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Finding Roots of Nonlinear Equation for Optoelectronic Device

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Abstract. New three iterative methods in order to solve non-linear problems for PV cell equations with various data of R (load resistance) have been investigated. A series of hybrid algorithms Newton's, Predictor-Corrector Type (A1), Predictor-Corrector Type (A2) and Dekker's are implemented to obtain approximate solutions for non-linear functions. The purpose of the present paper is to analysis on numerical comparison between the standard Newton's algorithm with A1, A2 and DM algorithms. It is evidenced that these methods have nearly eight computations while; the proposed method has six computations per iteration. The Numerical and illustrative results reveal that the new suggested technique (DM) is more accurate, least iterations for convergence than other numerical methods and a computational Matlab 18a is used for this paper.

Keywords: Dekker's Formula; Predictor-Corrector Type (A2); Predictor-Corrector Type (A1); $f(x) = 0$; absolute error; roots of the equation

1. Introduction

Two, three and multipoint iterative methods for solving nonlinear equations are of good practical importance. Some of these iterative methods require second order derivative of the function while some of them need only first order of derivative of the function. The zeros of the function $f(x)$ are defined as the values for which the value of the function becomes equal to zero. Finding the roots of $f(x)$ means solving the equation $f(x) = 0$. For a large number of problems it is not possible to find exact values for the roots of the function so we have to find the approximations instead. In order to know the advantages and disadvantages of an iterative method, the error decreases rapidly with each iteration, the speed of an iterative method after comparison with other method, the convergence of the iterative method is very important. Recently, several researchers has been expressed that the iterative methods can be employ to betterment some iterative techniques in order to solve nonlinear examples in variant areas such as pure and science and engineering [1- 15].



This paper presents four hybrids numerical iterative Newton's, Predictor-Corrector Type (A1), Predictor-Corrector Type (A2) and Dekker's formulas concepts in order to generate faster and more accurate technique for solving the zeros of non-linear functions have been demonstrated here. The following steps are demonstrate the procedure of the present work: section two, three, four and five investigating the analytical model and the root finding of Newton's, Predictor-Corrector Type (A1), Predictor-Corrector Type (A2) and Dekker's formulas. Section six and seven show numerical problems, discussion and conclusion

2. Single-Diode PV Cell Modeling

The KCL Kirchoff's law is applied on the electrical circuit of PV cell-single-diode scheme [15-58]

$I = I_{ph} - I_D$ where $I_D = I_0 \left(e^{\frac{-V_{pv}}{nV_T}} - 1 \right)$, and $I = I_{ph} - I_0 \left(e^{\frac{-V_{pv}}{mV_T}} - 1 \right)$, $V_T = \frac{kT}{q} = 27.5 \text{ mV}$, $k = 1.38 \times 10^{-23} \text{ J/K}$ =Boltzmann constant, I_0 = reverse saturation current of the diode= 10^{-12} A , I_{ph} = the photocurrent, m values is between 1 to 2 indicate the recombination factor, T = p – n junction temperature, $q = 1.6 \times 10^{-19} \text{ C}$ = electron charge .

$$I_{ph} = I_{source}, I_D = I_s * \left(e^{\frac{V_D}{nV_T}} - 1 \right)$$

Substitute the value of I, yield

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

$$I_{pv} = \frac{V_{pv}}{R}; P_{pv} = I_{pv} \times V_{pv} \quad (2)$$

3. Predictor-Corrector Type (A1)

Step 1: assume the initial value as A_0

Step 2: A_0 , calculate A_{n+1} (approximate solution) by the iterative scheme

$$A_{n+1} = A_n - \frac{f(A_n)}{f'(A_n)} \quad (3)$$

$$A_{n+1} = A_n - \frac{6 \times f(A_n)}{f'(A_n) + 4 \times f\left(\frac{A_n + A_{n+1}^*}{2}\right) + f'(A_{n+1}^*)}, n = 0, 1, 2, 3, \dots \quad (4)$$

Step 3: If $|A_{n+1} - A_n| < \epsilon$, $|f(A_n)| < \epsilon$, $\epsilon = 10^{-9}$ as a tolerance; stop else go to Step 1.

4. Predictor- Corrector Type (A2)

Step 1: Let A_0 is a given initial value.

Step 2: calculate A_{n+1} by the iterations

$$A_{n+1} = A_n - \frac{6 \times f(A_n) \times f'(A_n)}{2 \times (f'(A_n))^2 - f(A_n) \times f''(A_n)} \quad (5)$$

Step 3: calculate

$$A_{n+1} = A_n - \frac{6 \times f(A_n)}{f'(A_n) + 4 \times f\left(\frac{A_n + A_{n+1}^*}{2}\right) + f'(A_{n+1}^*)}, n = 0, 1, 2, 3, \dots \quad (6)$$

Step 4: If $|A_{n+1} - A_n| < \epsilon$, $|f(A_n)| < \epsilon$, $\epsilon = 10^{-9}$ as a tolerance; stop else go to Step 1.

5. Dekker's Formula (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

$$y_{n+1} = \begin{cases} y_n - \frac{y_n - y_{n-1}}{f(y_n) - f(y_{n-1})} f(y_n) & \text{if } f(y_{n-1}) \neq f(y_n) \\ m & \text{otherwise} \end{cases} \quad (7)$$

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

$$m = \frac{a_n + b_n}{2} \quad (8)$$

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 $f(a_n)$ and $f(b_n)$ have opposite signs, so the interval $[a_n, b_n]$ consist of the solution.

6. Numerical Examples with Results and Discussion

The same initial value $v_0 = 1$ is utilized for four algorithms in order to obtain the roots of Eq. 1 (non-linear formula) are obtained by means of Newton's method (NRM), Predictor-Corrector Type (A1), Predictor-Corrector Type (A2) and Dekker's Formula (DM) by Eqns. 3, 4, 6 and 7 with predict guess. The approximate solutions produced by these four techniques, five various numerical experiments are utilized based on Eq. 1 which are depending on the resistance values (load resistance) differs from 1 to 5 ohm.

Tables and Figs. 1 to 5 show that DM algorithm need 6 iterations while NRM, A1 and A2 need 9, 8 and 8 iterations respectively in order to reach to the convergence which proves that DM is faster than the other algorithms.

Table 1. The iteration scheme of the A1, A2 and DM methods with starting value $v_0=1$.

<i>Iterations</i>	V_{pv} -NRM	I_{pv} -NRM	P_{pv} -A1	V_{pv} -A1	I_{pv} -A1	P_{pv} -A1
1	1	1	1	0.956353318	0.956353318	0.914611669
2	0.971416861	0.971416861	0.943650719	0.935681181	0.935681181	0.875499273
3	0.946732606	0.946732606	0.896302627	0.924882295	0.924882295	0.85540726
4	0.929865706	0.929865706	0.864650231	0.922517684	0.922517684	0.851038878
5	0.923247893	0.923247893	0.852386673	0.922423278	0.922423278	0.850864704
6	0.922434	0.922434	0.850884484	0.922423135	0.922423135	0.850864439
7	0.922423136	0.922423136	0.850864443	0.922423135	0.922423135	0.850864439
8	0.922423135	0.922423135	0.850864439			
9	0.922423135	0.922423135	0.850864439			
<i>Iterations</i>	V_{pv} -A2	I_{pv} -A2	P_{pv} -A2	V_{pv} -DM	I_{pv} -DM	P_{pv} -DM
1	0.909061968	0.909061968	0.826393662	0.924812944	0.924812944	0.85527898
2	0.912675411	0.912675411	0.832976406	0.922746426	0.922746426	0.851460967
3	0.920491417	0.920491417	0.847304449	0.922425145	0.922425145	0.850868148
4	0.922359246	0.922359246	0.850746579	0.922423135	0.922423135	0.850864439
5	0.922423038	0.922423038	0.850864262	0.922423135	0.922423135	0.850864439
6	0.922423135	0.922423135	0.850864439			
7	0.922423135	0.922423135	0.850864439			

<i>Iterations</i>	ε -NRM	ε -A1	ε -A2	ε -DM
1	0.077576865	0.033930183	0.013361166	0.002389809
2	0.048993727	0.013258047	0.009747723	0.000323292
3	0.024309472	0.002459161	0.001931717	2.01066E-06
4	0.007442571	9.45499E-05	6.38884E-05	9.90161E-11
5	0.000824759	0.922423278	9.61287E-08	0
6	1.08655E-05	3.33067E-13	2.23932E-13	
7	1.9025E-09	0	0	
8	1.11022E-16			
9	0			

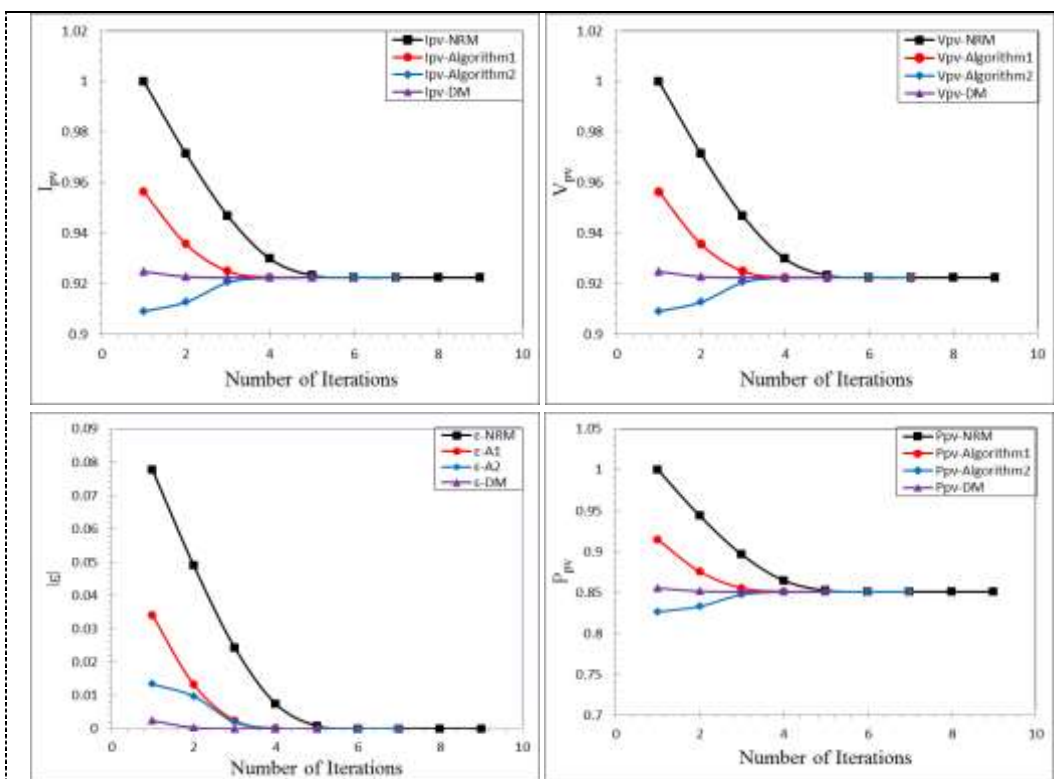


Figure 1. The approximated roots using Newton's method (NRM), Predictor-Corrector Type (A1), Predictor-Corrector Type (A2), Dekker's Formula (DM) via initial value, number of iterations needed to converge and load resistance $R = 1$.

Table 2. The iteration scheme of the A1, A2 and DM methods with starting value $v_0=1$.

<i>Iterations</i>	V_{pv} -NRM	I_{pv} -NRM	P_{pv} -A1	V_{pv} -A1	I_{pv} -A1	P_{pv} -A1
1	1	0.5	0.5	0.955521013	0.477760507	0.456510203
2	0.971030472	0.485515236	0.471450089	0.93345809	0.466729045	0.435672003
3	0.945421967	0.472710983	0.446911348	0.920709796	0.460354898	0.423853264
4	0.926834477	0.463417238	0.429511073	0.917245217	0.458622609	0.420669394
5	0.918438746	0.459219373	0.421764865	0.917036095	0.458518047	0.4204776
6	0.917066885	0.458533442	0.420505836	0.917035382	0.458517691	0.420476946
7	0.917035399	0.458517699	0.420476961	0.917035382	0.458517691	0.420476946
8	0.917035382	0.458517691	0.420476946			
9	0.917035382	0.458517691	0.420476946			
<i>Iterations</i>	V_{pv} -A2	I_{pv} -A2	P_{pv} -A2	V_{pv} -DM	I_{pv} -DM	P_{pv} -DM
1	0.904579258	0.452289629	0.409131817	0.919679286	0.459839643	0.422904994
2	0.905657295	0.452828647	0.410107568	0.917632869	0.458816434	0.421025041
3	0.914052791	0.457026396	0.417746253	0.917042599	0.458521299	0.420483564
4	0.916889024	0.458444512	0.420342741	0.917035384	0.458517692	0.420476947
5	0.917034902	0.458517451	0.420476505	0.917035382	0.458517691	0.420476946
6	0.917035382	0.458517691	0.420476946	0.917035382	0.458517691	0.420476946
7	0.917035382	0.458517691	0.420476946			
<i>Iterations</i>	ε -NRM	ε -A1	ε -A2	ε -DM		
1	0.082964618	0.038485631	0.012456124	0.002643903		
2	0.05399509	0.016422708	0.011378087	0.000597487		
3	0.028386584	0.003674413	0.002982591	7.21624E-06		
4	0.009799094	0.000209835	0.000146358	1.14432E-09		
5	0.001403363	0.917036095	4.80851E-07	0		
6	3.15024E-05	8.24774E-12	5.61473E-12			
7	1.61176E-08	0	0			
8	4.21885E-15					
9	0					

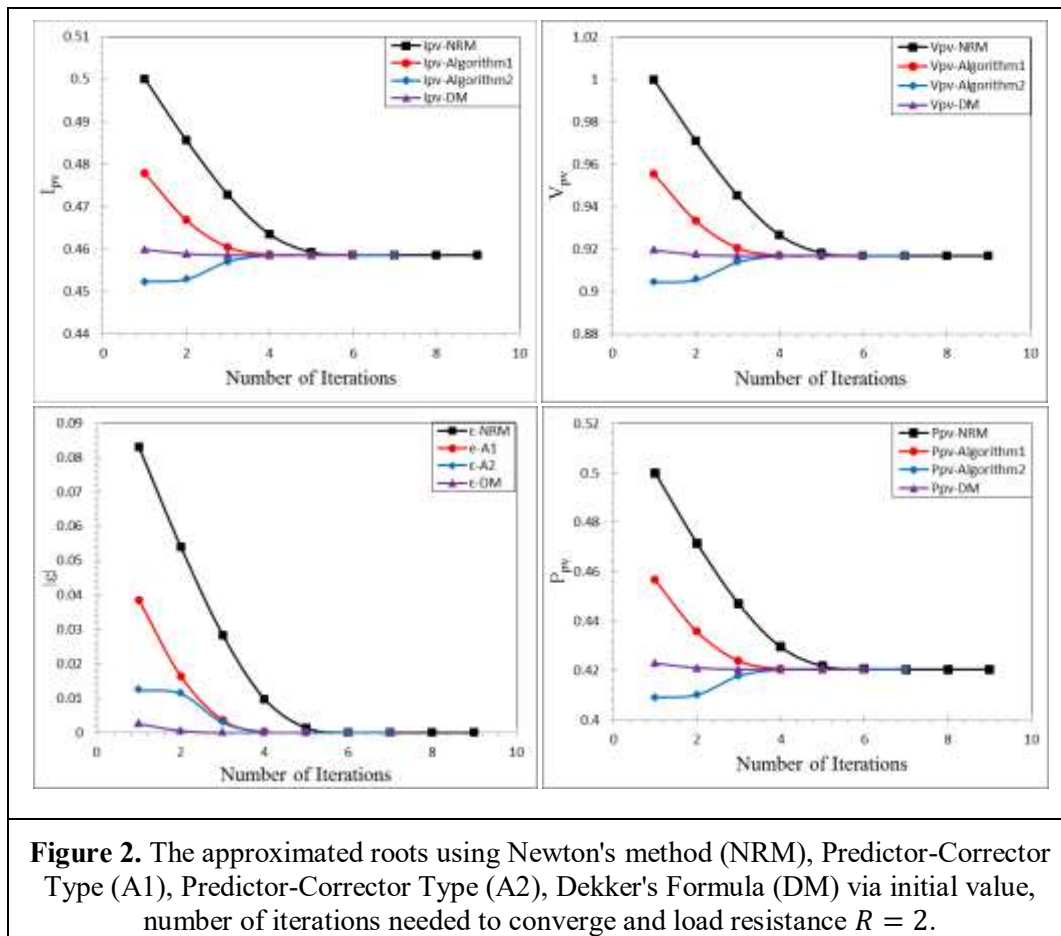


Table 3. The iteration scheme of the A1, A2 and DM methods with starting value $v_0=1$.

Iterations	$V_{pv}-NRM$	$I_{pv}-NRM$	$P_{pv}-A1$	$V_{pv}-A1$	$I_{pv}-A1$	$P_{pv}-A1$
1	1	0.333333333	0.333333333	0.954680538	0.318226846	0.303804977
2	0.970643792	0.323547931	0.31404979	0.931137845	0.310379282	0.289005896
3	0.944084232	0.314694744	0.297098346	0.916052182	0.305350727	0.2797172
4	0.923594243	0.307864748	0.284342109	0.910893833	0.303631278	0.276575858
5	0.91287784	0.304292613	0.277781984	0.910407299	0.3034691	0.276280483
6	0.910501262	0.303500421	0.276337516	0.910403374	0.303467791	0.276278101
7	0.910403531	0.303467844	0.276278197	0.910403374	0.303467791	0.276278101
8	0.910403374	0.303467791	0.276278101			
9	0.910403374	0.303467791	0.276278101			
Iterations	$V_{pv}-A2$	$I_{pv}-A2$	$P_{pv}-A2$	$V_{pv}-DM$	$I_{pv}-DM$	$P_{pv}-DM$
1	0.899816691	0.299938897	0.269890026	0.91301331	0.30433777	0.277864435
2	0.897407275	0.299135758	0.268446606	0.911519924	0.303839975	0.27695619
3	0.905697121	0.30189904	0.273429092	0.910432146	0.303477382	0.276295564
4	0.910042334	0.303347445	0.276059017	0.91040339	0.303467797	0.276278111
5	0.910400684	0.303466895	0.276276468	0.910403374	0.303467791	0.276278101
6	0.910403374	0.303467791	0.276278101	0.910403374	0.303467791	0.276278101
7	0.910403374	0.303467791	0.276278101			

<i>Iterations</i>	ϵ -NRM	ϵ -A1	ϵ -A2	ϵ -DM
1	0.089596626	0.044277164	0.010586683	0.002609936
2	0.060240418	0.020734471	0.012996099	0.00111655
3	0.033680858	0.005648808	0.004706253	2.87722E-05
4	0.013190869	0.000490459	0.00036104	1.60093E-08
5	0.002474466	0.910407299	2.69045E-06	0
6	9.78883E-05	2.53289E-10	1.75739E-10	
7	1.57417E-07	0	0	
8	4.07563E-13			
9	0			

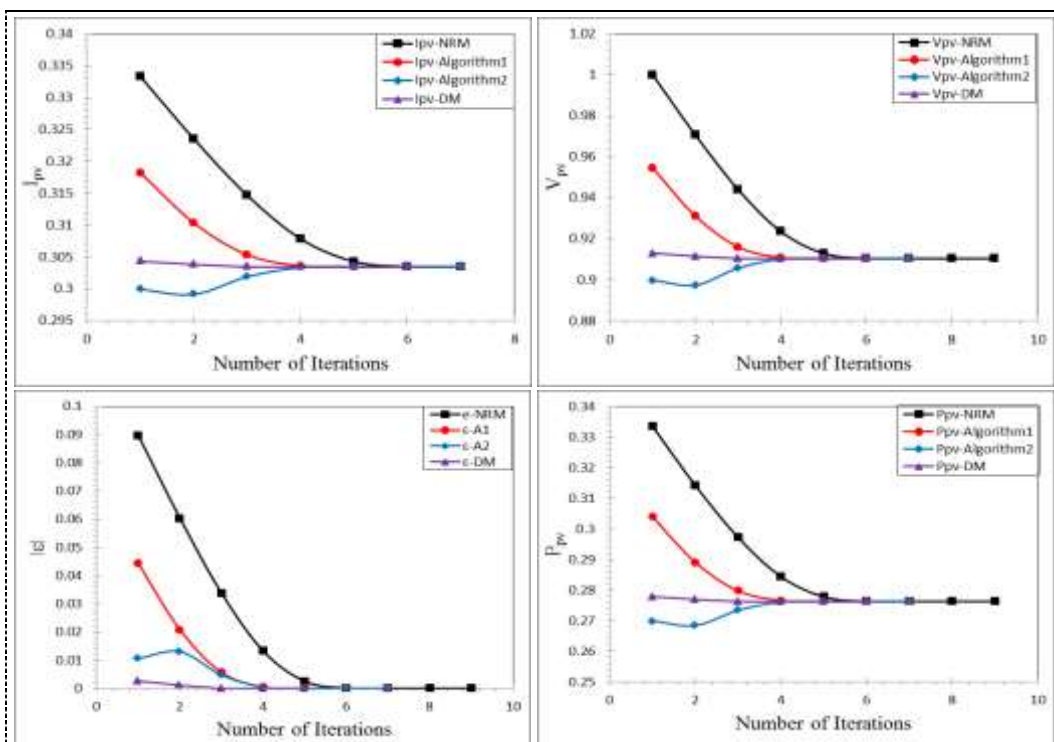


Figure 3. The approximated roots using Newton's method (NRM), Predictor-Corrector Type (A1), Predictor-Corrector Type (A2), Dekker's Formula (DM) via initial value, number of iterations needed to converge and load resistance $R = 3$.

Table 4. The iteration scheme of the A1, A2 and DM methods with starting value $v_0=1$.

<i>Iterations</i>	V_{pv} -NRM	I_{pv} -NRM	P_{pv} -A1	V_{pv} -A1	I_{pv} -A1	P_{pv} -A1
1	1	0.25	0.25	0.953831829	0.238457957	0.227448789
2	0.970256822	0.242564205	0.235349575	0.928714508	0.232178627	0.215627659
3	0.94271872	0.23567968	0.222179646	0.910814499	0.227703625	0.207395763
4	0.920123009	0.230030752	0.211656588	0.902979093	0.225744773	0.20384281
5	0.906346494	0.226586624	0.205365992	0.9017659	0.225441475	0.203295434
6	0.902077706	0.225519427	0.203436047	0.901740613	0.225435153	0.203284033
7	0.901742503	0.225435626	0.203284885	0.901740602	0.22543515	0.203284028
8	0.901740602	0.225435151	0.203284028	0.901740602	0.22543515	0.203284028
9	0.901740602	0.22543515	0.203284028			
<i>Iterations</i>	V_{pv} -A2	I_{pv} -A2	P_{pv} -A2	V_{pv} -DM	I_{pv} -DM	P_{pv} -DM
1	0.894754474	0.223688618	0.200146392	0.903639094	0.225909773	0.204140903
2	0.88761038	0.221902595	0.196963047	0.903806911	0.225951728	0.204216733
3	0.894168824	0.223542206	0.199884471	0.90187436	0.22546859	0.20334434
4	0.900742902	0.225185726	0.202834444	0.901740905	0.225435226	0.203284165
5	0.901722644	0.225430661	0.203275931	0.901740602	0.22543515	0.203284028
6	0.901740594	0.225435149	0.203284025	0.901740602	0.22543515	0.203284028
7	0.901740602	0.22543515	0.203284028			
8	0.901740602	0.22543515	0.203284028			
<i>Iterations</i>	ε -NRM	ε -A1	ε -A2	ε -DM		
1	0.098259398	0.052091227	0.006986128	0.001898492		
2	0.06851622	0.026973906	0.014130222	0.002066309		
3	0.040978118	0.009073897	0.007571778	0.000133758		
4	0.018382407	0.001238491	0.0009977	3.02829E-07		
5	0.004605892	0.9017659	1.79584E-05	0		
6	0.000337104	1.07408E-08	7.70016E-09			
7	1.90088E-06	0	0			
8	6.06911E-11					
9	0					

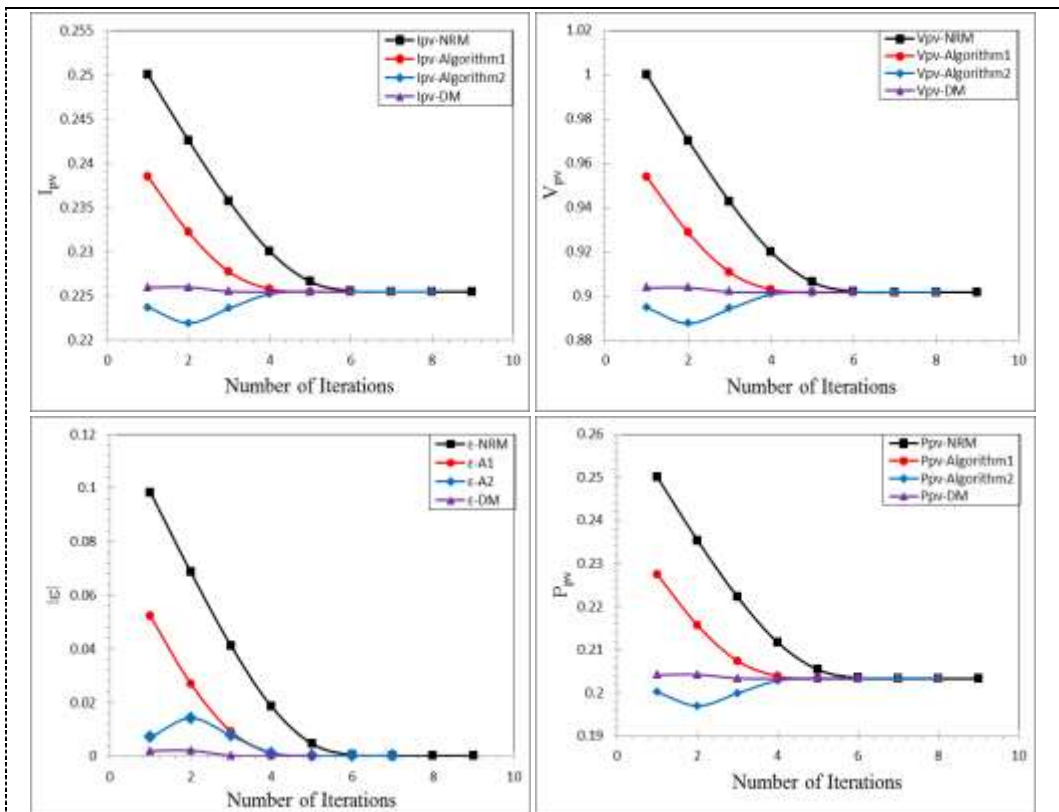


Figure 4. The approximated roots using Newton's method (NRM), Predictor-Corrector Type (A1), Predictor-Corrector Type (A2), Dekker's Formula (DM) via initial value, number of iterations needed to converge and load resistance $R = 4$.

Table 5. The iteration scheme of the A1, A2 and DM methods with starting value $v_0=1$.

<i>Iterations</i>	V_{pv} -NRM	I_{pv} -NRM	P_{pv} -A1	V_{pv} -A1	I_{pv} -A1	P_{pv} -A1
1	1	0.2	0.2	0.952974818	0.190594964	0.181632201
2	0.96986956	0.193973912	0.188129393	0.926181706	0.185236341	0.171562511
3	0.941324731	0.188264946	0.17721845	0.904877121	0.180975424	0.163760521
4	0.916395843	0.183279169	0.167956268	0.892668197	0.178533639	0.159371302
5	0.898535645	0.179707129	0.161473261	0.88930602	0.177861204	0.15817304
6	0.890477009	0.178095402	0.158589861	0.889093511	0.177818702	0.158097454
7	0.889125763	0.177825153	0.158108925	0.889092715	0.177818543	0.158097171
8	0.889092734	0.177818547	0.158097178	0.889092715	0.177818543	0.158097171
9	0.889092715	0.177818543	0.158097171			
10	0.889092715	0.177818543	0.158097171			
<i>Iterations</i>	V_{pv} -A2	I_{pv} -A2	P_{pv} -A2	V_{pv} -DM	I_{pv} -DM	P_{pv} -DM
1	0.889371467	0.177874293	0.158196321	0.889021793	0.177804359	0.15807195
2	0.875855338	0.175171068	0.153424515	0.892522023	0.178504405	0.159319112
3	0.876941816	0.175388363	0.15380539	0.889885306	0.177977061	0.158379171
4	0.885772918	0.177154584	0.156918733	0.889102851	0.17782057	0.158100776
5	0.888923198	0.17778464	0.158036891	0.889092717	0.177818543	0.158097172
6	0.889092102	0.17781842	0.158096953	0.889092715	0.177818543	0.158097171
7	0.889092715	0.177818543	0.158097171	0.889092715	0.177818543	0.158097171
8	0.889092715	0.177818543	0.158097171			
<i>Iterations</i>	ε -NRM	ε -A1	ε -A2	ε -DM		
1	0.110907285	0.063882103	0.000278752	7.09216E-05		
2	0.080776845	0.037088991	0.013237377	0.003429308		
3	0.052232016	0.015784406	0.012150899	0.000792591		
4	0.027303128	0.003575482	0.003319796	1.01362E-05		
5	0.00944293	0.000213306	0.000169516	1.82848E-09		
6	0.001384294	7.96314E-07	6.12875E-07	1.11022E-16		
7	3.30483E-05	1.11464E-11	8.69149E-12	0		
8	1.91907E-08	0	0			
9	6.43929E-15					
10	0					

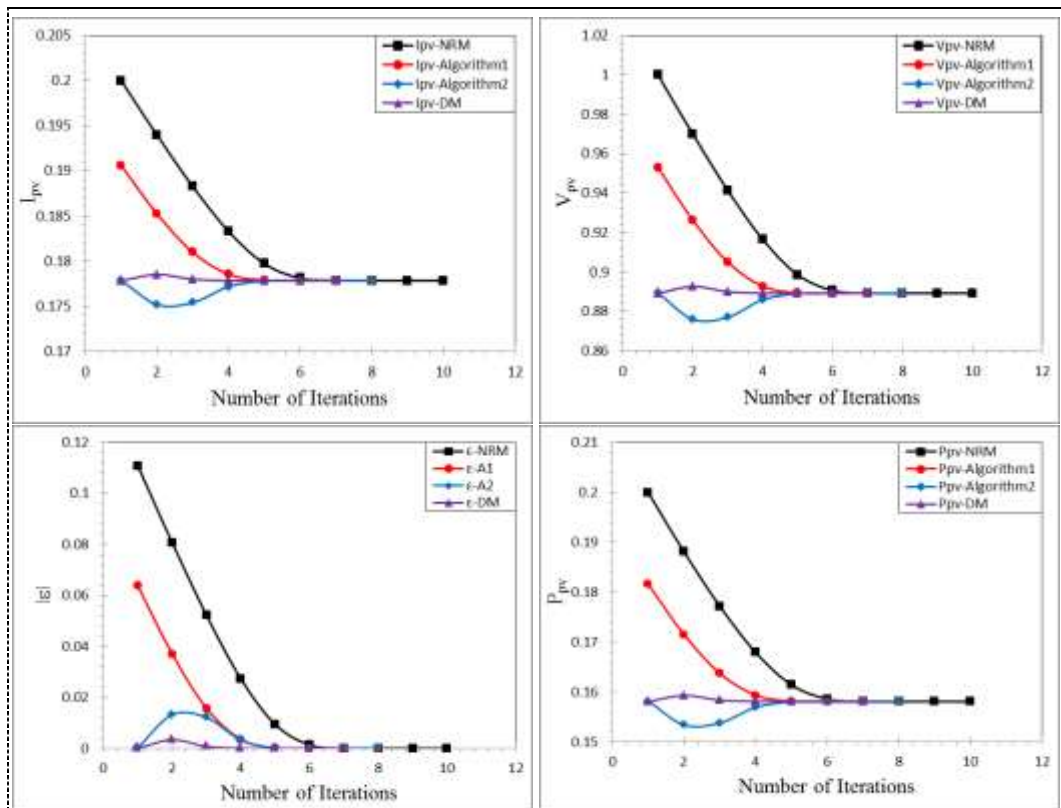


Figure 5. The approximated roots using Newton's method (NRM), Predictor-Corrector Type (A1), Predictor-Corrector Type (A2), Dekker's Formula (DM) via initial value, number of iterations needed to converge and load resistance $R = 5$.

In the Figures and Tables from 1 to 5, it is conclude that the proposed method (DM) selects a lesser number of iterations (6) than the other three algorithms (NRM, A1 and A2 (9, 8 and 8), respectively in accelerating the convergence rate in order to solve non-linear functions. In addition, the results acquired in the last column for the Tables show the tolerance error's data is least for of the (DM) technique comparing with other techniques, then the computing time is reduced and the (DM) technique is faster.

7. Conclusion

In this study, we have structured new iterative methods is used in order to solve non-linear equation of solar cell based on single diode model. From the obtained results in the tables 1-5 based on a number of examples; it can be concluded that the number of iterations of the proposed method DM is five and leaser than the other iterative methods Predictor-Corrector Type (A1), Predictor-Corrector Type (A2). The stopping criterion has been taken as $|x_{n+1} - \alpha| + |f(x_{n+1})| < 10^9$ for the numerical evaluations displayed here.

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