Journal of Engineering, Technology & Applied Science
p-ISSN: 2721-7949, e-ISSN: 2721-8090

Original Research Paper

The Differences between Single Diode Model and Double Diode Models of a Solar Photovoltaic Cells: Systematic Review

Val Hyginus Udoka Eze[1,2], Kalyankolo Umaru[3], Enerst Edozie[2], Ritah Nafuna[3], Nansukusa Yudaya[3]

[1] *Department of Publication and Extension, Kampala International University, Uganda.*
[2] *Department of Electrical, Telecommunication and Computer Engineering, Kampala International University, Uganda.*
[3] *Department of Computer Science and Electrical Engineering, Muni University, Uganda.*

Article History
Received:
17.06.2023

Revised:
10.07.2023

Accepted:
21.08.2023

***Corresponding Author:**
Eze Val Hyginus Udoka
Email:
ezehyginusudoka@gmail.com

Abstract: This research paper systematically reviewed and investigated single diode model and double diode model of a solar photovoltaic systems in terms of accuracy, differences under major unknown PV parameters, different optimization and fabrication. This research paper reviewed the differences and the similarities between the single diode model and double diode model. From the review, it was clear that single diode model has less computation time and number of unknown parameters compared to double diode model. The double diode model on its own superiority is more accurate under solar shading condition effect than single diode model but single diode model performs better under high insolation levels. None of the two models is superior than the other but the solar photovoltaic modelers/installers should bear the solar irradiance of the environment before installation.

Keywords: Double Diode, Photovoltaic, Renewable Energy, Single Diode, Solar.

1. Introduction

The quest to have a stable and consistent energy with very low cost has been the desire of the society. Due to this the research for a stable, low cost and steady energy in this 21st century has shifted to renewable energy. The increase in population, industrialization and urbanization has led to increase in fossil fuel usage which is no more sufficient [1]. Renewable energy has come to serve as a source and as well as an alternative energy supply to the society. The conversion of solar energy into electricity has been conventionally used for some years now. The IEA's comprehensive and comparative study of the world energy consumption reviewed that in 2050, more than 45% of necessary generated and transmitted energy in the world will be exclusively produced by solar PV arrays. IEA also stated that as regional energy consumption falls by 7%, the new generation will grow by 41% with renewable sources providing 81% of total output by 2050 which is the largest share in the world [2].

Furthermore, one of the most lucrative and efficient renewable sources of energy supply is the solar photovoltaic. The system of modelling solar photovoltaic cells is dived into two (1) single diode modelling technique and (2) double diode modelling technique. The main issue associated with single-diode PV model and double diode models were the problems of identifying the five major unknown parameters known as ideality factor (a), series resistance (Rs), shunt resistance (Rp), reverse saturation current (Io) and solar photovoltaic current (Ipv). Identification of these parameters by a suitable method is essential in order to accurately predict the PV module characteristics.

This paper will systematically review and identify the similarities and the differences in the five unknown photovoltaic parameter when modelled with single diode and double diode. This paper will also follow the qualitative and quantitative research ethics to review and write this paper [3]. This review research work will further be divided four sections namely; single diode model section, double diode model section, similarities and differences between single diode model and double diode model section and finally ended with conclusion.

2. Literature Review

2.1. Single Diode Models

A single diode model from different scholars will be reviewed, analyzed and techniques used to be compared for effective understanding. This section will review the most recent and comprehensive articles in single diode model. Figure 1 is the equivalent circuit of a single diode model of a solar PV cell with the resistances connected in series and parallel (shunt). The current of the photovoltaic panel derived from equivalent circuit of the PV cell (Figure 1) applying Kirchhoff's law is as shown in Equation 1.

$$I = Iph - ID - Ish \tag{1}$$

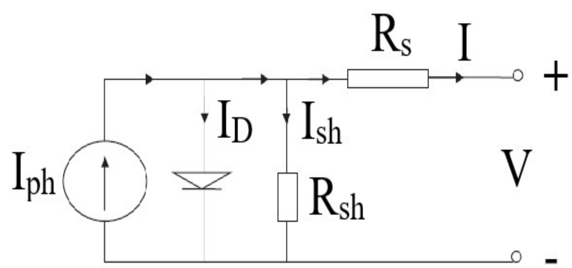

Figure 1. Equivalent Circuit of a Single Diode Model of a PV cell

2.2. Double Diode Model of a Solar Photovoltaic Panel

The double diode model of a solar PV panel is a solar PV panels that were made up of double diode as shown in Figure 2. The solar PV double diode model is made up of two diodes connected in parallel with the shunt resistance.

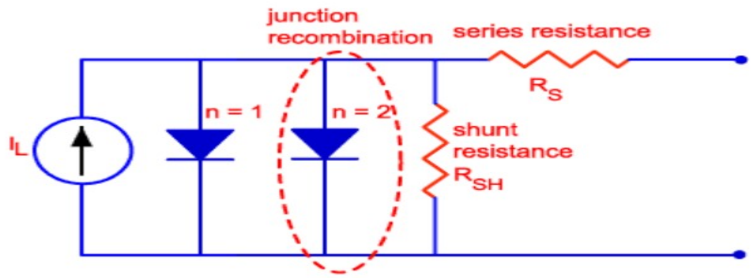

Figure 2. Circuit Diagram of the Double Diode Model Including The Parasitic Series And Shunt Resistances

3. Methodology

Modeling of photovoltaic (PV) systems is essential for the designers of solar generation plants to do a yield analysis that accurately predicts the expected power output under changing environmental conditions. This paper presents a comparative analysis of PV module modeling methods based on the single-diode model with series and shunt resistances. Parameter estimation techniques within a modeling method were used to estimate the five unknown parameters in the single diode model. Two sets of estimated parameters were used to plot the I–V characteristics of two PV modules, i.e., SQ80 and KC200GT, for the different sets of modeling equations, which are classified into models 1 to 5 in this study. Each model is based on the different combinations of diode saturation current and photo-generated current plotted un- der varying irradiance and temperature. Modeling was done using MATLAB/Simulink software, and the results from each model were first verified for correctness against the results produced by their respective authors. Then, a comparison was made among the different models with respect to experimentally measured and datasheet I–V curves. The resultant plots were used to draw conclusions on which combination of parameter estimation technique and modeling method best emulates the manufacturer specified characteristics.

4. Finding and Discussion

4.1. Single Diode Models

The author in [4] developed Maximum power point (MPP) tracking technique based an optimized adaptive differential conductance technique using single diode model. The developed algorithm using single diode model was evaluated at solar irradiance of 1,000, 800 and 600 W/m2 and at temperature of 298, 328 and 358 K. From the simulation results, it was observed that the impedance of the panel decreases as the irradiance increases while the impedance of the load is not affected by the irradiance. It was concluded that the developed technique using single diode model outperformed the existing one by 6.0558% compared to the conventional INC technique. The simulation was done using Matrix Laboratory (MATLAB).

A comprehensive review was done on electric charging station using single diode model. In this research the author reviewed the EV charging stations and classified into renewable, nonrenewable and hybrid based on its sources of energy generation using single diode model. From the review it was discovered that there are standards set for EV charging station that were dependent on the charging time and the Efficiency Enhancement (EE)components and connectors. These EE components and connectors enhance and improve power harness from the source to the EV station for fast charging. Finally, this review showed that the best design for EV station is the hybrid of single diode renewable energy sources with a specified EE components and connectors [1]. This authors [2], [4], [5] reviewed the single diode model of a PV system based on their maximum power point tracking techniques. They further classified the optimization techniques of a single diode model into intelligent and non-intelligent MPPT techniques. The review also showed that two algorithms can be combined to form MPPT techniques in hybridized form which also curtail some of the problems of MPPT with high performance. However, for non-intelligence based MPPT techniques reviewed in this paper it was discovered that Enhanced Adaptive Extremum- Seeking Control (EAESC) has the best performance as it is easily implemented and involves less programming language with high degree of accuracy. EAESC tracks the real MPP at a very recommendable speed with high degree of accuracy. From the review the author in two [2] showed that the best optimization technique of a single diode model is the hybridization technique.

In [6], the researcher researched on Identification of Unknown Parameters of a Single Diode Photovoltaic Model Using Particle Swarm Optimization. From the research work the researcher used particle swarm optimization (PSO) technique with binary constraints as one of the maximum power point tracking technique to identify the unknown parameters of a single diode model of solar PV module. A Multi-crystalline and 1 mono-crystalline technology based PV modules were considered in this study because of its market potential and availability. From the results obtained by the researcher it has was concluded that PSO algorithm yields a high value of accuracy irrespective of temperature variations.

The following steps were taken by [6] to formulate a working PSO algorithm for maximum power tracking of PV panel for ∀I and ∀j (where 'i' represents particle and 'j' its dimension):

Step 1. Set parameter ω_{min}, ω_{max}, c_1 and c_2 of PSO
Step 2. Initialize population of particles having positions **X** and velocities **V**
Step 3. Set iteration k = 1
Step 4. Calculate fitness of particles $F^k_i = f(\mathbf{X}^k_i)$ and find the index of the best particle b
Step 5. Select $\mathbf{Pbest}^k_i = \mathbf{X}^k_i$ and $\mathbf{Gbest}^k = \mathbf{X}^k_b$
Step 6. Take $\omega = \omega max - k \times (\omega max - \omega min)/Max_{iteation}$
Step 7. Update velocity and position of particles as;

$$V^{k+1}_{i,j} = w \times V^k_{ij} + C_1 \, x \, rand() \, x \, (Pbest^k_j - X^k_{i,j}) + C_2 \, x \, rand() \, x \, (Gbest^k_j - X^k_{i,j}) \;\; \forall j \text{ and } \forall i$$
$$X^{k+1}_{i,j} = X^k_{ij} + V^{k+1}_{I,j} \, ; \;\; \forall j \text{ and } \forall i$$

Step 8. Evaluate fitness $F^{k+1}_i = f(\mathbf{X}^{k+1}_i)$ and find the index of the best particle b1
Step 9. Update Pbest of population

If $F^{k+1}_i < F^k_i$, then, $Pbest^{k+1}_i = X^{k+1}_i$ else $Pbest^{k+1}_i = Pbest^k_i$

Step 10. Update Gbest of population

If $F^{k+1}_{b1} < F^k_b$, then, $\mathbf{Gbest}^{k+1} = \mathbf{Pbest}^{k+1}_b$ *and set b=b1* else $\mathbf{Gbest}^{k+1} = Gbest^k$

Step 11. If $k = Max_{ite}$ then k = k+1 and go to step 6 else go to step 12
Step 12. Print optimum solution as $\mathbf{Gbest}^k$

Based on the randomly generated population, the PSO technique provides a collection of different solutions for a, Rs and Rp with each new execution of the optimization technique.

The developed model by [6] is as shown in Equation 2.

$$\varepsilon_i = \left| P_{mp},m_i\,(T) - P_{mp},e(T) \right| + \left| V_{mp},m_i(T) - V_{mp},e(T) \right| \tag{2}$$

Where ε is the overall model error and subscript i signifies the specific curve under assessment. From all the possible optimized solution, outcome with the least value of ε is selected as the best. This research technique completely eliminated the ideality factor assumption during modelling and also includes the temperature variations to identify the unknown parameters.

The authors in [4], [7]–[10] developed, fabricated and anayzed the optimization and fabrication techinques of a single diode model of solar PV system. The scholar in [9], [10] investigated the Optimum silver contact sputtering parameters for efficient perovskite solar cell fabrication and how to Improve the efficiency and stability of in-air fabricated perovskite solar cells using the mixed antisolvent of methyl acetate and chloroform. The use of magnetron sputtering for deposition of the metal electrode in perovskite solar cells has been limited because of the damage to the organic hole transport layer by high kinetic energy particles during the sputtering process. This paper systematically investigated the effect of sputtering power, argon flow rate, sputtering duration, and argon pressure on the performance of the perovskite. The devices also exhibit an excellent short-current density of 22.56 mA/cm2, an open-circuit voltage of 1.10 V and a fill factor of 73.7%. The investigation reveals that sputtering power is the most critical factor that needs to be carefully controlled to minimise the damage to the hole transport layer. This study demonstrates that highly efficient perovskite solar cells can be fabricated using magnetron sputtering if the sputtering parameters are optimised [9].

The author in [11] researched on topic titled a comparative study of an improved single-diode model parameters extraction at different operating conditions with a view of modeling a photovoltaic generator. The researcher used advanced analytical, numerical and genetic algorithm (GA) approaches for retrieving the parameters of photovoltaic (PV) cells. Five parameters of a single diode PV model is presented using datasheet values, a numerical based Newton- Raphson algorithm to investigate the current-voltage relation of a single diode solar PV model. GA technique was used to improve the solar PV performance. Table 1 is the summary of all the results irradiance graphs investigated in this research work reviewed. This paper has presented accurately the modeling of an electrical equivalent circuit of a single diode model. The developed models which describe the integral system have been designed to develop a static behavior of photovoltaic generator. An analytical and numerical based Newton-Raphson algorithm models have been mainly used to determine the five parameters of the PV panel. Furthermore, a genetic algorithm model has been applied to improve the performance of the parameters extraction. These previous three models were designed to adapt to the variations in solar radiation and temperature and to ensure a more reasonable I-V and P-V characteristics. Convincing obtained results since the formulated approaches were considered as an optimization problem in determining the five dominating parameters of the single diode model. These different developed models were experimentally validated; their accuracy and performance were discussed. Furthermore, it has been proven that the GA approach has a more satisfactory performance compared with the two other models and its RMSE and EX for different particular points do not exceed 5% and 1% respectively.

Table 1. Summary of Graphs Under Varying Irradiance

TEMP	Method A		Method B	
20 °C	*Voc*	*Isc*	*Voc*	*Isc*
Model 1	22.20484	4.843	22.20479	4.843
Model 2	22.20136	4.84300	22.20242	4.843001
Model 3	22.20451	4.84119	22.2046	4.842109
Model 4	22.15290	4.84300	22.15788	4.842109
Model 5	22.20484	4.84300	22.20461	4.842109
Measured	22.20	4.839	22.20	4.839
TEMP	**Method A**		**Method B**	
30 °C	*Voc*	*Isc*	*Voc*	*Isc*
Model 1	21.38991	4.85700	21.38825	4.857
Model 2	21.38632	4.85700	21.38576	4.856999
Model 3	21.38959	4.85518	21.38807	4.856106
Model 4	21.44186	4.85700	21.43454	4.856106
Model 5	21.38991	4.85700	21.38806	4.856106
Measured	21.50	4.851	21.50	4.851
TEMP	**Method A**		**Method B**	
40 °C	*Voc*	*Isc*	*Voc*	*Isc*
Model 1	20.58050	4.871	20.57906	4.871
Model 2	20.57704	4.870992	20.57669	4.870996
Model 3	20.58023	4.869179	20.57891	4.870103
Model 4	20.73592	4.870992	20.71694	4.870103
Model 5	20.58050	4.870992	20.57887	4.870103
Measured	20.90	4.872	20.90	4.872
TEMP	**Method A**		**Method B**	
50 °C	*Voc*	*Isc*	*Voc*	*Isc*
Model 1	19.77402	4.885	19.77372	4.885
Model 2	19.77043	4.884987	19.77121	4.884993
Model 3	19.77378	4.883173	19.77359	4.884101
Model 4	20.03502	4.884987	20.00486	4.884101
Model 5	19.77402	4.884987	19.77351	4.884101
Measured	20.00	4.890	20.00	4.890
TEMP	**Method A**		**Method B**	
60 °C	*Voc*	*Isc*	*Voc*	*Isc*
Model 1	18.95958	4.899	18.9579	4.898999
Model 2	18.95616	4.898982	18.95553	4.89899
Model 3	18.9594	4.897168	18.95782	4.898098
Model 4	19.33915	4.898982	19.29812	4.898098
Model 5	18.95958	4.898982	18.95769	4.898098
Measured	19.45	4.900	19.45	4.900

Modeling of photovoltaic (PV) systems is essential for the designers of solar generation plants to do a yield analysis that accurately predicts the expected power output under changing environmental conditions. This paper presents a comparative analysis of PV module modeling methods based on the single-diode model with series and shunt resistances. Parameter estimation techniques within a modeling method were used to estimate the five unknown parameters in the single diode model. Two sets of estimated parameters were used to plot the I–V characteristics of two PV modules, i.e., SQ80 and KC200GT, for the different sets of modeling equations, which are classified into models 1 to 5 in this study. Each model is based on the different combinations of diode saturation current and photo-generated current plotted un- der varying irradiance and temperature. Modeling was done using MATLAB/Simulink software, and the results from each model were first verified for correctness against the results produced by their respective authors. Then, a comparison was made among the different models with respect to experimentally measured and datasheet I–V curves. The resultant plots were used to draw conclusions on which combination of parameter estimation technique and modeling method best emulates the manufacturer specified characteristics.

The described model was verified against the results being produced by the authors. From the results above it clear that they match, which renders the accuracy of further using them to be valid. The author finally concluded that the iterative method of extracting parameters (method A) produced more comparable results. Therefore, as long as there is convergence the iteration techniques produce more accurate results. This is mainly due to the fact that it includes all specific conditions of operation [12].

The effect of seven single diode model parametric analysis of photovoltaic cells were investigated and analyzed in this research. The effect of solar irradiation was investigated and was concluded that increase in solar radiation leads to increase in current-voltage curve and its maximum power point. Increase in cell temperature increases short circuit current and decreases open circuit voltage. Increase in series resistance slightly changes the short circuit current and has no effect on the open current voltage. The shunt resistance has a very good effect and impact on current-voltage curve. Increase in shunt resistance increases current-voltage, open circuit voltage but short circuit current remains same. Increase in photovoltaic current increases the current-voltage curve of a PV cells maximum power. In conclusion from the reviewed work, the effects of the behaviors of the seven single diode parameters were presented, analyzed, compared and this exposed knowledge about the parameters may help on a more efficient use [13].

This investigated three algorithms applied in calculating the characteristics output of a single-diode solar PV cells modules based on certain metrics: speed of computation, memory requirement, ease of implementation, accuracy of the algorithm in calculating the true value and robustness of algorithm. The following conclusions are made: In terms of accuracy, a generic statement cannot be easily made as to which of the method has the best performance. That is, there is no one algorithm that performs best in all the parameter prediction. (ii) When speed of computation is the focus, T. Esram algorithm performs best. (iii) Although all the algorithms require small memory space, but T. Esram requires relatively lesser memory compared to any of the other two. (iv) Based on the author’s experience, T. Esram algorithm is easier to implement compared to the others followed by Villalva algorithm. (v) In term of robustness, Vika is sensitive to changes in initial guess values whilst Villalva algorithm stands out as being relatively immune to changes in the starting guess values [14] [15]

In order to predict the performance of a PV system, a reliable and accurate simulation design of PV systems before being installed is a necessity. The present study concerns the development of single diode model of solar PV system and ensures the best suited model under specific environmental condition for accurate performance prediction. The information provided in the manufacturers’ data sheet is not sufficient for developing a Simulink based single diode models of PV module. These parameters are crucial to predict accurate performance of a PV module. These parameters of the proposed solar PV models have been calculated using an efficient iterative technique. This paper compares the simulation results of both the models with manufacturer's data sheet to investigate the accuracy and validity. This reviewed the mathematical modelling of a single diode models based on their equivalent circuits. The study is carried out under the real operating conditions as well as under controlled atmospheric conditions in order to investigate the effect of varying atmospheric conditions. Also the effect of parameters such as varying ideality factor (n) series resistance (Rs) and shunt resistance (Rsh) are investigated to determine the difference in power generated for both the models with respect to ideal PV module. The fill factor and efficiency of a solar cell decreases due to both shunt and series resistance losses. The utilization of iterative method guided the researcher to identify the values of photo-generated current (Iph), ideality factor (n), series resistance (Rs) and shunt resistance (Rsh). It is found that the output power of PV module is extensively affected even with a small variation in series resistance (Rs), thus this value is kept very small [16]. A MATLAB/Simulink based comparative performance analysis of these models under inconsistent atmospheric conditions and the effect of variations in model parameters has been carried out. Despite the simplicity, these models are highly sensitive and respond to a slight variation in temperature and insolation. This showed that single diode model of a PV system has the potentials to investigate the five main parameters of a PV system [16] [17].

The single diode model as reviewed in this paper investigated all the five major parameters of a single diode solar photovoltaic solar panel and its effect. The investigation showed that single diode model developed using different optimization techniques was a perfect one in terms of efficiency, robustness and accuracy.

4.2. Double Diode Model of a Solar Photovoltaic Panel

The Practical measurements of the solar illumination based on illuminated equation are difficult as there must be small fluctuations in the light intensity overwhelm the effects of the second diode. Since the double diode equation is used to characterize the diode, it is more common to look at the double diode equation in the dark. Equation (3) and (4) are the equivalent circuit of a solar photovoltaic cells under darkness and illuminations respectively.

$$J = J_{01}exp\left[\frac{q\left(V - JR_s\right)}{kT}\right] + J_{02}exp\left[\frac{q\left(V - JR_s\right)}{2kT}\right] + \frac{V - JR_s}{R_{shunt}} \quad (3)$$

$$J = J_L - J_{01}exp\left[\frac{q\left(V + JR_s\right)}{kT}\right] - J_{02}exp\left[\frac{q\left(V + JR_s\right)}{2kT}\right] - \frac{V + JR_s}{R_{shunt}} \quad (4)$$

Equation (3) is under darkness while Equation (4) under illumination

In a solar PV silicon device, the recombination components are a complex function of the carrier concentration.

This investigates the authenticity of the full current-voltage characteristics of a photovoltaic cell from the limited information provided by the manufacturer's data sheet. Double diode model is always more accurate for solar PV silicon cells. In this research paper the diode ideality factors have been set to n1 =1 and n2 =2 to account for diffusion and recombination currents respectively, the double-diode model of the PV cell consists of five parameters. The cell's data sheet values Voc, Isc,Vm, and Im yield four independent equations (three data points of the IV- curve and its derivative at MPP), thus allowing to express four of these parameters (Rsh,Iph,Is1,Is2) as functions of the last (Rs). Thus, if Voc, Isc,Vm, and Im are known by the double diode formulas as in equation (2) and (3) a good boundary needs to be created. These boundaries can be used to restrict the search region or provides suitable initial values for fitting procedures if additional IV- curve data points are available. If no additional data are available various methods can be exploited to guess the double diode parameters. In the simplest approach, the remaining parameter Rs is arbitrarily chosen within the physically allowed range. Alternatively, an approximate fifth condition can be demanded to hold exactly yielding a nonlinear equation for Rs. The different methods are tested for cells whose double diode parameters are known, either from literature or from fits to full IV- curve data. These "approved" parameters are compared to the extracted. Two error measures have been introduced, accounting for the accuracy of either parameter or IV- curve reproduction. As benchmark for the newly introduced methods, an adapted version of an elsewhere published method relying on approximating the slope of the IV- curve at short- circuit is included in the evaluation. Taking the medium value of Rs within the allowed range and calculating the other parameters already gives better results than this method for both error measures and does not require the solution of an additional equation. Its performance can be surpassed by a newly derived approach relying on approximating the slope of a secant in the vicinity of the short circuit point with the slopes of the tan-gents of its endpoints. In particular, for modern cells with high- quality production standards and therefore presumably high shunt resistances accurate parameter guesses are possible and the new method provides an automated procedure for a reliable parameter extraction from cell data sheet values only. When cells are connected to modules an exact calculation of the maximum power output requires the knowledge of the full IV- curves of the constituent single cells. The actual values of the double diode parameters are less important in this case. The parameter set gained from the lowest possible value of Rs yields a further reduced curve reproduction error com- pared to the 2tangs-method, though it is often accompanied by an unphysical, infinite shunt resistance. Since no additional equation has to be solved, an easily implementable, fast algorithm to obtain reliable IV-curves from cell data sheet values only is achieved [18] [19][20].

The equivalent of the electrical representation of the PV cell is as shown in Figure 3. This paper detailed the parameter estimation technique for the double-diode electrical model based on the physical behavior of the photovoltaic (PV) module with respect to variations of the environmental conditions. This means that different sets of parameters are found for each environmental condition, providing results that do not represent I-V curves correctly. Thus, the parameters pro- vide only a mathematical representation with lack of physical meaning. This technique executed the parameter estimation only once, because the model is valid for all range of values of the environmental conditions available on datasheets or experimental curves. Moreover, the restrictions imposed on each parameter makes the model capable of emulating the physical behavior of the PV module, particularly useful in fault diagnosis, predictive and corrective maintenance of PV systems. Comparison results based on datasheet and experimental curves were done to verify the effectiveness of the authors parameter estimation technique [21]. The equivalent electrical circuit of double diode model is represented in Figure 3.

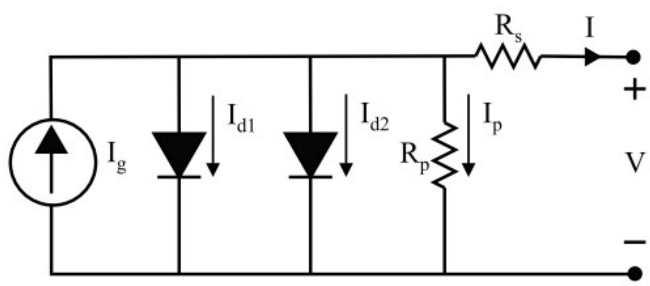

Figure 3. Equivalent Electrical Representation of a PV Cell

In this paper modelling of solar photovoltaic (PV) module is carried out through MATLAB programming. The two most commonly used electrical equivalent circuit models: single- diode and double-diode model, are used and their various characteristics are explained in detail. The necessary non-linear mathematical equations are described and used for modelling of solar PV module in obtaining unknown parameters of single- diode and double-diode models. A flowchart has been developed for estimation of solar cell output current, for single-diode and double-diode model, using Newton-Raphson iterative technique which is then programmed in MATLAB script file accordingly. A typical 60W multi-crystalline solar module specifications is used for model accuracy evaluation. The characteristic I-V and P-V curves were obtained with the use of manufacturer`s data sheet and it shows the precise correspondence for both the models. The aspects of theses curves are hence discussed and criteria for selection of a model under all possible conditions for all time are then described [22] [16][23][24][25].

The main aim of this paper was to show the difference in I-V and P-V characteristics of electrical equivalent circuit of solar PV cell, single diode and double diode equivalent circuits, which were produced after implementation of these models in MATLAB through programming using a flowchart formulated as shown in Fig. 4. Solarex MSX-60 multi crystalline PV module datasheet has been used for verification of MATLAB program. Hence, after observing all characteristic curves by varying solar irradiance G and temperature T and potting I-V and P-V curves accordingly, this can be concluded that double diode model gives more precise characteristics close to practical photovoltaic solar cell as compared to single diode model characteristics [22] [26][19].

Major Differences Between Single Diode Model and Double Diode Model of a Solar PV Systems

1. Double diode model gives more precise characteristics close to practical photovoltaic solar cell as compared to single diode model characteristics.
2. The double diode model is more accurate under low solar intensity (shading) than single diode model but single diode model performs better under high insolation levels.
3. The solar photovoltaic current generated by double diode model is always higher due to high shunt resistance.
4. For power system planning purpose, single diode model is better as it will save time with almost accurate results. While for study of PV cell characteristics at critical points double diode model is more preferable as it will show exact curves.

5. Conclusion

A comparison between single-diode model and double-diode model, in terms of accuracy and computation time, under Standard Testing Condition (STC) and variable temperature was systematically reviewed. The comparison shows that both of the models have the same ability to investigate accurately the five major unknown solar photovoltaic parameters. It can be concluded that single-diode model has less computation time and less number of unknown parameters whereas double-diode model has the superiority of keeping its accuracy much better than single-diode model under variable temperature. Finally, double diode model is more accurate under solar shading condition than single diode model but single diode model performs better under high insolation levels (none shading).

References

[1] V. H. U. Eze, M. C. Eze, C. C. Ogbonna, S. A. Ugwu, K. Emeka, and C. A. Onyeke, "Comprehensive Review of Recent Electric Vehicle Charging Stations," *Global Journal of Scientific and Research Publications*, vol. 1, no. 12, pp. 16–23, 2021.

[2] V. H. U. Eze, U. O. Oparaku, A. S. Ugwu, and C. C. Ogbonna, "A Comprehensive Review on Recent Maximum Power Point Tracking of a Solar Photovoltaic Systems using Intelligent , Non-Intelligent and Hybrid based Techniques," *International Journal of Innovative Science and Research Technology*, vol. 6, no. 5, pp. 456–474, 2021.

[3] C. N. Ugwu and V. H. U. Eze, "Qualitative Research," *IDOSR of Computer and Applied Science*, vol. 8, no. 1, pp. 20–35, 2023.

[4] V. H. U. Eze, O. N. Iloanusi, M. C. Eze, and C. C. Osuagwu, "Maximum power point tracking technique based on optimized adaptive differential conductance," *Cogent Engineering*, vol. 4, no. 1, 2017, doi: 10.1080/23311916.2017.1339336.

[5] V. H. U. Eze, M. C. Eze, C. C. Ogbonna, S. Valentine, S. A. Ugwu, and C. E. Eze, "Review of the Implications of Uploading Unverified Dataset in A Data Banking Site (Case Study of Kaggle)," *IDOSR Journal of Applied Science*, vol. 7, no. 1, pp. 29–40, 2022.

[6] S. Bana and R. P. Saini, "Identification of unknown parameters of a single diode photovoltaic model using particle swarm optimization with binary constraints," *Renewable Energy*, vol. 101, pp. 1299–1310, 2016, doi: 10.1016/j.renene.2016.10.010.

[7] V. H. U. Eze, "Development of Stable and Optimized Bandgap Perovskite Materials for Photovoltaic Applications," *IDOSR Journal of Computer and Applied Science*, vol. 8, no. 1, pp. 44–51, 2023.

[8] V. H. U. Eze, M. C. Eze, V. Chijindu, E. Chidinma E, U. A. Samuel, and O. C. Chibuzo, "Development of Improved Maximum Power Point Tracking Algorithm Based on Balancing Particle Swarm Optimization for Renewable Energy Generation," *IDOSR Journal of Applied Sciences*, vol. 7, no. 1, pp. 12–28, 2022.

[9] M. C. Eze et al., "Solar Energy Materials and Solar Cells Optimum silver contact sputtering parameters for efficient perovskite solar cell fabrication," *Solar Energy Materials and Solar Cells*, vol. 230, no. 2020, p. 111185, 2021.

[10] M. C. Eze et al., "Improving the efficiency and stability of in-air fabricated perovskite solar cells using the mixed antisolvent of methyl acetate and chloroform," *Organic Electronics*, vol. 107, pp. 1–10, Aug. 2022.

[11] A. Abbassi, R. Gammoudi, M. Ali Dami, O. Hasnaoui, and M. Jemli, "An improved single-diode model parameters extraction at different operating conditions with a view to modeling a photovoltaic generator: A comparative study," *Solar Energy*, vol. 155, pp. 478–489, 2017.

[12] S. Shongwe and M. Hanif, "Comparative Analysis of Different Single-Diode PV Modeling Methods," *IEEE Journal of Photovoltaics*, vol. 5, no. 3, pp. 938–946, 2015.

[13] M. T. Ahmed, T. Goncalves, and M. Tlemcani, "Single Diode Model Parameters Analysis of Photovoltaic Cells," in 5th International Conference on Renewable Energy Research and Applications, 2016, vol. 5, pp. 396–400.

[14] T. R. Ayodele, A. S. O. Ogunjuyigbe, and E. E. Ekoh, "Evaluation of numerical algorithms used in extracting the parameters of a single-diode photovoltaic model," *Sustainable Energy Technologies and Assessments*, vol. 13, pp. 51–59, 2016.

[15] W. O. Okafor, S. O. Edeagu, V. C. Chijindu, O. N. Iloanusi, and V. H. U. Eze, "A Comprehensive Review on Smart Grid Ecosystem," *IDOSR Journal of Applied Science*, vol. 8, no. 1, pp. 25–63, 2023.

[16] S. Bana and R. P. Saini, "A mathematical modeling framework to evaluate the performance of single diode and double diode based SPV systems," *Energy Reports*, vol. 2, pp. 171–187, 2016.

[17] C. C. Ogbonna, V. H. U. Eze, E. S. Ikechuwu, O. Okafor, O. C. Anichebe, and O. U. Oparaku, "A Comprehensive Review of Artificial Neural Network Techniques Used for Smart Meter-Embedded forecasting System.," *IDOSR Journal of Applied Science*, vol. 8, no. 1, pp. 13–24, 2023.

[18] G. Sulyok and J. Summhammer, "Extraction of a photovoltaic cell's double-diode model parameters from data sheet values," *Energy Science and Engineering*, vol. 6, no. 5, pp. 424–436, 2018.

[19] J. P. Ram, H. Manghani, D. S. Pillai, T. S. Babu, M. Miyatake, and N. Rajasekar, "Analysis on solar PV emulators: A review," *Renewable and Sustainable Energy Reviews*, vol. 81, no. July 2017, pp. 149–160, 2018.

[20] S. J. Yaqoob, A. L. Saleh, S. Motahhir, E. B. Agyekum, A. Nayyar, and B. Qureshi, "Comparative study with practical validation of photovoltaic monocrystalline module for single and double diode models," *Scientific Reports*, vol. 11, no. 1, pp. 1–18, 2021.

[21] A. J. Nascimento, M. C. Cavalcanti, F. Bradaschia, E. A. Silva, L. Michels, and L. P. Pietta, "Parameter estimation technique for double-diode model of photovoltaic modules," 14th Brazilian Power Electronics Conference, *COBEP 2017*, vol. 2018-Janua, pp. 1–6, 2017.

[22] V. Tamrakar, S. C. Gupta, and Y. Sawle, "Study of characteristics of single and double diode electrical equivalent circuit models of solar PV module," in International Conference on Energy Systems and Applications, *ICESA 2015*, 2016, no. Icesa, pp. 312–317.

[23] B. S. S. Ganesh Pardhu and V. R. Kota, "Radial movement optimization based parameter extraction of double diode model of solar photovoltaic cell," *Solar Energy*, vol. 213, no. May 2020, pp. 312–327, 2021.

[24] B. K. Dey, I. Khan, M. N. Abhinav, and A. Bhattacharjee, "Mathematical modelling and characteristic analysis of Solar PV Cell," 7th IEEE Annual Information Technology, Electronics and Mobile Communication Conference, *IEEE IEMCON 2016*.

[25] J. K. Sayyad and P. S. Nasikkar, "Solar photovoltaic module performance characterisation using single diode modeling," *E3S Web of Conferences*, vol. 170, 2020.

[26] N. M. A. Alrahim Shannan, N. Z. Yahaya, and B. Singh, "Single-diode model and two-diode model of PV modules: A comparison," in Proceedings - 2013 IEEE International Conference on Control System, Computing and Engineering, *ICCSCE 2013*, 2013, pp. 210–214.