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COMPARESION THE ELECTRICAL PARAMETERS OF PHOTOVOLTAIC CELL USING NUMERICAL METHODS

Ahmed Shawki Jaber
Department of Mathematics Science
College of Science[1]

Mimoon Ismael
Department of Mathematics
College of Education for Pure Science
University of Anbar
55 Ramadi, Anbar, Iraq, 31001

Taha Rashid
College of Arts
Al-Iraqia University
22 Saba Abkar, Baghdad, Iraq, 00964
Department of Computer and Microelectronic Systems
Universiti Teknologi Malaysia (UTM)
39 Jalan Iman, Skudai, Johor Bahru, Malaysia, 81310

Mohammed Abdulhadi Sarhan
Department of Mathematics Science
College of Science[1]

Mohammed Rasheed✉
Department of Applied Sciences
University of Technology-Iraq
18310 Al-Sina'a, Baghdad, Iraq, 10066
Moltech-Anjou
2 Bd Lavoisier, Angers, France, 49045
rasheed.mohammed40@yahoo.com

Ilaf Mohamed Sala
Subject Teacher for Secondary School
Malmö University
10 Nordenskiöldsgatan, Malmö, Sweden, 21119

[1]*Mustansiriyah University*
10052 Al Mustansiriya, Baghdad, Iraq, 00964

✉**Corresponding author**

Abstract

For a research problem: as a single-diode model (electrical circuit) is difficult to discover the precise answer to employing analytical approaches, develop and compute the electrical parameters of the PV cell roughly using numerical algorithms. Therefore, the goal of this work is to create an algorithm that aids in the approximate solution of the electrical parameters of solar cells. Three methods have been proposed for these calculations, each of which has a quicker calculation time and a higher level of accuracy.

By streamlining the calculation process, the proposed method solves the problems of complexity and precision. The I–V and P–V characteristic curves of solar cells can then be utilized to compare the efficacy of the tested methods. In addition, the analysis of root mean square error indicates that the proposed method is more applicable than alternative methods. In fact, this extraction procedure can be regarded as an efficient and precise method for estimating the single diode model parameters of solar cells.

The results indicate that this precise and effective strategy can play an important role in the retrieval of single diode model parameters. In fact, the method proposed in this paper makes numerically implementing parameter models in technology simpler. In addition, it provides an optimization suggestion for the production of solar cells.

Keywords: Illinois algorithm, Regula Falsi algorithm, electrical parameters, PV cell, load resistance.

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1. Introduction

Many iterative methods are achieved numerous nonlinear instances that have passed through different fields have been solved utilizing numerical approaches, the photovoltaic system, polymer, ceramic and many other photovoltaic applications. One of the standard techniques is Newton which is simple algorithm used in order to solve this kind of equations such as nonlinear equation, which has first derivative function with second order convergence. Researchers have treated nonlinear equations propose to modify Newton's technique. The order methods for numerical examples of nonlinear equations [1], the PV is the technology that generates DC current electrical power calculated based on semiconductors as they are illuminated by photons [2]. In order to understanding of the physical mechanisms inside PV cell, the electrical parameters values should be determined. These parameters are not directly measurable by means of set-ups (experimental). Many numerical algorithms have been used for the identification of these parameters for example the newton's method [3, 4]. The mathematical model (equation) is utilized for describing the voltage-current relationship of solar cell, therefore; the iteration's parameters have been the subject for demonstration of many researchers [5]. In nature, in the fields of engineering and science, several of the transcendental and non-linear problems of the style $f(x) = 0$, are complex, because it isn't always thinkable to acquire the exact solution of the function under testing by the common algebraic methods. The iterative numerical algorithms are often used to obtain the approximate solution of such problems [6].

Newton's technique is classical has linear convergence to simple, quadratic and multiple zeros respectively. For accelerating the convergence of this technique, some modifications are needed. Many researchers based on the inclusion of extra evaluations of functions and a derivative improves the local order of convergence for Newton's method of convergence [7].

A broad discussion for obtaining the electrical parameters of PV cell for example single-diode design is given by [8], presented a non-iterative Lagrangian method for calculating the cell characteristics are derived from the current–voltage characteristic of light produced current, this method was employed for different PV cell technologies for example the silicon. [9], improved an identification algorithm of the parameters by means of Newton's technique by MATLAB program. [10], has studied the electrical parameters of PV cell based on (I–V curve) by using Nelder-Mead simplex search method for recognizing the models and PV cell characteristics which including shunt resistance, saturation current, and series resistance. The properties of the solar cell that were extracted are collected at various operation conditions. [11], has analyzed the equivalent electrical circuit of PV cell derived experimentally from (I–V curve) involved the voltage and current of the highest power point, as well as the voltage and current of the open circuit voltage, short-circuit current based on NRM that is being used to resolve the electrical parameters of the cell because of non-linear transcendental equations. [12], obtained a satisfactory agreement with the experimental results and has high respond and sensitive to climatic conditions variation: temperature and irradiance. [13], showed the use of a performance optimization strategy based on discrete symbiotic organism search to improve overall performance to solve the global optimization for nonlinear problems, this algorithm is different from Newton's method. [14], investigated the parameters extracted from PV cell in renewable energy field. Chicken swarm optimization (CSO) is applied parameter extraction of PV cell. Different parameters of PV cell have evaluated with the help of MATLAB software utilizing chicken swarm optimization. A comparison is made with culture algorithm (CA). [15], presented the decomposition of for I–V characteristics non-linear equation. This means that the starting values of PV parameters are not essential to know like in the Newton-Raphson technique. [16], determined the PV cell electrical parameters utilizing a simple iterative method. [17], reported a new optimization method, Tree Growth Procedure (TGP), is used for efficient and accurate extraction of PV module unknown parameters and solar cell. A comparison was made between the application of TGA results and different algorithms obtained in the literature. [18], made an attempt to study a developed iterative algorithm are used to determine output characteristics of PV modules. A comparison was made between real test data and simulation results together with different conditions. [19], a technique for extracting solar cell and module characteristics from datasheet information has been developed that is both easy and improved. The parameters are as follows: ideality factor (n), series resistance (R_s) shunt resistance (R_{sh}), photocurrent I_{ph}, and saturation current I_o [20], has analyzed the equivalent electrical circuit of PV cell derived experimentally from (I–V curve) involved V_{oc} and $I_{\max}$, short-circuit current based on Newton Raphson technique which is utilized to resolve the cell electrical parameters because of non-linear transcendental equations [20–29].

For describing the problem physically, the non-linear boundary value problem is solved numerically using Newton's, RFM, and IRFM algorithms. For the research problem, derive and calculate the PV cell's electrical parameters approximately by numerical algorithms for a single – diode model (electrical circuit) because it's difficult to find the exact solution of this equation using the analytical methods.

The Idea of the project is to develop an algorithm that helps researchers to find the approximate solutions for the electrical parameters of solar cell; three algorithms have been suggested for these calculations with more accurate and faster analysis parameters of PV.

The objectives are: First to create a mathematical model for a PV cell (single-diode). Second to apply three numerical algorithms on the electrical circuit of PV cell to predict the approximate values of the electrical parameters of the cell with the comparison between them, third to calculate the current, power and voltage of the solar cell for this type of model. Fourth, to identify what problem in the sing-diode model (electrical circuit) classification is to be applied. Fifth, to obtain the accuracy of the numerical algorithms of the electrical parameters obtained for a model by means of iterations and tolerance.

2. Materials and Methods

2. 1. Research Design Matrix

The project presents the research design matrix as a technique of planning research project in which the components of a research project fit, including the purpose, time, facilities (tools), financial support, and technical support.

The experimental work involves validating the accuracy of numerical algorithms by comparing between them by means of iterations and tolerance as seen in **Table 1**.

Table 1
Research design matrix of the project

Data Collection/Resources	Data Collection	Mathematical	Simulation	Experimental
Purpose	To obtain primary values for approximate solution of non-linear equation	To construct explicit expression for operational matrix of derivative with respect to x and y	To obtained the values of a system algebraic equation using MATLAB software	To validate the accuracy of suggested method by comparing between them
Time	6 months	6 months	6 months	6 months
Facilities/Tools	MATLAB program	Available: MATLAB software	Available: MATLAB software	None
Financial Support	None	None	None	None

2. 2. Procedure of The PV Electrical Circuit Model Design

In science and electrical engineering, an electrical circuit points to a theoretical circuit, this preserves the parameters for a given circuit. An equivalent electrical model is obtained to describe the original solar cell behavior. Such model bases on known electrical components in which it is easy to analyze and study. **Fig. 1** illustrates the simple PV cell circuit (an equivalent electrical circuit).

The expression of the PV electrical circuit by means of Kirchhoff's current law-KCL of the current I based on **Fig. 1**, is given by [30–33]:

$$I = I_{ph} - I_{Diode} \text{ and } I_{Diode} = I_o\left[\exp\left(\frac{-v_{pv}}{nV_T}\right) - 1\right],$$

where

$$I = I_{ph} - I_o\left(e^{\left(-V_{pv}/mV_T\right)} - 1\right), I_D = I_o\left(e^{-V_{pv}/nV_T} - 1\right)$$

and $V_T = kT/q = 27.5$ mV, $k = 1.38\times10^{-23}$ J/K=Boltzman const.

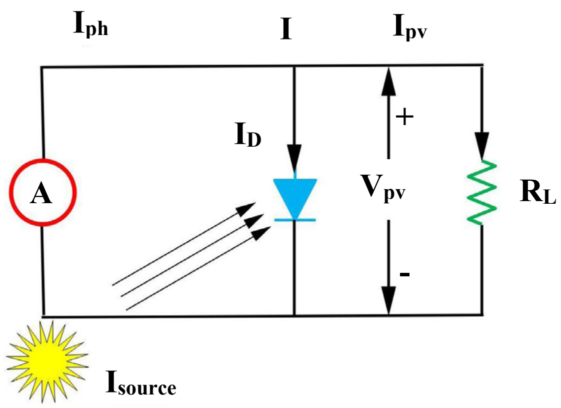

Fig. 1. Electrical Circuit Design – PV: the model type single-diode

These constants exists in all the physical systems, I_o – diode's reverse saturation current, $I_o = 10^{-12}$ A, I_{ph} – generated current, $n = 1$ to 2 – imply the factor involved in recombination, $T = p - n$ – the junction's temperature, $q = 1.6\times10^{-19}$ °C – charge of an electron, the current and P_{pv} is the power of the cell is given by [34–36]:

$$I_{pv} = \frac{V_{pv}}{R}; P_{pv} = I_{pv}\times V_{pv}.$$

Obtaining the final equation from the circuit, there is [37–40]:

$$\left(I_{source}\right) - \left(e^{\frac{-v}{1.2\times0.026}} - 1\right)\times10^{-12} = \frac{V}{R_L}. \quad (1)$$

2. 3. Newton-Raphson Algorithm

False Position (RFM) and Illinois algorithms are used to find the zeros for a non-linear problem (polynomial). If a given function is differentiable, this method can be applied and otherwise this method cannot be applied. Then the first derivative of the function should be finding and an initial guess root of the function should be taken such as v_o. Then in order to get new better approximate of the root for the given function such as V_{n+1} [1].

False Position Algorithm (RFM) [21]:

Step 1: Suppose $f(v_1) = b_1$, $f(v_2) = b_2$.

Step 2: $f(v) = av + b$.

Step 3:

$$v = \frac{b_1 v_2 - b_2 v_1}{\left(b_1 - b_2\right)}. \quad (3)$$

Illinois Model (IRFM) [22]:
Step 1: Recognize the equation $y = f(v_n) = 0$.
Step 2: Choose the starting point for the calculation v_o, v_1.
Step 3: Let $f(v_1) = b_1$, $f(v_2) = b_2$.
Step 4: Utilizing the equation, determine the value of:

$$v = \frac{b_1 v_2 - b_2 v_1}{(b_1 - b_2)}.$$

Step 5: Calculate Illinois Algorithm by:

$$c_k = \frac{\frac{1}{2} f(b_k) a_k - f(a_k) b_k}{\frac{1}{2} f(b_k) - f(a_k)}. \quad (4)$$

For the two algorithms, the tolerance is $\varepsilon = 10^{-9}$. If:

$$|f(a_n)| \geq |f(b_n)|, \ |f(v_n)| < \varepsilon. \quad (5)$$

3. Results and discussion

Three iterations numerically are presented for determining the PV electrical parameters, the describing of the Newton's algorithm represented in (2) with one initial value x_0. False Position Method (FPM) represented in (3). The suggested algorithm, Illinois Algorithm (IRFM) represented in (4). The RFM and IRFM need two initial values x_0 and x_1. Let's compare the two algorithms NRM and FRM with IRFM algorithm. For convergence requirements, the distance between two successive iterates must be smaller than or equal to 10^{-9} as defined in (5). Five instances in (1) are utilized for numerical testing with R_L values ranging from 1 to 5 ohm, which indicates the circuit's (load resistance). All determinations are made using the algorithm precision described in **Fig. 1–5**, and the required number of function evaluations is calculated using (1). Three strategies for solving (1) provide numerical examples and approximate answers, (2)–(4).

The accompanying **Fig. 2**–**6** respectively provides more information the NRM, FRM and IFRM algorithms and the comparison between them.

Fig. 2 illustrate the numerical solutions of (2) by means of three techniques with a load resistance $R_L = 1$.

Fig. 3 illustrates the numerical solutions of (2) by means of three techniques with a load resistance $R_L = 2$.

Fig. 4 illustrates the numerical solutions of (2) by means of three techniques with a load resistance $R_L = 3$.

Fig. 5 illustrates the numerical solutions of (2) by means of three techniques with a load resistance $R_L = 4$.

Fig. 6 illustrates the numerical solutions of (2) by means of three techniques with a load resistance $R_L = 5$.

Numerical results in **Fig. 2–6** means that the presented algorithms converge to the solution. For example, it can be observed that the voltage of the PV cell using classical Newton Raphson v_{pv} NRM, False Position v_{pv} – RFM and Illinois v_{pv} – IRFM algorithms have 9, 5 and 4 iterations respectively to converge to the required voltage value. Based on Illinois iterative algorithm, further modification is given to obtain higher order convergence with less than other two algorithms.

In **Fig. 6**, iteration numbers of the three presented methods RFM, NRM and IRFM for three the parameters v_{pv} and p_{pv} and are reported. They are 9, 6 and 5 for RFM, NRM and IRFM respectively.

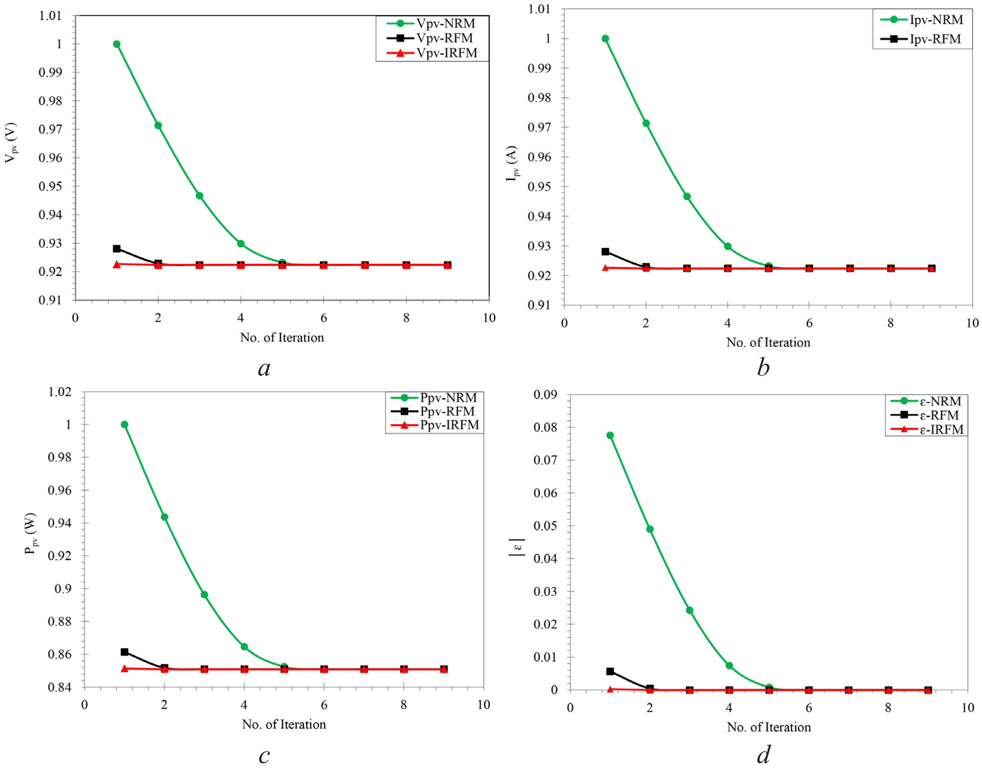

Fig. 2. Numerical solutions of solved PV equation (2) by means of three techniques: *a* – voltage of PV cell (V_{pv}); *b* – current of PV cell (I_{pv}); *c* – power of PV cell (P_{pv}); *d* – tolerance value of the techniques (ε)

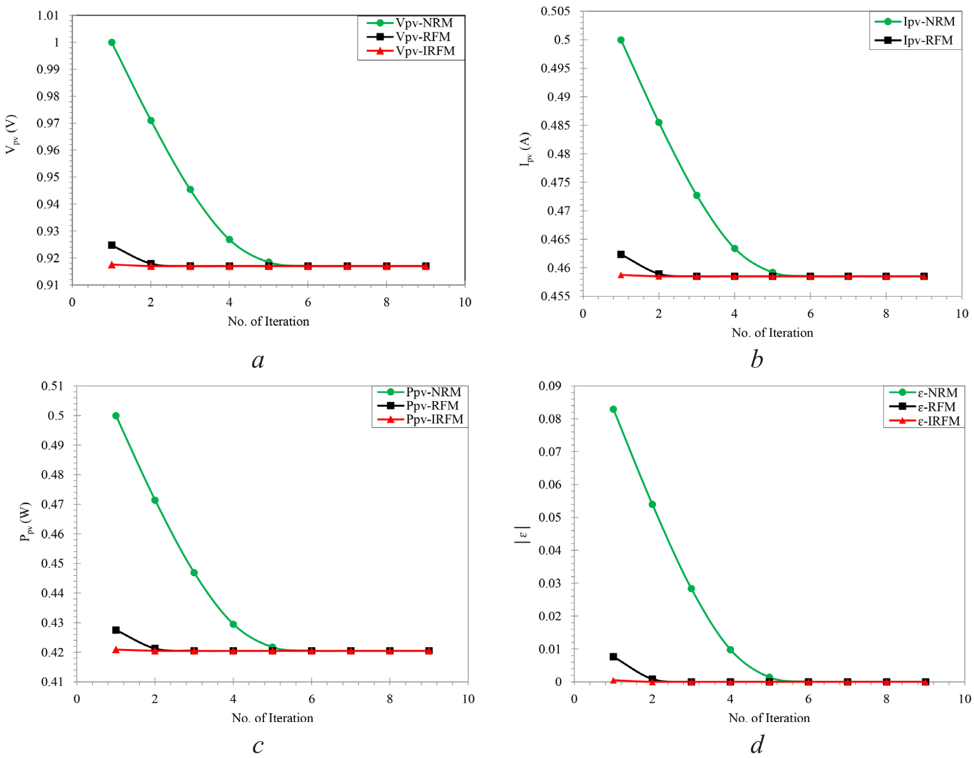

Fig. 3. Numerical solutions of solved PV equation (2) by means of three techniques: *a* – voltage of PV cell (V_{pv}); *b* – current of PV cell (I_{pv}); *c* – power of PV cell (P_{pv}); *d* – tolerance value of the techniques (ε)

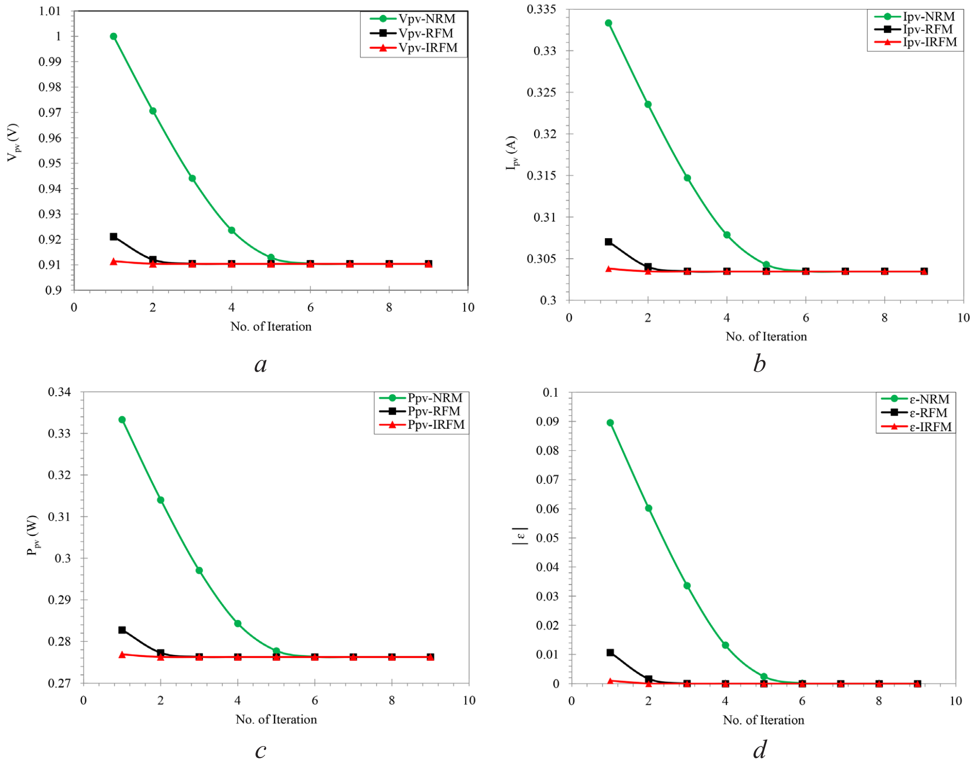

Fig. 4. Numerical solutions of solved PV equation (2) by means of three techniques: *a* – voltage of PV cell (V_{pv}); *b* – current of PV cell (I_{pv}); *c* – power of PV cell (P_{pv}); *d* – tolerance value of the techniques (ε)

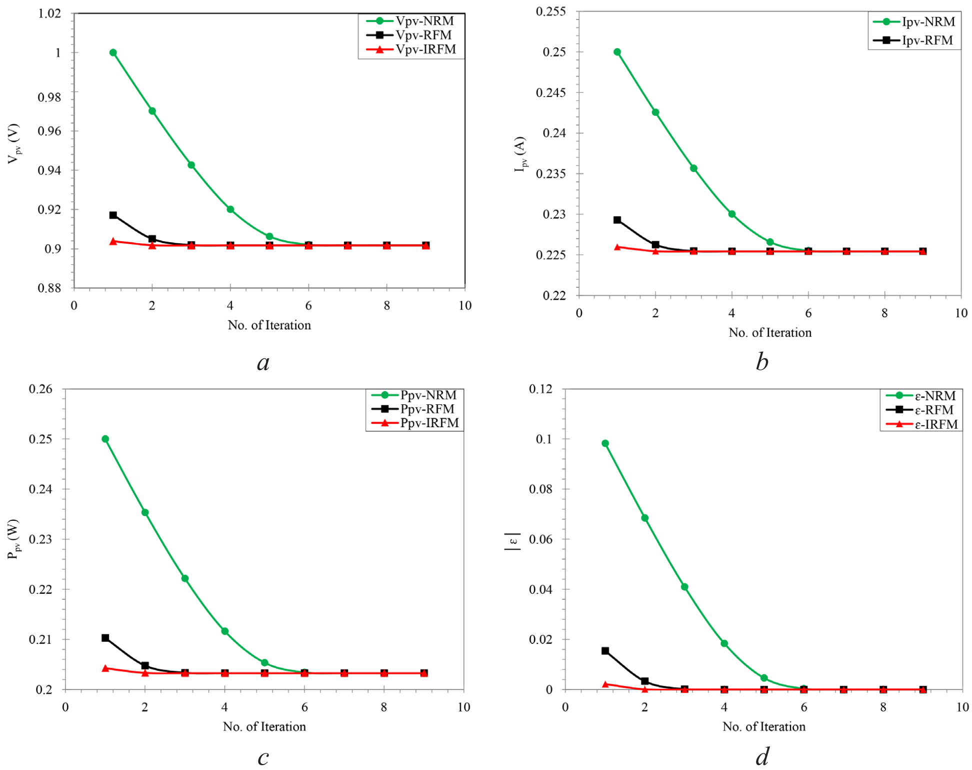

Fig. 5. Numerical solutions of solved PV equation (2) by means of three techniques: *a* – voltage of PV cell (V_{pv}); *b* – current of PV cell (I_{pv}); *c* – power of PV cell (P_{pv}); *d* – tolerance value of the techniques (ε)

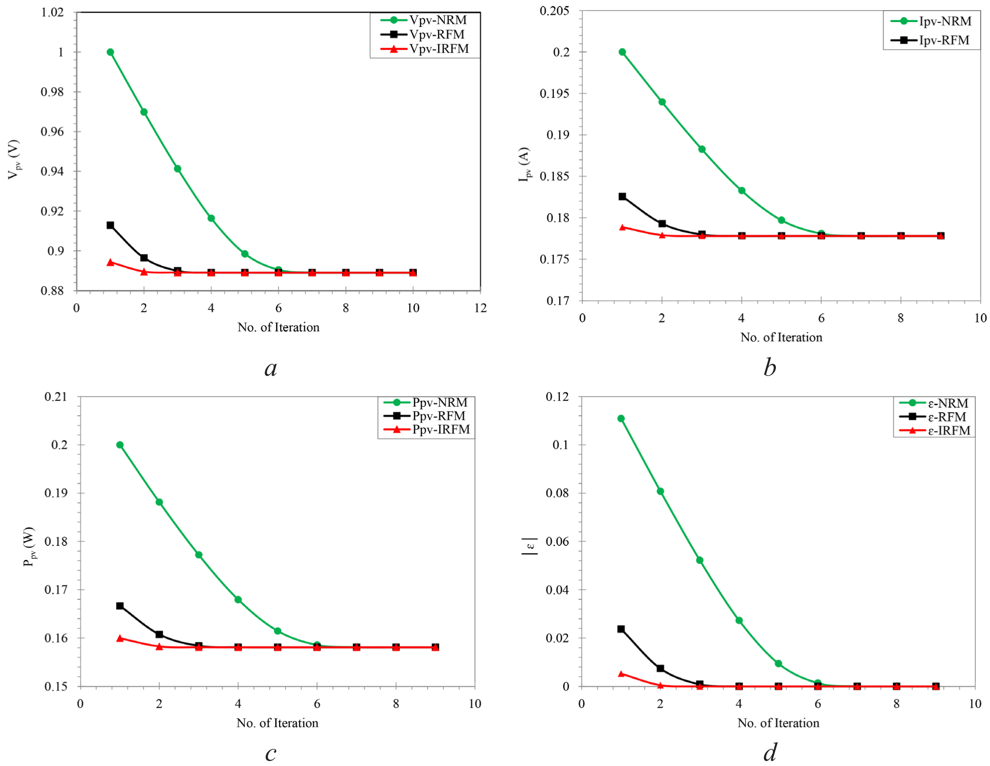

Fig. 6. Numerical solutions of solved PV equation (2) by means of three techniques: *a* – voltage of PV cell (V_{pv}); *b* – current of PV cell (I_{pv}); *c* – power of PV cell (P_{pv}); *d* – tolerance value of the techniques (ε)

The circuit used in this study is an ideal single-diode model, but until a real single-diode model is used that studies the impact of shunt and series electrical circuit resistances, (1) will change. Due to the fact that this study does not calculate various performance parameters, precise results cannot be derived. It excludes the comprehensive modeling of the one-diode model under varying levels of irradiation and temperature. Using an iterative procedure, a one-diode model is thoroughly analyzed and the output curve with the smallest error is determined. It does not evaluate the performance parameters, and a two-diode model analysis is missing it.

Using a one-diode model, the equivalent circuit model of solar cells was studied using various methodologies. It exhibited the smallest mean absolute error. Due to the fact that it does not calculate various performance parameters, it is not possible to obtain precise results. In addition, several subcases (Diode-1 to Diode-3 and Diode-6 to Diode-8) are absent, making it difficult to describe the in-depth analysis of one-diode models. In this investigation, the MATLAB solar module was used to illustrate the effects of various parameters. It provided precise output curves. No analysis is performed for detailed modeling of the solar model (Diode-1 to Diode-8) and there is no calculation of performance parameters. Consequently, this does not provide a genuine real-time output. Solar cell modeling results in an in-depth understanding of performance parameters and is highly recommended because solar energy is the least expensive energy source.

4. Conclusions

A new improvement of Illinois numerical method is introduced in this paper, which involve Regula Falsi numerical method. The mathematical model of a single-diode solar cell is derived from the electrical circuit of this cell. It is observed that the suggested technique produces results that are equivalent to those achieved using the Newton and Regula Falsi algorithms in all circumstances. The results obtained from this study indicates that by using Newton's Raphson numerical method; it is necessary 9 iterations, while for Regula Falsi numerical method – 6 iterations and Illinois Algorithm numerical method – 5 iterations. Values obtained from the suggested numerical method (Illinois) were found to be sufficient, data for a single-diode solar cell were calculated with fast convergence compared with the other algorithms based on number of iterations, and tolerance ε.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

Manuscript has no associated data.

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