergence which proves that the DM is faster than SM.

Table 1 - Determination of Eq. 2 of the results obtained by different numerical algorithms SM and DM.

Iterations	V_{pv}-SM	I_{pv}- SM	P_{pv}-SM	V_{pv}-DM	I_{pv}-DM	P_{pv}-DM	ε-SM	ε-DM
1	0.956342897	0.956342897	0.914591738	0.928076971	0.928076971	0.861326864	0.033919763	0.005653836
2	0.935676402	0.935676402	0.875490329	0.922905033	0.922905033	0.851753700	0.013253267	0.000481898
3	0.924881651	0.924881651	0.855406068	0.922426829	0.922426829	0.850871255	0.002458516	3.6943E-06
4	0.922517679	0.922517679	0.851038869	0.922423135	0.922423135	0.850864440	9.45447E-05	2.18963E-10
5	0.922423278	0.922423278	0.850864704	0.922423135	0.922423135	0.850864439	1.43773E-07	0

6	0.922423135	0.922423135	0.850864439				3.33178E-13	
7	0.922423135	0.922423135	0.850864439				0	

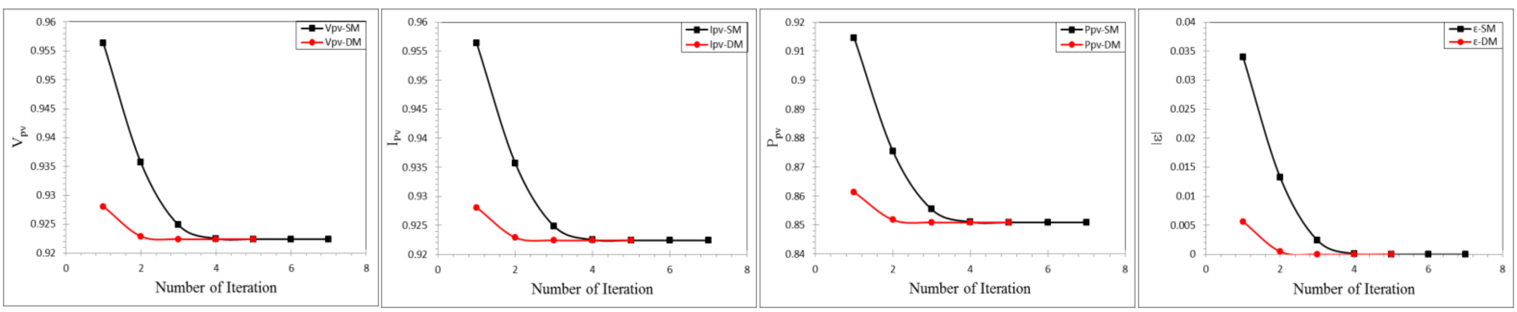

Fig. 1 – Solved SM and DM algorithms by means of Eq. 2.

Table 2 - Determination of Eq. 2 of the results obtained by different numerical algorithms SM and DM.

Iterations	V_{pv}-SM	I_{pv}- SM	P_{pv}-SM	V_{pv}-DM	I_{pv}-DM	P_{pv}-DM	ε-SM	ε-DM
1	0.955509809	0.477754904	0.456499497	0.924712910	0.462356455	0.427546983	0.038474426	0.007677528
2	0.933452268	0.466726134	0.435666569	0.917911499	0.458955750	0.421280760	0.016416886	0.000876117
3	0.920708719	0.460354360	0.423852273	0.917047635	0.458523817	0.420488182	0.003673337	1.22522E-05
4	0.917245199	0.458622600	0.420669378	0.917035385	0.458517692	0.420476949	0.000209817	2.42601E-09
5	0.917036095	0.458518047	0.420477600	0.917035382	0.458517691	0.420476946	7.12519E-07	0
6	0.917035382	0.458517691	0.420476946				8.24774E-12	
7	0.917035382	0.458517691	0.420476946				0	

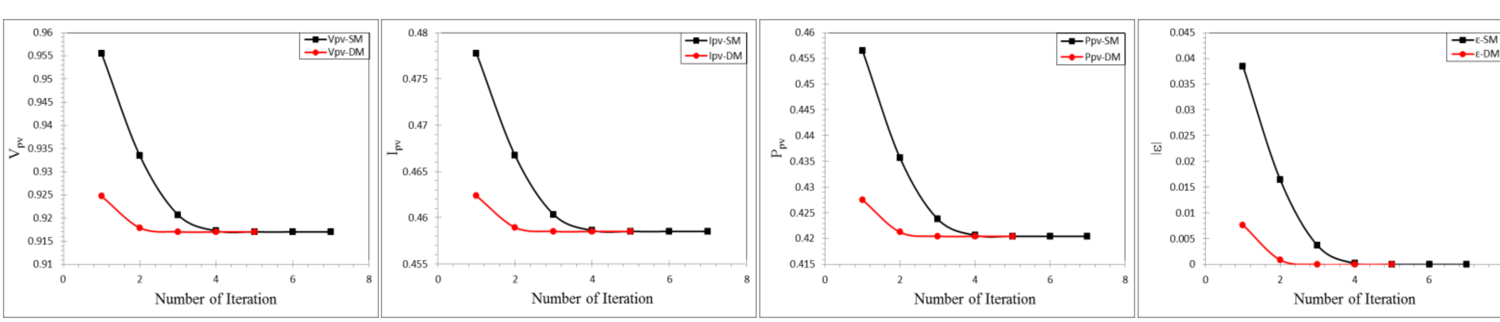

Fig. 2 – Solved SM and DM algorithms by means of Eq. 2.

Table 3 - Determination of Eq. 2 of the results obtained by different numerical algorithms SM and DM.

Iterations	V_{pv}-SM	I_{pv}- SM	P_{pv}-SM	V_{pv}-DM	I_{pv}-DM	P_{pv}-DM	ε-SM	ε-DM
1	0.954668501	0.318222834	0.303797316	0.921077731	0.307025910	0.282794729	0.044265127	0.010674357
2	0.931130761	0.310376920	0.289001498	0.912060122	0.304020041	0.277284556	0.020727387	0.001656748
3	0.916050375	0.305350125	0.279716096	0.910447324	0.303482441	0.276304776	0.005647001	4.39496E-05
4	0.910893770	0.303631257	0.276575820	0.910403406	0.303467802	0.276278120	0.000490396	3.15643E-08
5	0.910407299	0.303469100	0.276280483	0.910403374	0.303467791	0.276278101	3.92473E-06	1.64313E-14
6	0.910403374	0.303467791	0.276278101	0.910403374	0.303467791	0.276278101	2.53289E-10	0
7	0.910403374	0.303467791	0.276278101				0	

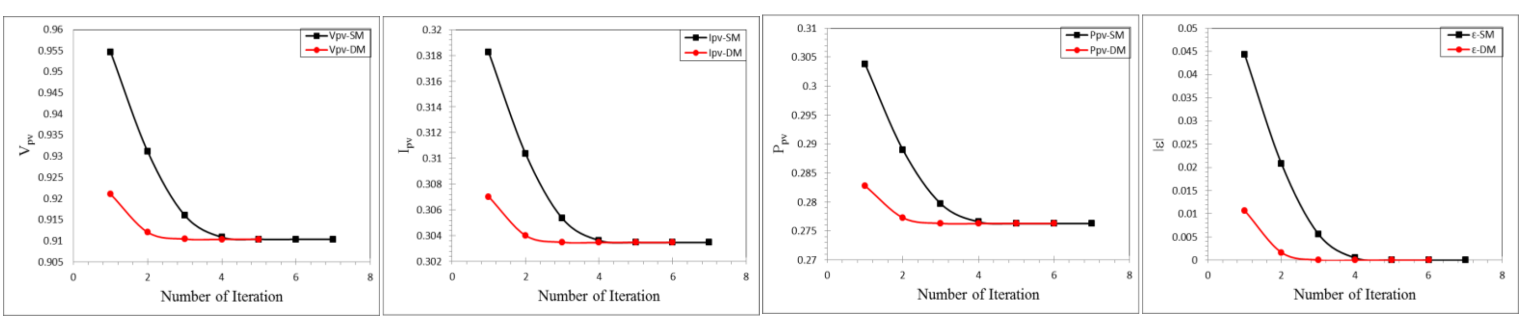

Fig. 3 – Solved SM and DM algorithms by means of Eq. 2.

Table 4 - Determination of Eq. 2 of the results obtained by different numerical algorithms SM and DM.

Iterations	V_{pv}-SM	I_{pv}- SM	P_{pv}-SM	V_{pv}-DM	I_{pv}-DM	P_{pv}-DM	ε-SM	ε-DM
1	0.953818908	0.238454727	0.227442627	0.917137477	0.229284369	0.210285288	0.052078306	0.015396875
2	0.928705897	0.232176474	0.215623661	0.905065248	0.226266312	0.204785776	0.026965295	0.003324646
3	0.910811452	0.227702863	0.207394375	0.901917691	0.225479423	0.203363880	0.009070850	0.000177089

4	0.902978861	0.225744715	0.203842706	0.901741124	0.225435281	0.203284264	0.001238259	5.22069E-07
5	0.901765899	0.225441475	0.203295434	0.901740602	0.225435150	0.203284028	2.52971E-05	4.56313E-12
6	0.901740613	0.225435153	0.203284033	0.901740602	0.225435150	0.203284028	1.07408E-08	0
7	0.901740602	0.22543515	0.203284028				1.9984E-15	
8	0.901740602	0.22543515	0.203284028				0	

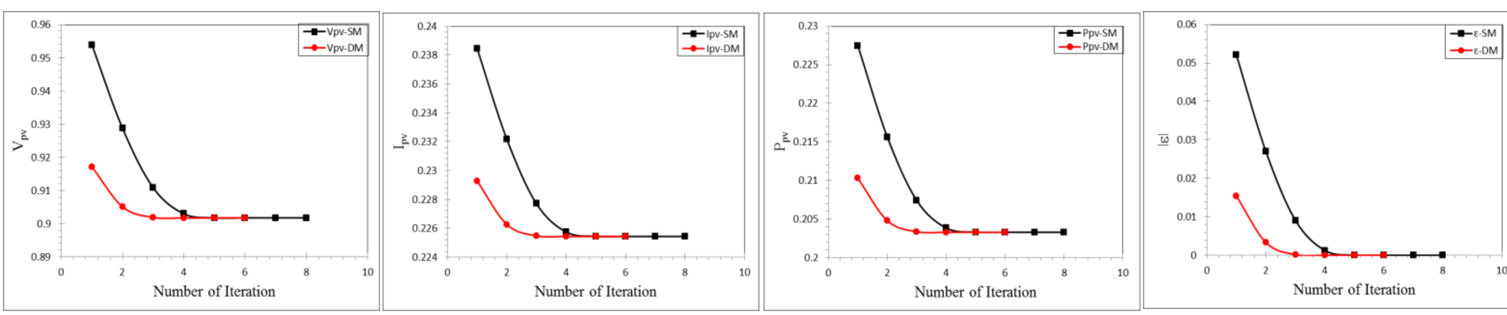

Fig. 4 – Solved SM and DM algorithms by means of Eq. 2.

Table 5 - Determination of Eq. 2 of the results obtained by different numerical algorithms SM and DM.

Iterations	V_{pv}-SM	I_{pv}- SM	P_{pv}-SM	V_{pv}-DM	I_{pv}-DM	P_{pv}-DM	ε-SM	ε-DM
1	0.952960959	0.190592192	0.181626918	0.912852792	0.182570558	0.166660044	0.063868245	0.023760077
2	0.926171251	0.185234250	0.171558637	0.896503075	0.179300615	0.160743553	0.037078536	0.00741036
3	0.904871952	0.180974390	0.16375865	0.889962786	0.177992557	0.158406752	0.015779238	0.000870071
4	0.892667280	0.178533456	0.159370975	0.889105769	0.177821154	0.158101814	0.003574566	1.3054E-05
5	0.889306005	0.177861201	0.158173034	0.889092718	0.177818544	0.158097172	0.00021329	2.98126E-09
6	0.889093511	0.177818702	0.158097454	0.889092715	0.177818543	0.158097171	7.96312E-07	2.22045E-16
7	0.889092715	0.177818543	0.158097171	0.889092715	0.177818543	0.158097171	1.11464E-11	0
8	0.889092715	0.177818543	0.158097171				0	

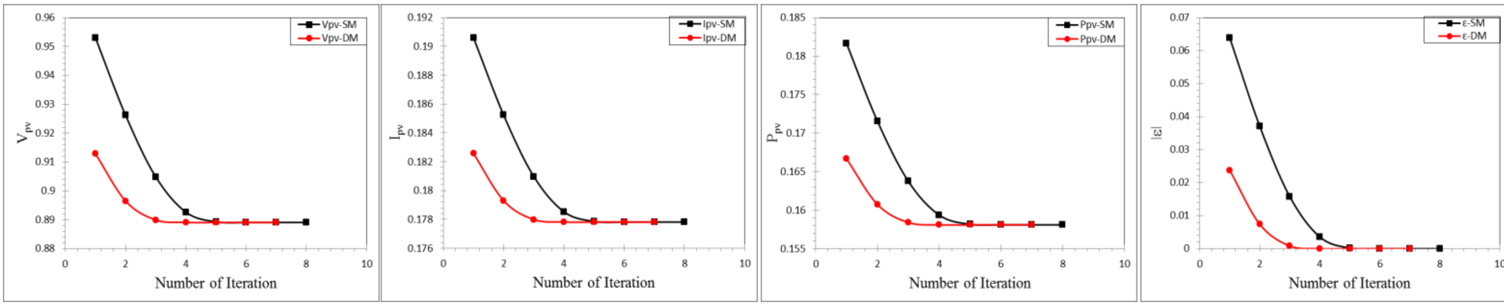

Fig. 5 – Solved SM and DM algorithms by means of Eq. 2.

6. Conclusion

We have investigated the performance of two iterative methods with three-step method in this paper. These methods are namely the secant and Dekker's methods. The main payer of the improvement of these new methods was to develop the sixth to fifth order using free from derivatives. The effectiveness of these methods has been examined by observing the accuracy of the zeros of a nonlinear equation for a single diode of a solar cell. The main purpose of investigating these methods for many kinds of nonlinear equations with variant values of load resistance from the equivalent circuit of the cell was illustrating the accuracy of the approximate solution. In fact, we have shown numerically and belayed that the new proposed methods have lesser evaluation than the standard one.

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