On the Solution of Nonlinear Equation for Photovoltaic Cell Using New Iterative Algorithms

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Abstract. Root finding is a basic example that still remnant an interest to several researchers. Several hybrid experiments are developed to obtain approximate solutions for nonlinear equations. Thus, this paper presents an analysis on numerical comparison between common method and the other methods. An evaluation iterative method MATLAB is utilized for this paper. Numerical and interpretative results prove that Dekker's Formula is acceptably efficient, accurate, and easy to use compared with other iterative methods.

Keywords: Newton's Method; Predictor-Corrector Halley's formula; Accelerated Predictor-Corrector Halley's method; Dekker's Formula; approximation; starting point.

1. Introduction

Iterative methods supplied as a promising method in order to solve nonlinear experiments in several fields of engineering, pure and science Newton's formula is the numerical method popular for it is accuracy and efficiency which is verified for it is 2^{nd} order of convergence. This method do not require second derivative of the function like other numerical methods. This paper indicates hybrid methods in order to produce more fast and effective ways for obtaining the zeros of non-linear examples of the function in the kind $f(x) = 0$. Many researchers are focused on this branch for solving the roots of nonlinear equation of solar cell bases on single diode form [1-10]. Various kinds of iterative methods have been utilized in order to solve non-linear problems [11-21]. In addition, these methods can be used for solving many problems in physics and engineering [22-40]. For more applications of different algorithms have been used in celestial mechanics [41-58].

Four new numerical iterative algorithms Newton's Method; Predictor- Corrector Halley's formula; Accelerated Predictor-Corrector Halley's method and Dekker's Formula based on several numerical techniques for predicted the roots of bob-linear examples have been investigated in this paper. The following steps are investigate the procedure of this work: section two and three investigating the

analytical model and the root finding of Newton's method. Section four, five and six demonstrated the zeros finding of Predictor-Corrector Halley's formula, Accelerated Predictor-Corrector Halley's method and Dekker's Formula. Section seven investigate the root finding of Accelerated Predictor-Corrector Halley's method; section 6 introduce the root finding of Dekker's Formula; section 7 and eight indicated numerical example, discussion and conclusion.

2. A Model for Solar Cells Module Optimization

The KCL Kirchhoff's law is applied on the electrical circuit of PV cell-single-diode scheme [10-20]

$I = I_{ph} - I_D$ where $I_D = I_0\left(e^{\frac{-V_{pv}}{nV_T}} - 1\right)$, and $I = I_{ph} - I_0\left(e^{\frac{-V_{pv}}{mV_T}} - 1\right)$, $V_T = \frac{kT}{q} = 27.5\ mV$, $k = 1.38 \times 10^{-23} J/K$=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, $q = 1.6 \times 10^{-19}$ 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. Newton's Algorithm (NRM)

[1] $x_0 = 1$ (Initial value).
[2] x_{n+1} (Approximate solution).
[3] Step 1: Set $x = 0$
[4] Step 2: while $i \le x_0$
[5] Step 3: Calculate the equation
$x_{n+1} = x_n - \frac{f(x_n)}{\hat{f}(x_n)}$ for $n = 0, 1, 2, ...$ (3)
[6] Step 4: if $|x_i - x_{i-1}| < \varepsilon$; then OUTPUT x_{n+1} and stop.
[7] Step 5: $i = i + 1$; $n = n + 1$ and go to Step 2.
[8] Step 6: OUTPUT

4. Predictor- Corrector Halley's Formula (HM)

The following steps indicate Predictor- Corrector Halley's Method (HM)
[1] Step 1: consider the initial values of x_0
[2] Step 2: compute y_n using the following equation $y_n = x_n - \frac{f(x_n)}{\hat{f}(x_n)}$
[3] Step 3: calculate x_{n+1} using the following formula $x_{n+1} = y_n - \frac{2 \times f(y_n)\hat{f}(y_n)}{2 \times \hat{f}(y_n)^2 - f(y_n) \times \hat{\hat{f}}(y_n)}$ (4)
[4] Step 4: If $|x_{n+1} - x_n| < \varepsilon$, $|f(x_n)| < \varepsilon$, $\varepsilon = 10^{-9}$ as a tolerance; stop else go to Step 1.

5. Accelerated Predictor-Corrector Halley's Method (AHM)

The following steps describe this method
[1] Step 1: let x_n is initial value

[2] Step 2: calculate Algorithm 1: Newton's Method (NRM) using the equation

$$x_{n+1} = x_n - \frac{f(x_n)}{\acute{f}(x_n)},\ n = 0, 1, 2, 3, \ldots \quad (5)$$

[3] Step 3: determine Algorithm 2: Predictor- Corrector Hally Method (HM) using the equations $y_n = x_n - \frac{f(x_n)}{\acute{f}(x_n)}$ (6)

$$x_{n+1} = y_n - \frac{2\times f(y_n)\acute{f}(y_n)}{2\times \acute{f}(y_n)^2 - f(y_n)\times \acute{\acute{f}}(y_n)} \quad (7)$$

[4] Step 4: examine Algorithm 3: Accelerated Predictor- Corrector Hally Method (AHM) using the equations $y_n = x_n - \frac{f(x_n)}{\acute{f}(x_n)}$ (8)

$$x_{n+1} = y_n - \frac{2\times f(y_n)\acute{f}(y_n)}{2\times \acute{f}(y_n)^2 - f(y_n)\times \acute{\acute{f}}(y_n)},\ n = 0, 1, 2, 3, \ldots \quad (9)$$

$$z_n = x_n - \frac{(x_{n+1} - x_n)^2}{x_{n+2} - 2\times x_{n+1} + x_n},\ n = 0, 1, 2, 3, \ldots \quad (10)$$

[5] Step 5: If $|x_{n+1} - x_n| < \varepsilon$, $|f(x_n)| < \varepsilon$, $\varepsilon = 10^{-9}$ as a tolerance; stop else go to Step 2.

6. 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

$$x_{n+1} = \begin{cases} x_n - \frac{x_n - x_{n-1}}{f(x_n) - f(x_{n-1})} f(x_n) & \text{if } f(x_{n-1}) \neq f(x_n) \\ m & \text{otherwise} \end{cases} \quad (11)$$

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

$$m = \frac{a_n + b_n}{2} \quad (12)$$

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.

7. Results and Discussion

Predictor guess $x_0 = 1$ is used in order to find the zeros of Eq. 1 (non-linear formula) are obtained by means of four algorithms Newton's method (NRM) and the proposed algorithms, Predictor-Corrector Halley's Formula (HM), Accelerated Predictor-Corrector Halley's Method (AHM) and Dekker's Formula (DM) by Eqns. 3, 4, 10 and 11 with predict guess. The approximate solutions produced by these techniques, five various numerical experiments are utilized based on Eq. 1 which are depending on the resistance values (load resistance) which varies from 1 to 5 ohm.

The results in Tables 1 to 5 and Figs. 2 to 6 show that DM algorithm need 4 iterations while NRM, HM and AHM need 10, 9 and 6 iterations respectively in order to reach to the convergence which proves that DM is faster than the other techniques.

Table 1. Numerical experiment results of the existing algorithm, Newton's method (NRM) and the proposed algorithms, Predictor-Corrector Halley's Formula (HM), Accelerated Predictor-Corrector Halley's Method (AHM) and Dekker's Formula (DM) using starting point x_0=1.

Iterations	V_{pv} *-NRM*	I_{pv} *-NRM*	P_{pv} *-NRM*	V_{pv} *-HM*	I_{pv} *-HM*	P_{pv} *-HM*
1	1	1	1	0.97141684	0.97141684	0.943650676
2	0.971416861	0.971416861	0.943650719	0.946732533	0.946732533	0.89630249
3	0.946732606	0.946732606	0.896302627	0.929865621	0.929865621	0.864650074
4	0.929865706	0.929865706	0.864650231	0.923247877	0.923247877	0.852386643
5	0.923247893	0.923247893	0.852386673	0.922434	0.922434	0.850884484
6	0.922434	0.922434	0.850884484	0.922423136	0.922423136	0.850864443
7	0.922423136	0.922423136	0.850864443	0.922423135	0.922423135	0.850864439
8	0.922423135	0.922423135	0.850864439	0.922423135	0.922423135	0.850864439
9	0.922423135	0.922423135	0.850864439			

Iterations	V_{pv} *-AHM*	I_{pv} *-AHM*	P_{pv} *-AHM*	V_{pv} *-DM*	I_{pv} *-DM*	P_{pv} *-DM*
1	0.893473351	0.893473351	0.79829463	0.924329807	0.924329807	0.854385591
2	0.918974893	0.918974893	0.844514854	0.922428985	0.922428985	0.850875231
3	0.922319869	0.922319869	0.850673942	0.922423135	0.922423135	0.85086444
4	0.922422989	0.922422989	0.850864171	0.922423135	0.922423135	0.850864439
5	0.922423135	0.922423135	0.850864439			
6	0.922423135	0.922423135	0.850864439			
Iterations	ε *-AHM*	ε *-AHM*	ε *-AHM*	ε *-DM*		
1	0.077576865	0.048993705	0.028949783	0.924329807		
2	0.048993727	0.024309399	0.003448242	0.922428985		
3	0.024309472	0.007442487	0.000103265	0.922423135		
4	0.007442571	0.000824743	1.45059E-07	0.922423135		
5	0.000824759	1.08652E-05	3.33067E-13			
6	1.08655E-05	1.90246E-09	0			
7	1.9025E-09	1.11022E-16				
8	1.11022E-16	0				
9	0					

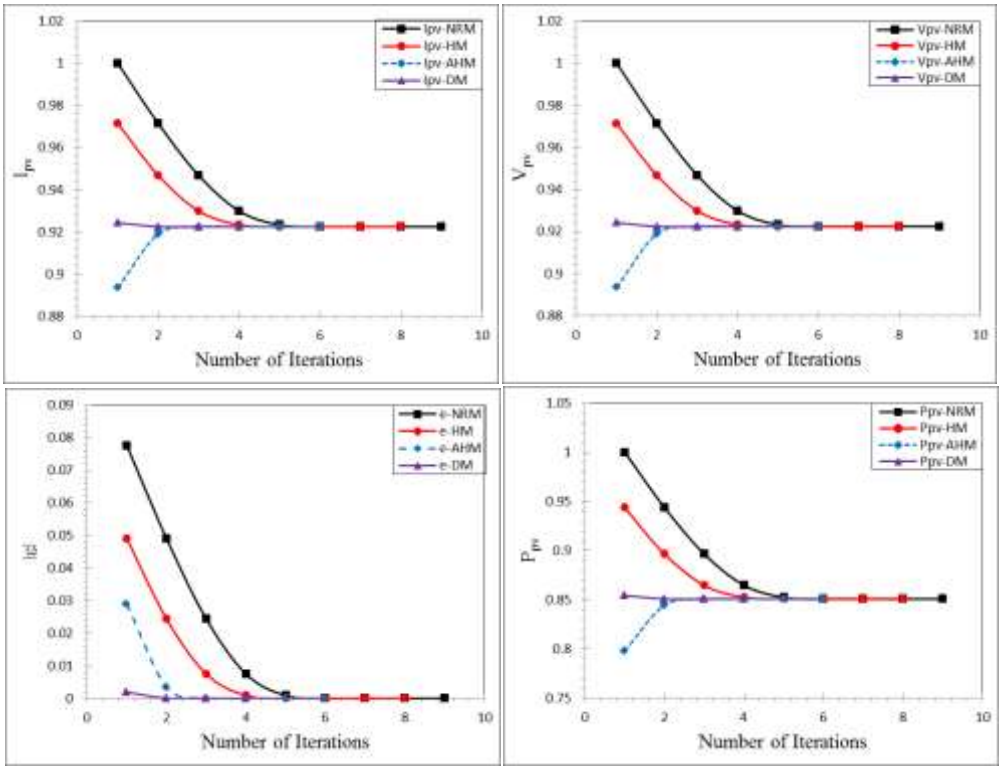

Figure 1. Comparison of Newton's algorithm (NRM) and the proposed algorithms, Predictor-Corrector Halley's Formula (HM), Accelerated Predictor-Corrector Halley's Method (AHM) and Dekker's Formula (DM) using $R = 1$.

Table 2. Numerical experiment results of the existing algorithm, Newton's method (NRM) and the proposed algorithms, Predictor-Corrector Halley's Formula (HM), Accelerated Predictor-Corrector Halley's Method (AHM) and Dekker's Formula (DM) using starting point x_0=1.

Iterations	V_{pv} *-NRM*	I_{pv} *-NRM*	P_{pv} *-NRM*	V_{pv} *-HM*	I_{pv} *-HM*	P_{pv} *-HM*
1	1	0.5	0.5	0.971030449	0.485515224	0.471450066
2	0.97103047	0.48551524	0.47145009	0.945421879	0.47271094	0.446911265
3	0.94542197	0.47271098	0.44691135	0.926834345	0.463417173	0.429510952
4	0.92683448	0.46341724	0.42951107	0.918438709	0.459219354	0.421764831
5	0.91843875	0.45921937	0.42176486	0.917066884	0.458533442	0.420505835
6	0.91706688	0.45853344	0.42050584	0.917035399	0.458517699	0.420476961
7	0.9170354	0.4585177	0.42047696	0.917035382	0.458517691	0.420476946
8	0.91703538	0.45851769	0.42047695	0.917035382	0.458517691	0.420476946
9	0.91703538	0.45851769	0.42047695			
Iterations	V_{pv} *-AHM*	I_{pv} *-AHM*	P_{pv} *-AHM*	V_{pv} *-DM*	I_{pv} *-DM*	P_{pv} *-DM*
1	0.877625589	0.438812794	0.385113337	0.921533764	0.460766882	0.424612239
2	0.911522753	0.455761377	0.415436865	0.91705724	0.45852862	0.420496991
3	0.916798952	0.458399476	0.420260159	0.917035385	0.458517693	0.420476949
4	0.917034659	0.458517329	0.420476283	0.917035382	0.458517691	0.420476946
5	0.917035382	0.458517691	0.420476946	0.917035382	0.458517691	0.420476946
6	0.917035382	0.458517691	0.420476946			

Iterations	*ε-AHM*	*ε-AHM*	*ε-AHM*	*ε-DM*
1	0.082964618	0.053995066	0.039409793	0.004498381
2	0.05399509	0.028386497	0.005512629	2.18578E-05
3	0.028386584	0.009798963	0.000236431	2.78276E-09
4	0.009799094	0.001403327	7.23492E-07	0
5	0.001403363	3.15015E-05	8.25018E-12	
6	3.15024E-05	1.61171E-08	0	
7	1.61176E-08	4.21885E-15		
8	4.21885E-15	0		
9	0			

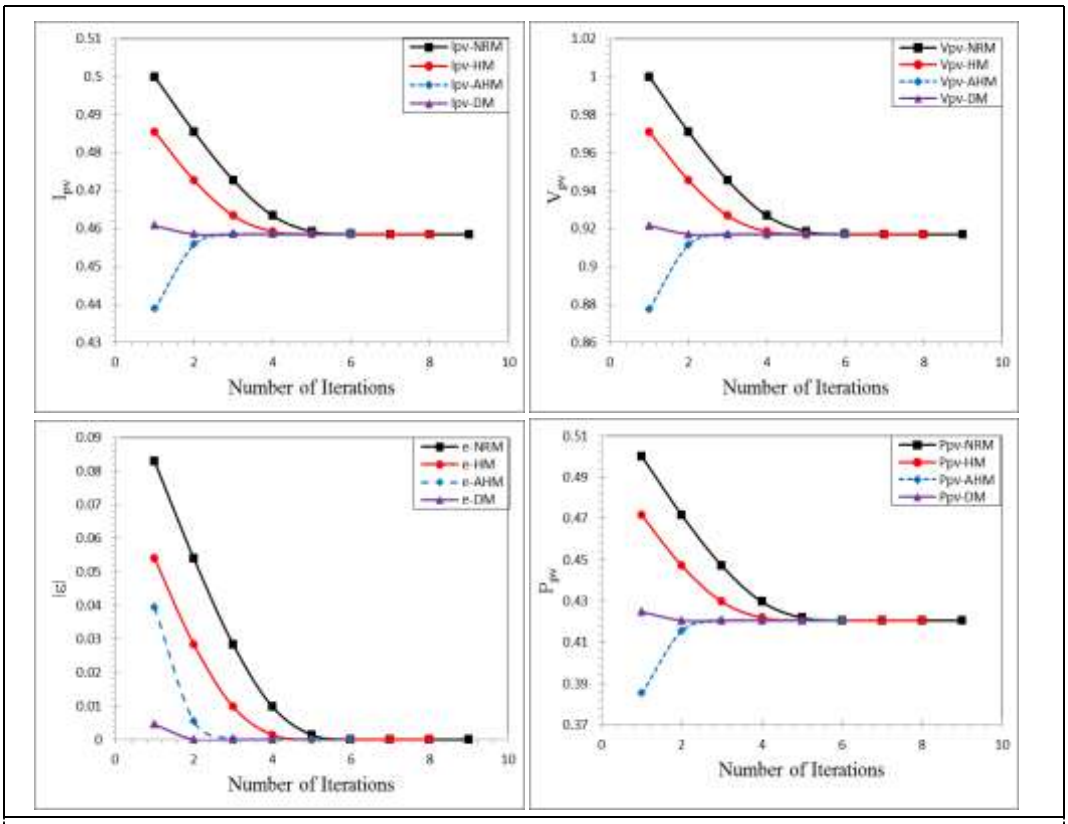

Figure 2. Comparison of Newton's algorithm (NRM) and the proposed algorithms, Predictor-Corrector Halley's Formula (HM), Accelerated Predictor-Corrector Halley's Method (AHM) and Dekker's Formula (DM) using $R = 2$.

Table 3. Numerical experiment results of the existing algorithm, Newton's method (NRM) and the proposed algorithms, Predictor-Corrector Halley's Formula (HM), Accelerated Predictor-Corrector Halley's Method (AHM) and Dekker's Formula (DM) using starting point x_0=1.

Iterations	V_{pv} *-NRM*	I_{pv} *-NRM*	P_{pv} *-NRM*	V_{pv} *-HM*	I_{pv} *-HM*	P_{pv} *-HM*
1	1	0.333333333	0.333333333	0.970643767	0.323547922	0.314049774
2	0.970643792	0.323547931	0.31404979	0.944084126	0.314694709	0.297098279
3	0.944084232	0.314694744	0.297098346	0.923594034	0.307864678	0.28434198
4	0.923594243	0.307864748	0.284342109	0.912877747	0.304292582	0.277781927
5	0.91287784	0.304292613	0.277781984	0.910501258	0.303500419	0.276337514
6	0.910501262	0.303500421	0.276337516	0.910403531	0.303467844	0.276278197
7	0.910403531	0.303467844	0.276278197	0.910403374	0.303467791	0.276278101
8	0.910403374	0.303467791	0.276278101	0.910403374	0.303467791	0.276278101
9	0.910403374	0.303467791	0.276278101			
Iterations	V_{pv} *-AHM*	I_{pv} *-AHM*	P_{pv} *-AHM*	V_{pv} *-DM*	I_{pv} *-DM*	P_{pv} *-DM*
1	0.854421872	0.284807291	0.243345578	0.922832	0.307611	0.283873
2	0.901128093	0.300376031	0.27067728	0.910497	0.303499	0.276335
3	0.909824059	0.303274686	0.275926606	0.910403	0.303468	0.276278
4	0.91039934	0.303466447	0.276275653	0.910403	0.303468	0.276278
5	0.910403374	0.303467791	0.276278101	0.910403	0.303468	0.276278
6	0.910403374	0.303467791	0.276278101			
Iterations	ε *-AHM*	ε *-AHM*	ε *-AHM*	ε *-DM*		
1	0.082964618	0.053995066	0.039409793	0.004498381		
2	0.05399509	0.028386497	0.005512629	2.18578E-05		
3	0.028386584	0.009798963	0.000236431	2.78276E-09		
4	0.009799094	0.001403327	7.23492E-07	0		
5	0.001403363	3.15015E-05	8.25018E-12			
6	3.15024E-05	1.61171E-08	0			
7	1.61176E-08	4.21885E-15				
8	4.21885E-15	0				
9	0					

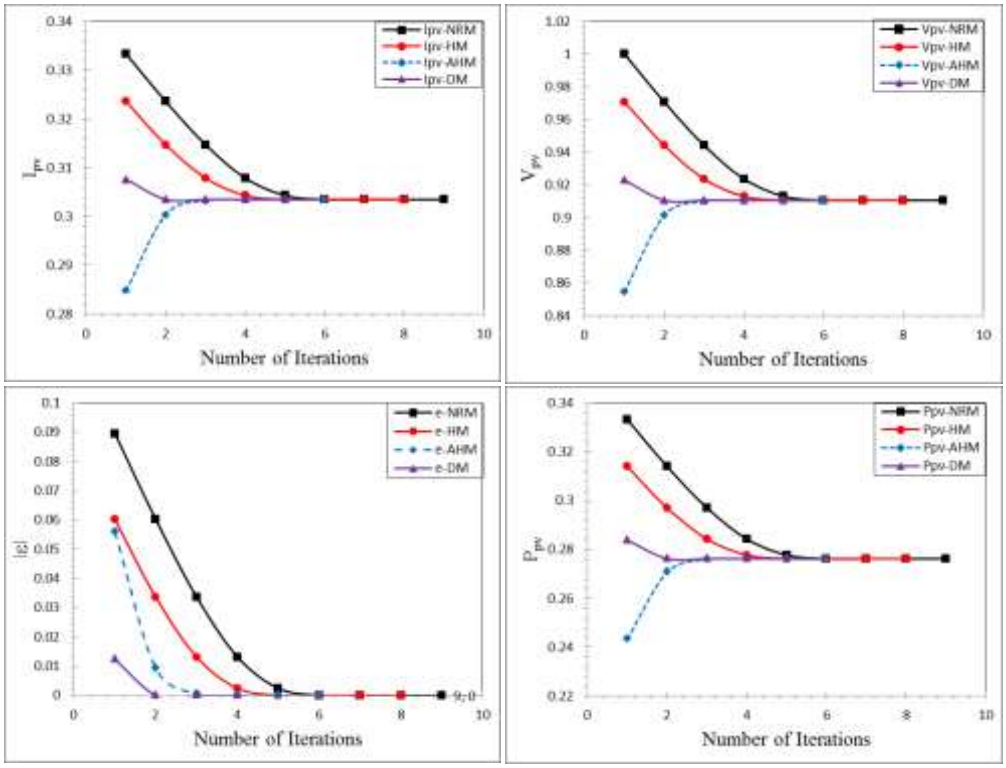

Figure 3. Comparison of Newton's algorithm (NRM) and the proposed algorithms, Predictor-Corrector Halley's Formula (HM), Accelerated Predictor-Corrector Halley's Method (AHM) and Dekker's Formula (DM) using $R = 3$.

Table 4. Numerical experiment results of the existing algorithm, Newton's method (NRM) and the proposed algorithms, Predictor-Corrector Halley's Formula (HM), Accelerated Predictor-Corrector Halley's Method (AHM) and Dekker's Formula (DM) using starting point x_0=1.

Iterations	V_{pv} *-NRM*	I_{pv} *-NRM*	P_{pv} *-NRM*	V_{pv} *-HM*	I_{pv} *-HM*	P_{pv} *-HM*
1	1	0.25	0.25	0.970256795	0.242564199	0.235349562
2	0.970256822	0.242564205	0.235349575	0.942718592	0.235679648	0.222179586
3	0.94271872	0.23567968	0.222179646	0.920122669	0.230030667	0.211656431
4	0.920123009	0.230030752	0.211656588	0.906346232	0.226586558	0.205365873
5	0.906346494	0.226586624	0.205365992	0.902077679	0.22551942	0.203436035
6	0.902077706	0.225519427	0.203436047	0.901742503	0.225435626	0.203284885
7	0.901742503	0.225435626	0.203284885	0.901740602	0.225435151	0.203284028
8	0.901740602	0.225435151	0.203284028	0.901740602	0.22543515	0.203284028
9	0.901740602	0.22543515	0.203284028			
Iterations	V_{pv} *-AHM*	I_{pv} *-AHM*	P_{pv} *-AHM*	V_{pv} *-DM*	I_{pv} *-DM*	P_{pv} *-DM*
1	0.816814932	0.204203733	0.166796658	0.950272425	0.237568106	0.22575442
2	0.884826813	0.221206703	0.195729622	0.902242967	0.225560742	0.203510593
3	0.900161317	0.225040329	0.202572599	0.901741316	0.225435329	0.20328435
4	0.901713941	0.225428485	0.203272008	0.901740602	0.22543515	0.203284028
5	0.901740591	0.225435148	0.203284023	0.901740602	0.22543515	0.203284028
6	0.901740602	0.22543515	0.203284028			
Iterations	ε *-AHM*	ε *-AHM*	ε *-AHM*	ε *-DM*		
1	0.098259398	0.068516193	0.08492567	0.048531823		
2	0.06851622	0.04097799	0.016913789	0.000502365		
3	0.040978118	0.018382067	0.001579285	7.14223E-07		
4	0.018382407	0.00460563	2.66608E-05	0		
5	0.004605892	0.000337077	1.07788E-08			
6	0.000337104	1.90073E-06	0			
7	1.90088E-06	6.0686E-11				
8	6.06911E-11	0				
9	0					

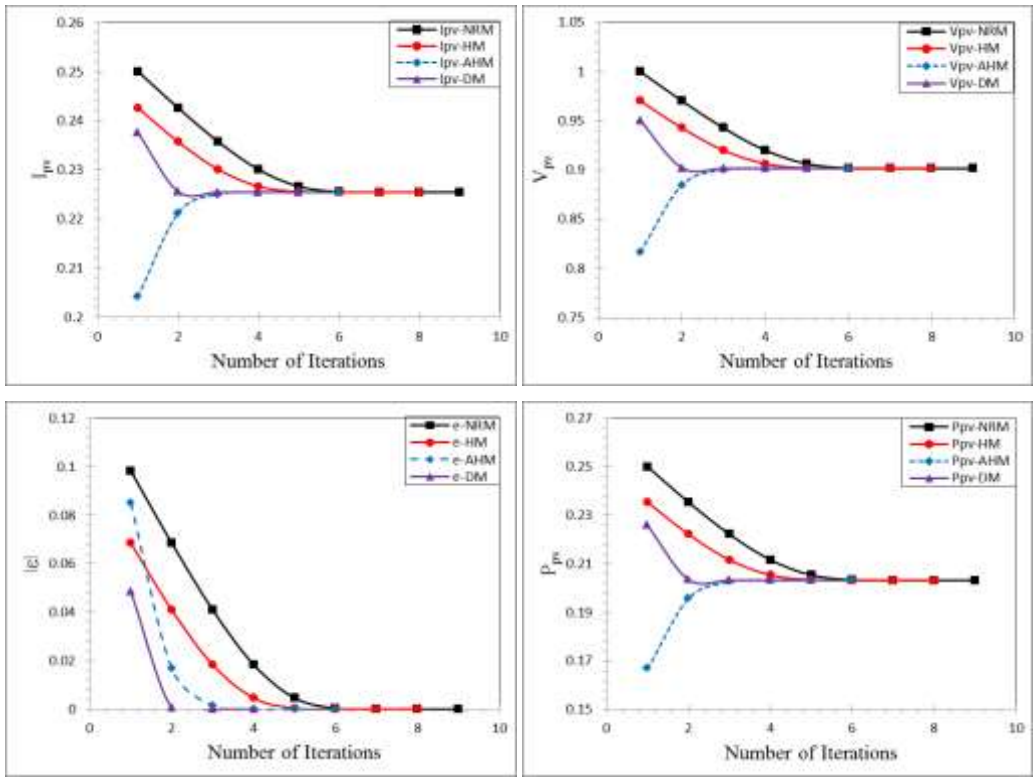

Figure 4. Comparison of Newton's algorithm (NRM) and the proposed algorithms, Predictor-Corrector Halley's Formula (HM), Accelerated Predictor-Corrector Halley's Method (AHM) and Dekker's Formula (DM) using $R = 4$.

Table 5. Numerical experiment results of the existing algorithm, Newton's method (NRM) and the proposed algorithms, Predictor-Corrector Halley's Formula (HM), Accelerated Predictor-Corrector Halley's Method (AHM) and Dekker's Formula (DM) using starting point x_0=1.

Iterations	V_{pv} *-NRM*	I_{pv} *-NRM*	P_{pv} *-NRM*	V_{pv} *-HM*	I_{pv} *-HM*	P_{pv} *-HM*
1	1	0.2	0.2	0.971725743	0.194345149	0.188850184
2	0.971725764	0.194345153	0.188850192	0.947773164	0.189554633	0.179654794
3	0.947773227	0.189554645	0.179654818	0.932203228	0.186440646	0.173800572
4	0.932203287	0.186440657	0.173800594	0.92676445	0.18535289	0.171778469
5	0.926764458	0.185352892	0.171778472	0.926239165	0.185247833	0.171583798
6	0.926239165	0.185247833	0.171583798	0.92623547	0.185247094	0.171582429
7	0.92623547	0.185247094	0.171582429	0.926235475	0.185247095	0.171582431
8	0.926235475	0.185247095	0.171582431	0.926235475	0.185247095	0.171582431
9	0.926235475	0.185247095	0.171582431	0.926235475	0.185247095	0.171582431
10	0.926235475	0.185247095	0.171582431			
Iterations	V_{pv} *-AHM*	I_{pv} *-AHM*	P_{pv} *-AHM*	V_{pv} *-DM*	I_{pv} *-DM*	P_{pv} *-DM*
1	0.903283595	0.180656719	0.163184251	0.912885516	0.182577103	0.166671993
2	0.923844714	0.184768943	0.170697811	0.92407823	0.184815646	0.170784115
3	0.926183008	0.185236602	0.171562993	0.92618314	0.185236628	0.171563042
4	0.926235444	0.185247089	0.171582419	0.926235444	0.185247089	0.171582419
5	0.926235475	0.185247095	0.171582431	0.926235475	0.185247095	0.171582431
6	0.926235475	0.185247095	0.171582431	0.926235475	0.185247095	0.171582431
7	0.926235475	0.185247095	0.171582431			
Iterations	ε *-AHM*	ε *-AHM*	ε *-AHM*	ε *-DM*		
1	0.073764525	0.045490268	0.02295188	0.013349959		
2	0.045490289	0.021537689	0.002390761	0.002157245		
3	0.021537752	0.005967752	5.24669E-05	5.2335E-05		
4	0.005967812	0.000528974	3.14315E-08	3.14314E-08		
5	0.000528982	3.68955E-06	3.1164E-13	3.1164E-13		
6	3.68961E-06	5.25837E-09	0	0		
7	5.25845E-09	7.80676E-12				
8	7.80687E-12	1.15463E-14				
9	1.15463E-14	0				
10	0					

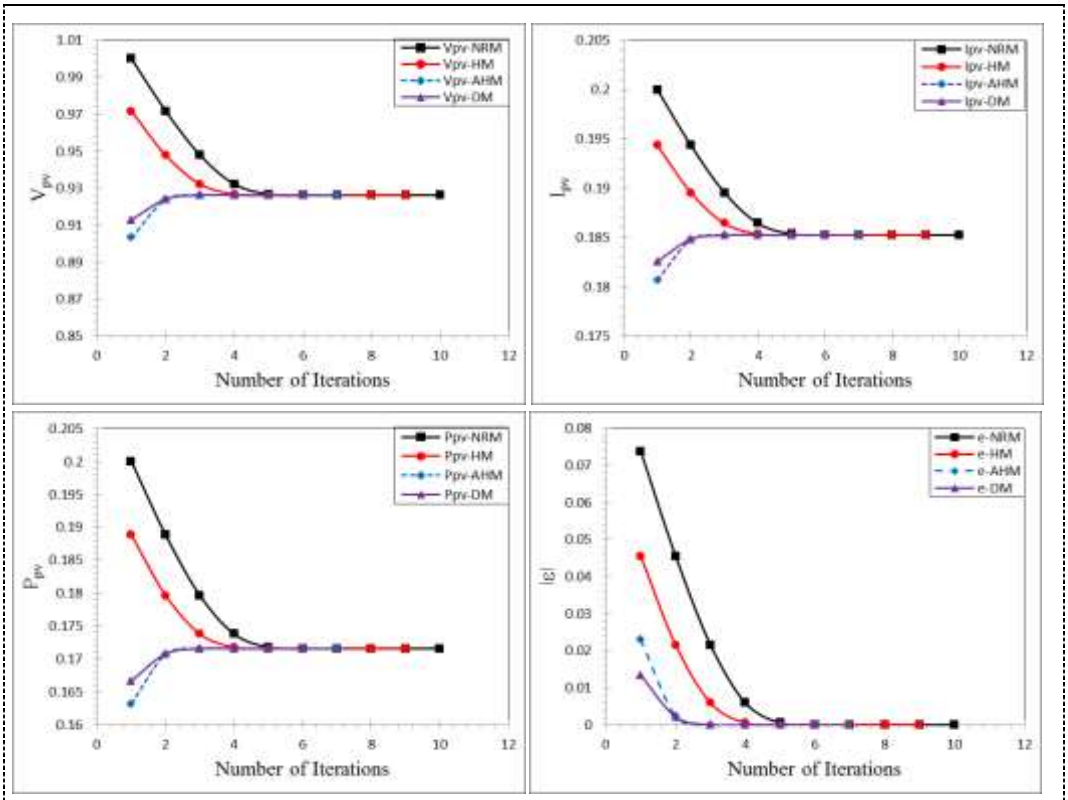

Figure 5. Comparison of Newton's algorithm (NRM) and the proposed algorithms, Predictor-Corrector Halley's Formula (HM), Accelerated Predictor-Corrector Halley's Method (AHM) and Dekker's Formula (DM) using $R = 5$.

For the Tables 1 to 5 and Figures 2 to 6, firstly the main notices prove that the suggested algorithm picks a lesser number of iterations than the other three algorithms. Secondly the results obtained in the last column for the Tables appears the estimate error's data is least for of the suggested algorithm as compared with the other algorithms in order to reach to the convergence. So, the suggested algorithm is faster.

8. Conclusion

It is concluded that the proposed iterative method Dekker's Formula is an effective promising method in accelerating a number of iterations for solving non-linear examples comparing with the other iterative algorithms Predictor-Corrector Halley's Formula (HM), Accelerated Predictor-Corrector Halley's Method (AHM). All these numerical methods have starting point x_0 the stopping criterion has been taken as $|x_{n+1} - \alpha| + |f(x_{n+1})| < 10^9$, in addition it is very important to have proper initial value in order to ensure fast convergence and reducing the computing time.

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