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A Simplified Two Diode Photovoltaic Module:
Modeling and Performance Analysis

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Abstract: The accurate modeling and characterization of the Solar Photovoltaic model is mainly depending on the extraction of parameters of the Photovoltaic cell. These parameters are very essential to study the physical behavior of the photovoltaic module under partial shading conditions. The main contribution of this work is to propose the modeling and analysis of four parameters two-diode photovoltaic model based on the constructor's information datasheet. The constraints of these two-diode model have been estimated by using an analytical and effective iteration method. The consequence of changing irradiance and temperature on voltage, current, and power at maximum power point is examined under inconsistent ecological conditions. The proposed system requires only four constraints for modeling in comparison to the earlier proposed seven-parameter models with reduced computational complexity. The accuracy and consistency of proposed technique is confirmed by comparing the estimated values with the results of previous developed method. From results and performance comparison analysis it has been seen that the simplified Two-diode photovoltaic model is more precise and has improved performance compared to the one-diode photovoltaic model, specifically at smaller irradiance and higher temperature. The proposed photovoltaic model is implemented by using MATLAB/Simulink environment by analyzing the current-voltage equations and is validated on multicrystalline and monocrystalline photovoltaic cells under Standard Test Conditions (STC).

Keywords: One-diode Photovoltaic model, Two-diode Photovoltaic model, Monocrystalline solar cell, Polycrystalline solar cell, Four Parameters, Iteration Procedure

1. Introduction

Modelling of photovoltaic (PV) cells and accurate evaluation of parameters of the model are very important to analyze the performance of actual photovoltaic cells under varying irradiance and temperature points. In general for modeling of PV cell the most common technique employed is the electrical circuit model that contains both linear and non-linear behaviour. These parameters are very essential to study the physical behavior of the photovoltaic module under several ecological conditions according to the information datasheet. In general, most of the manufacturer provides data only about some parameters like open circuit voltage (V_o), short circuit current (I_{sc}), peak or maximum power (P_{mpp}), current at $P_{mpp}(I_{mpp})$ and voltage at $P_{mpp}(V_{mpp})$ at STC and inappropriately these constraints are not closer to the data which are important for modelling of PV cell, since it is used to work at different environmental conditions.

The accuracy of modeling and interpretation of the Photovoltaic model is mainly depending on the extraction of constraints of that model. The parameters involve are incident current, saturation current, diode ideality factors, series, and shunt resistance. These Solar cell constraints are very important in the forecast of the actual behavior of the photovoltaic model under various ecological conditions. Consequently, it is significant to develop a actual system of a PV cell with a reduced computational energy. The challenging task is now to estimate the constraints of the solar photovoltaic model with better accurateness and efficiency while keeping a precise computation energy.

In recent year many models have been proposed for instance like one-diode R_s model, R_p model, two-diode, and three-diode model [1], [2], [3] The ideal model is a one-diode PV model it consists of only three constraints like diode ideality factor, current and voltage at STC. With the insertion of resistance Rs in series to the one diode results in more enhanced type of the model [4]. Though this enhanced model has certain advantages but the accuracy of model will get effected with the different temperatures as it not taken the temperature coefficient of voltage (γ_v) in

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to interpretation. The improved type of the both R_s and the R_p one diode model is by the addition of parallel resistance to the electrical circuit [3]. However this R_p model has enhanced precision but with the addition of series and parallel resistances leads to extra computational energy and more parameters to be evaluated.

Some investigators have proposed various approaches for the approximation of photovoltaic cell parameters based on the complexity of the model [5], [6], [7], [8], [9], [10], [11] Many authors have developed several estimation methods for parameters evaluation for photovoltaic models. This approaches comprise the valuation of five parameters, four parameters, three parameters, two or even one parameters has demonstrated in reference [9]. Some researcher has proposed effective algorithms, curve fitting approach, analytical and numerical approaches for the valuation of seven constraints of two-diode photovoltaic model like Brent method [5] and New analytical approach [12]. Although these methods have improved accuracy and their certain advantages but extraction of more parameters involves computational complexity [13].

The main objective of this work is to propose the accurate modeling of Two diode photovoltaic (PV) cells and an analytical and effective iterative technique is proposed to evaluate the constraints of PV model. The analysis of the non-linear equation is being carried out at three operating points (V_o, I_{sc} and P_{mpp}). The constraints of these developed models have been estimated by using the effective iteration method to reduce the parameters to four instead of five with the reduced computational energy. The proposed modeling of the two-diode model is carried out on basis of electrical equivalent circuits. An effective iterative method is proposed to evaluate R_{SE} and R_{SH} resistances. The accurateness of the proposed photovoltaic model is verified on two different solar photovoltaic cells from the manufacturer data and the results are compared with one diode R_{SH} models under standard operating conditions. The findings of this work are helpful for investigators who studies on the cell modelling and simulation of photovoltaic model.

2. Methodology

A. *Two-Diode Photovoltaic (PV) Cell: Mathematical Modeling*

The Two-diode PV cell is shown in Figure 1 [14]. The diode saturation current I_{DS2} and ideality factor C_2 are the added constraints essential to be measured. The effect of depletion region recombination loss [2] compensates by diode current I_{DS2}.

By using KCL in Fig.1 we can obtain the relation for current I:

$$I = I_L - I_{D1} - I_{D2} - I_{SH} \tag{1}$$

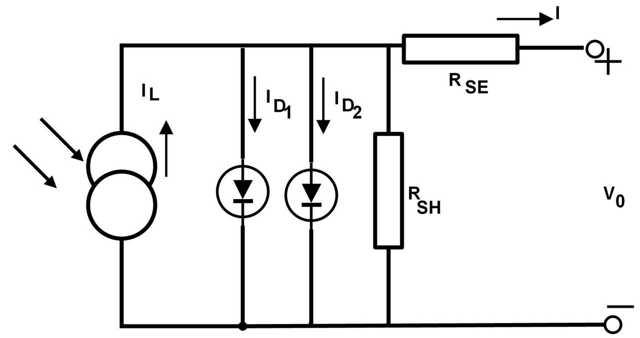

Figure 1. Electric circuit model: Two-Diode Photovoltaic Cell

$$I = I_L - I_{D1} - I_{D2} - \frac{V_0 + IR_{SE}}{R_{SH}} \tag{2}$$

I_L is the Light or Photo current, I_{D1} and I_{D2} is Diode Currents, I_{SH} is shunt resistor current, and I - output current of module [15]. Currents through diode 1 and 2 are given by

$$I_{D1} = I_{DS1}[(e^{\frac{V_0+IR_{SE}}{C_1 V_T N_{SE}}}) - 1] \tag{3}$$

$$I_{D2} = I_{DS2}[(e^{\frac{V_0+IR_{SE}}{C_2 V_T N_{SE}}}) - 1] \tag{4}$$

$$I = I_L - I_{DS1}[(e^{\frac{V_0+IR_{SE}}{C_1 V_T N_{SE}}}) - 1] - I_{DS2}[(e^{\frac{V_0+IR_{SE}}{C_2 V_T N_{SE}}}) - 1] - \frac{V_0 - IR_{SE}}{R_{SH}} \tag{5}$$

where I_{DS1} and I_{DS2} are diode saturation current, C_1 and C_2 is Diode Ideality factors, N_{SE} is number of PV cells in series, V_T is thermal voltage = $\frac{kT_{Ac}}{q}$, q is $(1.602X10^{-19})$, C is the electron charge, K is $(1.38X10^{-23})$ $\frac{Joule}{Kelvin}$ is a Boltzmann constant. Light or Photocurrent [11] is given by

$$I_L = (I_{SC} + \gamma_{sc}\delta T_{Ac})\frac{G_{ir}}{G_{sc}} \tag{6}$$

where G_{ir}-irradiance in (W/m^2), G_{sc}-irradiance at STC in (W/m^2), $\delta T_{Ac} = T_{Ac}$ - $T_{Ac,ref}$ (Kelvin), $T_{Ac,ref}$ - (25+273 = 298 Kelvin), I_{SC} is Cell's short circuit current at STC (25^0 C), γ_{sc} is Current temperature coefficient (A/K).

$$I_{DS} = I_{DS1} = I_{DS2} = \frac{I_{SC} + \gamma_{sc}\delta T_{Ac}}{[(e^{\frac{V_0+\gamma_V \delta T_{Ac}}{V_T[\frac{C_1+C_2}{P}]}}) - 1]} \tag{7}$$

In order to make analysis simple, the seven parameters are reduced to four by making an assumption that the currents $I_{DS} = I_{DS1} = I_{DS2}$ and $(\frac{C_1+C_2}{P}) = 1$. Therefore

$$I_{DS} = I_{DS1} = I_{DS2} = \frac{I_{SC} + \gamma_{sc}\delta T_{Ac}}{[(e^{\frac{V_0+\gamma_V\delta T_{Ac}}{V_T}}) - 1]} \tag{8}$$

B. Determination of Photovoltaic (PV) Cell Parameters

Owing to its difficulty in analysis the parameter estimation of Two-Diode model is not so easy for developing model of PV model. The following assumptions are considered: the $I_{DS} = I_{DS1} = I_{DS2}$, initial values of $C_1 = 1$ and $C_2 \geq 1.2$ and $(\frac{C_1+C_2}{P}) = 1$ to make the analysis easy. These modifications make a PV model to a more precise model and ease in analysis for PV system modelling. The light current I_L and diode saturation current I_D can be estimated by using Equation (6) and (8) with the information presented by constructor data. By evaluating the module current shown below at the three conditions (V_o, I_{sc}, P_{mpp}).

$$I = I_L - I_{D1} - I_{D2} - \frac{V_0 + IR_{SE}}{R_{SH}} \tag{9}$$

At short circuit condition

$$I = I_{SC,STC}; V_0 = 0 \tag{10}$$

$$I_{SC,STC} = I_{L,STC} - I_{D1,STC} - I_{D2,STC} - \frac{I_{SC,STC}R_{SE}}{R_{SH}} \tag{11}$$

where,

$$I_{D1,STC} = I_{DS1,STC}[(e^{\frac{I_{SC,STC}R_{SE}}{C_1 V_T N_{SE}}}) - 1] \tag{12}$$

$$I_{D2,STC} = I_{DS2,STC}[(e^{\frac{I_{SC,STC}R_{SE}}{C_2 V_T N_{SE}}}) - 1] \tag{13}$$

At open circuit condition

$$I = 0; V_0 = V_{0,STC} \tag{14}$$

$$0 = I_{L,STC} - I_{D1,STC} - I_{D2,STC} - \frac{V_{0,STC}}{R_{SH}} \tag{15}$$

From Equation (15)

$$I_{L,STC} = I_{D1,STC} + I_{D2,STC} + \frac{V_{0,STC}}{R_{SH}} \tag{16}$$

where,

$$I_{D1,STC} = I_{DS1,STC}[(e^{\frac{V_{0,STC}}{C_1 V_T N_{SE}}}) - 1] \tag{17}$$

$$I_{D2,STC} = I_{DS2,STC}[(e^{\frac{V_{0,STC}}{C_2 V_T N_{SE}}}) - 1] \tag{18}$$

At maximum power condition

$$I_{mpp,STC} = I_{L,STC} - I_{D1,STC} - I_{D2,STC} - \frac{V_{mpp,STC} + I_{mpp,STC}R_{SE}}{R_{SH}} \tag{19}$$

From Equation (19)

$$R_{SH} = \frac{V_{mpp,STC} + I_{mpp,STC}R_{SE}}{I_{L,STC} - I_{D1,STC} - I_{D2,STC} - I_{mpp,STC}} \tag{20}$$

C. Determination of R_{SE} and R_{SH} Constraints

Several analytical and curve fitting approaches have been described by some authors to estimate the constraints for PV models like Analytical method [10], Effective method for Current (I) – Voltage (V) curve fitting [11], Current (I) – Voltage (V) curve reproduction [16], Current (I) – Voltage (V) curve fitting [17], Pattern Search Technique [18], and New Iterative Technique [19] and in this analysis the constraints R_{SE} and R_{SH} is evaluated by the same technique as explained in [17].

The parameters R_{SE} and R_{SH} can be estimated using Equation (20) with the help of an actual iteration procedure according to Newton-Raphson method [20]. The value of R_{SE} and R_{SH} are carefully chosen such that estimated power ($P_{mpp,c}$) essentially match accurately with the value of experimental power ($P_{mpp,STC}$) specified by the information datasheet. The developed Iteration method is shown in Figure 2. This iteration process initiates from $R_{SE} = 0$, $C_1 = 1$ and $C_2 \geq 1.2$ which essentially varies until it matches to the estimated peak power to $P_{mpp,STC}$ and simultaneously R_{SH} is then calculated [21]. The analysis of non-linear equation is carried out at three characteristic points. The constraints of the two-diode photovoltaic cell are evaluated by using effective iteration procedure. The following are the steps involved:

1) Assume an initial value of C_1, C_2 and $R_{SE,int}$.
2) Light current I_L is evaluated by Equation (6).
3) Saturation currents I_{DS} is evaluated by Equation (8).
4) Shunt resistance R_{SH} is evaluated by Equation (20).
5) If calculated power ($P_{mpp,c}$) is equal to power at STC ($P_{mpp,STC}$) then first iterative procedure is concluded, otherwise adjust the values of C_1, C_2 assume a new value of $R_{SE,int}$. Repeat the sequence of steps starting from step4 till the error is within the tolerance value [14].

3. Proposed Simplified Two-Diode Model: Simulation

The overall sub-system of PV module is executed in MATLAB/Simulink are represented in Figure 3. Using Equation (5), (6), (7), and (8) the complete simulink model were executed in MATLAB/Simulink. Figure 4 demon-

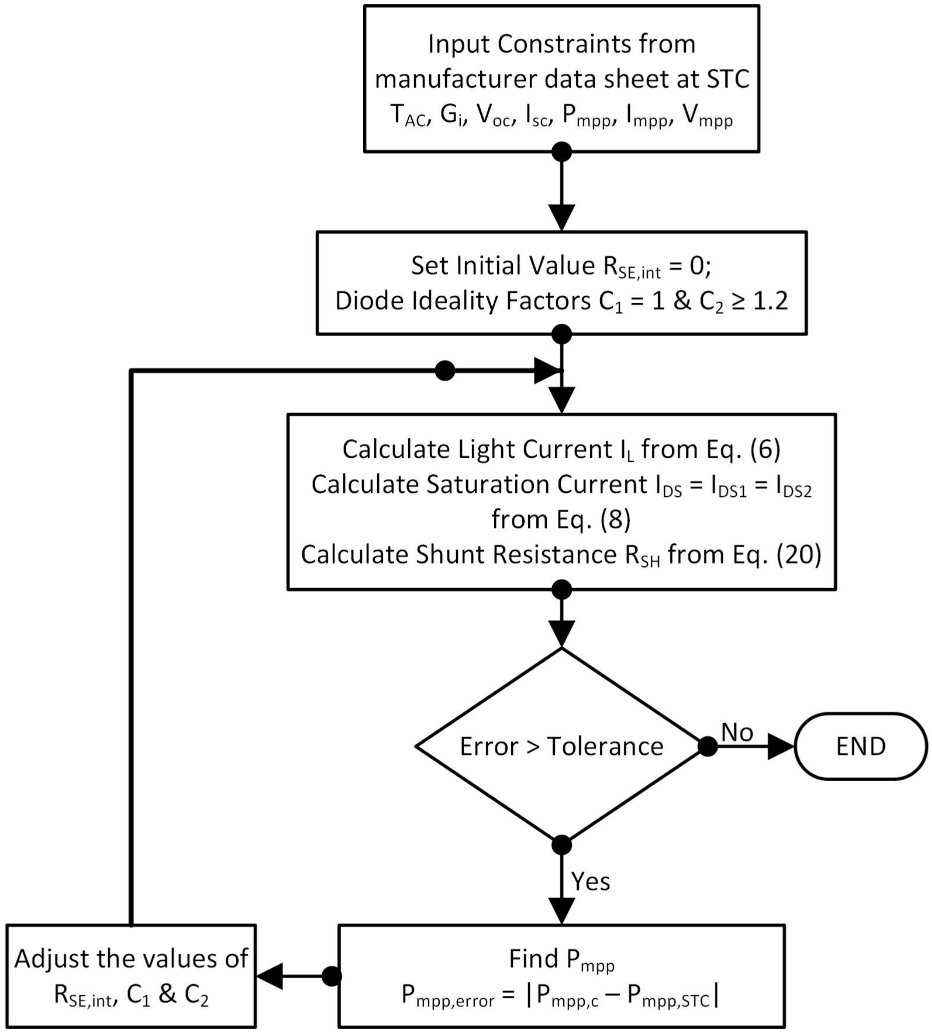

Figure 2. Flow Chart for Iteration Procedure

strates the Implementation of the saturation current in MATLAB/Simulink. Implementation of the incident current and the output current of module in MATLAB/Simulink are shown in Figure 5 and Figure 6. Table I represents the PV module specifications of both solar cells. The estimated values of the simplified and One-Diode R_{SH} model are represented in Table II. The percentage relative error of P_{mpp}, V_{mpp}, I_{mpp}, V_0 and I_{SC} for mono-crystalline solar cell are demonstrated in Table III. The percentage relative error of P_{mpp}, V_{mpp}, I_{mpp}, V_0 and I_{SC} for multi-crystalline solar cell are demonstrated in Table IV. The developed approach needs only four parameters for modelling as we assume that currents the $I_{DS} = I_{DS1} = I_{DS2}$, are equal, whereas $C_1 = 1$ and $C_2 \geq 1.2$ and the value of p is suggested to be higher than 2.2 [15].

4. Results and Discussion

The model developed in this study is validated by estimating constraint values of different PV cells. The PV modules specifications are considered based on the constructor's information sheet; mono-crystalline *DSA180* [14] and multi-crystalline *MSX64* [21] are used for validation. We can conclude that the extracted values slightly diverge away from the manufacture datasheet at STC. Though, multi-crystalline (*MSX64*) precisely close to the information datasheet for the simplified photovoltaic model. Performance analysis of evaluated values at P_{mpp} of both proposed and R_{SH} model for monocrystalline (*DSA180*) and multi-crystalline (*MSX64*) solar module are represented in Table III and Table IV.

The P-V characteristics of R_{SH} and simplified model for both photovoltaic cells at STC are demonstrated in Figure 7 and Figure 8. Performance valuation of I-V characteristics of both photovoltaic models for *DSA180* solar cell at STC with different environmental conditions are demonstrated in Figure 9 and Figure 10. Performance valuation of I-V characteristics for both photovoltaic models for *MSX64* solar cell at STC with different environmental conditions

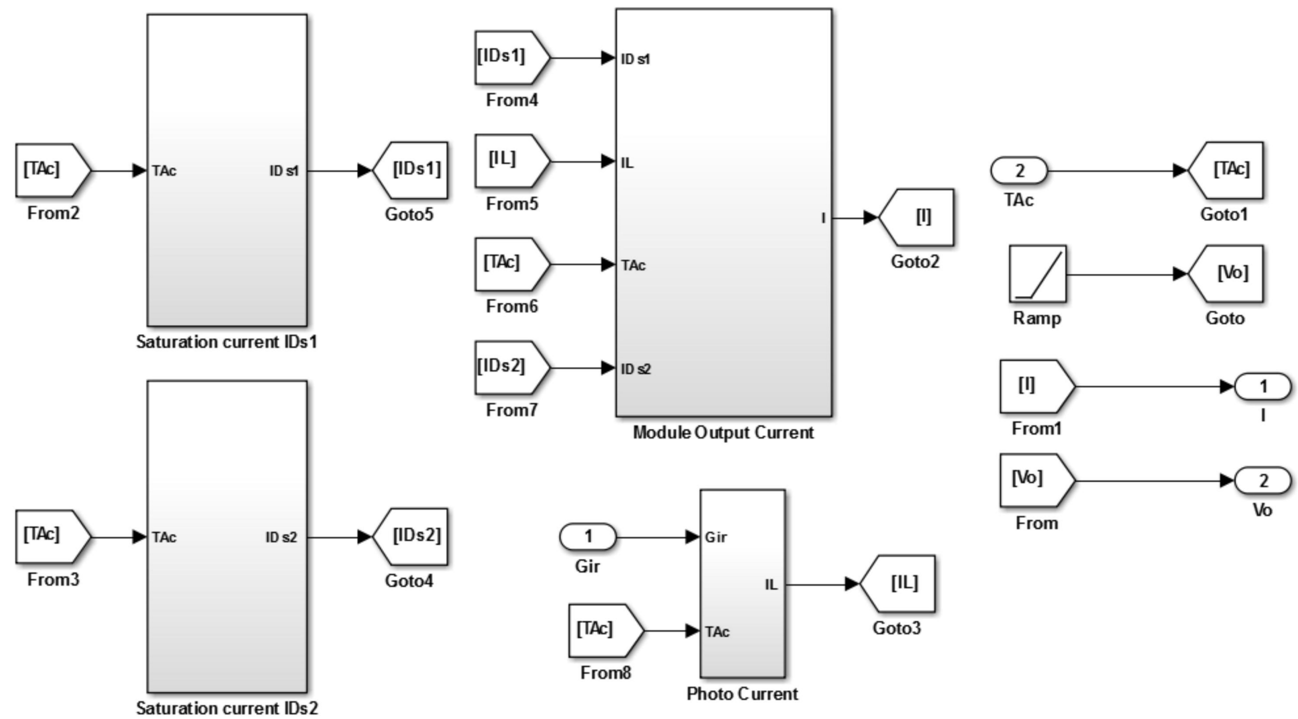

Figure 3. Overall Sub-system Model Implementation in MATLAB/Simulink

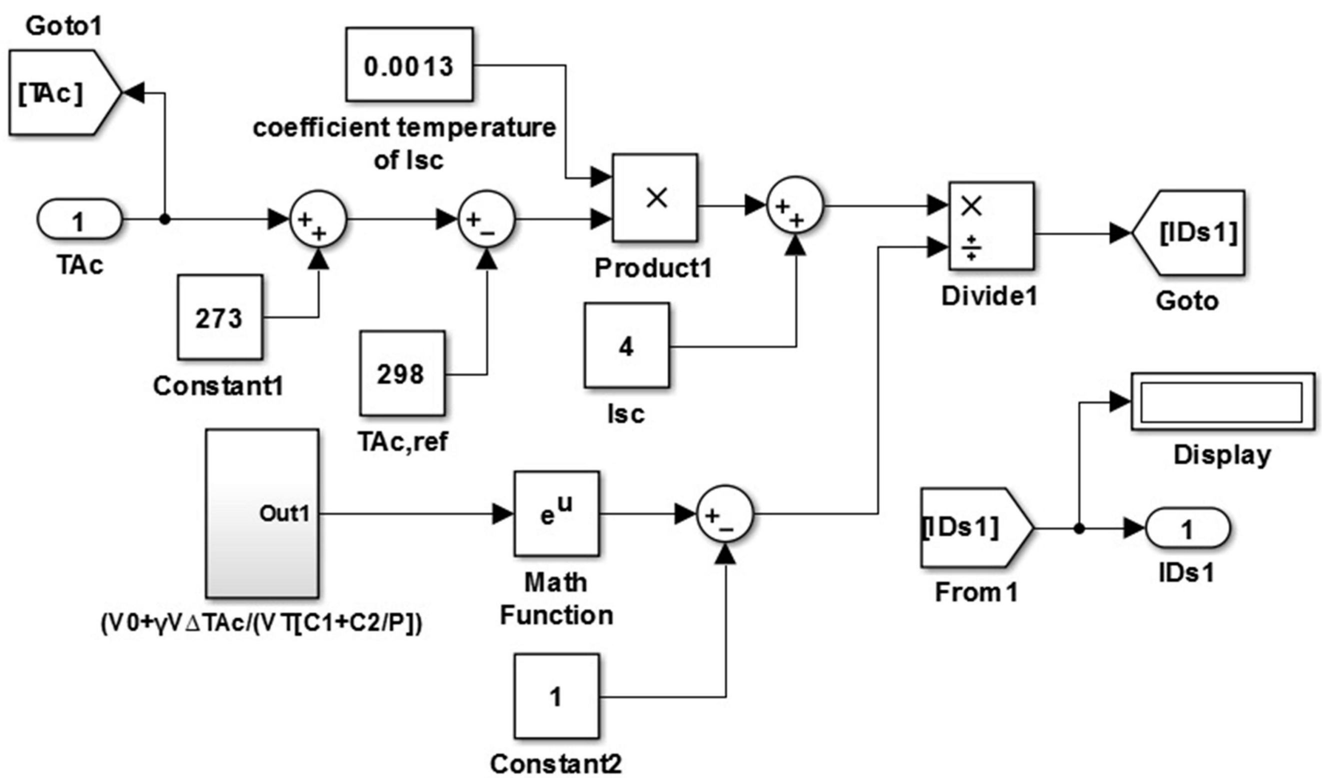

Figure 4. Saturation Current (I_{DS}) in MATLAB/Simulink

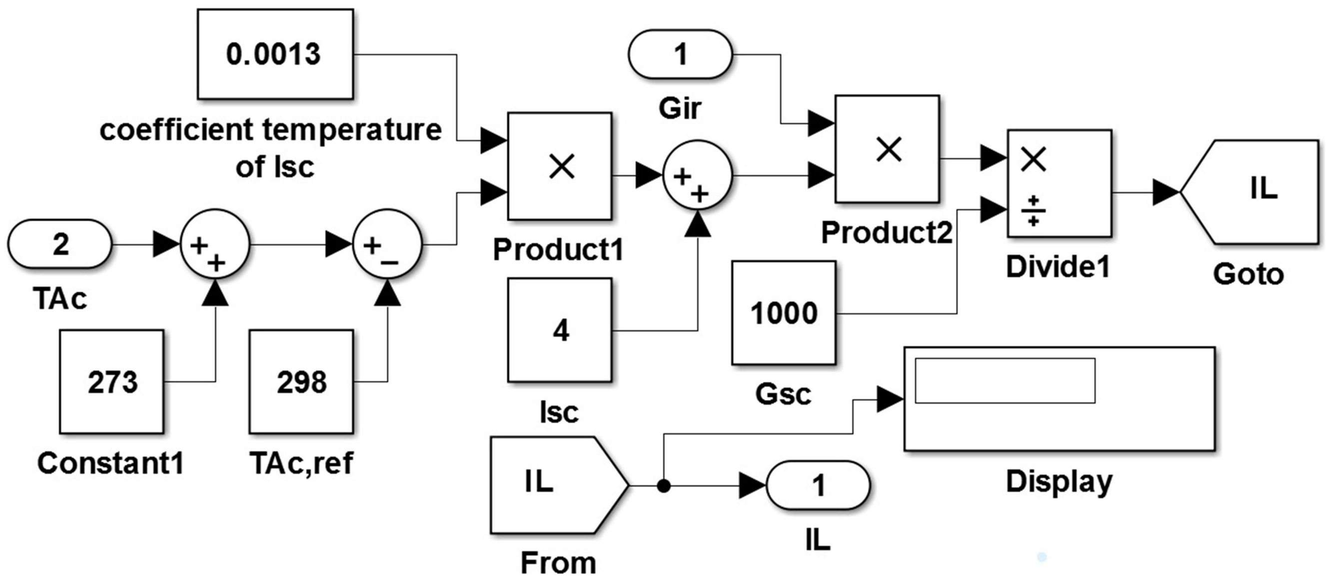

Figure 5. Implementation of Light Current (I_L) in MATLAB/Simulink

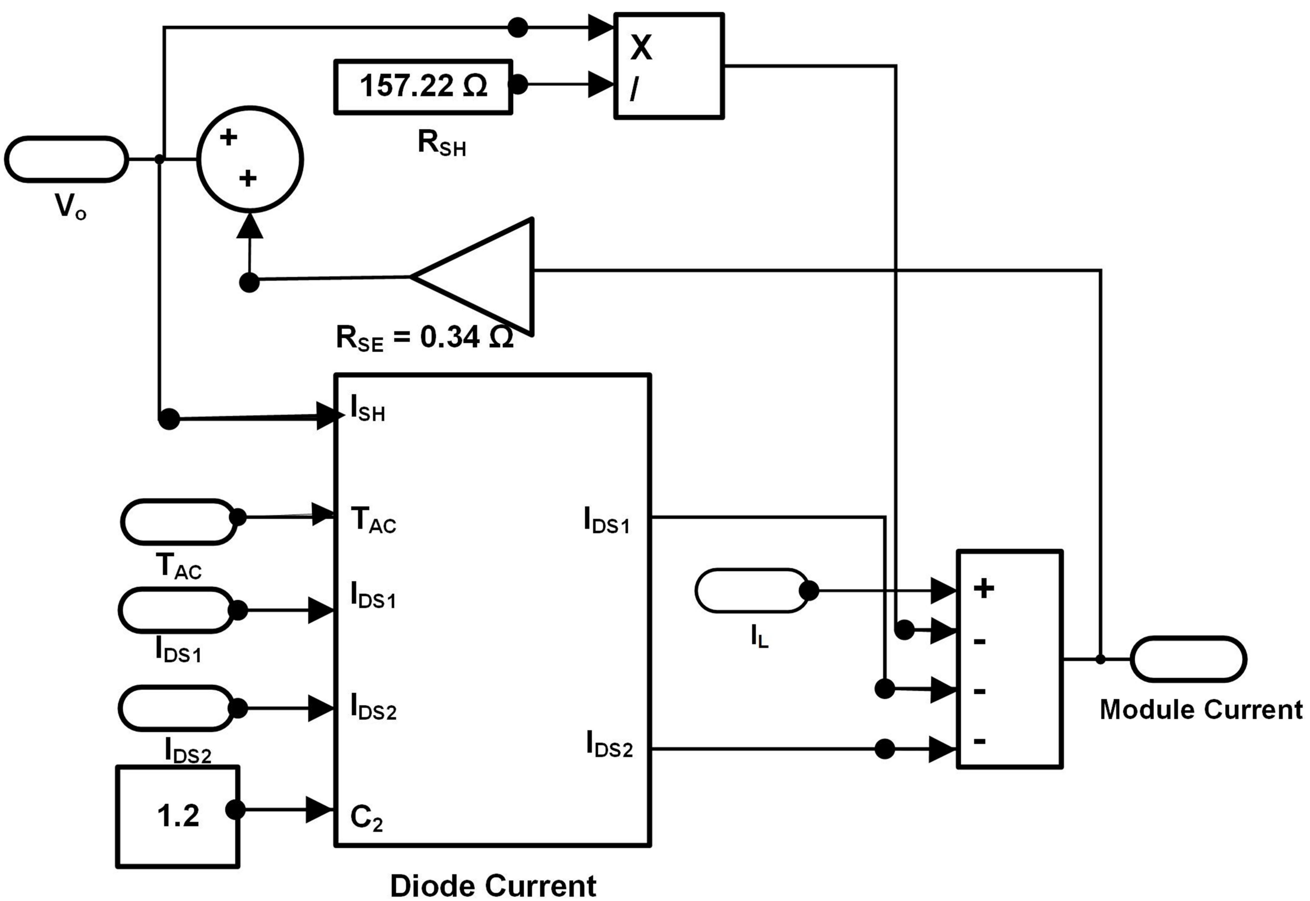

Figure 6. Module Output Current (I) in MATLAB/Simulink

TABLE I. Solar Cell Specifications from Constructor Data-sheet

Constraints	Mono-crystalline (*DSA180*) Solar Module	Solarex Multi-crystalline (*MSX64*)
Maximum Power (P_{mpp})	80 W	64 W
Voltage at P_{mpp} (V_{mpp})	17.2 V	17.5 V
Current at P_{mpp} (I_{mpp})	4.66 A	3.66 A
Voltage at open circuit (V_0)	21.30 V	21.30 V
Current at short circuit (I_{SC})	5.29 A	4 A
Number of Series PV cells (N_{SE})	36	36
Voltage Temperature coefficient (γ_v)	$-0.38V/^0C$	$80mV/^0C$
Current Temperature coefficient (γ_{sc})	$0.13A/^0C$	$0.65mA/^0C$

TABLE II. Extracted Values of Simplified Two diode and R_{SH} Model

Constraints	Mono-crystalline (*DSA180*) Solar Module (Two-Diode Model)	Solarex Multi-crystalline (*MSX64*) (Two-Diode Model)	Mono-crystalline (*DSA180*) Solar Module (One-Diode Model)	Solarex Multi-crystalline (*MSX64*) (One-Diode Model)
Maximum Power (P_{mpp})	80.08 W	64.159 W	80.07 W	63.55 W
Voltage at P_{mpp} (V_{mpp})	17.04 V	17.46 V	16.61 V	17.46 V
Current at P_{mpp} (I_{mpp})	4.69 A	3.67 A	4.67 A	3.64 A
Voltage at open circuit (V_0)	21.30 V	21.30 V	21.30 V	21.30 V
Current at short circuit (I_{SC})	5.29 A	4 A	5.29 A	4 A
Light Current (I_L)	5.29 A	4.01 A	5.28 A	4.01 A
Saturation Currents ($I_{DS1} = I_{DS2}$)	$5.207X10^{-10}$ A	$3.937X10^{-10}$ A	$2.423X10^{-}8$ A	$1.82X10^{-8}$ A
Diode Ideality Factor (C)	$C_1 = 1.1$, $C_2 = 1.8$	$C_1 = 1.1$, $C_2 = 1.8$	1.2	1.2
Series Resistance (R_{SE})	0.34 Ω	0.35 Ω	0.22 Ω	0.2 Ω
Shunt Resistance (R_{SH})	148.33 Ω	167.25 Ω	283.33 Ω	310 Ω

TABLE III. Performance analysis of evaluated values at P_{mpp} of Two diode model and R_{SH} model for monocrystalline (*DSA180*) Solar Cell

Constraints	Information Sheet at STC	Two-Diode Model	One-Diode Model	Percentage Relative Error (Two-Diode Model)	Percentage Relative Error (One-Diode Model)
Maximum Power (P_{mpp})	80 W	80.08 W	80.07 W	0.099	0.087
Voltage at P_{mpp} (V_{mpp})	17.2 V	17.04 V	16.61 V	0.938	3.552
Current at P_{mpp} (I_{mpp})	4.66 A	4.69 A	4.67 A	0.639	0.214
Voltage at open circuit (V_0)	21.30 V	21.30 V	21.30 V	0	0
Current at short circuit (I_{SC})	5.29 A	5.29 A	5.29 A	0	0

TABLE IV. Performance analysis of evaluated values at P_{mpp} of Two diode model and R_{SH} model for multicrystalline (*MSX64*) Solar Cell

Constraints	Information Sheet at STC	Two-Diode Model	One-Diode Model	Percentage Relative Error (Two-Diode Model)	Percentage Relative Error (One-Diode Model)
Maximum Power (P_{mpp})	64 W	64.15 W	63.55 W	0.247	0.708
Voltage at P_{mpp} (V_{mpp})	17.5 V	17.47 V	17.47 V	0.171	0.171
Current at P_{mpp} (I_{mpp})	3.66 A	3.67 A	3.64 A	0.272	0.549
Voltage at open circuit (V_0)	21.30 V	21.30 V	21.30 V	0	0
Current at short circuit (I_{SC})	4 A	4 A	4 A	0	0

are demonstrated in Figure 11 and Figure 12.

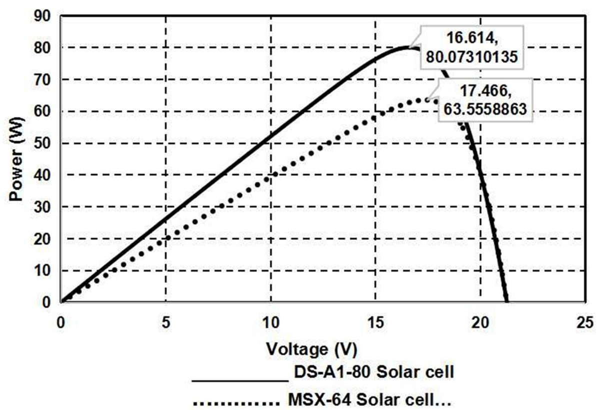

Figure 7. P-V Characteristics of Simplified Two diode model for *DSA180* and *MSX64* at STC (25^0C and 1000 W/m^2)

Comparative analysis of power-voltage characteristics between R_{SH} and simplified model for *DSA180* solar cells at changing environment conditions are demonstrated in Figure 13 and Figure 14. Comparative analysis of power-voltage characteristics between R_{SH} and simplified model for *MSX64* solar cells at changing environment conditions are demonstrated in Figure 15 and Figure 16. From the simulation results, we can observe that both models exhibits the similar characteristics at standard operating conditions. Hence, the simplified model proves enhanced performance in comparison to R_{SH} module exactly at smaller irradiance condition particularly for V_0.

Performance analysis of Power versus Voltage characteristics of Simplified model and R_{SH} model for *KG-200GT* solar cell is illustrated in Figure 17. Comparison of estimated values of Proposed method for multi-crystalline (*KG-200GT*) solar cell with Newton-Raphson results from Elbaset [22] are shown in Table V. From Table V we can witness that the evaluated values of both methods is closely

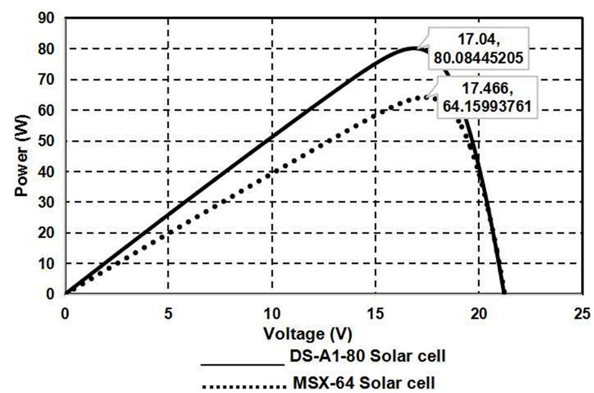

Figure 8. P-V Characteristics of One diode R_{SH} model for *DSA180* and *MSX64* at STC (25^0C and 1000 W/m^2)

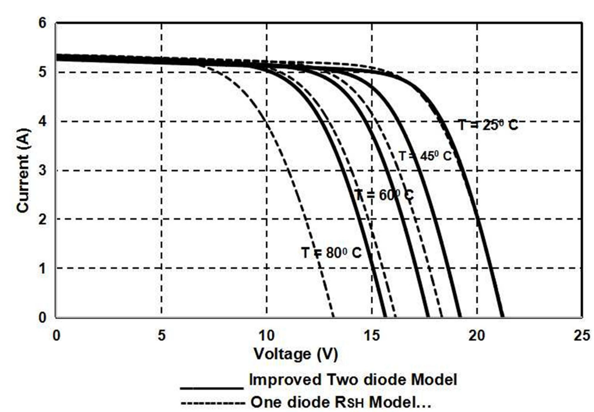

Figure 9. Performance valuation of I-V Characteristics for Simplified Two diode model and R_{SH} model for *DSA180* with varying temperature condition at STC (1000 W/m^2)

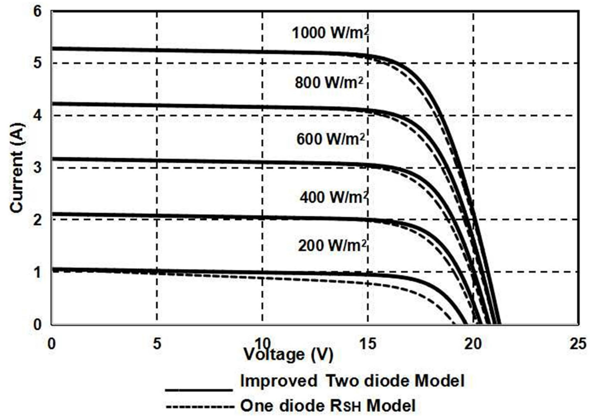

Figure 10. Performance valuation of I-V Characteristics for Simplified Two diode model and R_{SH} model for *DSA180* with varying irradiance condition at STC (25^0C)

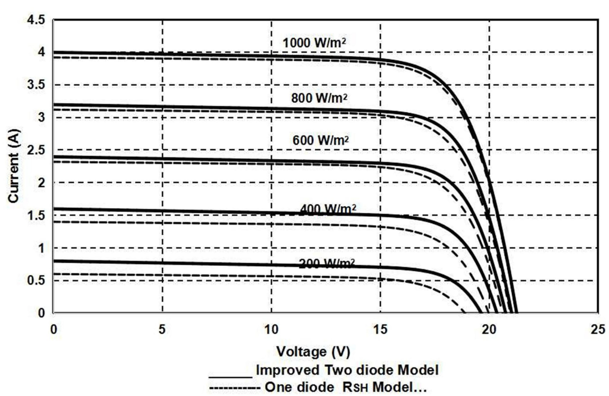

Figure 11. Performance valuation of I-V Characteristics for Simplified Two diode model and R_{SH} model for *MSX64* with varying irradiance condition at STC (25^0C)

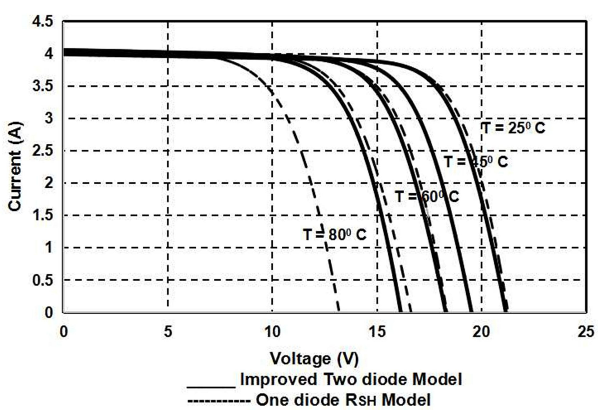

Figure 12. Performance valuation of I-V Characteristics for Simplified Two diode model and R_{SH} model for *MSX64* with varying temperature condition at STC (1000 W/m^2)

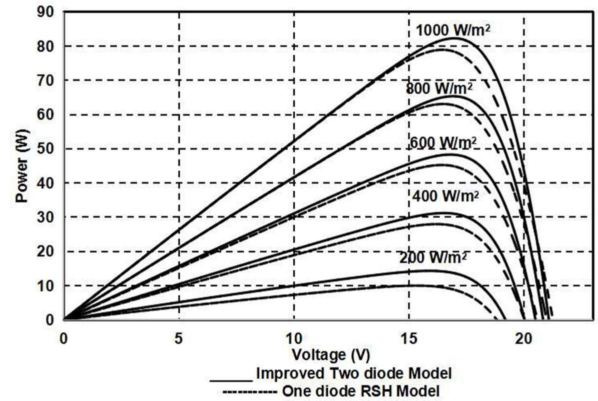

Figure 13. Performance valuation of P-V Characteristics for Simplified Two diode model and R_{SH} model for *DSA180* with varying irradiance condition at STC (25^0C)

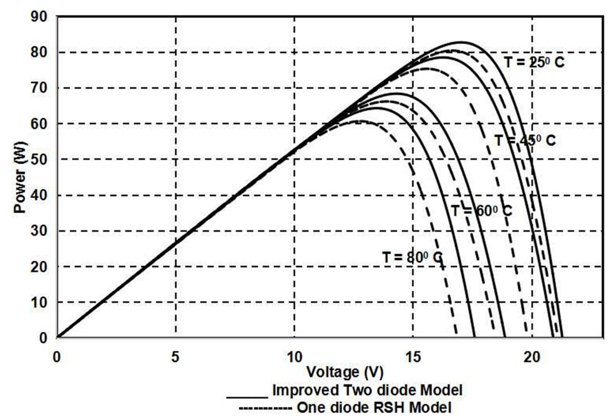

Figure 14. Performance valuation of P-V Characteristics for Simplified Two diode model and R_{SH} model for *DSA180* with varying temperature condition at STC (1000 W/m^2)

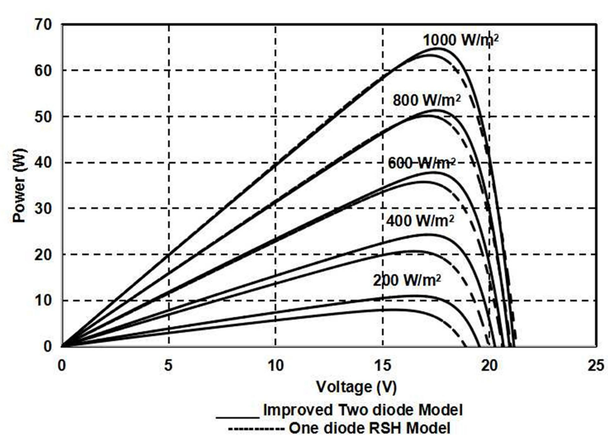

Figure 15. Performance valuation of P-V Characteristics for Simplified Two diode model and R_{SH} model for *MSX64* with varying irradiance condition at STC (25^0C)

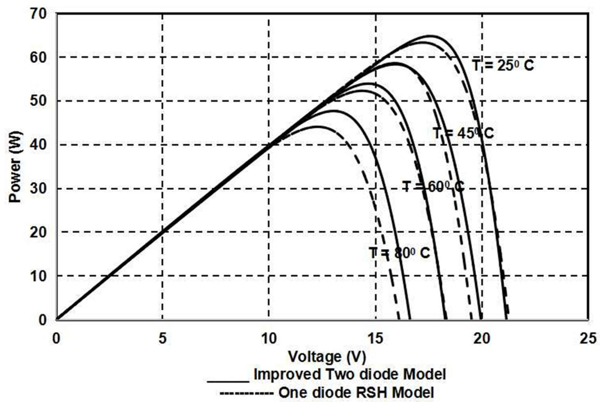

Figure 16. Performance valuation of P-V Characteristics for Simplified Two diode model and R_{SH} model for *MSX64* with varying temperature condition at STC (1000 W/m^2)

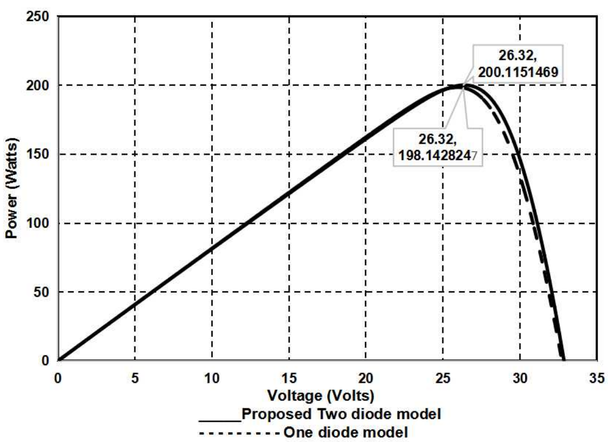

Figure 17. Performance Comparison of P-V Characteristics of Simplified Two diode and R_{SH} model for *KG-200GT* at STC (25^0C and 1000 W/m^2)

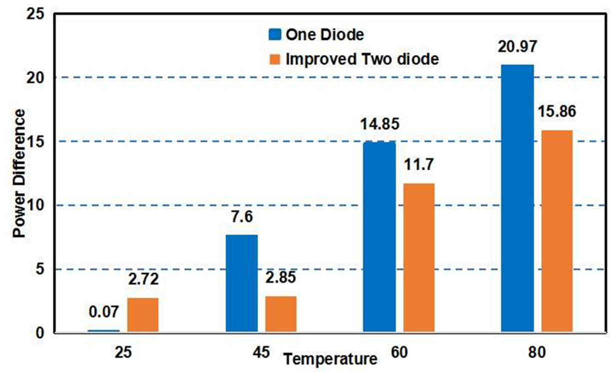

Figure 18. Comparison of the output power of Simplified Two diode model and R_{SH} model for *DSA180* with output power at STC with different temperature points

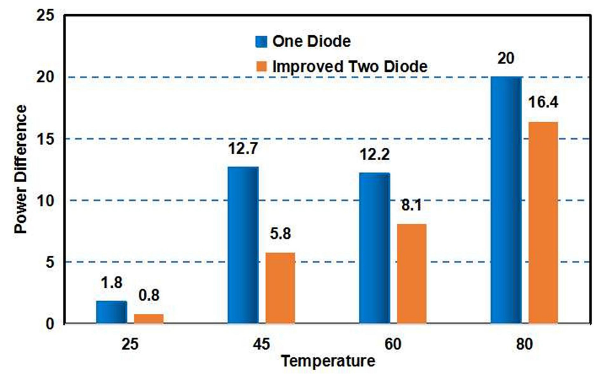

Figure 19. Comparison of the output power of Simplified Two diode model and R_{SH} model for *MSX64* with output power at STC with different temperature points

matching with the manufacturer's datasheet values at STC. However, the percentage relative error of proposed method is lower than the results of reference [22]. Hence, it proved that the proposed method has better accuracy.

Effect of change in Temperature and Irradiance on outputs of Two-diode and One-diode (R_{SH}) for *DSA180* and *MSX64* Photovoltaic model is represented in Table VI and Table VII for ideality factors of $C_1 = 1.2$ for One-Diode and $C_1 = 1.1$, $C_2 = 1.8$ for Two-Diode model. We can witness that with an increase in irradiance and temperature both current (I_{mpp}) and power (P_{mpp}) increases and however with an increase in temperature the value of current (I_{mpp}) and voltage (V_{mpp}) decreases.

The power output of both R_{SH} and proposed photovoltaic cell for *DSA180* and *MSX64* working under changing temperature and irradiance is compared with the output power of ideal photovoltaic cell (For example $P_{Two-diode}$ = 80 - 77.15 = 2.85 W/m^2 and $P_{Two-diode}$ = 80 - 72.4 = 7.6 W/m^2). The comparison in terms of the power difference between the R_{SH} and simplified photovoltaic cell with the ideal photovoltaic cell at different temperature points is shown in Figure 18 and Figure 19. The comparison in terms of the power difference between the R_{SH} and simplified photovoltaic cell with the ideal photovoltaic cell at different irradiance points is shown in Figure 20 and Figure 21. As the value of irradiance decreases, the difference of output of the proposed photovoltaic cell is decreased. The output power of proposed model is more than the R_{SH} model precisely at a lesser irradiance point.

5. Conclusions and Future Work

In this work, the simplified Two-Diode typical system aimed at photovoltaic cell module is proposed. The constraints of these developed models have been estimated by using the analytical approach and effective iteration method. The proposed work needs the estimation of four parameters only with the reduced computational time. A fast and effective iterative technique are used for evaluation of R_{SE} and R_{SH}. The comparison with the information provided by manufacturer data of two different solar cell

TABLE V. Comparison of estimated values of Proposed method for multi-crystalline (*KC-200GT*) Solar Cell with Newton-Raphson results from Elbaset [22]

Constraints	Manufacturer Data at STC	Proposed Method	Percentage Relative Error (Two-Diode Model)	Newton-Raphson Results from Reference [22]	Percentage Relative Error of Results from Reference [22]
Maximum Power (P_{mpp})	200.143 W	200.11 W	0.0164 W	199.60 W	0.271
Voltage at P_{mpp} (V_{mpp})	26.3 V	26.32 V	−0.0760	26.10 V	0.760
Current at P_{mpp} (I_{mpp})	7.61 A	7.603 A	0.091	7.646 A	−0.473
Voltage at open circuit (V_0)	32.90 V	32.90 V	0.00	32.85 V	0.151
Current at short circuit (I_{SC})	8.21 A	8.21 A	0.00	8.21 A	0.00

TABLE VI. Effect of Temperature on outputs of Two diode and One-diode (R_{SH}) Model for *DSA180* and *MSX64* Photovoltaic Cell

Temperature	Constraints	Proposed model (*DSA180*)	R_{SH} Model (*DSA180*)	Proposed model (*MSX64*)	R_{SH} Model (*MSX64*)
25^0C	P_{mpp} (W)	82.72	80.07	63.2	62.2
	V_{mpp} (V)	17.04	17.04	17.46	18.3
	I_{mpp} (A)	4.85	4.69	3.62	3.39
45^0C	P_{mpp} (W)	77.15	72.4	58.2	51.3
	V_{mpp} (V)	16.61	15.76	16.18	15.33
	I_{mpp} (A)	4.64	4.6	3.60	3.35
60^0C	P_{mpp} (W)	68.3	65.15	55.9	51.8
	V_{mpp} (V)	14.8	14.33	16.69	15.72
	I_{mpp} (A)	4.61	4.54	3.35	3.30
80^0C	P_{mpp} (W)	64.14	59.03	47.6	44.0
	V_{mpp} (V)	14.36	13.63	14.4	13.4
	I_{mpp} (A)	4.46	4.33	3.31	3.29

TABLE VII. Effect of Irradiance on outputs of Two diode and One-diode (R_{SH}) Model for *DSA180* and *MSX64* Photovoltaic Cell

Irradiance	Constraints	Proposed model (*DSA180*)	R_{SH} Model (*DSA180*)	Proposed model (*MSX64*)	R_{SH} Model (*MSX64*)
$1000W/m^2$	P_{mpp} (W)	82.90	78.79	64.2	63.2
	V_{mpp} (V)	17.04	16.61	17.46	16.76
	I_{mpp} (A)	4.86	4.74	3.68	3.77
$800W/m^2$	P_{mpp} (W)	65.34	63.06	1.3	49.2
	V_{mpp} (V)	17.04	16.61	17.46	17.04
	I_{mpp} (A)	3.83	3.79	2.94	2.87
$600W/m^2$	P_{mpp} (W)	48.22	44.77	38.8	35.40
	V_{mpp} (V)	17.04	17.04	17.46	17.46
	I_{mpp} (A)	2.82	2.62	2.22	2.02
$400W/m^2$	P_{mpp} (W)	35	26.8	28.2	20.47
	V_{mpp} (V)	16.61	16.81	17.46	17.83
	I_{mpp} (A)	2.10	1.63	1.61	1.14
$200W/m^2$	P_{mpp} (W)	19.1	9.93	14.6	6.5
	V_{mpp} (V)	15.76	15.23	17.04	17.46
	I_{mpp} (A)	1.21	0.65	0.85	0.37

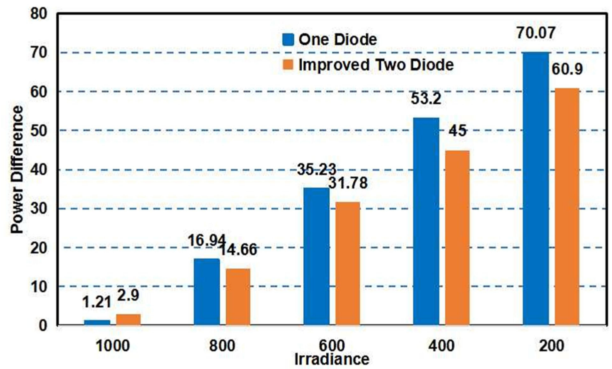

Figure 20. Comparison of the output power of Simplified Two diode model and R_{SH} model for *DSA180* with output power at STC with different irradiance points

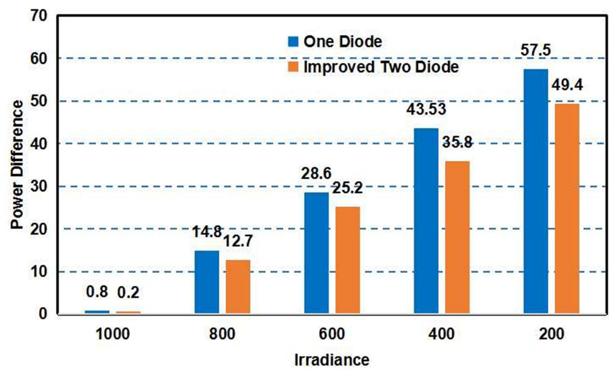

Figure 21. Comparison of the output power of Simplified Two diode model and R_{SH} model for *MSX64* with output power at STC with different irradiance points

modules has confirmed the consistency of the developed model. To confirm the precision of the developed technique, the evaluated values are correlated with the results of earlier developed method and with R_{SH} model. The effect of varying irradiance and temperature on V_{mpp}, I_{mpp} and P_{mpp} are examined to estimate the difference in power output of both R_{SH} and two-diode photovoltaic cell with respect to the ideal photovoltaic model. This difference of output power value for Two-Diode model is smaller than the R_{SH} model precisely at lesser irradiance conditions. In comparison to R_{SH} model, it shows the enhanced performance and precision specifically at smaller irradiance condition. The proposed work is confirmed for the monocrystalline and multicrystalline PV cell under STC. Thus, the findings of this work can be helpful for choosing the exact model under various operating conditions.

In future work we can implement the effective iteration procedure for extraction of parameters for Three-diode photovoltaic model.

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