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Comparative Analysis of Photovoltaic Module Electrical Characteristics Using A Two-Diode Model With Single-Diode Model And Its Application Under PSC

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ABSTRACT: Performance of PV System is examined in this work by using Twodiode model(TDM) and related with single diode model(SDM) by implementing MPPT Algorithm. Solar PV system VI and PV characteristics have been analyzed for various parameters of irradiation and temperature. Using algorithmic approach peak power variations with respect to different physical parameters have been identified from the characteristics.P&O algorithm is used to validate the MPPT operation usingTDM under diverse environmental circumstances, the same has been verified with theoretical approach in this paper.

KEYWORDS: *PV System, Single Diode Model, MPPT Algorithm, P&O algorithm.*

INTRODUCTION

Solar photovoltaics is a field that allows us to harness the enormous amount of energy that enters the earth. The amount of irradiation reaching Earth is sufficient to meet our energy needs. Solar cells, which are the basic unit of a PV system, convert solar energy into electrical energy. To build a PV array, these solar panels are combined in various series and parallel configurations. The solar PV array's ability to generate electrical energy is dependent on several elements.

A Diode

Non-Linear behaviour of solar PV Cell leads difficult in study and extracts maximum power from it. Photovoltaic panels were evaluated and their features plotted using Matlab/Simulink software. For simulation, solar panels with a rating of 250 V and 4 kW were used. For altering radiation and temperature, different P-V along with I-V characteristics have been drawn andtoanalyse properties, the radiation was

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wide-ranging from 1000 W/m^2 to 200 W/m^2. In second case, temperature was altered from 45 to 5 degrees Celsius, and the features were plotted. The voltage is affected by temperature in this case; nevertheless, the fluctuation is not significant. When it comes to temperature, there is a slight change, but the current is practically consistent. Furthermore, the maximum power point is being altered. It means that the maximum point values are modified during the day as the temperature changes [2]. Monitoring the maximum power during the day is essential.

B One-Diode Model

The PV Diode SDM is most common and it is configured with a diode, current source and two resistors as shown in figure 1(a). By using network analysis, the relation between V and I is defined.

$$I = I_{ph} - I_0 \left[\exp\left(\frac{V+R_SI}{n_1N_SV_t}\right) - 1\right] - \left[\frac{V+IR_s}{R_P}\right] \quad \& \quad V_t = \frac{N_SkT}{q} \tag{1}$$

The photocurrent is denoted by I_{PV},Reverse saturation current of diodeI_0, A stands for the diode's ideal factor, R_S series resistance, R_P parallel resistance, Boltzmann constant given by K, PN-junction absolute temperature T, Charge of an electron is q, Thermal voltageV_t.I_{PV}, I_0, n, R_S, and R_P are the 5 unknown parameters. The parameter estimate approach aims to establish appropriate values based on available data with the below equations.

$$I_{ph} = \left(I_{sc_STC} + k_i \Delta T\right)\frac{G}{G_{STC}} \tag{2}$$

C Two-Diode Model

An addition of a diode in parallel to a SDM results TDM as shown in Figure 1(b) additionally it's helpful to simulate the recombination losses in the depletion zone [14] and the I-V relation which is summarized below.

$$I = I_{pv} - I_{01}\left[\exp\left(\frac{V+R_SI}{n_1N_SV_t}\right) - 1\right] - I_{02}\left[\exp\left(\frac{V+R_SI}{n_2N_SV_t}\right) - 1\right] - \frac{V+R_SI}{R_P} \tag{3}$$

Two diode-related terms appear in Equation (3), with I_{01} and I_{02}signifying the flow of reverse saturation current, and n_1, n_2 stand for the ideality factors of two diodes. At lower irradiance levels the two-diode concept provides for increased precision due to the second diode, and is typically associated with superior performance [1], [12]. Unknown values (I_{PV}, I_{01}, I_{02}, n_1, n_2, R_S, R_P), which adds difficulty inestimation of parameters.

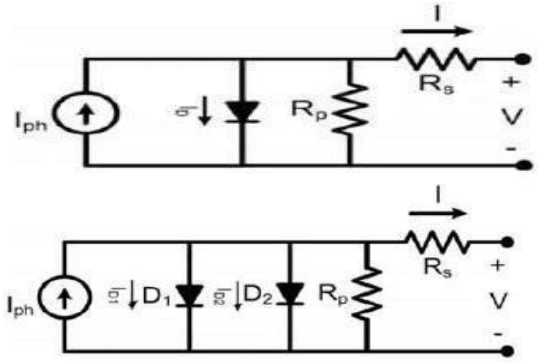


FIGURE1. *Equivalent Circuit of (a) SDM&(b) TDM PV Cell*

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D Mathematical Modeling of Photovoltaic Module

Only the analogous circuit may be replicated in order to analyse the physical properties of a PV cell.A TDMis recommended for achieving the characteristics of a PV cell, although an electrical comparable circuit can be used for the estimation of PV cell working in Matlab/Simulink. The TDM, shown in Figure 1(b), achieves improved accuracy by paying attention to recombination loss. To approximate the values of RS&Rshhere in this work Newton Raphson computational iteration which is simple and quick convergence technique is utilized

$$I = I_{Ph} - I_D \quad (4)$$

$$I_D = I_0[\exp\left(\frac{qV}{AKT}\right) - 1] \quad (5)$$

$$I = I_{Ph} - I_0[\exp\left(\frac{qV}{AKT}\right) - 1] \quad (6)$$

$$V^{kn} = \begin{cases} V - I_{ph}^{kn} R_{sh} + I_o R_{sh}\left(e\left(\frac{V^{kn} + IR_s}{V_t}\right) - 1\right) \\ + I_s^k (R_S + R_P), & I^{kn} > I_s^k \\ 0 & I^{kn} \le I_s^k \end{cases} \quad (7)$$

A simplified variant known as the SDMis created if the current flowing through diode D_2 because of charge recombination is sufficiently low, as seen in Figure 1. (a). Mathematical modelling in the SDM allows the use of such equations to relate the PV cell terminal voltage and output current. It is worth noting that the basic equation for the I-V characteristics of actual cells are not represented by PV cells(3). By combining RS and RP characteristics with the current structure, PV Module combinations will meet the demands of the applications. A 2nd diode is added to the model, which is connected in parallel to the circuit as in figure 1(b).

The permutation of charge in the semiconductor depletion area causes a change in light current levels, the diode gives a more accurate V-I characteristic curve. The superiority in terms of accuracy and characteristics of double diode PV when related to single diode leads to some issues in terms of non-linearity. For calculation of current and voltage KCL is used here.

$$I = I_{Ph} - I_{D1} - I_{D2} - I_{sh} \quad (8)$$

$$I = I_{ph} - I_{01}\left[\exp\left(\frac{qv}{A_1kT}\right) - 1\right] - I_{02}\left[\exp\left(\frac{qv}{A_2kT}\right) - 1\right] - \frac{V+IR_S}{R_p} \quad (9)$$

$$I_{D1} = I_{01}\left[\exp\left(\frac{qv}{A_1kT}\right) - 1\right] \quad (10)$$

$$I_{D2} = I_{02}\left[\exp\left(\frac{qv}{A_2kT}\right) - 1\right] \quad (11)$$

$$I = I_{ph} - I_{01}\left[\exp\left(\frac{qv}{A_1kT}\right) - 1\right] - I_{02}\left[\exp\left(\frac{qv}{A_2kT}\right) - 1\right] - I_{sh} \quad (12)$$

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RS and RP are two different factors in the applied PV module that should be included in the equation (8). PV Cell output current can be expressed in equation (20),

$$V_t = \frac{N_S kT}{q} \quad (13)$$

Where, Electron Charge =q= 1.602*10-19 C,
K=Boltzmann Constant=1.38*10-23 J/K,
$I_{ph} = \text{Photocurrent}$; A1, A2= Diode Ideality factors.
I01, I02=Diodes reverse saturation currents
Vt=Thermal Voltage,Ns, NP= Series and Parallel connected cells

Single PV-Cell output current is shown in Equation (8). Several cells joined in parallel, series to achieve the required output current and voltage values. In a Photovoltaic module with parallel-connected cells, the current is represented as

$$I_{module}=I_{cell} * N_p \quad (14)$$

Iteration is used to determine the unidentified factors in equation number (9): A_1, A_2, R_S, R_P, to approximate the features of the PV cell [10]. The simulated evaluation of the P-V curve is compared to the maximum power point of the Photovoltaic modules found from the given name plate details using approximate value of the previously mentioned factors. This may be performed by raising the quantities of R_S,A_1 repeatedly while determining the value of R_P, A_2 at the same time. Computed power P_{MAX},Cusing these quantities equals the mentionexciting power P_{MAX},D in use from the given ratings.I_{Ph},I_{01},I_{02},R_S,A_1,A_2 and R_P are the parametersunknown to be discovered. I_{01} will lead you to I_{02}. I_{Ph},A_1,A_2,I_{01},I_{02},R_S, and R_P are the remaining six unknown parameters that must be estimated. The PV current equation is as follows:

$$I_{Ph} = (I_{SC} + K_i \Delta T) \frac{G}{G_{STC}} \quad (15)$$

where
I_{SC}=SC current under STC, $\Delta T = T - T_{STC}(\text{InKelvin, TSTC} = 25°C)$
G=Solar Cell surface irradiance, G_{STC}=Global Irradiance atSTC (1000W/m2)
Ki=coefficient of SC current.
The expression for the diode saturation current $I_{01}$with respect to temperature is given by:

$$I_{01} = I_{0,n}\left(\frac{T_n}{T}\right)^3 \exp\left[\frac{qE_g}{A_1 K}\left(\frac{1}{T_n} - \frac{1}{T}\right)\right] \quad (16)$$

Where,
E_g= Band-gap of Semi-conductor Energy (Eg=1.12eV at 25°C)Poly Crystalline Silicon,
I0,n = Standard Test Condition(STC) saturation current is given by :

$$I_{0,n} = \frac{I_{sc,n}}{\left[\exp\left(\frac{V_{oc,n}}{V_{t,n} A_1}\right) - 1\right]} \quad (17)$$

Fromeq (16) and (17) Max Saturation current is stated with an enhanced equationobtained which admitexpression as:

$$I_{01} = \frac{I_{SC,n} + K_i \Delta T}{\exp\left[(V_{OC,n} + K_V \Delta T)/A_1 V_{t,n}\right] - 1} \quad (18)$$

where,KV=Coefficient of OC voltage, which is accessible on data sheets.
Generally, it is identified that the amount of I_{02} is threeor four times better than I01and expresses as:

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$$I_{02} = \left(\frac{T^{\frac{2}{5}}}{3.77}\right) I_{01} \quad (19)$$

$$\overline{\overline{2}} \quad \frac{C}{Kn \left[\frac{h^{-1}\left(1 x \frac{C}{1K} - 1\right)}{02}\right] + 1} \quad (20)$$

To compute the idealistic constants A_1&A_2matching iterative algorithm is preferred.Ideality constants computation can be done by the following procedure follows in phased mannerby the flowchart given in the figure2(a).

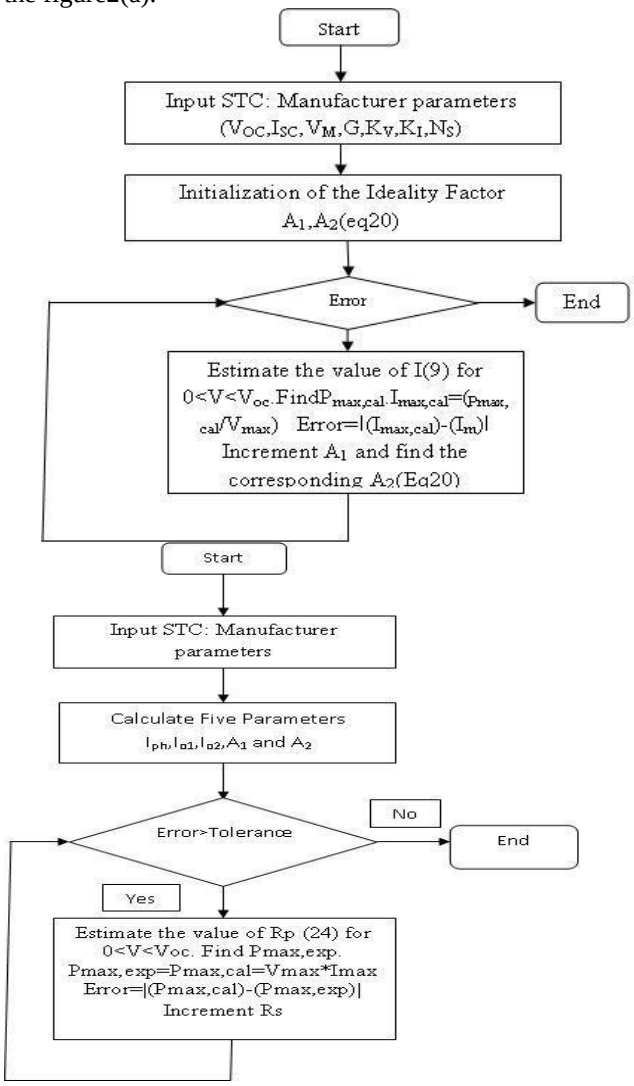


FIGURE2: *Matching Iterative algorithm for ideality constants a) A1andA2, b) Rs and RpR_s&R_p Calculations:*

Iteratively, Rs and Rp are calculated. To match the calculated power curve maximum with the corresponding power curve (V_{Mp}, I_{Mp}) the value of the RS needs to increase slightly in phased manner while calculating the value of RP using equations (22) &(23).While iteration for $P_{Max,Cal}$computed equals PMax,Exp experimental from datasheet, the values of Rs and Rp are attained. Figure 2(b) shows a simple

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iteration flowchart. The I-V pair recorded at the MPP may also be substituted into Eq (9) to produce the equation 3.

The measured voltage current pair at the MPP will be replaced into Eq (9) to obtain the third equation where $V=V_{MP}$ and $I=I_{MP}$

$$I_{mp} = I_{ph} - I_{D1} - I_{D2} - \frac{V_{mp}+I_{mp}R_S}{R_p} \quad (20)$$

$$P_{max,cal} = P_{max,exp} = V_{mp}I_{mp} \quad (21)$$

Using above equation 20 and 21 the RP expression written in the MPP condition,

$$R_p = \frac{V_{mp}(V_{mp}+I_{mp}R_S)}{[V_{mp}(I_{ph}-I_{D1}-I_{D2})-P_{max,exp}]} \quad (22)$$

With initial conditions both resistances are expressed with equation as

$$V_S = \sum_{n=1}^{k} V_{kn} \qquad I = \sum_{k=1}^{k} I_s \quad (23)$$

RS0=0; and $R_{P0} = \frac{V_{mp}}{I_{scn}-I_{mp}} - \frac{V_{ocn}-V_{mp}}{I_{mp}}$ (24)

PV ARRAY OUTPUT CHARACTERISTICS IN PARTIAL SHADING CONDITIONS

Multiple PV modules stacked in parallel and series topologies make form a PV array. For bypass diode operation under partial shading circumstances, switching from a non-shaded module to a shaded module is necessary. The output voltage of the Nth module may be ascertained by comparing its photocurrent with the associated string current, ISK:

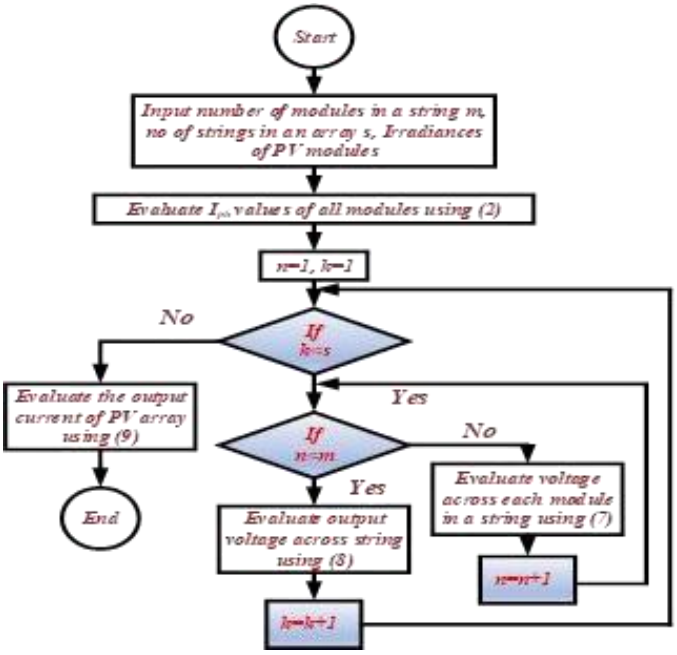


FIGURE3. *Modelling Flowchart of PV system under PSC*

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where, V_{kn} is the varying voltage across the nth module of the K_{th} string with respect to the string current, $I_s$fluctuates between zero and the cell's photocurrent at higher irradiation levels (Zhu et al., 2019; Robles Campos H.R. et al., 2019). Kth leg's voltage output,total count of panels(m) in a leg. The created model is used to simulate and verify partial shading scenarios (Kyocera KG200GT). Maximum power achieved under regular settings (1000 W and 25°C) is 250W.

PV MODULE SIMULATION, MODELLING, AND RESULTS

The characteristics of the Photovoltaic Fig. 7 shows irradiance from 150 W/m² to 1000 W/m² and varied temperatures from 15ºC to 55ºC under standard irradiation conditions (GSTC=1000 W/m²). Table 1 lists the PV Module's Kyocera KC 200GT specifications.

TABLE 1. *Parameters of the testing module*

Parameter	Data	Parameter	Data
Maximum Power (PMP)	200 W	Maximum Power current (IMP)	7.61 A
OC Voltage (VOC)	32.9 V	Temperature coefficient of Voltage (KV)	-1.23 x 10-1 V/ºC
SC Current (ISC)	8.21 A	Temperature coefficient Current (KI)	3.18 x 10-3 A/ºC
Max Power Voltage (VMP)	26.3 V		

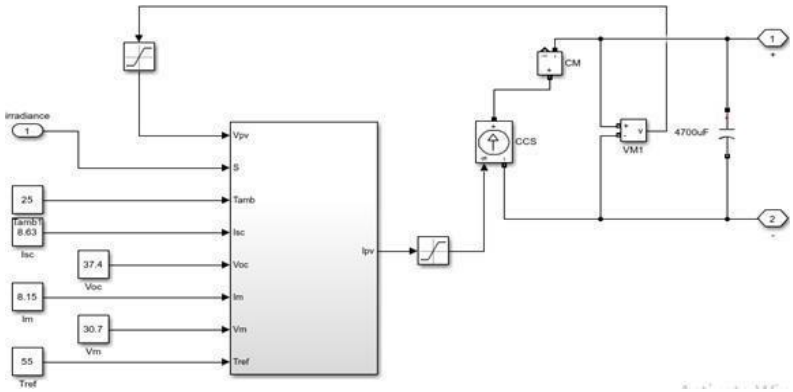


FIGURE.4.*Shows the PV SDM with R_{se}&R_P developed in MATLAB/ Simulink*

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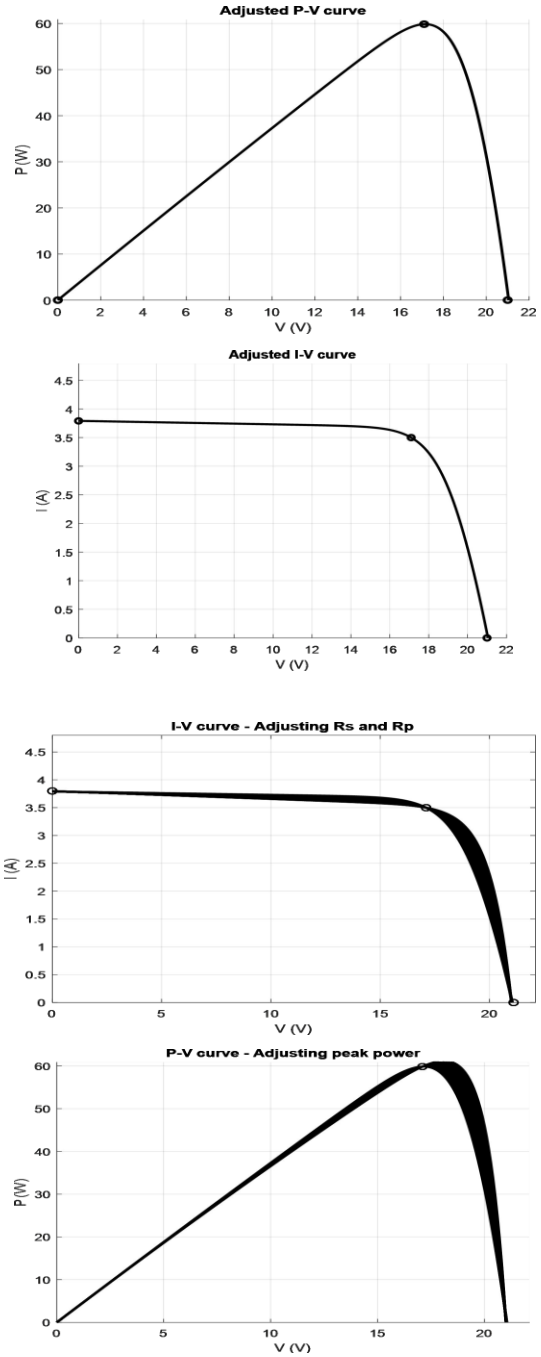


FIGURE. 5.*Output Waveforms of SDM PV System*

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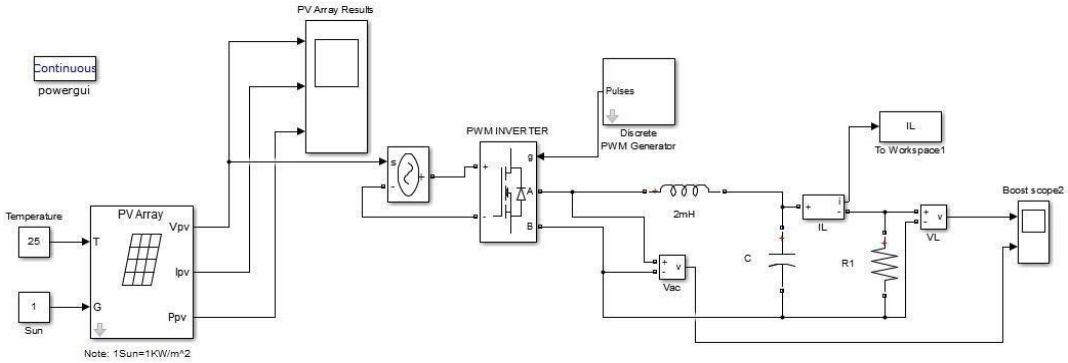


FIGURE 6.*TDM of PV Array through Conventional MPPT and Boost Converter*

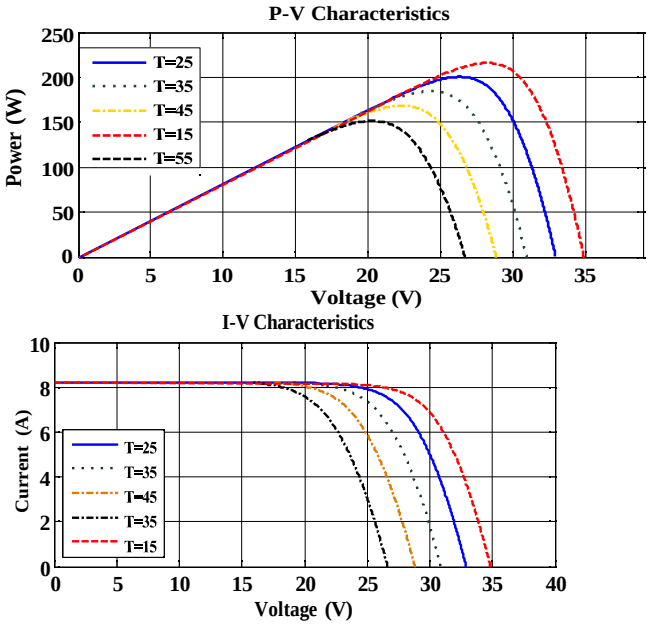


FIGURE 7.*P-V &I-V Characteristics of TDM PV Arrayat variable temperatures*

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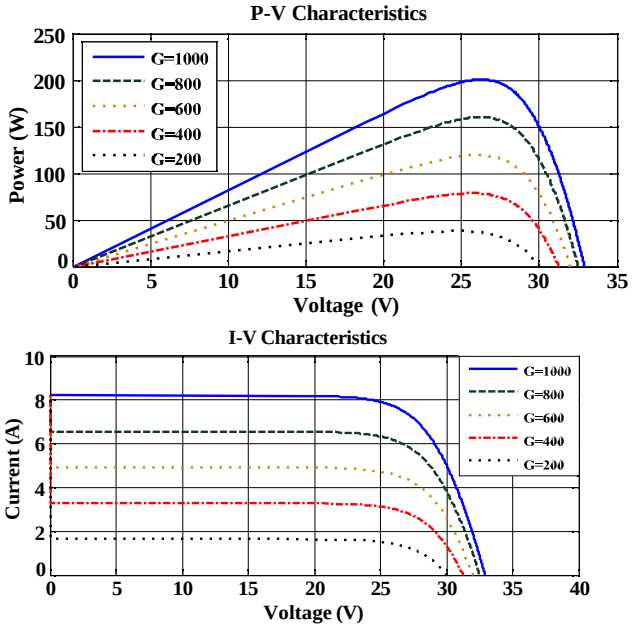


FIGURE 8.*P-V &I-V Characteristics of TDM PV Arrayat variable irradiances*

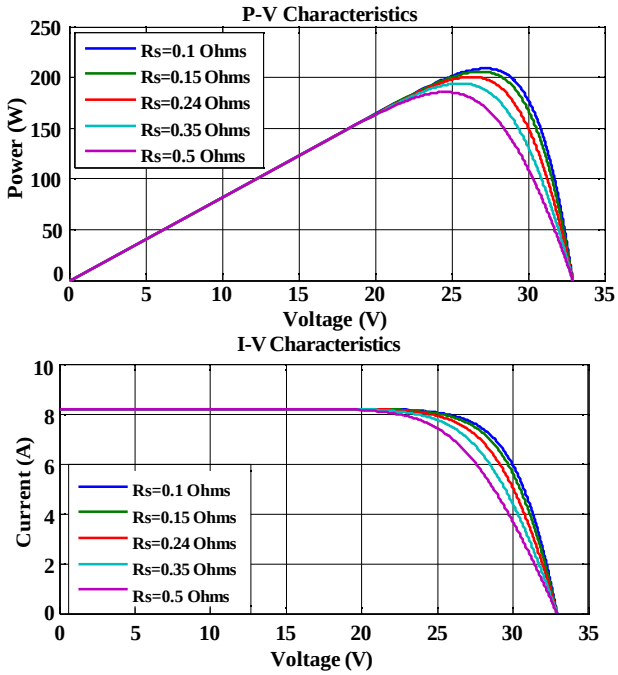


FIGURE.9. *Characteristics of TDM PV Module for changes in R_{Se}I-V & P-V curves*

TABLE 2.*Patterns of shading for the suggested Model PV System*

Shading Patterns(P)	Irradiance(G) W/M^2							
	G_1	G_2	G_3	G_4	G_5	G_6	G_7	G_8
P_0	1000							
P_1	1000		600		400		200	
P_2	1000	900	800	600	500	400	300	200

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TABLE 3.*Analytical model outputs from current and suggested models are compared with output data in real time.*

Shading Patterns(P)	One Diode PV				Double Diode PV				Real-time system data With Double Diode PV		
	(V) Vm	(A) Im	(W) Pm	Error%	Vm	Im	Pm	Error	Vm	Im	Pm
P_0	210.5	7.62	1600	0	210.5	7.62	1600	0	210.5	7.62	1600
P_1	192.5	1.49	286.8	4.48	194.5	1.50	292.7	2.15	197.3	1.51	300.3
P_2	190.1	1.51	287.0	5.04	197.5	1.51	296.1	1.36	198.6	1.51	302.3

In a Matlab/Simulink environment, the Kyocera KC 200GT PV Module was used to construct one and double diode PV models, and the properties includes I-V and P-V for various temperatures and irradiance(G) levels were drawn. Table 3 shows the results of a comparison study of the outcome values and the real-time value where errors were found.

CONCLUSION

At various cell temperatures and irradiation levels, this paper explored the mathematical analysis and performance of a TDM and a SDM developed in Matlab/Simulink.Hence, aforesaidPV model PV and IV characteristics are very similar with photovoltaic cell specifications stated in the manufacturer's datasheet. In addition, utilizing bypass diodes under mismatch or partial shadowed situations, this paper provided a precise technique for modeling P-V and IV characteristicsof PV module's, which was compared to real-time data. Finally, it has been demonstrated that by placing bypass diodes between the PV modules, mismatch losses are greatly reduced, allowing for the deployment of more MPP algorithms and the extension of the same.

REFERENCES

1. J. P. Benner and L. Kazmerski, "Photovoltaics gaining greater visibility," IEEE spectrum, vol. 36, pp. 34-42, 1999.
2. M. G. Villalva, J. R. Gazoli, and E. Ruppert Filho, "Comprehensive approach to modeling and simulation of photovoltaic arrays," IEEE Transactions on power electronics, vol. 24, pp. 1198-1208, 2009.
3. D. S. Chan and J. C. Phang, "Analytical methods for the extraction of solar-cell single-and double-diode model parameters from IV characteristics," IEEE Transactions on Electron devices, vol. 34, pp. 286-293, 1987.
4. W. Xiao, W. G. Dunford, and A. Capel, "A novel modeling method for photovoltaic cells," in Power Electronics Specialists Conference, 2004. PESC 04. 2004 IEEE 35th Annual, 2004, pp. 1950-1956.
5. J. Gow and C. Manning, "Development of a photovoltaic array model for use in power-electronics simulation studies," IEE Proceedings-Electric Power Applications, vol. 146, pp. 193-200, 1999.
6. Z. Salam, K. Ishaque, and H. Taheri, "An improved two-diode photovoltaic (PV) model for PV system," in Power Electronics, Drives and Energy Systems (PEDES) & 2010 Power India, 2010 Joint International Conference on, 2010, pp. 1-5.
7. B. C. Babu and S. Gurjar, "A novel simplified two-diode model of photovoltaic (PV) module," IEEE journal of photovoltaics, vol. 4, pp. 1156-1161, 2014.
8. Y. Jiang, J. A. A. Qahouq, and I. Batarseh, "Improved solar PV cell Matlab simulation model and comparison," in Circuits and Systems (ISCAS), Proceedings of 2010 IEEE International Symposium on, 2010, pp. 2770-2773.
9. A. Cheknane, H. S. Hilal, F. Djeffal, B. Benyoucef, and J.-P.Charles, "An equivalent circuit approach to organic solar cell modelling," Microelectronics Journal, vol. 39, pp. 1173-1180, 2008.
10. K. Ishaque, Z. Salam, and H. Taheri, "Accurate MATLAB simulink PV system simulator based on a two-diode model," Journal of Power Electronics, vol. 11, pp. 179-187, 2011.

07 July 2026 08:18:26

11. S. Gupta, H. Tiwari, M. Fozdar, and V. Chandna, "Development of a two diode model for photovoltaic modules suitable for use in simulation studies," in Power and energy engineering conference (APPEEC), 2012 Asia-Pacific, 2012, pp. 1-4
12. V. J. Chin, Z. Salam, and K. Ishaque, ``Cell modelling and model parameters estimation techniques for photovoltaic simulator application:A review," Appl. Energy, vol. 154, pp. 500_519, Sep. 2015.
13. A. M. Humada, M. Hojabri, S. Mekhilef, and H. M. Hamada, ``Solar cell parameters extraction based on single and double-diode models:A review," Renew. Sustain. Energy Rev., vol. 56, pp. 494_509, Apr. 2016.
14. A. R. Jordehi, ``Parameter estimation of solar photovoltaic (PV) cells: A review," Renew. Sustain. Energy Rev., vol. 61, pp. 354_371, Aug. 2016.
15. R. Abbassi, A. Abbassi, M. Jemli, and S. Chebbi, ``Identi_cation of unknown parameters of solar cell models: A comprehensive overview ofavailable approaches," Renew. Sustain. Energy Rev., vol. 90, pp. 453_474,Jul. 2018.
16. G. Apostolou, A. Reinders, and M. Verwaal, ``Comparison of the indoor performance of 12 commercial PV products by a simple model," Energy Sci. Eng., vol. 4, no. 1, pp. 69_85, Jan. 2016.
17. I. Mathews, P. J. King, F. Stafford, and R. Frizzell, ``Performance of III_V solar cells as indoor light energy harvesters," IEEE J. Photovolt., vol. 6, no. 1, pp. 230_235, Jan. 2016.
18. P. Spachos and A. Mackey, ``Energy ef_ciency and accuracy of solar powered BLE beacons," Comput.Commun., vol. 119, pp. 94_100, Apr. 2018.
19. N. F. Tinsley, S. T. Witts, J. M. R. Ansell, E. Barnes, S. M. Jenkins, D. Raveendran, G. V. Merrett, and A. S. Weddell, ``Enspect: A complete tool using modeling and real data to assist the design of energy harvesting systems," in Proc. 3rd Int. Workshop Energy Harvesting Energy Neutral Sens. Syst., 2015, pp. 27_32.

07 July 2026 08:18:26