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# On Solving Nonlinear Equation Via Numerical Analysis for Photovoltaic Cell

***Mohammed RASHEED [a,*], Ahmed Rashid [b], Taha Rashid [c], Saad Hussin Abed Hamad [d], Mohammed Hussein Jasim AL-Kinani [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] *Azman Hashim International Business School, Skudai 81310, Johor Bahru, Malaysia, e-mail: h.jasim@graduate.utm.my.*

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ABSTRACT

Several numerical formulas have been introduced and analyzed in this paper. Based on the initial value x_0 used with each methods; these methods is used for solving the nonlinear equation of PV cell (single-diode). Several experiments are employed in order to examine these methods. Comparison of the results acquired in terms of number of evaluations reveal promising application of the proposed new method for nonlinear examples.

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*Corresponding author: Mohammed RASHEED

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

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## 1. Introduction

Newton's method display accurate and fast numerical results as compared with other algorithms and applicable to several areas of knowledge. Several experiments have been done in finding the results for the zeros of equations of the kind of $f(x) = 0; x\epsilon\Re$. This popular and standard method has free second derivative of the desired functions. Usage of division in the expression of this method is not very efficient in the matter of computational time is one of the disadvantages of the standard iterative Newton's iterative formula. Another known method in solving nonlinear examples is secant method, which is a global numerical method used in variant engineering, pure and applied science fields [1-115].

The suggested algorithm HM 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 HM and DM algorithms respectively while; section five and six indicate the numerical problems, discussion and conclusion results respectively.

## 2. Simplification of PV Equation: Nonlinear

KCL Kirchhoff's law is employed in order to depict the electrical parameters of PV cell scheme [15-20]

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

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. Predictor- Corrector Halley's Formula (HM)

Predictor- Corrector Halley's Method (HM)

Step 1: consider the initial values of $x_0$

Step 2: compute $y_n$ using the following equation

$$y_n = x_n - \frac{f(x_n)}{\acute{f}(x_n)}$$

Step 3: calculate $x_{n+1}$ using the following formula

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

## 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 Predictor- Corrector Halley's Formula (HM) 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 HM algorithm needs 8 iterations while DM technique need 6 iterations to reach to the convergence which proves that DM is faster than HM.

**Table 1 - Numerical methods for solving Eq. 2: nonlinear equation.**

| Iterations | $V_{pv}$-AHM | $I_{pv}$- AHM | $P_{pv}$-AHM | $V_{pv}$-DM | $I_{pv}$-DM | $P_{pv}$-DM | ε-AHM | ε-DM |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.971416840 | 0.971416840 | 0.943650676 | 0.935676361 | 0.935676361 | 0.875490253 | 0.048993705 | 0.013253227 |
| 2 | 0.946732533 | 0.946732533 | 0.896302490 | 0.924881618 | 0.924881618 | 0.855406007 | 0.024309399 | 0.002458483 |
| 3 | 0.929865621 | 0.929865621 | 0.864650074 | 0.922517676 | 0.922517676 | 0.851038863 | 0.007442487 | 9.45419e-05 |
| 4 | 0.923247877 | 0.923247877 | 0.852386643 | 0.922423278 | 0.922423278 | 0.850864704 | 0.000824743 | 1.43768e-07 |
| 5 | 0.922434000 | 0.922434000 | 0.850884484 | 0.922423135 | 0.922423135 | 0.850864439 | 1.08652e-05 | 3.33178e-13 |
| 6 | 0.922423136 | 0.922423136 | 0.850864443 | 0.922423135 | 0.922423135 | 0.850864439 | 1.90246e-09 | 0 |
| 7 | 0.922423135 | 0.922423135 | 0.850864439 | | | | 1.11022e-16 | |
| 8 | 0.922423135 | 0.922423135 | 0.850864439 | | | | 0 | |

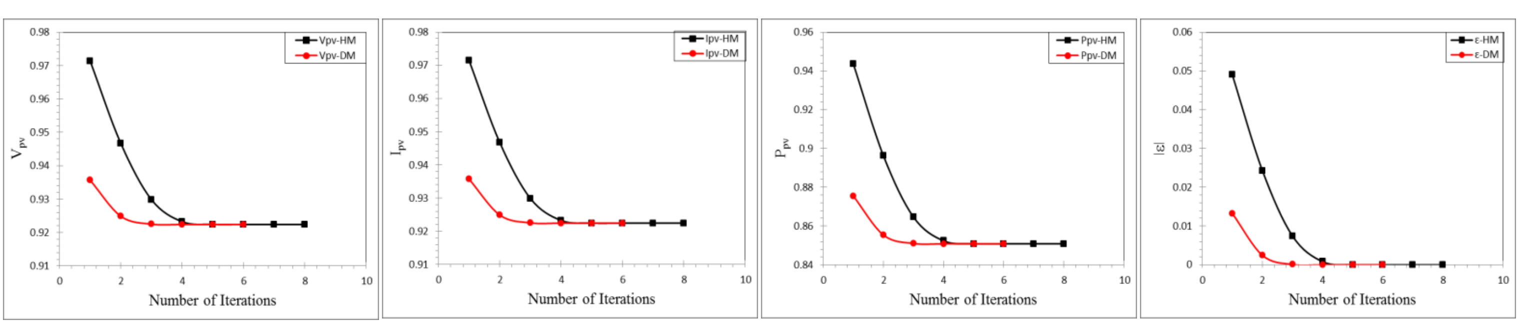


**Fig. 1 – Determination of numerical properties of Eq. 2 by experimental, Analytical and numerical methods.**

**Table 2 - Numerical methods for solving Eq. 2: nonlinear equation.**

| Iterations | $V_{pv}$-AHM | $I_{pv}$- AHM | $P_{pv}$-AHM | $V_{pv}$-DM | $I_{pv}$-DM | $P_{pv}$-DM | ε-AHM | ε-DM |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.971030449 | 0.485515224 | 0.471450066 | 0.933452217 | 0.466726109 | 0.435666521 | 0.053995066 | 0.016416835 |
| 2 | 0.945421879 | 0.47271094 | 0.446911265 | 0.920708663 | 0.460354331 | 0.423852221 | 0.028386497 | 0.00367328 |
| 3 | 0.926834345 | 0.463417173 | 0.429510952 | 0.917245191 | 0.458622596 | 0.420669370 | 0.009798963 | 0.000209809 |
| 4 | 0.918438709 | 0.459219354 | 0.421764831 | 0.917036095 | 0.458518047 | 0.420477600 | 0.001403327 | 7.1248e-07 |
| 5 | 0.917066884 | 0.458533442 | 0.420505835 | 0.917035382 | 0.458517691 | 0.420476946 | 3.15015e-05 | 8.24729e-12 |
| 6 | 0.917035399 | 0.458517699 | 0.420476961 | 0.917035382 | 0.458517691 | 0.420476946 | 1.61171e-08 | 0 |
| 7 | 0.917035382 | 0.458517691 | 0.420476946 | | | | 4.21885e-15 | |
| 8 | 0.917035382 | 0.458517691 | 0.420476946 | | | | 0 | |

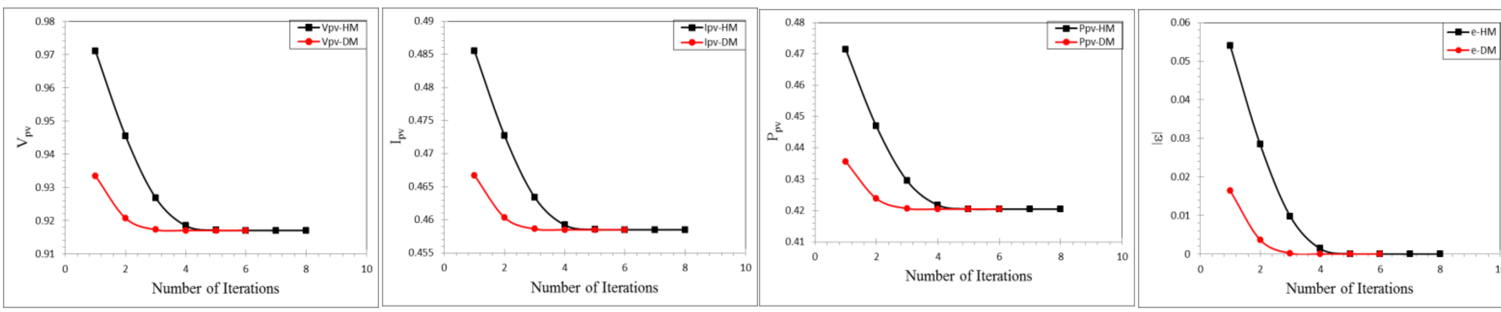


**Fig. 2 – Determination of numerical properties of Eq. 2 by experimental, Analytical and numerical methods.**

**Table 3 - Numerical methods for solving Eq. 2: nonlinear equation.**

| Iterations | $V_{pv}$-AHM | $I_{pv}$- AHM | $P_{pv}$-AHM | $V_{pv}$-DM | $I_{pv}$-DM | $P_{pv}$-DM | ε-AHM | ε-DM |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.970643767 | 0.323547922 | 0.314049774 | 0.931130698 | 0.310376899 | 0.289001459 | 0.060240393 | 0.020727324 |
| 2 | 0.944084126 | 0.314694709 | 0.297098279 | 0.916050276 | 0.305350092 | 0.279716036 | 0.033680752 | 0.005646902 |
| 3 | 0.923594034 | 0.307864678 | 0.284341980 | 0.910893745 | 0.303631248 | 0.276575805 | 0.01319066 | 0.000490371 |
| 4 | 0.912877747 | 0.304292582 | 0.277781927 | 0.910407298 | 0.303469099 | 0.276280483 | 0.002474373 | 3.92441e-06 |
| 5 | 0.910501258 | 0.303500419 | 0.276337514 | 0.910403374 | 0.303467791 | 0.276278101 | 9.78838e-05 | 2.53266e-10 |
| 6 | 0.910403531 | 0.303467844 | 0.276278197 | 0.910403374 | 0.303467791 | 0.276278101 | 1.5741e-07 | 0 |
| 7 | 0.910403374 | 0.303467791 | 0.276278101 | | | | 4.07563e-13 | |
| 8 | 0.910403374 | 0.303467791 | 0.276278101 | | | | 0 | |

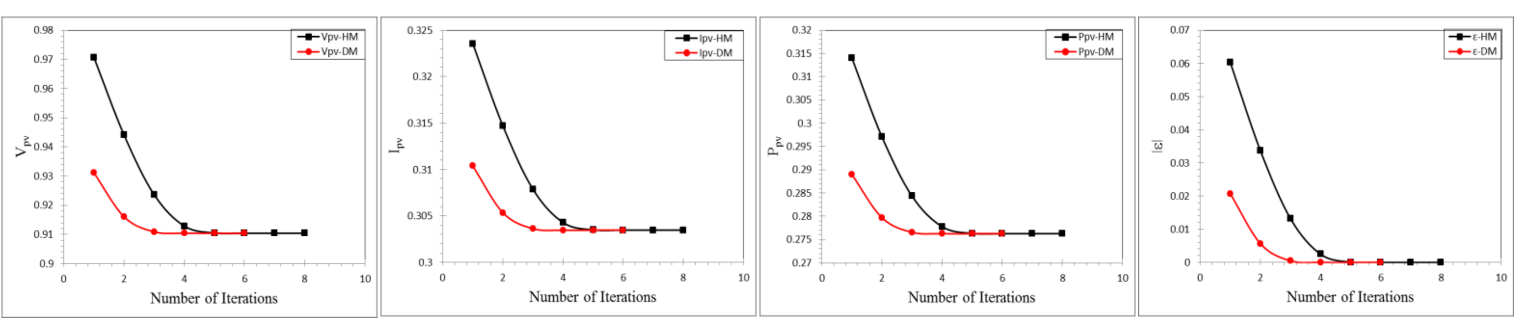


**Fig. 3 – Determination of numerical properties of Eq. 2 by experimental, Analytical and numerical methods.**

**Table 4 - Numerical methods for solving Eq. 2: nonlinear equation.**

| Iterations | $V_{pv}$-AHM | $I_{pv}$- AHM | $P_{pv}$-AHM | $V_{pv}$-DM | $I_{pv}$-DM | $P_{pv}$-DM | ε-AHM | ε-DM |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.970256795 | 0.242564199 | 0.235349562 | 0.928705817 | 0.232176454 | 0.215623624 | 0.068516193 | 0.026965215 |
| 2 | 0.942718592 | 0.235679648 | 0.222179586 | 0.910811274 | 0.227702819 | 0.207394294 | 0.04097799 | 0.009070672 |
| 3 | 0.920122669 | 0.230030667 | 0.211656431 | 0.902978772 | 0.225744693 | 0.203842666 | 0.018382067 | 0.00123817 |
| 4 | 0.906346232 | 0.226586558 | 0.205365873 | 0.901765896 | 0.225441474 | 0.203295433 | 0.00460563 | 2.52937e-05 |
| 5 | 0.902077679 | 0.22551942 | 0.203436035 | 0.901740613 | 0.225435153 | 0.203284033 | 0.000337077 | 1.07391e-08 |
| 6 | 0.901742503 | 0.225435626 | 0.203284885 | 0.901740602 | 0.22543515 | 0.203284028 | 1.90073e-06 | 1.9984e-15 |
| 7 | 0.901740602 | 0.225435151 | 0.203284028 | 0.901740602 | 0.22543515 | 0.203284028 | 6.0686e-11 | 0 |
| 8 | 0.901740602 | 0.22543515 | 0.203284028 | | | | 0 | |

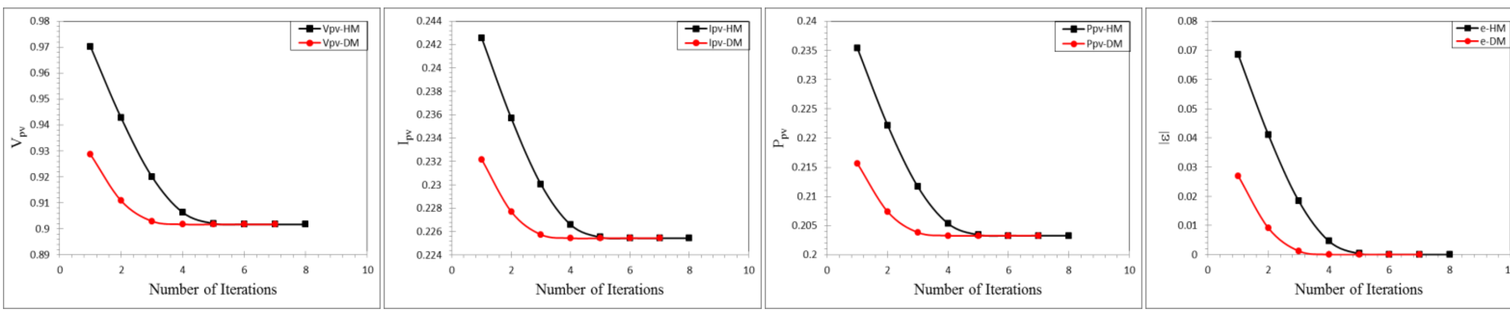


**Fig. 4 – Determination of numerical properties of Eq. 2 by experimental, Analytical and numerical methods.**

**Table 5 - Numerical methods for solving Eq. 2: nonlinear equation.**

| Iterations | $V_{pv}$-AHM | $I_{pv}$- AHM | $P_{pv}$-AHM | $V_{pv}$-DM | $I_{pv}$-DM | $P_{pv}$-DM | ε-AHM | ε-DM |
|---|---|---|---|---|---|---|---|---|
| 1 | 0.969869532 | 0.193973906 | 0.188129382 | 0.926171150 | 0.185234230 | 0.171558600 | 0.080776817 | 0.037078435 |
| 2 | 0.941324576 | 0.188264915 | 0.177218391 | 0.904871623 | 0.180974325 | 0.163758531 | 0.052231861 | 0.015778908 |
| 3 | 0.916395271 | 0.183279054 | 0.167956059 | 0.892666909 | 0.178533382 | 0.159370842 | 0.027302556 | 0.003574194 |
| 4 | 0.898534787 | 0.179706957 | 0.161472953 | 0.889305949 | 0.177861190 | 0.158173014 | 0.009442072 | 0.000213234 |
| 5 | 0.890476758 | 0.178095352 | 0.158589771 | 0.889093511 | 0.177818702 | 0.158097454 | 0.001384043 | 7.96007e-07 |
| 6 | 0.889125756 | 0.177825151 | 0.158108922 | 0.889092715 | 0.177818543 | 0.158097171 | 3.30416e-05 | 1.11419e-11 |
| 7 | 0.889092734 | 0.177818547 | 0.158097178 | 0.889092715 | 0.177818543 | 0.158097171 | 1.91868e-08 | 0 |
| 8 | 0.889092715 | 0.177818543 | 0.158097171 | | | | 6.43929e-15 | |
| 9 | 0.889092715 | 0.177818543 | 0.158097171 | | | | 0 | |

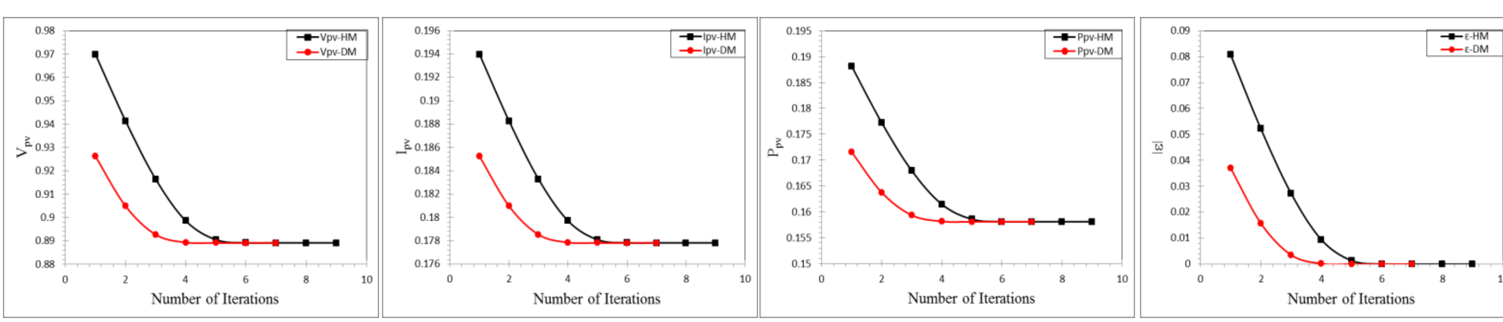


**Fig. 5 – Determination of numerical properties of Eq. 2 by experimental, Analytical and numerical methods.**

## 6. Conclusion

As investigated in the numerical results, Dekker's Formula free from second derivative of the function has lesser number of iterations than the standard one Predictor- Corrector Halley's Formula. In addition, absolute error of these numerical formulas has been investigated.

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