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Evaluation and Determination of the Parameters of a Photovoltaic Cell by an Iterative Method

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ABSTRACT

This paper presents an iterative method Predictor-Corrector Hally Method (HM) for finding the voltage of a solar cell single diode model from the equivalent circuit. The purposes of the obtained results are to reduce the number of iterations. Two numerically methods are applied and compared; newton's and Hally methods. The results showed that the proposed is the most efficient compare with NRM. The goal of the present work; the results obtained of PV parameters by means of various techniques and these results are compared and discussed. The acquired results presented the suggested technique (HM) was a sufficient and effective tool for solving the solar cell's model with a least iterations. All the calculations are achieved using Matlab program.

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1. Introduction

Numerical analysis is particularly attractive to scientific research workers. One of the reasons for this is that in some cases and after the tremendous development that has taken place in the field of informatics, it becomes easy to use numerical methods and then uses programs and algorithms to obtain the required solutions to any issues facing

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them accurately and quickly [1-10]. Numerical analysis involves many applications in various fields such as science and engineering to facilitate the solution of complex nonlinear equations [11-18]. Authors utilized numerical methods for solving non-linear equations of PV cell [19-23]. Nowadays, many researchers have developed different types of solar cells based on cost and efficiency. These solar cells were prepared using different and easy methods of preparation, depending on the materials used and the quality of solar cells and the goal is to reduce cost and increase efficiency [24-36]. Moreover, there are various materials can be used in order to improve the efficiency of PV cell [37-45]. Some researchers studied the parameters of solar cells practically and theoretically using fuzzy logic technique [46-48]. Rasheed et al. solved nonlinear equations of Kepler's and Barker's equations in celestial mechanics using numerical methods [49-63].

The current – voltage curve of PV cell gives the non-linear equation depending on Kirchhoff's current law (KCL), then, numerically this equation can be solved using some mathematical techniques. There are different models can be extracted from this the electrical circuit of PV cell such as one-diode or two-diode model, neglect or non-neglect the shunt or series resistance or both of them. The implicit equation can be obtained from these models and can solved numerically with the use of (KCL) in order to find the zeros of these equations.

The aim of this article is to present a new iterative method Predictor-Corrector Hally method to solve a nonlinear equation and reducing the root of iteration in the numerical solution of the nonlinear equation root. Systematic as the following steps: Section two, characterizing a model of a PV cell. Section three, establishing the zero-finding of Newton Raphson technique. Section four, Predictor-Corrector Hally method was analyzed. Section five, present the results and discussion. Section six shows the conclusions of acquired results.

2. Implicit Equation of PV Cell Model

Suppose an equivalent circuit of PV cell [18-20]

According to Kirchhoff's current law; the final equation of the solar cell current can be extracted according to this equivalent as follows

$$I = \mathrm{I_{ph}} - \mathrm{I_D} \tag{1}$$

$$\mathrm{I_D} = \mathrm{I_0} \times \left(e^{(-V_D/nV_T)} - 1\right) \tag{2}$$

$$\mathrm{I} = \mathrm{I_{ph}} - \mathrm{I_0}\left(\mathrm{e}^{(-V_{pv}/mV_T)} - 1\right) \tag{3}$$

where:

$\mathrm{I_{ph}}$: the photocurrent (A); $\mathrm{V_{pv}}$ and I are the delivered voltage and current, respectively; $\mathrm{I_0}$: saturation current of the diode (reverse bias); $\mathrm{V_T} = \mathrm{KT/q} = 0.0259\ \mathrm{V} = 26\ \mathrm{mV}$: thermic voltage in which T = 25 ºC and Air-Mass = 1.5); k: Boltzmann constant= 1.38×10^{-23} J/K; m: recombination factor $(1 < \mathrm{m} < 2)$,; T: p − n junction temperature (K); q: electron charge= 1.6×10^{-19} C.

$$\mathrm{I_{ph}} = \mathrm{I_{source}} \tag{4}$$

$$\mathrm{I_D} = \mathrm{I_s} * \left(\mathrm{e}^{(V_D/nV_T)} - 1\right) \tag{5}$$

substituting Eq. 4 in Eq. 5, we get

$$\mathrm{I_{source}} - 10^{-12}\left(e^{(-V\times q/m\times k\times T)} - 1\right) = \mathrm{V/R} \tag{6}$$

where: the reverse saturation current $\mathrm{I_s} = 10^{-12}$A.

Calculate $\mathrm{V_{pv}}$ is achieved based on Eq. 6 (1st derivative).

3. Newton's Technique

The following algorithm suggestion for solving Eq. 6 by using NRM

INPUT initial approximate solution $\mathrm{x_0} = 1$, N: maximum number of iterations and ε is tolerance.

OUTPUT approximate solution x_{n+1}

Step 1: Set $x = 0$

Step 2: while $i \leq x_0$

Step 3: Calculate

$$x_{n+1} = x_n - \frac{f(x_n)}{\acute{f}(x_n)} \text{ for } n = 0, 1, 2, ... \tag{7}$$

Step 4: if $|x_i - x_{i-1}| < \varepsilon$; then OUTPUT x_{n+1} and stop.

Step 5: Set $n = n + 1$; $i = i + 1$ and go to Step 2.

Step 6: OUTPUT

4. Predictor-Corrector Hally Method (HM)

To compare the different numerical methods of iterations, methods 1 has been used against the proposed method 2. In addition; Eq. 6. has been solved to demonstrate the performance of the new method, and determine the consistency and stability of results. The results are examined using two iterative methods

Method 1: Newton Raphson Method (NRM):

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

Method 2: Predictor- Corrector Hally Method (HM):

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

$$x_{n+1} = y_n - \frac{2 \times f(y_n)\acute{f}(y_n)}{2 \times \acute{f}(y_n)^2 - f(y_n) \times \acute{\acute{f}}(y_n)} \tag{8}$$

we take $\varepsilon = 10^{-9}$ (tolerance).

For estimating the zero, the following criteria can be used

$\sigma = |D_{n+1} - D_n| < \varepsilon, |f(D_n)| < \varepsilon$: is (stopping criteria) the mean absolute error (MAE), x_n and x_{n+1} is the roots of the equation.

5. Results and Discussion

In order to calculate and compare the accuracy of the optimization proposed method, Eq. 6 has been used.

The NRM and HM of the solution results; voltage V_{pv}; current I_{pv}; power P_{pv} of the solar cell are listed with $R = 1$ (load resistance of the circuit), is shown in Table 1. This table shows that NRM took 9^{th} iterations in order to converge to the root of the Eq. 6 in the value of (0.922423135); whereas the suggested method HM took 8^{th} iterations in order to obtain the same root of the equation.

Table 1 - Number of iterations by means of different techniques.

			Load Resistance $R = 1$			
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			

Figure 1 shows solutions of the PV equation defined by Eq. 6.

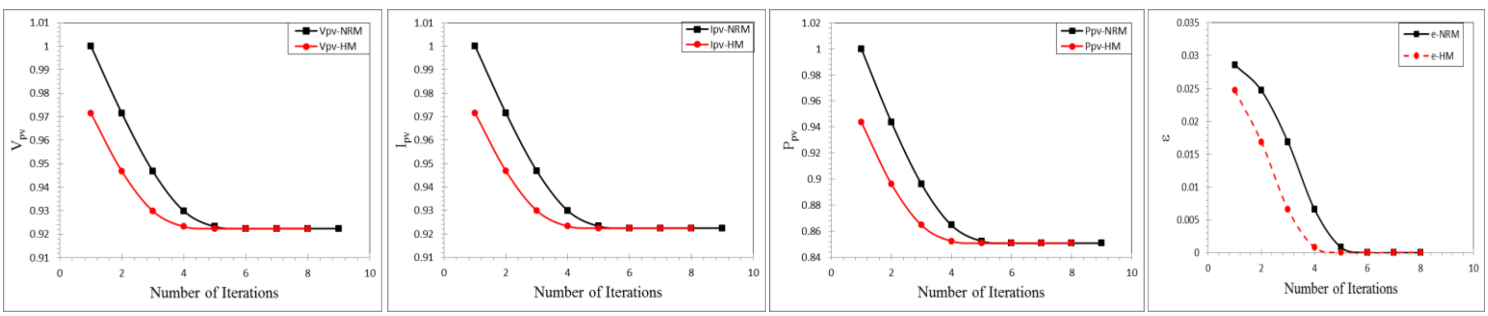

Fig. 2 – Solved Eq. 6 by means of various methods.

Table 2 - Number of iterations by means of different techniques.

			Load Resistance $R = 2$			
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	0.917035382	0.45851769	0.42047695	0.917035382	0.458517691	0.420476946
9	0.917035382	0.45851769	0.42047695			

Table 2 shows that NRM took 9th iterations in order to converge to the root of the Eq. 6 in the value of (0.917035382); whereas the suggested method HM took 8th iterations in order to obtain the same root of the equation.

Figure 2 shows solutions of the PV equation defined by Eq. 6.

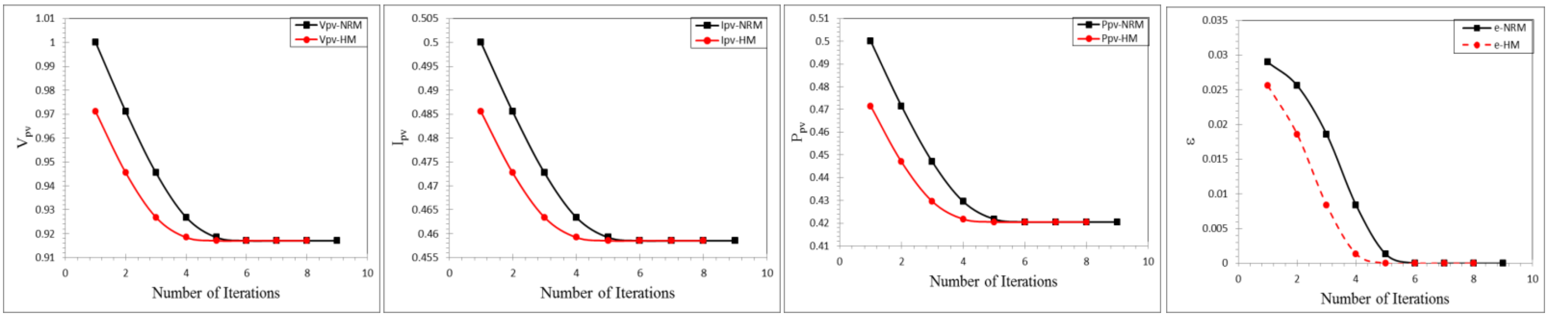

Fig. 2 - Solved Eq. 6 by means of various methods.

Table 3 depicts that NRM took 9th iterations in order to converge to the root of the Eq. 6 in the value of (0.910403374); whereas the suggested method HM took 8th iterations in order to obtain the same root of the equation.

Table 3 - Number of iterations by means of different techniques.

Load Resistance $R = 3$						
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			

Figure 3 shows solutions of the PV equation defined by Eq. 6.

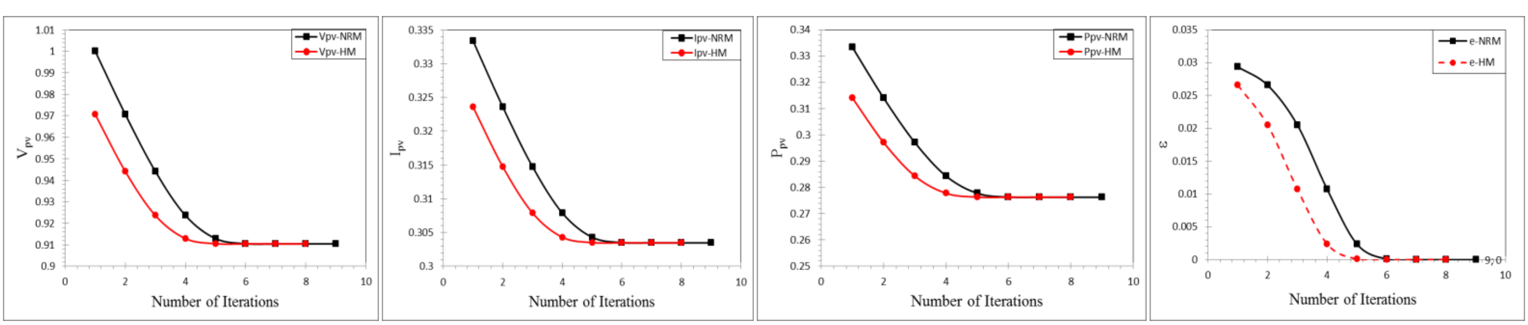

Fig. 3 - Solved Eq. 6 by means of various methods.

Table 4 reports that NRM took 9th iterations in order to converge to the root of the Eq. 6 in the value of (0.901740602); whereas the suggested method HM took 8th iterations in order to obtain the same root of the equation.

Table 4 - Number of iterations by means of different techniques.

			Load Resistance $R = 4$			
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			

Figure 4 shows solutions of the PV equation defined by Eq. 6.

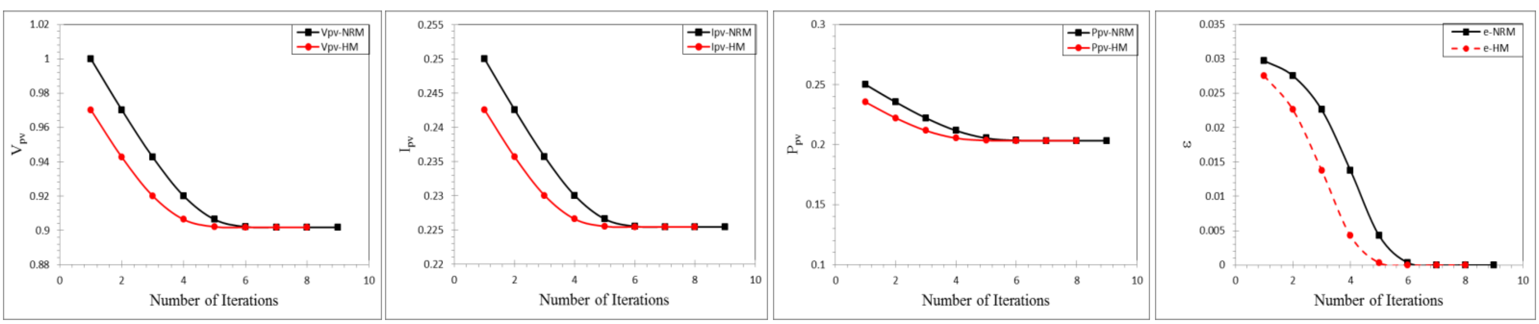

Fig. 5 - Solved Eq. 6 by means of various methods.

In Table 5 indicate that NRM took 10th iterations in order to converge to the root of the Eq. 6 in the value of (0.889092715); whereas the suggested method HM took 9th iterations in order to obtain the same root of the equation.

Table 5 - Number of iterations by means of different techniques.

			Load Resistance $R = 5$			
Iterations	**V_{pv}-NRM**	**I_{pv}- NRM**	**P_{pv}-NRM**	**V_{pv}-IHOM**	**I_{pv}-IHOM**	**P_{pv}-IHOM**
1	1	0.2	0.2	0.969869532	0.193973906	0.188129382
2	0.96986956	0.193973912	0.188129393	0.941324576	0.188264915	0.177218391
3	0.941324731	0.188264946	0.17721845	0.916395271	0.183279054	0.167956059
4	0.916395843	0.183279169	0.167956268	0.898534787	0.179706957	0.161472953
5	0.898535645	0.179707129	0.161473261	0.890476758	0.178095352	0.158589771
6	0.890477009	0.178095402	0.158589861	0.889125756	0.177825151	0.158108922
7	0.889125763	0.177825153	0.158108925	0.889092734	0.177818547	0.158097178
8	0.889092734	0.177818547	0.158097178	0.889092715	0.177818543	0.158097171
9	0.889092715	0.177818543	0.158097171	0.889092715	0.177818543	0.158097171
10	0.889092715	0.177818543	0.158097171			

Figure 5 shows solutions of the PV equation defined by Eq. 6.

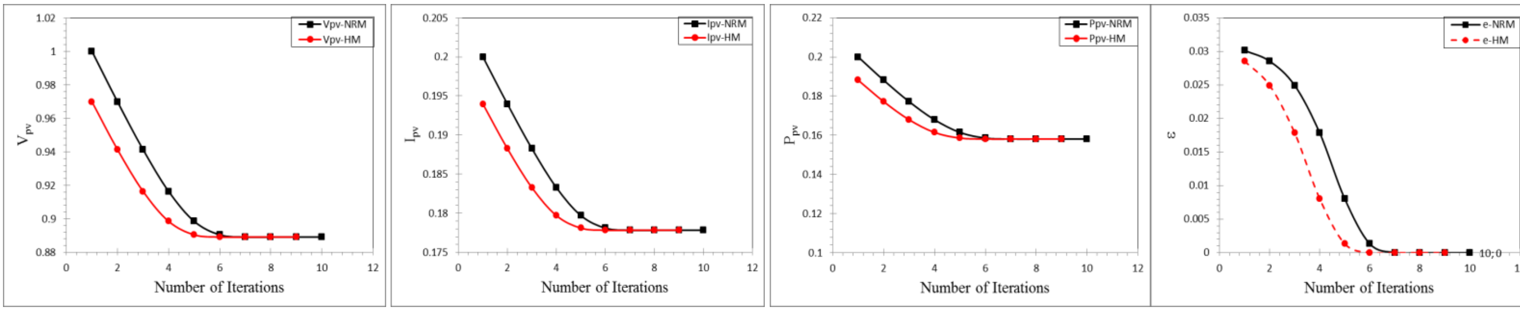

Fig. 6 - Solved Eq. 6 by means of various methods.

Based on the above tables and figures from 1 to 5, in this case for the both methods, the number of iterations ranges from 9th to 10 the get the root 0.922423135, 0.91703538, 0.910403374, 0.901740602, 0.889092715 for the initial value $x_0 = 1$. The proposed method takes only 8th iterations which is least number of the root and faster compared with NRM.

7. Conclusion

In this paper We observed that the efficiency of the new Predictor-Corrector Hally method considerably improve that of Newton method and the given two step method Remark that only 8 iterations are needed to reach the exact solution with small tolerance, while Newton's method requires 9 or 10 iterations. Data acquired from the proposed method HM were found to be sufficient and values for single diode solar cell were determined with fast convergence, more capable to determine these parameters and establishing towards the final values.

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