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Newton- Raphson Method and Algorithm in the Extraction for the Parameters of Solar Cell

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Abstract - To accurately simulate photovoltaic (PV) modules, it is essential to have access to characteristics that are not included in the manufacturer's data sheet. Emerging photovoltaic technology includes perovskite solar cells made from organometal halides. The precursor to today's widely used perovskite solar cells was the dye-sensitized cell. Light from visible sources may be converted into direct current using photovoltaic cells (PV cells), which are specialized semiconductor diodes (DC). Certain PV cells may even convert UV or IR light into DC current. We used a Non-Linear Equation Derived from an Electrical Circuit to determine the features of photovoltaic modules for static and dynamic studies of medium voltage electrical energy systems, Newton's and Two-step procedures, and mathematical approaches. When compared to NRM, the suggested technique yields the highest efficiency, and all the necessary computations are performed in a MATLAB environment. In the end, this study provides a quick and easy mathematical technique that may be used in real-world solar electrical engineering challenges.

Keywords - Newton- Raphson, Extraction, Parameter, Solar Cell

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1. INTRODUCTION

Clean, quiet, and widely available, solar energy may be harnessed for use in power generation via the solar thermal process or converted directly into electricity by a photovoltaic system. Even while solar photovoltaic systems have seen rapid expansion in recent decades, their low efficiency and reliance on favorable weather conditions mean that researchers need to find new ways to make the most of the energy they generate. Because of this, The accuracy of simulation is highly dependent on PV factors that are not published in manufacturers' data sheet, therefore modelling the proposed photovoltaic (PV) system before actual installation is necessary to offer accurate forecasts for planning reasons. Several methods for extracting PV parameters have been published and categorized, including analytical methods, numerical methods, and evolutionary methods. Analytical methods rely on mathematical equations to find answers; they are fast, produce answers that are close to correct, take less time to compute, and may be found with as little as one round of iteration. In the instance of the Rp-model, which includes five unknowns, however, they may not be able to find a solution since there are too many parameters that are not known.

A numerical extraction strategy based on some methodology may be used to fit the spots on the PV characteristic curve. The method is comprehensive in that it considers every value along the characteristic curve, it yields more precise results than the analytical approach. Numerical methods like Newton Raphson have the basic drawbacks of requiring a large amount of computation for convergence and producing unreliable results as the number of parameters to be evaluated grows and as close approximation of initial circumstances is needed. The inaccuracies in estimating PV parameters using analytical or iterative approaches may be mitigated by using Evolutionary algorithms instead. Inspired by the natural processes of evolution, evolutionary algorithms make incremental improvements over time. Now, standard evolutionary methods like artificial bee colony (ABC), particle swarm optimization (PSO), genetic algorithm (GA), simulated annealing (SA), etc. are used for parameter extraction of PV modules. Perovskite, a mineral discovered by a Russian mineralogist named L.A. Perovski, with the formula ABX3. The six X anions in the octahedral position stabilise the smaller B cation, whereas the twelve X anions in the cubo-octahedral site support the larger Acation. Oxide perovskites, because to their ferroelectricity or superconductivity, have been the focus of the majority of the study. Halide perovskites were largely disregarded till it was discovered that they underwent a semiconductor-to-metal transition when their dimensionality was increased via stacking organometal halide perovskites. There were shifts in electrical characteristics as well as a narrowing of the band gap with the transition from two to three dimensions. When used to solar cells, a small band gap is preferable.

2. LITERATURE REVIEW

Tummala, Ayyarao (2020) If you want to know how well your solar photovoltaic power system is doing, you'll need a mathematical model with very specific characteristics. This technical paper introduces a novel method for precisely predicting solar PV system characteristics. In contrast, nonlinear equations are solved using the NR approach in order to compute the objective function. Most algorithms estimate parameters using an objective function that ignores nonlinearities in I-V characteristics and is thus very inaccurate. The accuracy of such models may be too low for use in critical situations. The work presented here formulates an objective function that, when applied to the corresponding PV models, results in more precise parameters without ignoring nonlinearities. Parameters for the SDM, DDM, and PV module are estimated using the suggested technique. Results from various state-of-the-art algorithms are compared with the proposed QANO method to gauge its effectiveness. The suggested technique outperforms the majority of currently available algorithms, with an RMSE of 7.7300630E-04 for SDM and 7.5248E-04 for DDM, respectively.

Nunes, Hugo & Pombo, José & Mariano, Silvio & Calado, Maria Do Rosário. (2020) When metaheuristics are used, the output current is calculated using LWF and NRM, which are examples of indirect techniques, rather than the most popular way in the literature, the output current can be solved in a straightforward manner (DirectSolve). To do this, we estimated the PV parameters of the single-diode model using the GSK optimization method (SDM). In the study, both typical and experimentally measured datasets were included, as were a variety of operational settings. When taking into account LWF or NRM, the findings produced from both the indirect and direct methods were shown to be accurate and reliable. When comparing computational efficiency, LWF was 0.11 percentage points better than NRM on average. DirectSolve was, on average, 35% less accurate than indirect methods. Results demonstrated that LWF and NRM provide highly comparable performances in estimating PV parameters, with only minor differences in computing costs.

Gnetchejo, Patrick & Salomé, Ndjakomo & Dadje, Abdouramani & Ele, Pierre. (2021) Standard PV cells cannot be designed without first extracting relevant parameters. Heuristic algorithms have been shown to be the most efficient approach for determining the values of parameters. This paper's goal is to demonstrate that integrating heuristics algorithms with the Newton Raphson technique significantly improves the reliability of the obtained outcomes. The optimal constitutive parameters may be extracted with the use of a suggested artifact approach based on data from a control center simulation of a drone squadron. At the same time, this research sheds light on the methods previously described and suggested to construct objective function. Additionally, a comparative analysis of the top 10 heuristic methods currently available for PV estimate is performed. In addition, the convergence of algorithms under varying current-voltage characteristics is explored. This research indicates the greatest formulation accuracy and sheds insight on the key distinctions between the two formulations. Exact PV module parameters were extracted from the findings obtained from seven examples addressed in this research, using a combination of the Newton Raphson performance approach and Drone Squadron optimisation. Analyzing the point count, we find that fewer points on the I-V axis leads to faster convergence and better accuracy from the algorithm. On the other hand, if these data points are sparse, the algorithm will be hampered in its ability to provide desirable outcomes.

Sriabisha, R. & Hariharan, R. (2020) The efficiency of the solar system may be attributed in large part to the components utilized to make the solar panels. Solar cells, which are used to convert sunlight into usable power, are often made of silicon. Materials in the solar system may be employed to boost the efficiency of the solar cells, which is currently measured at 23%. The silicon cells' high price and poor performance are drawbacks. Researchers finding ways to boost solar cell efficiency is a critical aspect of the solar system's overall performance as a project. A more efficient alternative to silicon solar cells is the perovskite kind. Perovskite solar cells are 28 percent more efficient than conventional solar cells at converting solar energy into usable forms. However, this perovskite cell has the fundamental drawback of being unstable and containing lead that is easily soluble in water. This research examines the solar panel that makes use of perovskite solar cells.

Reza, M. Nahid & Mominuzzaman, Sharif (2018) Parameters in the equivalent circuit are crucial for modeling the behavior of a perovskite solar cell in order to find the optimal operating conditions. Extraction of these characteristics for perovskite solar cells is currently a topic of little scientific interest. Using the Newton-Raphson technique, the authors of this paper extract the device characteristics of a perovskite solar cell that incorporates carbon nanotubes. These factors are used to investigate the cell structure and the impact of inserting carbon nanotubes into various layers of the perovskite solar cell.

3. RESEARCH METHODOLOGY

- **Non-Linear Equation Derived from an Electrical Circuit**

Electronic equivalent circuit of a solar cell is shown in Figure 1 (neglecting Rs and Rsh).

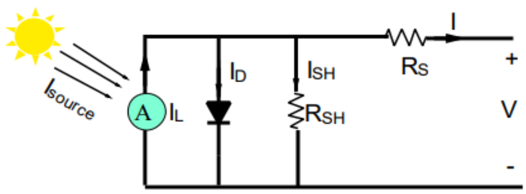

Figure 1: Single-diode electrical equivalent circuit of a solar cell

Based on this equivalency, we can get the complete equation for the current in the solar cell by using Kirchhoff's current law (KCL).

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

$$I_D = I_0\left(e^{\frac{-V_{pv}}{nV_T}} - 1\right) \quad (2)$$

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

where: I_0, I_{ph}, I measured in Ampere: the current in the cell, the photocurrent, and the reverse saturation current. In addition, the thermic voltage= 26 mV and the cell voltage's VPV are provided. Recombination factor about (1<m<2) and k = electron charge = 1.6× 10^{-19}; and the Boltzmann constant = 1.38 x 10^{-23} J/K.

$I_{ph} = I_{source}$ (4)

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

Put Eq. 4 in Eq. 5 yield

$$(I_{source}) - 10^{-12}\left(e^{\frac{-V}{1.2*0.026}} - 1\right) = \frac{V}{R} \quad (6)$$

Where: Is reverse saturation current=10^{-12} A. In a similar vein, VD=Vpv=V. Obtaining the numerical roots of Vpv requires the derivative of Eq. 6.

- **Newton's Technique (NRM)**

The Newton–Raphson technique is an iterative procedure that begins with a first estimation of the value of the function f(x) to be estimated. To acquire this technique, we use the Taylor series expansion in (x- x0) as shown below.

$$f(x) = f(x_0) + f'(x_0)(x - x_0) + \frac{1}{2}f''(x_0)(x - x_0)^2 + ... = 0$$

Let's pretend the first estimate is quite close to the correct root. In this case, the difference between (x - x0) is small enough that only the first terms matter when trying to estimate the value of the root given x0. The overall formula for Newton Raphson's technique may be found by truncating the series at the second term.

$$x_1 = x_0 - \frac{f(x_0)}{f'(x_0)} \quad (7)$$

Equation (7) and the accompanying picture (9) may be used to provide numerical and visual representations of this (7).

$$x_{n+1} = x_n - \frac{f(x_n)}{f'(x_n)} \quad (8)$$

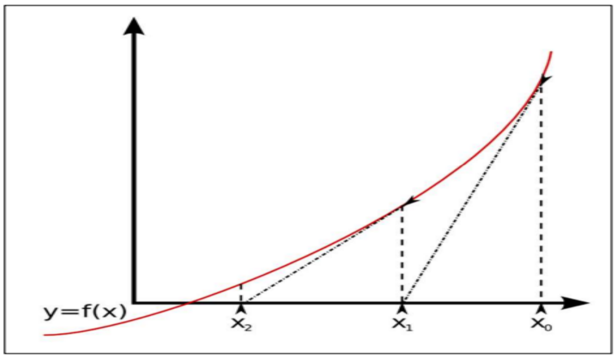

Figure 2: Illustration of the Newton Raphson Method

The Newton Raphson Method is guaranteed to converge for the interval [a,b] that contains the root of f(x) if f(x) and f'(x) are continuous in this interval and f()= 0, where is the root of f(x).

For the purpose of solving Eq. 6, the following approach is proposed utilizing NRM.

- INPUT initial approximate solution $x_0 = 1$, ε = tolerance, N= maximum number of iterations.
- Output x_{n+1} = approximate solution

1. Set $x = 0$
2. Step 2: while $i \leq x_0$
3. Step 3: Calculate $x_{n+1} = x_n - \frac{f(x_n)}{f(x_n)}$ for $n = 0, 1, 2, ...$
4. Step 4: If $|x_i - x_{i-1}| < \varepsilon$; so x_{n+1} = approximate solution output and stop.
5. Step 5: put $i = i + 1, n = n + 1$; go to Step 2.
6. Step 6: Output

- **Two Step Iterative Method (2SM)**

Technique 1 (NRM) and the suggested method have been utilized to evaluate and contrast the various numerical methods of iterations (2SM). Along with showing how well the new approach works, we also solved Eq. 6 to check for numerical consistency and stability. Some iteration is used to analyze the obtained findings.

$$y_n = d_n - \frac{2\times f(d_n)}{3\times f'(d_n)},\ n = 0, 1, 2, 3, \ldots$$

$$d_{n+1} = d_n - \frac{2\times f(d_n)}{f'(d_n)+f'(d_n)},\ n = 0, 1, 2, 3, \ldots$$

- **PV Module Modelling**

The manufacturer lists the following features of the photovoltaic module's technical specifications: As shown in Figure 3, a photovoltaic module's maximum power (PMP) is achieved when its maximum power current (IMP) and maximum power voltage (VMP) are both measured. The open circuit voltage VOC is measured when the module is not under any load, and the short circuit current (ISC) is measured when the module is shorted.

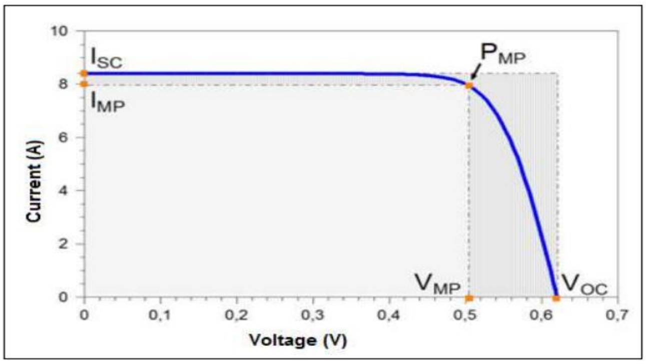

Figure3: Typical V-I curve of a PV cell

4. DATA ANALYSIS

Tables with varied values of load resistance of the proposed circuit show the results of nonlinear Eq. 6 in the PV single diode model is solved using NRM and 2SM, two numerical approaches.

Table 1: Comparison of different methods using NRM and 2SM

Iterations	V_{pv}-NRM	I_{pv}-NRM	P_{pv}-NRM	V_{pv}-2SM	I_{pv}-2SM	P_{pv}-2SM
1	1	1	1	0.962945371	0.962945371	0.927263787
2	0.971416861	0.971416861	0.943650719	0.940361045	0.940361045	0.884278896
3	0.946732606	0.946732606	0.896302627	0.926849876	0.926849876	0.859050692
4	0.929865706	0.929865706	0.864650231	0.922778557	0.922778557	0.851520266
5	0.923247893	0.923247893	0.852386673	0.922426883	0.922426883	0.850871355
6	0.922434	0.922434	0.850884484	0.922423135	0.922423135	0.85086444
7	0.922423136	0.922423136	0.850864443	0.922423135	0.922423135	0.850864439
8	0.922423135	0.922423135	0.850864439			
9	0.922423135	0.922423135	0.850864439			

In Table 1, with an initial value of x0=1, it is fascinating to see that the NRM technique converges to the root 0.922423135 at the 9th iteration, whereas the suggested method in Eq. 6 converges to the same approximate root 0.922423135 at the 7th iteration. The PV parameters derived using NRM and 2SM are shown in Figure 4.

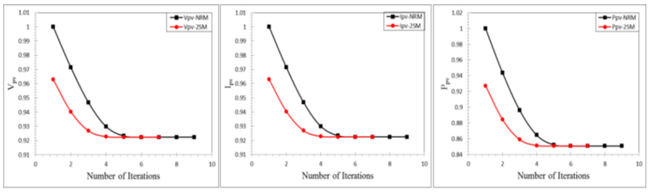

Figure4: Comparison of PV cell parameters obtained by NRM and 2SM

Since the results achieved by the proposed strategy are closer to the original approximation, it works better with this kind of model. It is well known that the best approximation to an exact root is generally closer to the beginning value. Additionally, the suggested approach 2SM seems to need less rounds.

The following outcomes were found after testing the Octave-built program:

Table 2: Initial Guess Used

INITIAL GUESS (IG)	
1º	x0 = [1.5; 0.5; 1.0; 0.5; 50]
2º	x0 = [2.0; 0.1; 1.0; 1.0; 100]
3º	x0 = [2.0; 1.0; 1.0; 1.0; 100]
4º	x0 = [2.0; 1.0; 1.0; 1.0; 50]
5º	x0 = [0.6; 2.5; 1.5; 2.0; 100]

Several educated estimates were made throughout the simulation runs, some of which eventually led to a solution and others which did not. As can be seen in Tables 3 and 4, fewer iterations were produced when the original estimate was closer to the root.

Table 3: Obtained Parameters of the Curve 1

CURVE 1						
IG	Iph(A)	Is.10-6 (µA)	m	Rs (Ω)	Rsh(Ω)	Iters
1º	0.6687	2.006	1.4288	1.1686	120.58	9
2º	0.6687	2.006	1.4288	1.1686	120.58	7
3º	0.6687	2.006	1.4288	1.1686	120.58	9
4º	0.6687	2.006	1.4288	1.1686	120.58	9
5º	0.6687	2.006	1.4288	1.1686	120.58	4

Table 4: Obtained parameters of curve 2

CURVE 2						
IG	Iph(A)	Is. 10-6 (µA)	m	Rs (Ω)	Rsh(Ω)	Iters
1º	1.8462	0.0441	1.0245	0.1979	58.92	5
2º	1.8462	0.0441	1.0245	0.1979	58.92	7
3º	1.8462	0.0441	1.0245	0.1979	58.92	8
4º	1.8462	0.0441	1.0245	0.1979	58.92	8

A simulation of the related curves was performed using the data in table 4. In Figure 5 and Figure 6, we see the link between current and voltage in both the actual world and in a computer simulation. The simulated curves can be shown to pass through all five of the problem's initial points, indicating that they are a close approximation to the true curve. The connection between power and voltage is seen in Figures 7 and 8. The simulated curves are similar in form to the actual curve and can be seen to have reached the locations of greatest power.

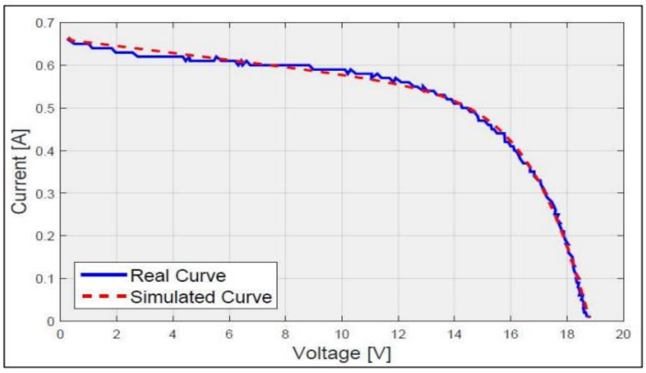

Figure 5: Curve I x V, T=25°C e G=225.0 W/m²

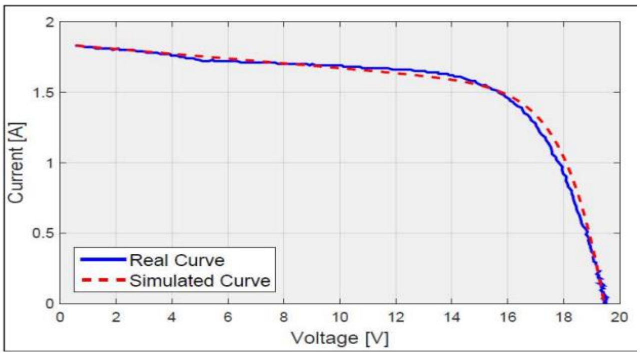

Figure 6: Curve I x V, T=35°C e G=596.8 W/m²

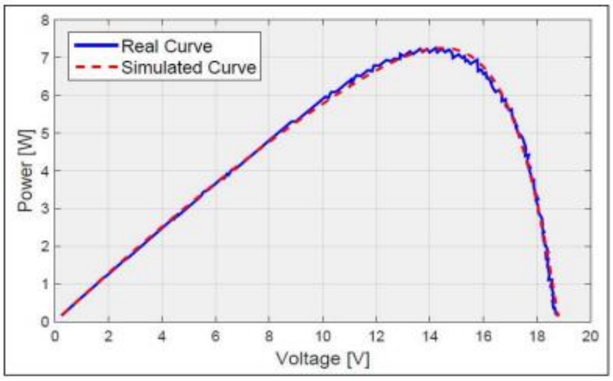

Figure 7: Curve P x V, T=25°C e G=225.0 W/m^2

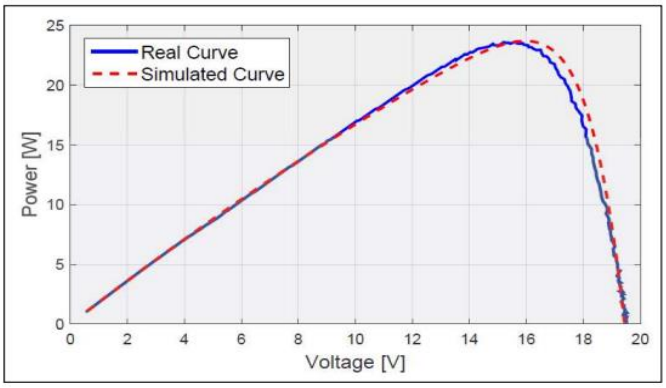

Figure 8: Curve P x V, T=35°C e G=596.8 W/m²

Knowledge of the desired approximation value is required for success with the Newton Raphson approach, since the first estimate must be quite near to the actual answer for the procedure to work. The Jacobian matrix that is calculated at each iteration must satisfy this condition, therefore understanding it is crucial.

5. CONCLUSION

We can say that non-linear equation of a solar cell was solved numerically using two-step and Newton's techniques. Different levels of the load resistance are used to test the procedures, and they have shown to be effective. Since approximative answers may be generated with just a few calculations using MATLAB, the computational procedure in these approaches is straightforward. This method is therefore quite effective. The success of the suggested strategy is determined on the value of x0 chosen at the outset. The parameters calculated from the VxI curve using the method proposed in this research matched the actual curve obtained from the solar module well. The Newton Raphson approach may be used to solve issues involving nonlinear equations in a wide range of scientific disciplines. However, as shown in this study, convergence cannot be attained without prior knowledge of a range of values near to the solution. In conclusion, this study provides a quick and easy mathematical technique that may be used in real-world solar electrical engineering challenges.

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