Modelling and Simulation of Solar Cell Mathematical Model Parameters Determination Based on Different Methods

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Abstract: Finding the roots of nonlinear equations is one of the most important computational problems and their applications. In this paper, a new algorithm is used to find the real roots of nonlinear equations of a single-diode solar cell by combining the Aitken's extrapolation algorithm (AEM) and the Newton-Raphson algorithm (NRM), describing, and comparing them. The extrapolation method in the form of Aitken Δ^2–acceleration is applied for improvement the convergence of the iterative method (Newton-Raphson) method. Using anew improve to Aitken technique enables one to acquire efficiently the numerical solution of the single-diode solar cell equation. The speed of the proposed algorithms is compared by different values of the load resistance (R) in the range of $R \in [1, 5]$ and with the given voltage of the cell V_{pv} as an initial value in room temperature. The results showed that the proposed technique (AEM) is faster than (NRM); in addition, the current and power of the cell have been described and calculated.

Keywords: Newton-Raphson Method; Aitken's Method; Extrapolation Technique; Solar Cell Parameters; Single-diode Model

1. Introduction

Solar cells are photovoltaic panels that convert solar energy into electrical energy by means of a photoelectric effect. The cell is made of semiconducting materials, which give it electrical properties when exposed to light, such as electric current, power, and voltage. The solar cell must also be able to absorb light and produce electrons, and the lifetime of different types of solar cells is between (10-30) years. Solar cells are generally made of semiconducting materials, such as crystalline silicon. The production of this type accounted for nearly 90% of the solar cell industry in 2013. The reason why silicon is used a lot in solar cells is a highly available material in nature, because of its reasonable price. The first generation of solar cells includes silicon cells. The first generation of solar cells includes silicon cells. There are many types of silicon solar cells; monocrystalline, polycrystalline and amorphous solar cells[1-15]. Third Generation of Solar Cells, this generation includes new types that are still under research and development, and did not reach the stage of commercial manufacturing and include the following types: Nano Solar Cells (Nano Crystal Based Solar Cells): The manufacture of crystals from semiconductor materials in very small dimensions, measured in nanometers, and the efficiency ranges from (7-8) %. Polymer Based Solar Cells: These cells are made by using a polymer that is capable of absorbing solar radiation. Their efficiency varies between (3-10) % and does not work well at high temperatures, but costs 50% less than silicon solar cells[15-27]. Organic solar cells: These cells are made in four parts: a thin layer of titanium dioxide that forms the negative semiconductor, a thin layer of the nickel oxide component of the positive semiconductor, and the light-sensitive chromosome, placed between two poles. The cell, a chip made of platinum or carbon, is about 10% efficient, but it takes a lot of time to install compared to other types. Concentrated Solar Cells: The principle of the work of these cells is to use many mirrors and lenses to produce high thermal energy, which is transferred to thermal motors, up to 40% efficiency, and is characterized by being thermally stable[28-30]. The important applications of Solar panels are used on spacecraft for two important purposes: first producing energy for measuring and exploration devices, providing heat for its operation or cooling, and for communication. Second generating energy to power a rocket motor or probe electric motor is sometimes called solar-electric propulsion. In space or Astrophysics, in addition laser communication nonlinear equations is important to solve Kepler and Barker equations[31-67].

The aim of this paper is to introduce a new algorithm in order to find the real roots of single-diode nonlinear equation of the PV cell. It is organized as follows: section 2 describing the mathematical analysis of a single-diode electric circuit model of the PV cell; Section 3 establishing the root finding NRM and AEM; section 4 results and discussion; section 5 conclusions of the obtained results. All the results are acquired using Matlab 2019.

2. Analysis of Single-Diode Solar Cells

Solar cell theory explains the process by which light energy in photons is converted into electric current when photons collide with a suitable semiconductor device. Theoretical studies are useful because they predict the basic limits of a solar cell and provide guidance on phenomena that contribute to the loss and efficiency of solar cells. To understand the electronic behavior of the solar cell, it is useful to create an electrically equivalent model, based on distinct ideal electrical components whose behavior is well defined. An ideal solar cell can be formed with an empty source in parallel with the diode; in practice, there is no ideal solar cell, so shunt resistance and the chain resistance component are added to the model. The resulting equivalent cell of a solar cell appears on the left. As shown, on the right, is a schematic representation of the solar cell to be used in circuit diagrams.

Characteristic equation

From the equivalent circuit, it is clear that the current produced by the solar cell is equal to that of the current source minus flowing through the diode minus that flows through the shunt resistor **Figure 1**.

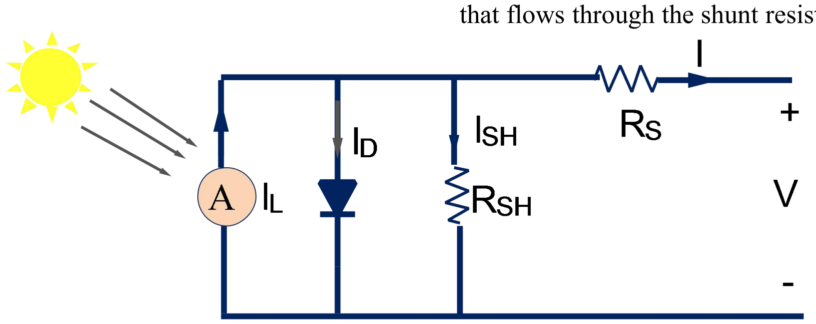


Figure 1. PV-cell equivalent-circuit models: single-diode model.

Equivalent characteristic equation of an ideal photovoltaic cell is given by

$$I = I_{ph} - I_D \quad (1)$$

The equation of the diode $I_D = I_0\left(e^{\frac{-V_{pv}}{nV_T}} - 1\right)$ (2)

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

where:

I_{ph} is the photocurrent (A); I_0 is reverse saturation current of the diode (A); I and V_{pv} are the delivered current and voltage, respectively (V); $V_T = \frac{kT}{q} = 0.0259\,V$ is thermic voltage = $27.5 \cong 26\ mV$ at ($T =$ 25 °C Air-Mass = 1.5); m is the recombination factor closeness to an ideal diode ($1 < m < 1.5$), k is Boltzmann constant= $1.38 \times 10^{-23} J/K$; T is *p-n* junction temperature (K); q is the electron charge=$1.6 \times 10^{-19}\ C$.

3. Mathematical Methods

The following algorithm suggestion for solving Eq. 15 by using NRM (see **Figure 2**)

INPUT initial approximation solution $x_0 = 1$, tolerance $\varepsilon = 10^{-9}$, maximum number of iterations N, f, df.

OUTPUT approximate solution x_{n+1}

Step 1: Set $i = 1$

Step 2: Calculate $x_{n+1} = x_n - \frac{f(x_n)}{\acute{f}(x_n)}$ for $n = 0, 1, 2, \ldots$

Step 3: If $|x_i - x_{i-1}| < \varepsilon$; then go to Step 6

Step 4: Set $x_0 = x$

Step 5: $n = n + 1, i = i + 1$, go back to Step 2.

Step 6: OUTPUT x_{n+1} and stop iteration.

Proposed AEM

Given: $x_0, \varepsilon = 10^{-9}, N, f, df$

Step 1: For $i = 1$ to 2

Step 2: Calculate $\overline{E}_n = \overline{E}_{n+2} - \frac{(\overline{E}_{n+2} - \overline{E}_{n+1})^2}{\overline{E}_{n+2} - 2\times\overline{E}_{n+1} + \overline{E}_n}$ for $n = 0, 1, 2, ...$

Step 3: If $f(x_i) = 0$ or $f(x_i) < \varepsilon$, then go to Step 6

Step 4: Set $\overline{E}_{n+1} = \overline{E}_n$

Step 5: $n = n + 1, i = i + 1$, go back to Step 2.

Step 6: OUTPUT x_{n+1} and stop iteration.

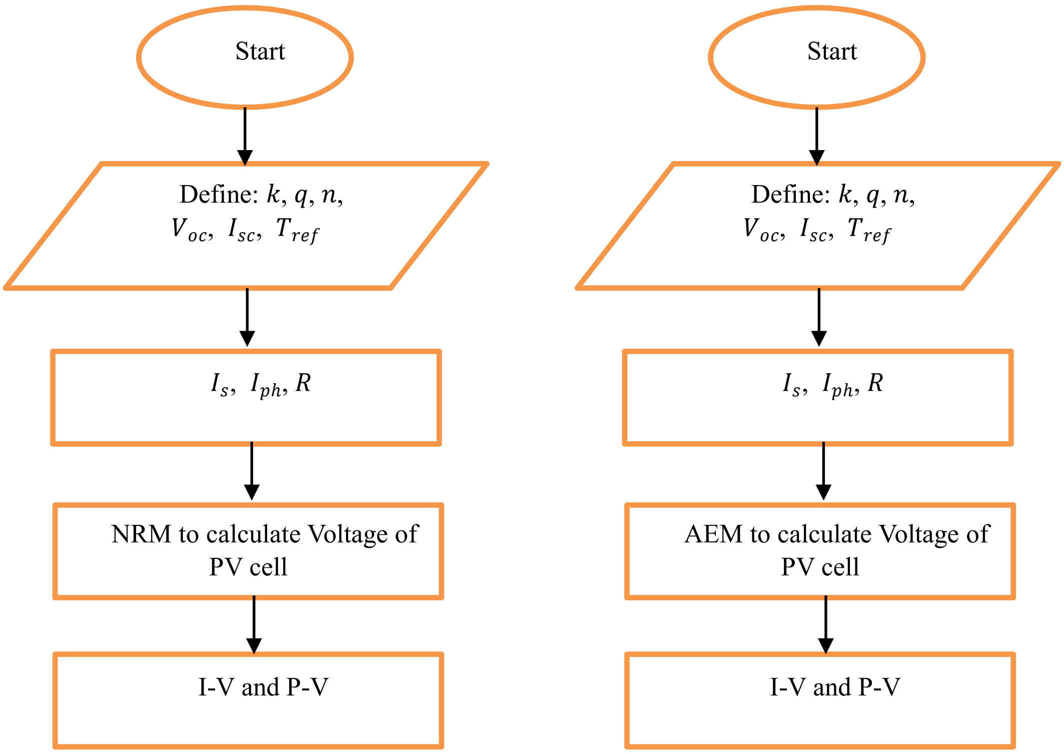


Figure 2. Simulation results.

From Figure 1 $I_{ph} \propto I_{so}$ suppose for $1000\ W/m^2$ of isolation $I_{ph} = 10$ A

$$I_{ph} = I_{so} * \left(\frac{10}{1000}\right) A \qquad (4)$$

$$I_D = I_s * \left(e^{\frac{V_D}{nkt}} - 1\right) A = I_s * \left(e^{\frac{V_D}{nV_T}} - 1\right) \qquad (5)$$

where n ideally factor $1 < n < 2$, I_s reverse saturation current= $10^{-12} A$. In parallel, $V_D = V_{pv} = V$

$$I = I_{ph} - I_D \qquad (6)$$

Where $V = I \times R \rightarrow I = \frac{R}{V}$ (7)

$$I = I_{ph} - \frac{R}{V} \qquad (8)$$

From **Eq. 4**,

$$I_{ph} - I = \frac{R}{V} \qquad (9)$$

$$I = I_{ph} - \frac{R}{V} \qquad (10)$$

then

$$I_{ph} - I_D = \frac{R}{V} \qquad (11)$$

Substitute **Eqs. 4** and **5** into **Eq. 11** we get

$$\left(\frac{I_{so}}{1000}\right) - 10^{-12}\left(e^{\frac{-V}{1.2*0.026}} - 1\right) = \frac{R}{V} \qquad (12)$$

Eq. 12 can be applied to determine V of the diode by using this equation and the first derivative of this equation.

NRM can be applied to calculate the voltage of a single-diode V as follows:

$$x_1 - x_0 = \frac{f(x_1) - f(x_0)}{\frac{df(x_0)}{dx_0}} \text{then} \qquad (13)$$

$$x_{n+1} = x_n - \frac{f(x_n)}{f(x_n)} \qquad (14)$$

This process is repeated until the convergence criterion is satisfied:

$$|x_i - x_{i-1}| < \varepsilon \qquad (15)$$

It is apparent that for every approximation x_{i-1}, a better one (x_i) of the actual solution x_i can be achieved through **Eq. 15**, x_i is at the intersection of the function's tangent at x_{i-1} and axis x.

4. Results and Discussion

The case study is **Eq. 12**, x_0 is the initial value equal to 1. The values of R is between 1 to 5 Ω. The values of the I and P depending on the extracted values of V based on NRM and AEM are calculated.

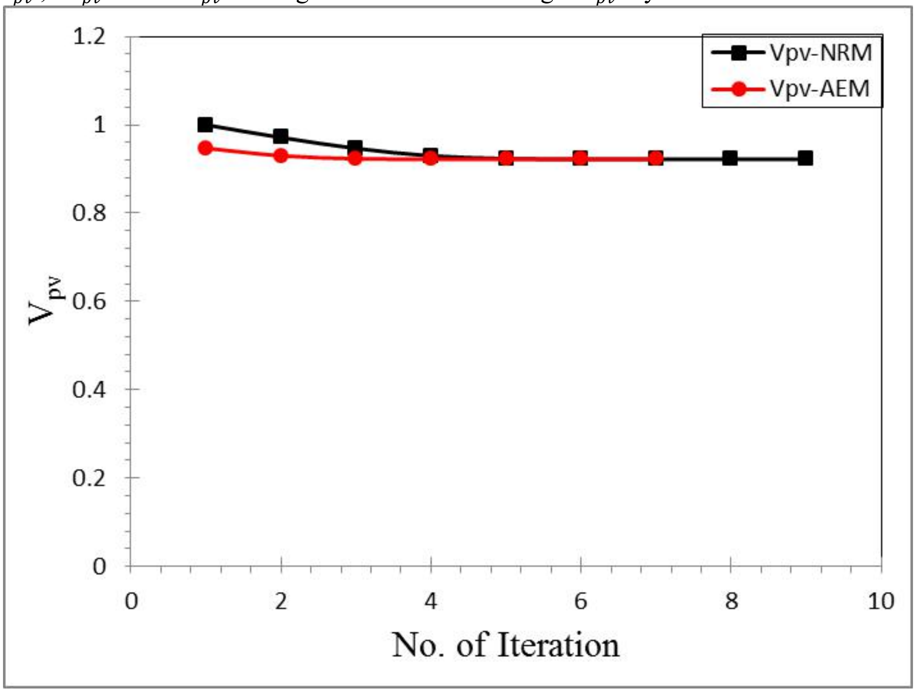
Table 1 shows the values of the I_{pv} and P_{pv} depending on the extracted values of V_{pv} and using the Eq. 12 based on NRM and AEM when the load resistance $R = 1$. Then the values of I_{pv} and P_{pv} can be calculated.

Iterations	R	X_n	Vpv-NRM	Ipv-NRM	Ppv-NRM	Vpv-AEM	Ipv-AEM	Ppv-AEM
1	1	x_0	1	1	1	0.947037857	0.947037857	0.896880703
2	1	x_1	0.971416861	0.971416861	0.943650719	0.930012729	0.930012729	0.864923676
3	1	x_2	0.946732606	0.946732606	0.896302627	0.923271149	0.923271149	0.852429615
4	1	x_3	0.929865706	0.929865706	0.864650231	0.922434357	0.922434357	0.850885144
5	1	x_4	0.923247893	0.923247893	0.852386673	0.922423136	0.922423136	0.850864443
6	1	x_5	0.922434	0.922434	0.850884484	0.922423135	0.922423135	0.850864439
7	1	x_6	0.922423136	0.922423136	0.850864443	0.922423135	0.922423135	0.850864439
8	1	x_7	0.922423135	0.922423135	0.850864439			
9	1	x_8	0.922423135	0.922423135	0.850864439			

Iterations	R	X_n	ε-NRM	ε-AEM
1	1	x_0	0.028583139	0.017025128
2	1	x_1	0.024684255	0.00674158
3	1	x_2	0.0168669	0.000836792
4	1	x_3	0.006617812	$1.12208e^{-05}$
5	1	x_4	0.000813893	$1.96644e^{-09}$
6	1	x_5	$1.08636e^{-05}$	$1.11022e^{-16}$
7	1	x_6	$1.9025e^{-09}$	0.000000000
8	1	x_7	$1.11022e^{-16}$	
9	1	x_8	0.000000000	

Table 1. Number of iterations using NRM and AEM with the value of tolerance.

Figure 3 shows number of iterations vers the solar cell parameters I_{pv}, P_{pv} and V_{pv}. Using NRM and AEM, from this Figure, one can see that the values of the voltage V_{pv} by AEM is faster than NRM.



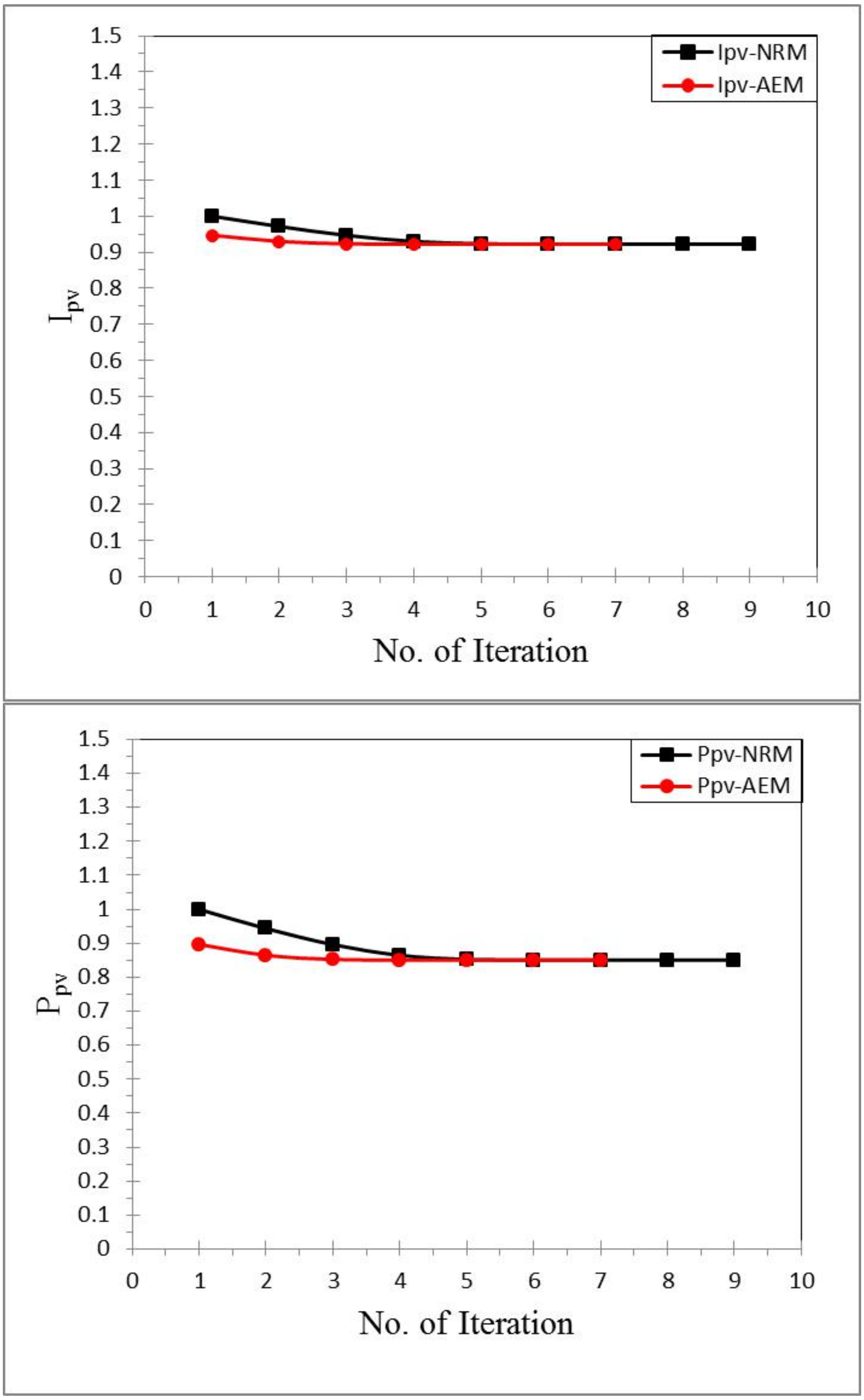


Figure 3. Number of iterations vers the solar cell parameters I_{pv}, P_{pv} and V_{pv} using NRM and AEM.

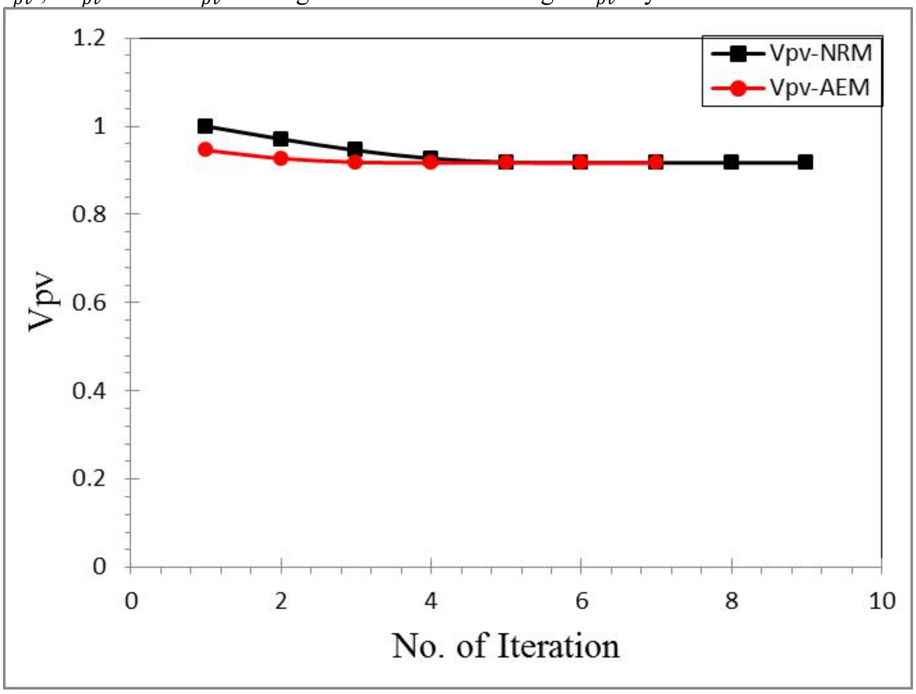
Table 2 shows the values of the I_{pv} and P_{pv} depending on the extracted values of V_{pv} and using the **Eq. 12** based on NRM and AEM when the load resistance $= 2$. Then the values of I_{pv} and P_{pv} can be calculated.

Iterations	R	X_n	Vpv-NRM	Ipv-NRM	Ppv-NRM	Vpv-AEM	Ipv-AEM	Ppv-AEM
1	2	x_0	1	0.5	0.5	0.945750417	0.472875208	0.447221925
2	2	x_1	0.971030472	0.485515236	0.471450089	0.927013023	0.463506512	0.429676573
3	2	x_2	0.945421967	0.472710983	0.446911348	0.918476227	0.459238113	0.421799289
4	2	x_3	0.926834477	0.463417238	0.429511073	0.917067904	0.458533952	0.42050677
5	2	x_4	0.918438746	0.459219373	0.421764865	0.917035399	0.4585177	0.420476962
6	2	x_5	0.917066885	0.458533442	0.420505836	0.917035382	0.458517691	0.420476946
7	2	x_6	0.917035399	0.458517699	0.420476961	0.917035382	0.458517691	0.420476946
8	2	x_7	0.917035382	0.458517691	0.420476946			
9	2	x_8	0.917035382	0.458517691	0.420476946			

Iterations	R	X_n	ε-NRM	ε-AEM
1	2	x_0	0.028969528	0.018737393
2	2	x_1	0.025608505	0.008536797
3	2	x_2	0.01858749	0.001408323
4	2	x_3	0.008395731	$3.25049e^{05}$
5	2	x_4	0.001371861	$1.66577e^{-08}$
6	2	x_5	$3.14863e^{-05}$	$4.32987e^{-15}$
7	2	x_6	$1.61176e^{-08}$	0.000000000
8	2	x_7	$4.21885e^{-15}$	

Table 2. Number of iterations using NRM and AEM with the value of tolerance.

Figure 4 shows number of iterations vers the solar cell parameters I_{pv}, P_{pv} and V_{pv}. Using NRM and AEM, from this Figure, one can see that the values of the voltage V_{pv} by AEM is faster than NRM.



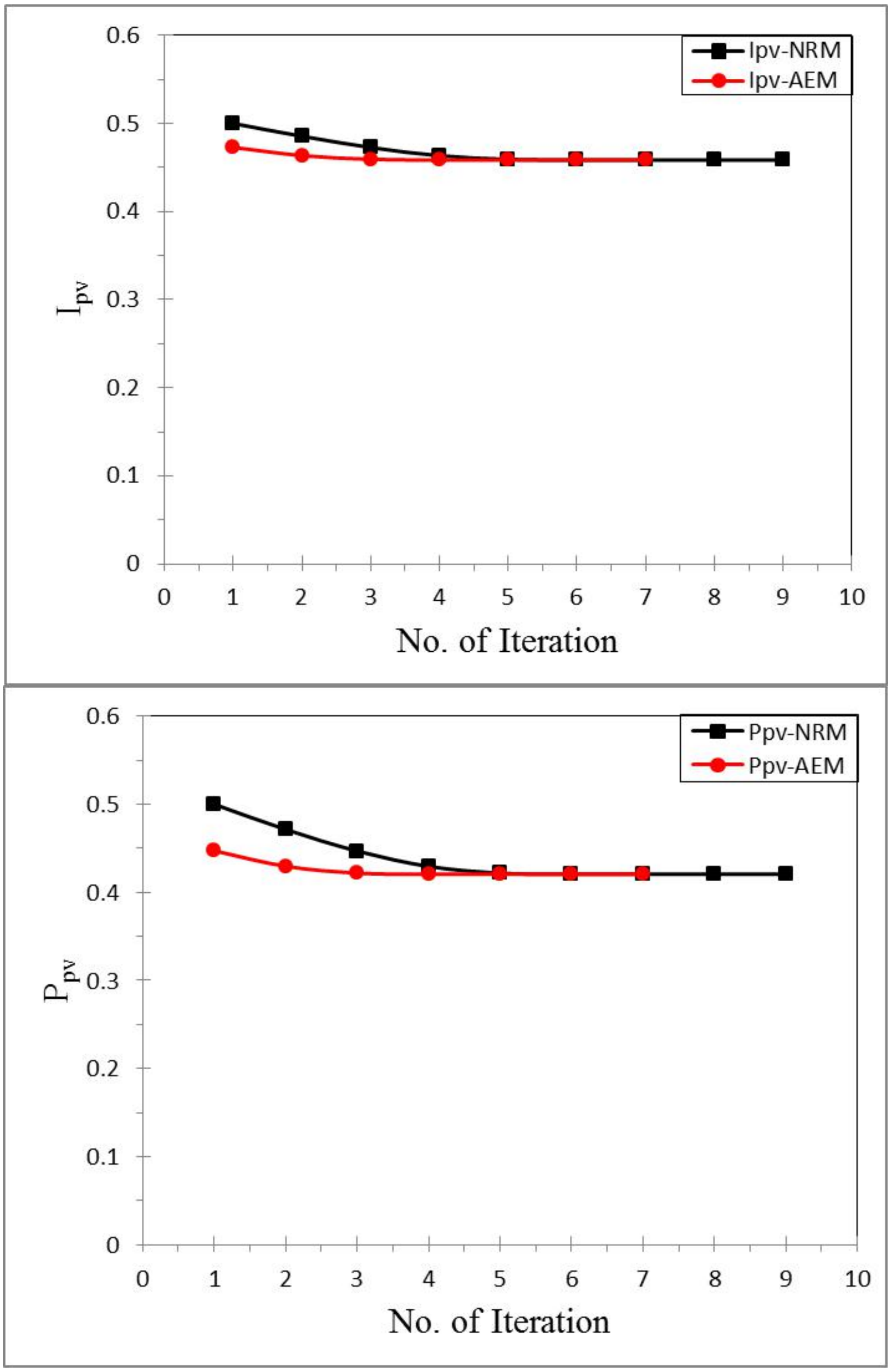


Figure 4. Number of iterations vers the solar cell parameters I_{pv}, P_{pv} and V_{pv} using NRM and AEM.

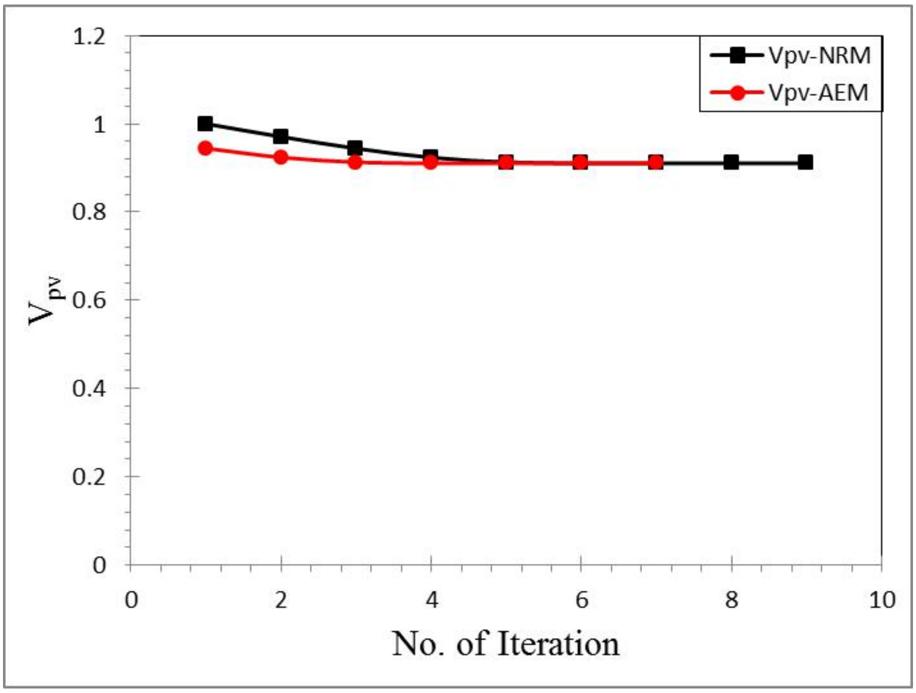
Table 3 shows the values of the I_{pv} and P_{pv} depending on the extracted values of V_{pv} and using the **Eq. 12** based on NRM and AEM when the load resistance $R = 3$. Then the values of I_{pv} and P_{pv} can be calculated.

Iterations	R	X_n	Vpv-NRM	Ipv-NRM	Ppv-NRM	Vpv-AEM	Ipv-AEM	Ppv-AEM
1	3	x_0	1	0.5	0.5	0.944437431	0.472218715	0.44598103
2	3	x_1	0.970643792	0.485321896	0.471074686	0.92381119	0.461905595	0.426713557
3	3	x_2	0.944084232	0.472042116	0.445647518	0.912938978	0.456469489	0.416728789
4	3	x_3	0.923594243	0.461797122	0.426513163	0.910504334	0.455252167	0.414509071
5	3	x_4	0.91287784	0.45643892	0.416672976	0.910403537	0.455201768	0.4144173
6	3	x_5	0.910501262	0.455250631	0.414506274	0.910403374	0.455201687	0.414417152
7	3	x_6	0.910403531	0.455201766	0.414417295	0.910403374	0.455201687	0.414417152
8	3	x_7	0.910403374	0.455201687	0.414417152			
9	3	x_8	0.910403374	0.455201687	0.414417152			

Iterations	R	X_n	ε-NRM	ε-AEM
1	3	x_0	0.029356208	0.020626241
2	3	x_1	0.02655956	0.010872212
3	3	x_2	0.020489989	0.002434644
4	3	x_3	0.010716403	0.000100797
5	3	x_4	0.002376578	$1.62654e^{-07}$
6	3	x_5	$9.77309e^{-05}$	$4.21219e^{-13}$
7	3	x_6	$1.57416e^{-07}$	0.000000000
8	3	x_7	$4.07563e^{-13}$	
9	3	x_8	0.000000000	

Table 3. Number of iterations using NRM and AEM with the value of tolerance.

Figure 5 shows number of iterations vers the solar cell parameters I_{pv}, P_{pv} and V_{pv}.Using NRM and AEM, from this Figure, one can see the number of iterations of the voltage V_{pv} by using AEM is smaller than those of NRM.



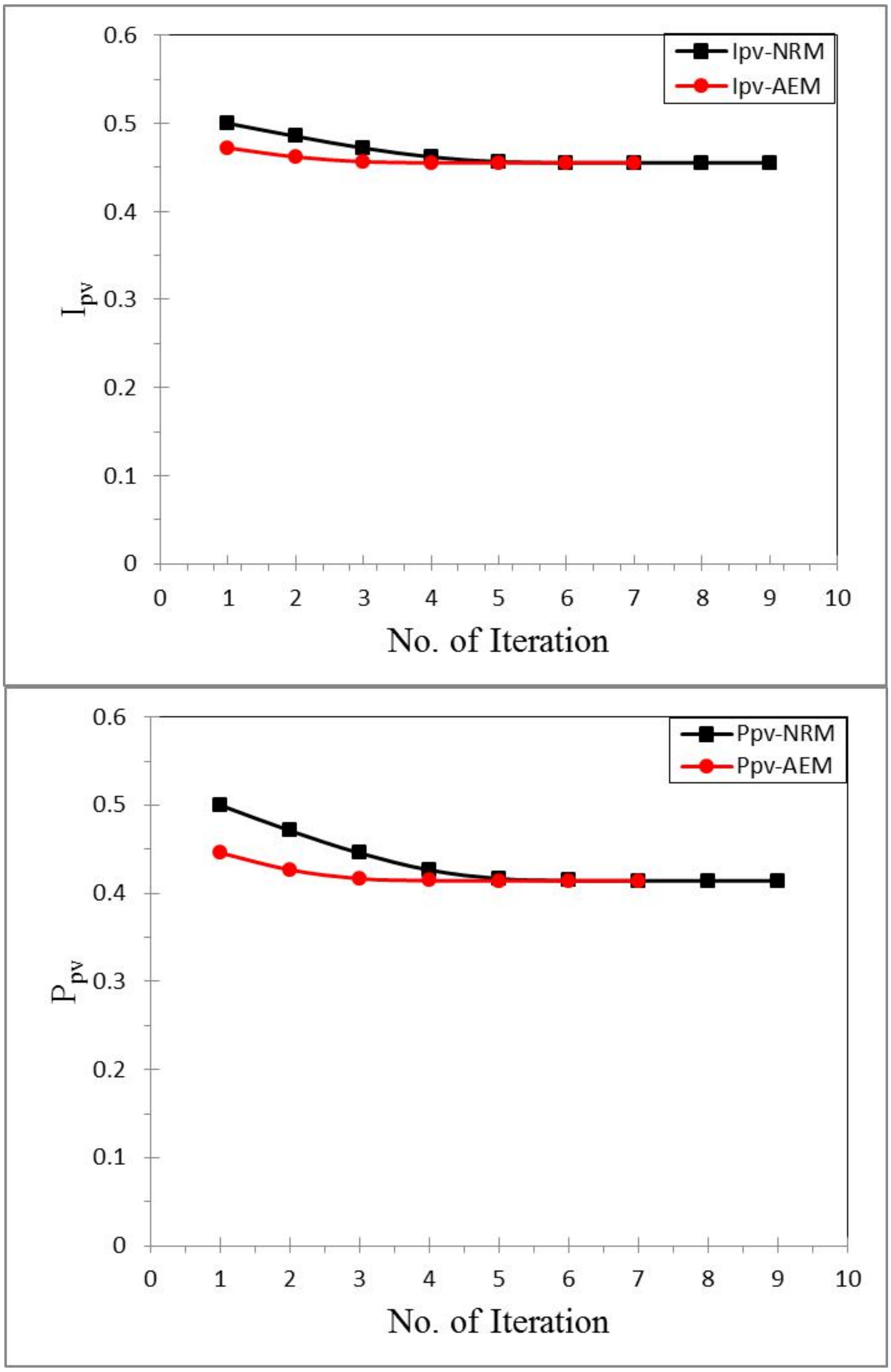


Figure 5. Number of iterations vers the solar cell parameters I_{pv}, P_{pv} and V_{pv} using NRM and AEM.

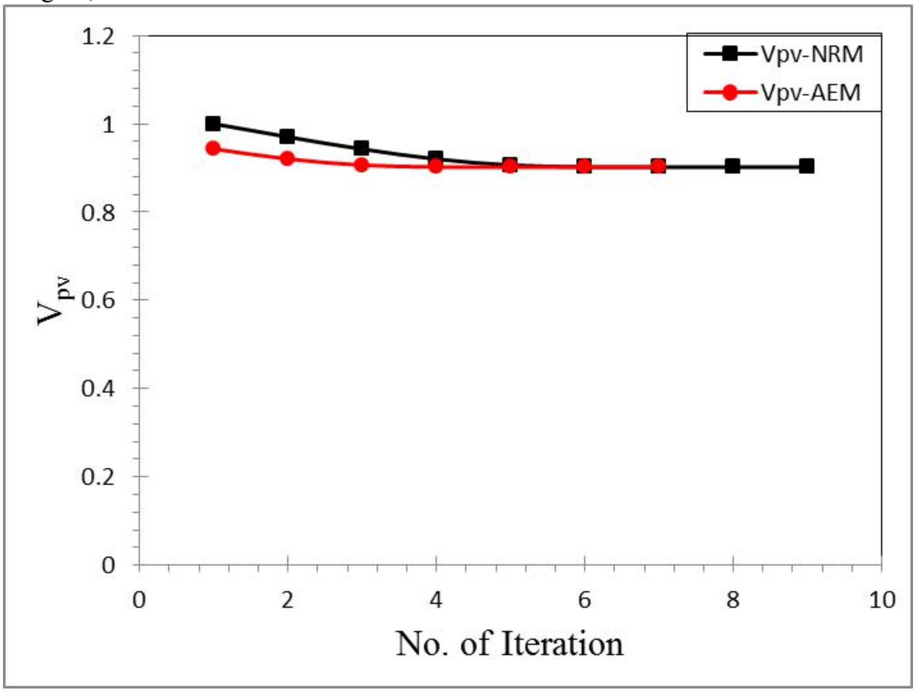
Table 4 shows the values of the I_{pv} and P_{pv} depending on the extracted values of V_{pv} and using the **Eq. 12** based on NRM and AEM when the load resistance $R = 4$. Then the values of I_{pv} and P_{pv} can be calculated.

Iterations	R	X_n	Vpv-NRM	Ipv-NRM	Ppv-NRM	Vpv-AEM	Ipv-AEM	Ppv-AEM
1	4	x_0	1	0.25	0.25	0.943098312	0.235774578	0.222358607
2	4	x_1	0.970256822	0.242564205	0.235349575	0.92038679	0.230096697	0.211777961
3	4	x_2	0.94271872	0.23567968	0.222179646	0.90644763	0.226611907	0.205411826
4	4	x_3	0.920123009	0.230030752	0.211656588	0.90208766	0.225521915	0.203440537
5	4	x_4	0.906346494	0.226586624	0.205365992	0.901742565	0.225435641	0.203284913
6	4	x_5	0.902077706	0.225519427	0.203436047	0.901740602	0.225435151	0.203284028
7	4	x_6	0.901742503	0.225435626	0.203284885	0.901740602	0.22543515	0.203284028
8	4	x_7	0.901740602	0.225435151	0.203284028			
9	4	x_8	0.901740602	0.22543515	0.203284028			

Iterations	R	X_n	ε-NRM	ε-AEM
1	4	x_0	0.029743178	0.022711522
2	4	x_1	0.027538101	0.01393916
3	4	x_2	0.022595711	0.00435997
4	4	x_3	0.013776515	0.000345095
5	4	x_4	0.004268788	$1.96294e^{-06}$
6	4	x_5	0.000335204	$6.26942e^{-11}$
7	4	x_6	$1.90082e^{-06}$	0.000000000
8	4	x_7	$6.06911e^{-11}$	
9	4	x_8	0.000000000	

Table 4. Number of iterations using NRM and AEM with the value of tolerance.

Figure 6 shows number of iterations vers the solar cell parameters I_{pv}, P_{pv} and V_{pv}. Using NRM and AEM, from this Figure, one can see the number of iterations of the voltage V_{pv} by using AEM is smaller than those of NRM.



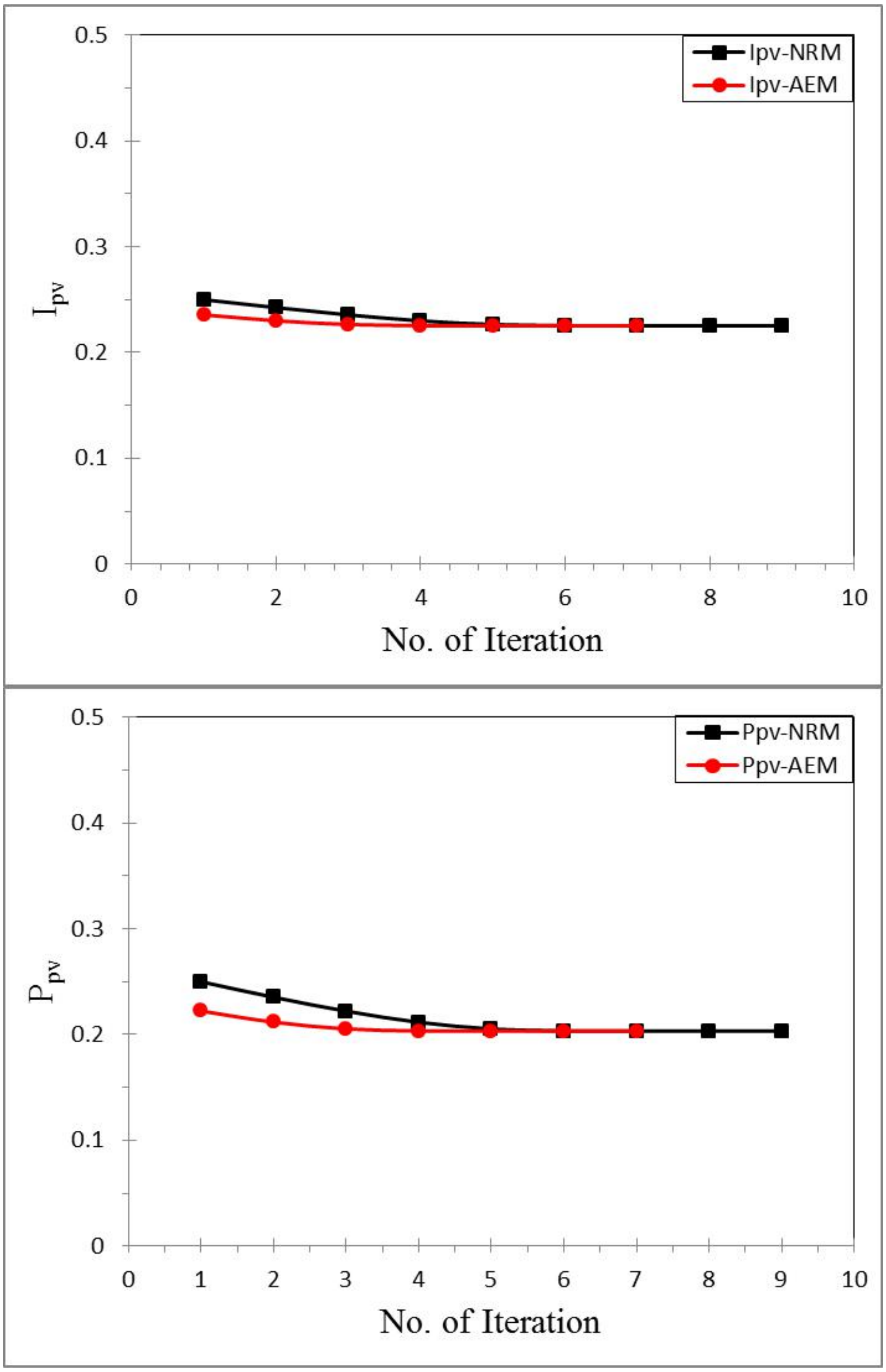


Figure 6. Number of iterations vers the solar cell parameters I_{pv}, P_{pv} and V_{pv} using NRM and AEM.

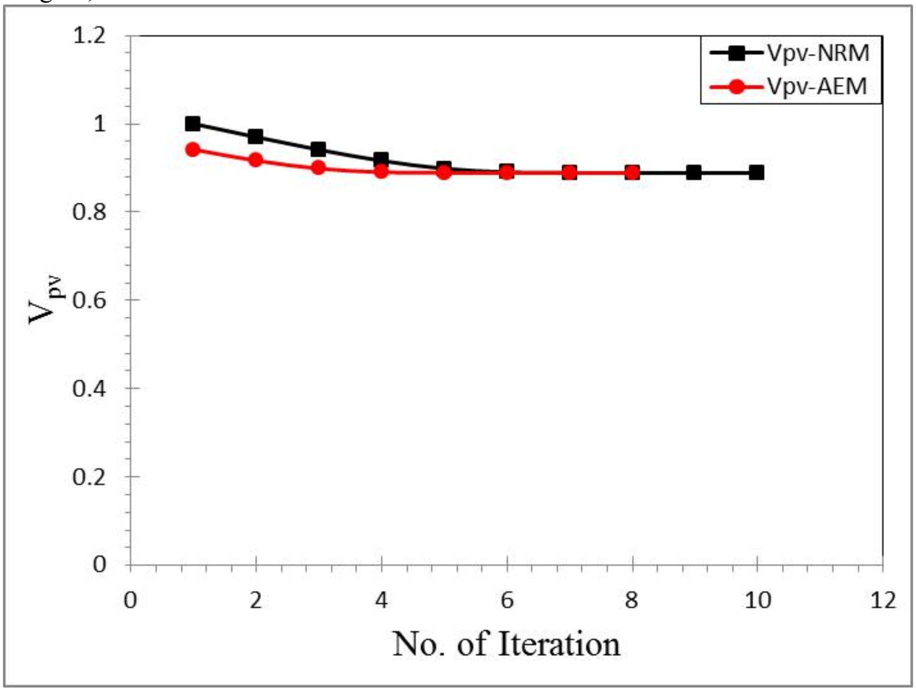
Table 5 shows the values of the I_{pv} and P_{pv} depending on the extracted values of V_{pv} and using the **Eq. 12** based on NRM and AEM when the load resistance $R = 5$. Then, the values of I_{pv} and P_{pv} can be calculated.

Iterations	R	X_n	Vpv-NRM	Ipv-NRM	Ppv-NRM	Vpv-AEM	Ipv-AEM	Ppv-AEM
1	5	x_0	1	0.2	0.2	0.941732458	0.188346492	0.177372004
2	5	x_1	0.96986956	0.193973912	0.188129393	0.916716819	0.183343364	0.168073945
3	5	x_2	0.941324731	0.188264946	0.17721845	0.898705719	0.179741144	0.161534394
4	5	x_3	0.916395843	0.183279169	0.167956268	0.890512633	0.178102527	0.15860255
5	5	x_4	0.898535645	0.179707129	0.161473261	0.889126783	0.177825357	0.158109287
6	5	x_5	0.890477009	0.178095402	0.158589861	0.889092735	0.177818547	0.158097178
7	5	x_6	0.889125763	0.177825153	0.158108925	0.889092715	0.177818543	0.158097171
8	5	x_7	0.889092734	0.177818547	0.158097178	0.889092715	0.177818543	0.158097171
9	5	x_8	0.889092715	0.177818543	0.158097171			
10	5	x_9	0.889092715	0.177818543	0.158097171			

Iterations	R	X_n	ε-NRM	ε-AEM
1	5	x_0	0.03013044	0.025015639
2	5	x_1	0.028544829	0.0180111
3	5	x_2	0.024928888	0.008193086
4	5	x_3	0.017860198	0.00138585
5	5	x_4	0.008058636	$3.40483e^{-05}$
6	5	x_5	0.001351246	$1.98037e^{-08}$
7	5	x_6	$3.30291e^{-05}$	$6.66134e^{-15}$
8	5	x_7	$1.91907e^{-08}$	0.000000000
9	5	x_8	$6.43929e^{-15}$	
10	5	x_9	0.000000000	

Table 5. Number of iterations using NRM and AEM with the value of tolerance.

Figure 7 shows number of iterations vers the solar cell parameters I_{pv}, P_{pv} and V_{pv}. Using NRM and AEM, from this Figure, one can see the number of iterations of the voltage V_{pv} by using AEM is smaller than those of NRM.



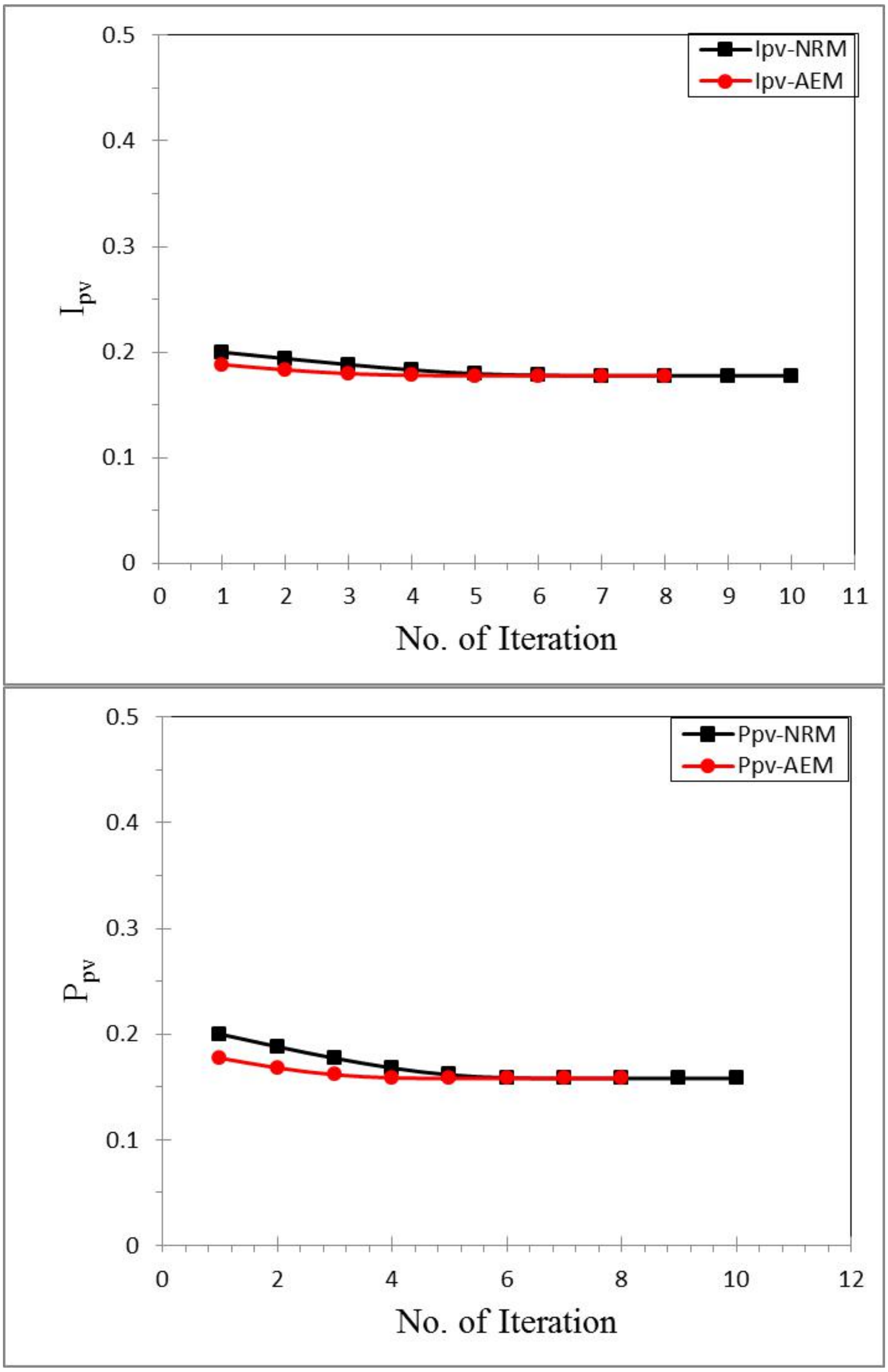


Figure 7. Number of iterations vers the solar cell parameters I_{pv}, P_{pv} and V_{pv} using NRM and AEM.

5. Conclusion

Mathematical model of the single-diode PV cells has successfully described. The physical parameters of the cell have been calculated using two methods NRM and AEM. The results showed that the number of iterations using AEM is smaller than those of NRM. In addition, the current and power of the PV cell is determined based on different methods and compared with the various values of load resistance.

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