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Research Article

The Numerical Algorithms and Optimization Approach Used in Extracting the Parameters of the Single-Diode and Double-Diode Photovoltaic (PV) Models

R. Thandaiah Prabu ,[1] S. Parasuraman ,[2] Satyajeet Sahoo ,[3] T. M. Amirthalakshmi ,[4] S. Ramesh ,[5] S. Agnes Shifani ,[6] S. Arockia Jayadhas ,[7] M. Indra Reddy,[8] Sami Al Obaid,[9] Saleh Alfarraj,[10] and S. S. Kumar[11]

[1]*Department of Electronics and Communication Engineering, Saveetha School of Engineering, SIMATS, Chennai, 602 105 Tamil Nadu, India*
[2]*Department of Electronics and Communication Engineering, Karpaga Vinayaga College of Engineering and Technology, Chennai, 603308 Tamil Nadu, India*
[3]*Department of Electronics and Communication Engineering, Vignan's Foundation for Science, Technology and Research (Deemed to be University), Vadlamudi, Guntur, 522213 Andhra Pradesh, India*
[4]*Department of Electronics and Communication Engineering, Rajalakshmi Institute of Technology, Chennai, Tamil Nadu, India*
[5]*Department of Electronics and Communication Engineering, St. Mother Theresa College of Engineering, Vagaikulam, 628102 Tamil Nadu, India*
[6]*Department of Electrical and Electronics Engineering, JP College of Engineering, Tenkasi, 627852 Tamil Nadu, India*
[7]*Department of EECE St. Joseph University in Tanzania, Tanzania*
[8]*Department of Mechanical Engineering, SRKR Engineering College, Bhimavaram 534204, India*
[9]*Department of Botany and Microbiology, College of Science, King Saud University, PO Box 2455, Riyadh 11451, Saudi Arabia*
[10]*Zoology Department, College of Science, King Saud University, Riyadh 11451, Saudi Arabia*
[11]*Department of Bioenvironmental Energy, College of Natural Resources & Life Science, Pusan National University, Miryang-si 50463, Republic of Korea*

Correspondence should be addressed to Satyajeet Sahoo; satyajeetsahoo.eltc@gmail.com and S. Arockia Jayadhas; arockia.jayadhas@sjuit.ac.tz

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The current-voltage association of the single-diode photovoltaic (PV) cell comparable circuit system was characterized by its nonlinear implicit logical equation that would be hard to be resolved numerically. Because of the difficulty, various strategies for explaining this equation by using numerical approaches have been developed. The double-diode model is used to depict the PV cell in this research. This design is more accurate at the low irradiance levels, allowing for an extra accurate estimate performance of the PV system. The number of input variables is decreased to four to save time, and the values of R_p and R_s are calculated using an effective iterative technique. This research analyzes and compares three commonly used strategies for explaining the current-voltage equation parameter of a single-diode solar PV model. The chaotic optimization approach (COA) is used to evaluate the single-diode and double-diode solar cell characteristics. The suggested method relies on experimentally established current-voltage (I-V) characteristics. The suggested approach uses the curves of I-V characteristics obtained in the research laboratory for several standards of the solar temperature and the radiation and demonstrates its applicability in terms of efficacy, accuracy, and the simplicity of execution in an extensive range of real-world situations. As a conclusion, COA-based restriction approximation is beneficial to photovoltaic power generator manufacturers that want a timely and efficient PV cell/module model. It demonstrates that no single approach performs the best among all parameters and the method selection is always a trade-off depending on the user's focus.

1. Introduction

Solar energy's contribution to the total production of electric energy is steadily increasing. The solar inverter and panel costs continue to fall; many countries were focusing on their energy policies to increase the usage of solar energy. Electric network research, particularly testing the integration sources of solar energy into a power grid, necessitates a precise estimate of a solar maximum output and also correct modeling of solar cells. There are two primary models of PV solar cell equivalent circuits in works: the single-diode model (SDM) and the double-diode model (DDM). DDM takes into an account the complex result of the junction's impartial area; as a result, it correctly simulates solar cells more. It is, nevertheless, distinguished by seven unknown properties. Because DDM is complex, some writers limit the number of unknown factors, which can have a significant impact on model accuracy [1].

In recent years, the desire to boost energy supply security, reduce the ecological pollution, and adopt job possibilities via emerging a new green technology makes clean and sustainable energy sources an unavoidable alternative to consider [2]. There are several sorts of renewable energy sources, each with its own set of conversion processes. However, a significant rise in research and growth activity in the domain of photovoltaic (PV) networks are increased to the world's most populous renewable energy technologies for power production. The accuracy of the model's characteristics improves as the number of diodes rises; but, the math formulation necessary to produce the feature outcome becomes increasingly difficult. The single-diode model of 5 parameters is a good compromise, although it is necessitating to solving several equations to obtain the initial values used by the model. This problem is exacerbated by the manufacturer datasheet's lack of information [3].

Some studies compared the algorithms used to extract parameters from solar PV simulators. Identification of parameters of the single-diode model of solar cell, for example, has been conducted by using an experimental characteristics as I-V of Si and the multijunction of the solar cells. The extraction was performed using three different optimization strategies to determine which strategy outperforms the others in relation to the information-to-fitting scheme. Their findings exposed that a Newton–Raphson approach is the commonly used for the extraction of the parameter. Another study evaluated the I-V and P-V curves for a generic PV panel at varied temperatures and irradiation using five different algorithms. The double-diode design is suggested for better accuracy [4].

Adding a second diode to upgrade the variables, the main problem is in estimating the parameters of all design parameters while keeping the number of iterations reasonable. Several computing methods are proposed; however, all of them incorporate an additional coefficient into the calculations, enhancing their computational loads. Furthermore, identifying the parameters' starting values is difficult; Heuristic methods must be considered in some cases [5].

Physical variables including the electron diffusion rate, minority charge lifetime, and intrinsic charge density, as well as other material parameters, can also be used to characterize the double-diode model [6]. While all these simulations can help you understand the physical behavior of a cell, it is essential to understand semiconductors that are not often found in photovoltaic datasheets. As a result, developing a usable PV model using such a concept is not practical because majority of the cases on PV designers lack detailed knowledge of semiconductor processes. Through a chaotic optimization approach, offer both exact and an effective variable solar cell optimization of SDM and DDM. COA has recently been used to solve a variety of the optimization problems, including an identification of the parameter of the model of Jiles-Atherton hysteresis, array antenna reflection coefficient synthesis, calculation of single-phase converter characteristics, and parameter development of PID for the automatic voltage control of a synchronous generators [7]. COA's key advantages over other optimization approaches are its ease of implementation and quick execution time. The ratios of the parallel and serial resistances are computed using a simple and fast iterative approach. Designers of PV power converters and circuit simulators require a simple, fast, and realistic photovoltaic module model.

2. Related Work

The five design variables of a single-diode photovoltaic (PV) model are extracted using a hybrid method presented in this study. Only two parameters, series (R_s) and shunt resistance (R_{sh}), are evaluated using metaheuristic algorithms in the proposed technique, which is a blend of analytical and optimization procedures. The sum of the squared error is calculated using information from three primary critical points in datasheets provided by manufacturers. The remaining unknown parameters, such as the diode ideality factor (D), photo-generated current (I_{ph}), and dark saturation current (I_0), can be determined analytically. To demonstrate the effectiveness of the method, achievement indices include PV features, the standard error, normalized root mean square error (nRMSE), power factor, and comparative maximum power error from various technologies. The new approach was proven to be reasonably accurate after comparison with experimental data contained in the module specification as well as the previous method [8].

Photovoltaic (PV) cells/modules are widely used in power generation as renewable radiation becomes a prominent renewable energy source. A variety of PV modules from various manufacturers are used to evaluate the performance of the models, and the findings are evaluated to all those produced using similar predictive methods published in the literature. By comparing experimental I-V curves provided by the supplier, the current-voltage (I-V) properties of the photovoltaic panels reviewed here are also modeled. The parameters acquired for the PV modules are compatible with those found to use other analysis methods, according to the findings. The curves are also demonstrating a maximum degree of the agreement with those generated using the literature's ideal parameters for double-diode models. Furthermore, the suggested model has a significant benefit in predicting control limitations in terms of convenience of use, demands of input information, dependence on preliminary situations, and consideration of characteristics that are overlooked in existing methods [9].

In this study, the whale optimization technique (WOA) is employed that predicts the design of single-, double-, and triple-diode PV modules. The simulation results, which were carried out using MATLAB programmed under various climatic conditions, validate the WOA-based PV models. The effectiveness of the WOA-based PV models is measured by reviewing the outcomes of the WOA-based PV models to those obtained using other optimization methodologies. To provide a genuine evaluation, these simulated outcomes are based on experimental results of a Kyocera KC200GT PV module. By comparing the relative confidence interval of the WOA-based PV model to the maximal error signal of other PV models, the absolute confidence interval of the WOA-based photovoltaic module was effectively examined. The implementation of the metaheuristic technique yields an efficient PV model. [10].

This research is offering a new hybrid method for calculating the properties of a double-diode photovoltaic (PV) module. It accomplishes the statistical approach's efficiency by relying purely on documentation knowledge, unlike previous methods. Four of the characteristics get determined analytically, and then, the enduring three are enhanced by using an evolutionary algorithm. A method for steering the Newton–Raphson iteration's initial conditions is presented. By comparing it to other well-known computing methodologies for crystalline silicon, polycrystalline, and thin-film components, the methodology is proven. When contrasted to empirical observations, the mean absolute error is reduced by a factor of two magnitudes and the speed is improved by three to four times. The standard error of the advances is less than 0.1 after 100 runs, showing that the improved technique is fairly consistent. Because of its accuracy and specificity, the technique is predicted to be very useful as a computational motor in PV simulations. [11].

This study uses the artificial immune system (AIS), a metaheuristic technique, to predict solar PV characteristics. The new technique is used to predict a variable of the double-Schottky diode. PV (solar power) characteristics are calculated by inserting estimated parameter values into a MATLAB model. For a performance study, the results obtained using AIS were associated with the results obtained using the genetic algorithm (GA) and a particle swarm optimization (PSO). To further confirm the recommended method, error graphs were created for two panels using AIS, GA, and PSO. The data reveal that the suggested AIS method outperforms GA and PSO in terms of factors which have the potential and standard deviation [12].

3. Materials and Methods

The modeling and evaluation of a PV system was a critical connection to an increase in PV system features, which in turn led to a development in the features of energy harvested from such systems. As a result, in the current work, the method for modeling and the characterization of PV systems was described and validated with measurement values. For the PV system, an accurate forecast model was developed and the outcomes were evaluated using comprehensive features resulting from simple computations.

3.1. PV Cell Modeling

3.1.1. Single-Diode PV Model. As exposed in Figure 1, the single-diode PV module formed the foundation for a PV model that was implemented. The step computations of current-voltage (I-V) and a power-voltage (P-V) parameters, depending on a specific equation, are included in the modeling of every PV cell. Meanwhile, creating a PV model that simulated various weather conditions and assisted in predicting the parameters of PV using a demonstrated manner is a significant undertaking [13]. Furthermore, the precision of the measurement characteristics of I-V and P-V was directly related to improving the level of solar panels and monitoring the effectiveness of PV systems.

Various strategies for applying numeric amounts of PV variables to PV modeling were reported in the literature. Following this trend, other researchers developed PV models based on five factors, while others developed PV products based on four, three, two, or even one parameter [14]. The five-parameter approach, on the other hand, had superior accuracy than other models and was more widely used, especially in outdoor situations. As a result, the five-parameter model is exact when all relevant DC variables are taken into account.

$$I = I_L - I_0\left[\exp\left(\frac{(IR_s)}{a}\right) - 1\right] - \frac{(IR_s)}{R_p}, \tag{1}$$

where I_L is represented as lighting diode current, I_0 is represented as diode's reverse saturation current and is indeed the adjusted effective area, R_s is represented as series resistance, R_p is the parallel resistance, and a is the changed factor of ideality. The major PV characteristics, as shown by the I-V characteristic curve, are described by equation (1). In the next part, look at the proposed equations for the existing parameters.

3.1.2. Double-Diode Model. The PV cell is represented by the double-diode model (DDM) in this research as shown in Figure 2, and the current-voltage (I-V) parameters can be determined as specified:

$$I = I_{ph} - I_{c1} - I_{c2} - I_{sh}. \tag{2}$$

The relationship between a diffusion diode current $I(I_{c1})$ and the voltage (V) across the cell is defined by

$$I_{c1} = I_{r1}\left[\exp\left(\frac{V + IR_s}{V_t a_1}\right) - 1\right]. \tag{3}$$

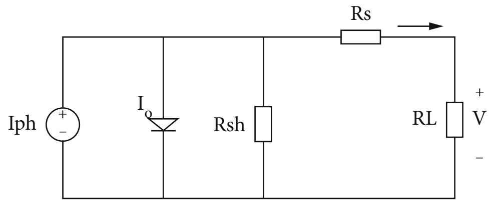

Figure 1: Single-diode PV model.

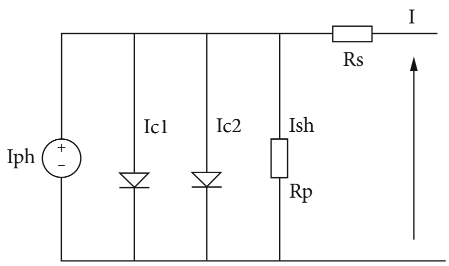

Figure 2: Double-diode PV model.

Similarly, the connection between diode 2's recombination current (I_{c2}) and V is as follows:

$$I_{c2} = I_{r2}\left[\exp\left(\frac{V + IR_s}{V_t a_2}\right) - 1\right]. \tag{4}$$

In addition, the following expression could be used to characterize the leakage current I_{sh} and then its connection to V throughout the cell.

$$\begin{aligned} I_{sh} &= \frac{V + IR_s}{R_p}, \\ V_t &= \frac{TK}{q}, \end{aligned} \tag{5}$$

where I_{sh} is represented as photogenerated current, I_{r1}, I_{r2} are the first and second diode reverse saturation currents, K is the Boltzmann constant $(K = 1.38 \times 10^{-23}\text{J/°K})$,$q$ is the electron charge $(q = 1.6 \times 10^{-19}\text{C})$,$(a_1 \& a_1)$ are the first and second diode ideality factors, V is node voltage, I is node current, T is the ambient temperature, R_s is the series resistance, R_p is the shunt resistance, and V_t is the thermal voltage. Many external circumstances have an impact on the PV unknown model parameters ($I_{r1}, I_{r2}, I_{ph}, R_s, R_p, a_2$, and EG). The ideality factors a_1 and a_2 are often 1.5 and 2 in classical semiconductor and p-n circuit physics, according to previous research [15]. The saturation currents I_{s1} and I_{s2} may be deemed equal, although a_2 is more than 1.2. Some approaches set R_s and R_p to zero for mathematical convenience, whereas others fix a_1 and a_2. Furthermore, the incorrect selection of ideality factors has been linked to inaccuracies in computing output results. Ignoring R_s, on the other hand, has a significant impact on the PV model's reliability, particularly for datasets at the open-circuit voltage (V_{oc}) area. These connections, however, are not always reliable and have no structural function [16]. These variables will be computed in this research depending on genuine data, with the material energy bandgap EG set to 1.12 for the two components under consideration.

3.1.3. Computational Improved Method. The simplification of the current saturation formula is as follows: the current PV formula as a function of the irradiation and temperature is as follows:

$$I_{\text{PV}} = (I_{\text{PV\_STC}} + K_1 \Delta T)\frac{G}{G_{\text{STC}}}, \tag{6}$$

where $I_{\text{PV\_STC}}$ (in Ampere) represents the light-produced current at STC, $\Delta T = T - T_{\text{STC}}$ (in Kelvin, $T_{\text{STC}} = 25°\text{C}$), G represents a cell's surface of irradiance, and GSTC ($1000\,\text{W/m}^2$) represents the irradiance at STC [17]. K_i is the short circuit of the current parameter, which is frequently supplied by the manufacturer. The well-known applied current formula for diodes is follows:

$$I_0 = I_{0,\text{STC}}\left(\frac{T_{\text{STC}}}{T}\right)^3 \exp\left[\frac{E_s q}{ka}\left(\frac{1}{T_{\text{STC}}} - \frac{1}{T}\right)\right], \tag{7}$$

where E_g is the semiconductor's bandgap energy and $I_{0,\text{STC}}$ is the nominal saturation current. $[x]$ is a better equation for describing the saturation current that takes temperature change into account:

$$I_0 = \frac{(I_{sc\_\text{STC}} + K_1 \Delta T)}{\exp\left[(V_{oc,\text{STC}} + K_v \Delta T)/aV_T\right] - 1}. \tag{8}$$

The open-circuit voltage ratio is represented by the constant K_v. This value can be found in the documentation. To make the model even more simple, both inverse saturation currents I_{01} and I_{02} are set to be comparable in magnitude in this study.

$$I_{01} = I_{02} = \frac{(I_{sc\_\text{STC}} + K_1 \Delta T)}{\exp\left[(V_{oc,\text{STC}} + K_v \Delta T)/\{(a_1 + a_2)/p\}\, V_T\right] - 1}. \tag{9}$$

Analytically, equation (8) can be evaluated. This is a benefit over other processes that involve mathematical computation to compute I_{01}, I_{02}. According to detailed investigations of (8), if $(a_1 + a_2)/p = 1$, the following expression for I_{01}, I_{02} is obtained:

$$I_{01} = I_{02} = \frac{(\text{I}_{sc\_\text{STC}} + K_1 \Delta T)}{\exp\left[(V_{oc,n} + K_v \Delta T)/V_T\right] - 1}. \tag{10}$$

The uncertainty in selecting the parameters of a_1 and a_2 can be removed with this generalization. Five parameters of this model, $I_{\text{PV}}, I_{01}, I_{02}$, a_1, and a_2, maybe easily found using (3) and (7). In addition, the iterative step for computing I_{01} and I_{02} is omitted, resulting in a shorter computation time.

3.1.4. R_s and R_p Determination Values. Iteration is used to determine the last two values, R_s and R_p. Several scholars have separately approximated these two factors, but the findings have been disappointing. R_s and R_p are determined simultaneously in this paper, following the approach proposed [18]. For the double-diode model, this method has not been used. The is goal to combine a predicted peak power ($P_{mp,C}$) and an observed peak power ($P_{mp,E}$) by raising the parameter of R_s repeatedly although computing the value of R_p. The equation for R_p can be adjusted and recast as follows from (1) at maximum power point condition:

$$R_p = \frac{V_{mp}\left(V_{mp}, +, R_s, I_m\right.}{\left[V_{mp}\{I_{\mathrm{PV}} - I_{c1} - I_{c2}\} - P_{E,\max}\right]}. \tag{11}$$

The technique of iteration to achieve the correct R_s value is depicted in Figure 3. For this example, KC200GT and MSX-60 PV modules were applied. In each example, R_s is enhanced until $P_{C,\max}$ and $P_{E,\max}$ are identical. Meanwhile, the value of R_p is determined simultaneously for each iteration. The output cell current may be computed by using a usual Newton–Raphson approach which has all seven variables available.

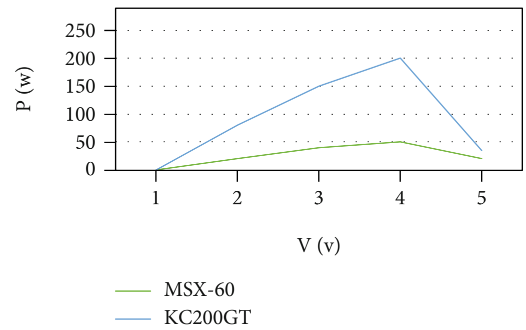

Figure 3: Methodology of PV curves for two PV modules.

3.2. Modeling of Single- and Double-Diode PV Cells. The analogous circuit of the DM system for solar cell modeling is depicted in Figure 4. The following expression can be used to define the relationship curves of I-V for this model:

$$I = I_{\mathrm{PV}} - I_0\left(e^{(V+R_sI)/V_{\mathrm{th}}.n} - 1\right) - \frac{V + R_sI}{R_p}. \tag{12}$$

Figure 4 depicts the solar cell's equivalent resistance with DDM. As a result, unlike the model of SDM, the DDM PV design of the PV solar cell includes one extra diode which is parallel to the diode rectifier that accounts for the space-efficient charge current. DDM's I-V feature is listed as follows.

$$I = I_{\mathrm{PV}} - I_{01}\left(e^{(V+R_sI)/V_{th}.n_1} - 1\right) - I_{02}\left(e^{(V+R_sI)/V_{th}.n_2} - 1\right) - \frac{V + R_sI}{R_p}. \tag{13}$$

The propagation and saturation oscillations are I_{01} and I_{02}, respectively, and the propagation and recombination diode ideality ratios are n_1 and n_2, respectively. The ideality factor is explored, and an equation for calculating the ideality component is presented.

3.3. Objective Function and COA. Chaos is a type of nonperiodic long-term behavior which arises in nonlinear predictable schemes with a sensitive dependence on the preliminary circumstances when specific circumstances are met. This is concerned with the stable equilibrium of system dynamics that are described by a partial differential equation or an iterative map. The system's behavior is determined by the values of its characteristics. The bifurcation parameter is a variable that can be adjusted [19]. Bifurcations, or qualitative alterations in the structure of the network, occur when the bifurcation parameter is changed. As a result, the system displays a variety of dynamic behavior, such as trajectories convergent to the equilibrium position, border ring, or confused attraction.

The sensitive dependency on the beginning conditions is a typical attribute of the chaotic dynamical system. If certain systems evolve from two nearest points, after a sufficient amount of time, they would be infinitely far apart. The chaotic attractor's time patterns are entirely irregular, with no recurrence in any monitoring period of the final length [20]. Although the state is generated by a deterministic equation, there is arbitrariness in the temporal domain and long-term uncertainty in the state. The chaotic time signal has a power spectral density that looks like noise.

The Lorenz system is one of the most well-known chaotic systems. While simulating an atmospheric scheme, meteorologist is Edward Lorenz uncovered a sensitive requirement on beginning conditions by accident. Lorenz uses three equations to explain this complex system, which has subsequently become known as the three-dimensional Lorenz system:

$$\begin{aligned} \frac{dx}{dt} &= \sigma(y - x), \\ \frac{dy}{dt} &= -xz + rx - y, \\ \frac{dz}{dt} &= xy - bz, \end{aligned} \tag{14}$$

with the solution of chaotic for $\sigma = 10$, $r = 28$, and $b = 8/3$.

Iterative maps with the Tent map, Lozi map, logistic map, and others exhibit chaotic behavior. The chaotic sequence was constructed in this article by using a well-known Logistic map provided by

$$y_{i+1} = ey_i(1 - y_i), \tag{15}$$

where i is denoted as the number of iterations and e is represented as the repetition rate. The stochastic equation represents a process that begins with exponential growth but

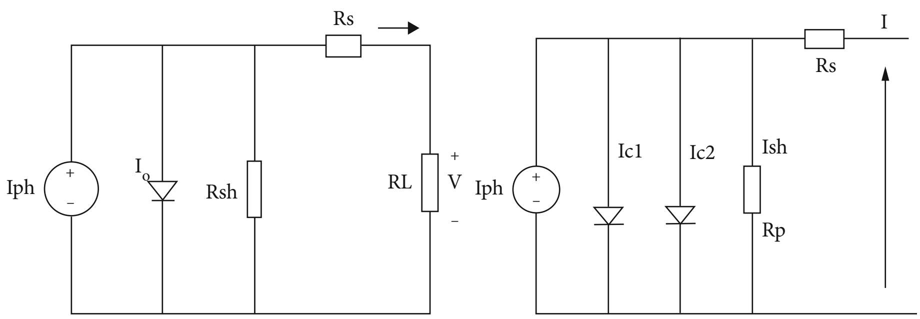

Figure 4: SDM and DDM of a PV cell.

eventually ceases due to nonlinearity. In this simple example, most of the common characteristics of chaos are present. COA's goal is to find an estimate for a set of unknown variables V that reduces the objective function (OF). In some cases, for a SDM, $V = [R_s, R_p, I_{pv}, I_0, n]$, and then DDM, $V = [R_s, R_p, I_{pv}, I_0, n_1, n_2]$.

As a result, vector $V = [v_1, v_2, \cdots, v_n$ contains parameters that are confined to the lowest (LV) and highest (UV) permissible values, i.e., $v_i \in [L_i, U_i]$. The OF for SDM, on either hand, is

$$\text{Objective function (OF)} = \sum_{t=1}^{p} \left(I_{pv} - I_0 \left(e^{(V_t + I_t R_s)/n.V_{th}} - 1 \right) - \frac{V_t + I_t R_s}{R_p} - I_t \right). \tag{16}$$

Whereas for DDM, it reads

$$\begin{aligned} \text{Objective function (OF)} &= \sum_{t=1}^{p} \left(I_{pv} - I_{01} \left(e^{(V_t + I_t R_s)/n_1.V_{th}} - 1 \right) \right. \\ &\quad \left. - I_{02} \left(e^{(V_t + I_t R_s)/n_2.V_{th}} - 1 \right) - \frac{V_t + I_t R_s}{R_p} - I_t \right), \end{aligned} \tag{17}$$

where P denotes the number of I-V pairs determined from the features of I-V, V_t andI_t are denoted as the voltage or current quantity of the pair t, respectively. The COA flowchart, shown in Figure 5, depicts the search procedure. The COA flowchart's detailed overview can be obtained.

The following COA variables were utilized in this study: $M = 1000, N = 50{,}000$. The root mean square error (RMSE) is used to compare COA-based estimation to other methodologies. It is specifically defined:

$$\text{RMSE} = \sqrt{\frac{\sum_{k=1}^{p} (I_{est,k} - I_{meas,k})^2}{P}}, \tag{18}$$

where $I_{est,k}$ and $I_{meas,k}$, with point k, reflect the predicted and observed values of the solar irradiance current, respectively.

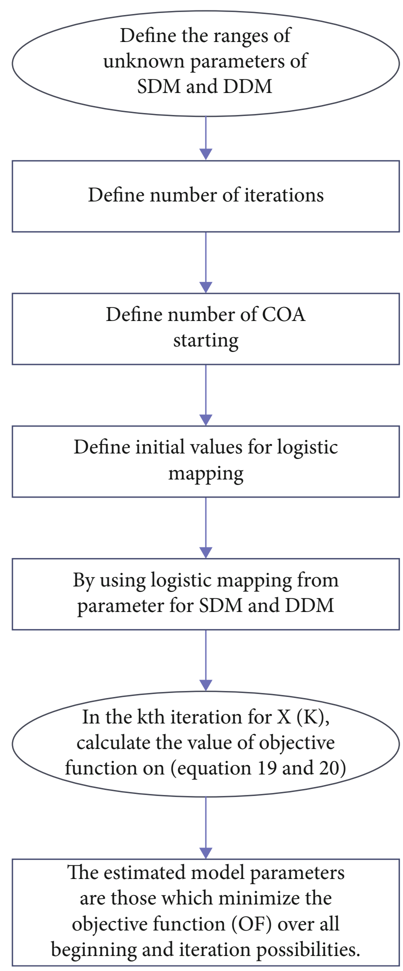

Figure 5: Flowchart of COA.

4. Results and Discussion

The accuracy test determines how closely the produced results correspond to the manufacturer's published experimental values. Three common statistical techniques are used to assess the algorithms' accuracy: the mean absolute percentage error (MAPE), mean absolute bias error (MABE), and root mean square error (RMSE). The arithmetical assessments can be stated accurately as (18), (19), and (20), respectively.

$$\mathrm{MABE} = \frac{1}{p}\sum_{k=1}^{p}\left|I_{est,k} - I_{meas,k}\right|, \tag{19}$$

$$\mathrm{MAPE} = \frac{1}{p}\sum_{k=1}^{p}\left|\frac{I_{est,k} - I_{meas,k}}{I_{est,k}}\right|, \tag{20}$$

where $I_{est,k}$ and $I_{meas,k}$, with point k, reflect the predicted and observed values of solar irradiance current, respectively. p is the number of modules considered at the specified operational point among measured I-V pairs. Recover single-diode PV sample parameters for selected PV modules in STC rated by three algorithms. After that the limitations were acquired, the techniques are utilized to forecast the PV modules' electrical characteristics. Figure 6 shows the comparison of the IV properties from one of the photovoltaic panels, the Kyocera Solar KD210GX-LPU, to the experimental data. The experimental and simulated results found better agreement.

Measured values of the chosen PV modules validate the double-diode model provided in this research. Table 1 summarizes the specs of these modules. The results of the computations were associated to the R_s and R_p models. The variables for the suggested double-diode model are listed in Table 2. Although the model has more variables, only four parameters were calculated because $I_{01} = I_{02}$, whereas a_1 and a_2 can be picked at random. Only the MSX-60 and KC200GT are used in the validation of the model for the sake of brevity. The verification of partial shading modeling will incorporate the SM55. For varying degrees of irradiation, the I-V curves for a single KC200GT component are shown in Figure 7.

The curves of I-V for the KC200GT module are displayed in Figure 7 for various amounts of irradiation. The proposed model of double-diode and R_p models' computed values are compared to measurement values from the datasheet of the manufacturer. At STC, the proposed hybrid model and the R_p model both produce the same results. This is to be predicted, given that both algorithms analyze the parameters of the model at STC using the same peak power similarity measure. However, as irradiance decreases, the double-diode model produces more accurate findings, particularly near the open voltage sensor. The R_p design deviates from the experimental results at V_{oc} implying that the R_p model is insufficient when compared with similar irradiance levels. This is expected to have a major effect when a partial shading is used. Following that, the models' efficiency when exposed to temperature variations is examined. All tests are carried out with a 1000 W/m^2 STC irradiance. An evaluation is made among the suggested model and the R_s model. The comparison was chosen expressly to demonstrate the R_s serious model's flaws when exposed to changes in temperature. The KC200GT and MSX-60 components were put to the test. The curves I-V created using the two-diode model fit the test data accurately for all humidity conditions, as shown in Figure 8. At a maximum temperature,

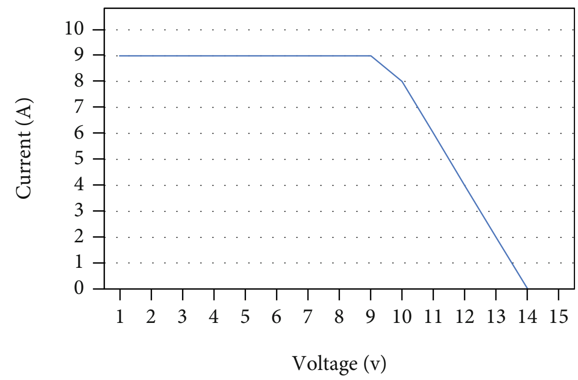

Figure 6: Kyocera Solar KD210GX-LPU at STC.

Table 1: Specification of the model.

Parameter	KC200GT	MSX-60
I_{mp}	7.62 Amp	3.5 Amp
I_{sc}	8.22 Amp	3.8 Amp
V_{oc}	32.8 vol	21.1 vol
V_{mp}	26.3 vol	17.1 vol
K_i	318 mA/°C	3 mA/°C
N_s	55	37
K_v	−124 mV/°C	−80 mV/°C

Table 2: Parameter of the double-diode model.

Parameter	KC200GT	MSX-60
I_{mp}	7.62 Amp	3.5 Amp
I_{sc}	8.22 Amp	3.8 Amp
V_{oc}	32.8 vol	21.1 vol
V_{mp}	26.3 vol	17.1 vol
I_{pv}	8.23 Amp	3.808 Amp
$I_{01} = I_{02}$	4.218×10^{-10} Amp	4.704×10^{-10} Amp
R_s	0.32 Ω	0.34 Ω
R_p	146 Ω	152.6 Ω

however, the model R_s findings depart significantly from a measured data.

Users also examined solar cells from the renewable energy training setup to test the usability and effectiveness of COA for photovoltaic estimation methods. The main reason for using these photovoltaic panels is that it allows for variable solar insolation, data tracking for a PC-assisted information collecting for analysis, and highly complex didactic application for control system and the real-time data monitoring. To start, we examined the I-V parameters at a temperature of 42°C and insolation of 1285 W/m^2. Thus, calculate THE single- and double-diode solar cell characteristics using the measured I-V pairings. The parameter ranges for the estimation of SDM are $R_s(\Omega) \in [0.4, 0.1]$; $I_{pv}(\mathrm{Amp}) \in [0.4, 0.2]$; $I_0(\mathrm{Amp}) \in [15 \times 10^{-8}, 5 \times 10^{-8}]$;

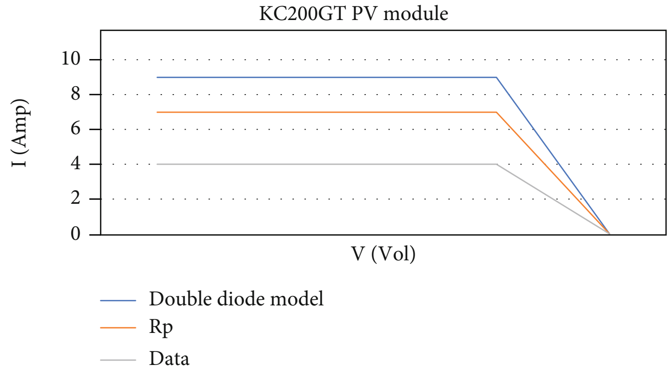

Figure 7: KC200GT PV module curves of I-V.

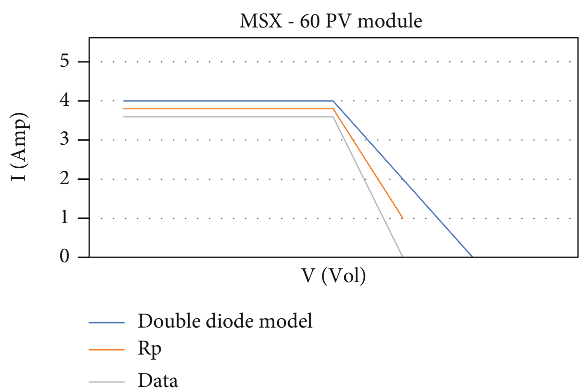

Figure 8: MSX-60 PV module curves of I-V.

Table 3: An estimated parameter value of the solar PV module.

SDM		DDM	
$R_s(\Omega)$	0.2284	$R_s(\Omega)$	0.2514
$R_p(\Omega)$	438.56	$R_p(\Omega)$	782.9912
I_{pv}(Amp)	0.2988	I_{pv}(Amp)	0.2973
I_o(Amp)	10.57×10^{-8}	I_{o1}(Amp)	6.8453×10^{-8}
		I_{o2}(Amp)	6.0644×10^{-8}
n	0.3442	n_1	0.3343
		n_2	1.9907
RMSE	4.3419×10^{-4}	*RMSE*	4.147×10^{-4}

$R_p(\Omega) \in [600, 200]$; and $n \in [1, 0.2]$, whereas DDM is $R_s(\Omega) \in [0.4, 0.1]$; $R_p(\Omega) \in [900, 600]$;

$I_{pv}(\text{Amp}) \in [0.4, 0.2]$; $I_{o1}(\text{Amp}) \in [15 \times 10^{-8}, 5 \times 10^{-8}]$; $I_{o2}(\text{Amp}) \in [15 \times 10^{-8}, 5 \times 10^{-8}]$; $n_1 \in [1, 0.2]$; and $n_2 \in [2, 1.95]$.

The I-V and P-V properties were then measured for various insolation and humidity data. The required simulated features were calculated by taking into account the change of variables with solar irradiance and humidity. The calculated and measured curves of I-V and P-V for various amounts of solar output and temperatures were shown. There is a clear correlation between both the measured and estimated features. Finally, we ran the estimating technique on all of the I-V characteristics that had been measured. The calculated values of the parameters were within 4% of the measured data, indicating that we can predict parameters using any of the measurable properties. On either hand, enough for a module, it is clear that the DDM was more efficient than the SDM which is based on the information in Table 3.

5. Conclusion

This research suggested that models of single diode and double diode can be improved. The number of input parameters is decreased to four to save time, and the values of R_p and R_s are calculated using an efficient iterative technique. Actual data from the producers confirm the accuracy of the proposed double-diode model. The double-diode model is found to be superior to the R_p and R_s models. COA is proposed as a very successful strategy for this aim in this research. The proposed method has been tested with real-world data from a variety of manufacturers. Its accuracy is verified by comparing its root mean square error (RMSE) to a variety of metaheuristics and a nonmetaheuristic approach for a different solar cell. COA's usefulness for parameter estimation was also tested experimentally in a laboratory setting. A high level of accuracy is proven in all of the circumstances evaluated. Besides that, the excellent match between the simulated curves of I-V and P-V and the observed features further validates the COA precision and usefulness for estimation methods.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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