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TEMPERATURE AND IRRADIANCE BASED ANALYSIS THE SPECIFIC VARIATION OF PV MODULE

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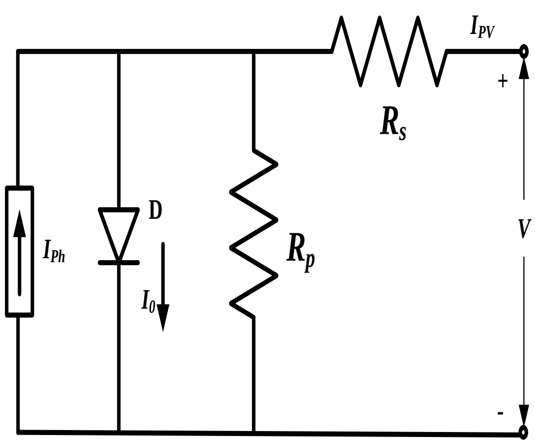
Graphical abstract



Abstract

The effect of irradiance and increase of temperature on the back surface of the PV module would decrease the standardized efficiency of PV. To overcome this problem observed results of solar module (ORSM) and Newton Raphson's (iterative) methods have been proposed in this research. This article compares ORSM and iterative methods of changing the specifications of a single diode model (SDM) extracted from a PV module beneath standard test conditions (STC) to calculate irradiance and various operating conditions. To make this comparison, the exact value of each diode parameter on the STC is essential. These are achieved by accepted algebraic values and iterative techniques. Newton Raphson's technique has been proven to be the mainly precise method to find these specifications in STC. Therefore, these specifications are used to different techniques that change the parameters of an SDM with radiation and temperature. The MATLAB model is designed to assess the conducting of individual techniques by PVM. The results are compared with the measured data, and the accuracy of photovoltaic module efficiency has been achieved through different technologies at different temperature and insolation levels.

Keywords: Single diode circuit, irradiance, PV Modules, standard test conditions, temperature

1.0 INTRODUCTION

Nowadays, the usage of renewable energy (RE) is important to reduce the environmental impact of fossil fuels by looking for other energy needs. Among many renewable energy sources (RES), one option is photovoltaic (PV) cells. Although, one of the limitations of its use is the low conversion rate of the commercial PV module (PVM), close to 18% [1, 2]. Because of the speedy increase in conservatory gas discharges, the rate of worldwide warming has twice since 1975 [3, 4], and a large number of industrialized production and the use of vestige stimulate account for about 65% of the greenhouse gas effect [5, 6].

In response to this situation, in recent years, large-scale RES has been established to meet the world's growing energy requirement and diminish carbon dioxide discharges. Formerly ten years, PV systems have become mainly admired substitues due to their ease of mechanism, relative scalability, low continuation costs, and high efficiency [7].

Two environmental factors of solar irradiance and unit temperature have a considerable impact on power generated by PV systems. To have an enhanced understanding of the relationship between meteorological specifics and PV power generation, the equivalent circuit model of the PV system can be considered. The electrical parameters of the circuit are vaguely written as nonlinear and difficult purposes like temperature and radiation of solar [8, 9].

Given the close relationship between PV performance and environmental circumstances, it is helpful to regard temperature and irradiance as indicators of the performance of PV. The development of trustworthy performance apparatus for measuring or predicting climate parameters can improve general function and increase economic feasibility [10].

Different researchers have their own opinions to make modeling of PV module and to analysis and check its complexity level using different approaches. The experimental model is constructed based on many research articles [11-14]. However, these models do not have any environmental dependencies or physical parameters, and are usually used to calculate the maximum power point or fill factor [15-18]. To use physical parameters to model the entire behavior of photovoltaic devices, there are usually two unusual thoughts [19, 20]. The first is the double-diode model (DDM), which simulates the propagation and combing of minority carrier phenomena in solar PV cells [21-24].

However, to avoid the difficulty caused by more unknowns in the nonlinear contained equation [25, 26], analysis tends to use the second ideas, which include a diode [27, 28]. The single diode model (SDM) aims to simulate the above two objectives trend through an ideality factor. While DDM is additional perfect at a low voltage below dark circumstances, the voltage is sufficient. Figure 1 illustrates the comparable model circuit with a single diode (SD). SD is defined as a "Single Diode, an electrical component that allows the flow of current in only one direction".

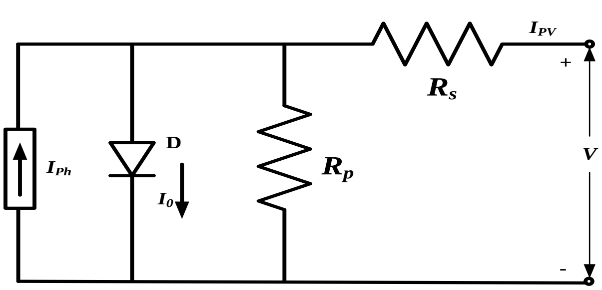


Figure 1 PV module Equivalent circuit [29]

Most solar cell manufacturers usually provide a panel data sheet that contains sequences like short circuit current, open-circuit voltage, battery and connection configuration, and maximum panel power point [30-32]. But, this information deliberate under standard test conditions (STC) [33, 34] is not sufficient to construct an accurate five-parameter predictive performance model [35-37]. Researchers have used various techniques to extort these limits with varying precision [38-40]. Broadly speaking, these technologies are separated into critical models and statistical models [41-43]. One feature of the analysis model is to generate a set of nonlinear equations by applying simplification, thereby defining unidentified constraints from the data [44, 45].

In this paper, two techniques have been used to compare and analyze the relationship between power-voltage (PV), current-voltage (IV) of PV module at different conditions of temperature and insolation.

2.0 PROPOSED PV MODULE MODELING

Newton Raphson's (NR) and observed results of solar module (ORSM) methods have been proposed in this research to verify the mathematical expression of PVM for current and power in terms of voltages I-V and P-V meets the actual values of the properties called the PV model. Since the PV array is made up of a diode circuit, these terms are therefore based on the I-V term from Shockley Diode presented in Equation 1 [52].

$$I = I_o\left[e^{\frac{eV}{KT}} - 1\right] \tag{1}$$

The ideal PVM contains an SD that is coupled in parallel to a power supply, shown in Figure 1. Equation of output current is presented in Equation 2 [53].

$$I_{PV} = I_{ph} - I_O \tag{2}$$

In which,

Ipv = o/p current of PV,

Iph = solar-generated current is presented in Equation 3 [1].

$$I_{ph} = \left(I_{ph\_Tref} + \alpha T_{dif}\right)\frac{G}{G_r} \tag{3}$$

The saturation current of the diode at any specific temperature is presented in Equation 4 [54].

$$I_{rs} = \frac{I_{ph}}{\left(e^{\left(\frac{qE_{oc}}{N_s KAT}\right)} - 1\right)} \tag{4}$$

From equation 4, the current saturation of diode (Io) is directly affected by the changes that occur in the environment and it can be calculated by the following statements is presented in Equation 5 [55].

$$I_O = I_{rs}\left[\frac{T}{T_{ref}}\right]^3 \exp\left[\frac{qE_g}{AK}\left(\frac{T}{T_{ref}T}\right)\right] \quad (5)$$

In the above formula, the self is called the bandgap energy of the silicon semiconductor, and its range is 1.1 to 1.2 volts. Lastly, as per the above Kirchhpff's current law, the o/p current of the PV module is the same as presented in Equation 6 [8].

$$I_p = I_{ph} - I_O\left[\exp\left(\frac{q(V_{PV}+I_{PV}R_S)}{AKT}\right)-1\right] - \left(\frac{V_{PV}+I_{PV}R_S}{R_P}\right) \quad (6)$$

The single solar cell's output power is not tough sufficient to be used in approximately all applications. To increase the capacity of the entire photovoltaic system, batteries must be composed in series and parallel. If Np and N are the no. of batteries joined in parallel and series, then Eq. 7 can be expressed as presented in Equation 7 [11].

$$I_{pv} = N_p I_{ph} - N_P I_O\left[\exp\left(\frac{q(V_{PV}+I_{PV}R_S)}{N_S AKT}\right)-1\right] - \left(\frac{N_P V_{PV} + N_P I_P R_S}{N_S R_P}\right) \quad (7)$$

It should be remembered that when Np is equal to 1 and Ns represents all batteries in the series, it is only connected to the PV module. Therefore, considering the elimination of the parallel resistance, the output current of the PV module must be changed as presented in Equation 8 [56].

$$I_{PV} = N_p I_{ph} - N_p I_o\left[\exp\left(\frac{q(V_{pv}+I_{pv}R_S)}{N_S AKT}\right)-1\right] \quad (8)$$

According to the non-linearity of the output current, in this case, appropriate non-linear methods should be used, like the easy fixed point method, Newton Raphson's technique. In this article, Newton Raphson's method has been chosen and can be presented as Equation 9 [57].

$$x_{n+1} = x_n - \frac{f(x_n)}{f'(x_n)} \quad (9)$$

By rearranging Equation 7 the output current of PVM can be rewritten as function as follows [11].

$$f(I_{pv}) = N_p I_{ph} - I_{pv} - N_p I_o\left[\exp\left(\frac{q(V_{pv}+I_{pv}R_S)}{N_S AKT}\right)\right]-1 \quad (10)$$

By subsisting f (Ipv) and f' (Ipv) in the formula of Newton Method we have Promoting this in equation 9 gives a subsequent iterative comparison and o/p current is calculated is presented in Equation 11 [55].

$$I_{pv(n+1)} = N_p I_{pvn} - \frac{N_p I_{ph} - I_{pv(n)} - N_p I_O\left[\exp\left(\frac{q(V_{pv}+I_{pv(n)}R_S)}{N_S AKT}\right)-1\right]}{-1-\frac{N_p I_O q R_S\left[\exp\left(\frac{qV_{pv}+I_{pv}R_S}{R_S AKT}\right)-1\right]}{N_S AKT_K}} \quad (11)$$

In the above eq., a series resistor (RS) is integrated. The RS corresponding to the resistance within each module and the conversion resistance Rp is ignored. Use a single parallel diode and specify the diode quality factor in the circuit to obtain the best output result [46].

3.0 RESULTS AND DISCUSSION

To analyze and compare the relationship of PVM between PV and IP at different levels of temperature and insolation observed results of solar module (ORSM) and iterative based methods have been used.

The specification of the PV Module which has been used for this research is shown in Table 1.

Table 1 PV Module Specification [50]

PV Module	Parameters	Value
Polycrystalline	P_m (W)	250
	V_m	30.1
	I_m	4.49
	V_{oc}	19.10
	I_{sc}	8.83A
	N_{cell}	60

Two models were selected for this study, the first model was used for the ORSM method, and the second model was used for the Newton-Raphson method (iterative) method.

3.1 Model I

Mathematically based PV Model is developed in MATLAB. The shokley diode equation is represented in above equation 1. Output current is calculated by inserting the PV equation presented in 12 [58].

$$I_{pv(n+1)} = I_{pv(n)} - \frac{I_{ph} - I_{pv(n)} - I_o\left(e^{\frac{q(V+I_n)}{nkT}} - 1\right)}{-1 - I_o\left(\frac{qR_S}{nkT}\right)e^{\frac{q(V+I_{pv(n)}R_S)}{nkT}}} \quad (12)$$

This PV module observes the values of the properties I-V and P-V at different values for temperature and solar radiation.

Total five (05) measures have been achieved and illustrated from Figures 2 to 5; from which maximum power (Pmax) 265 watt (W) and maximum current (Imax) 9.2 ampere (A) at 37.5 V obtained at maximum insolation of 900 W/m2. And at temperature 10 0C Pmax 270 W and Imax 9.2 A at 39 V have been obtained using the ORSM technique at different levels of temperature and insolation.

From the MATLAB outcomes of the first model and the comparison with the observed outcomes, it can be seen that the effectiveness of these model results is consistent in the linear region, consistent in the nonlinear region, but different in the saturated area result. In the I-V aspects under unusual saturation situations, the observed values are upper than the values of the model, but they are inversely proportional in the saturation region under different temperature conditions. On the other hand, under different saturation and temperature conditions, the observed value of the PV characteristic in the saturation region is greater than the model value.

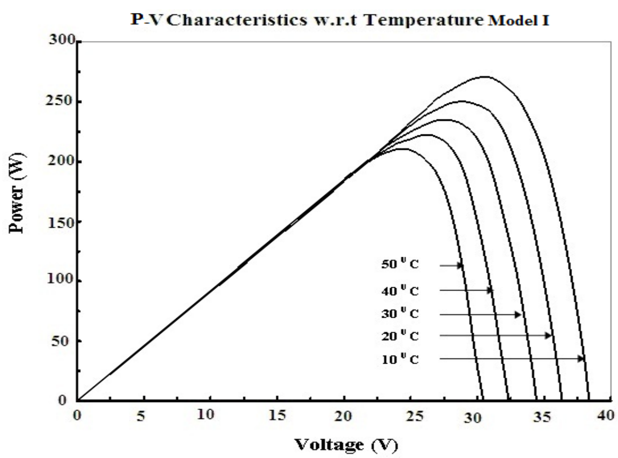


Figure 2 ORSM based contracting of P-V aspects regarding Temperature

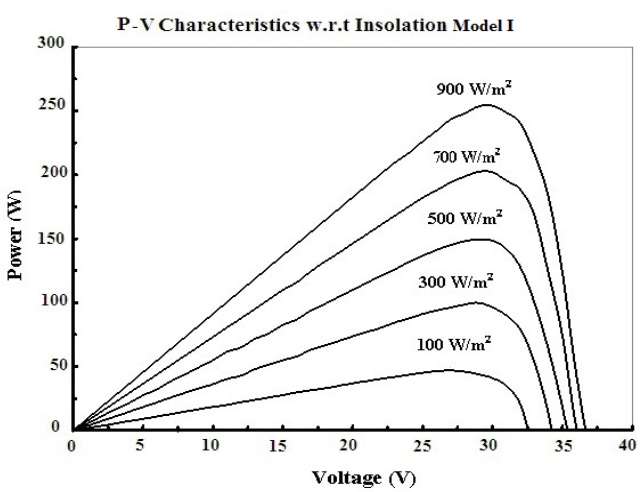


Figure 3 ORSM based contracting of P-V aspects regarding Insolation

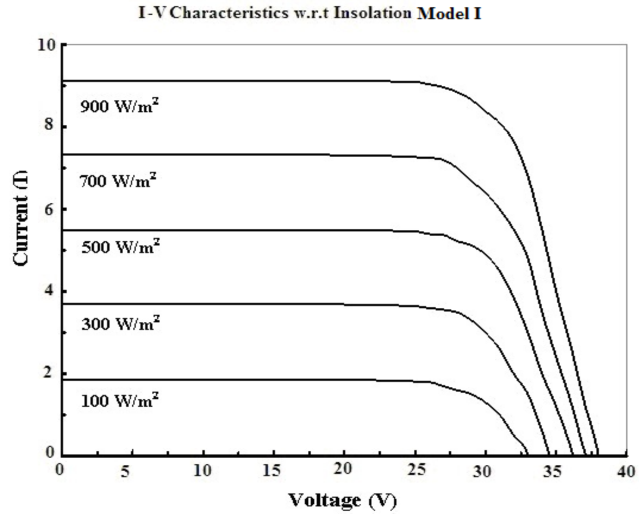


Figure 4 ORSM based contracting of I-V aspects regarding Insolation

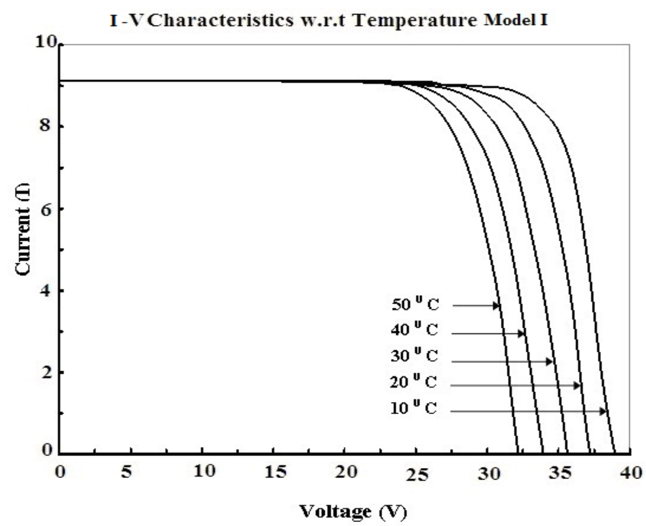


Figure 5 ORSM based contracting I-V aspects regarding Temperature

3.2 Model II

Output current is iteratively calculated by inserting the PV equation in 13. I-V and P-V aspects at unusual standards of insolation temperature have been achieved by the iterative method.

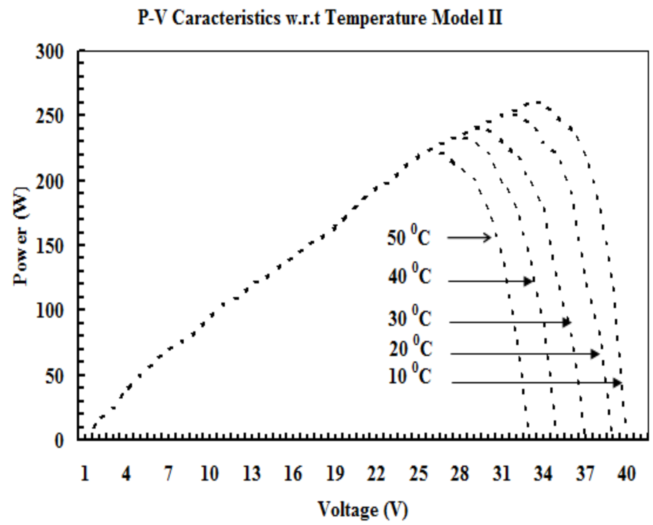


Figure 6 Iterative based contracting P-V aspects regarding Temperature

Calculated output current (I_{PV}) of PVM can be calculated using following Equation 13 [55].

$$I_{pv(n+1)} = N_p I_{pvn} - \frac{N_p I_{ph} - I_{pv(n)} - N_p I_o \left[\exp\left(\frac{q\left(V_{pv} + I_{pv(n)} R_S\right)}{N_S AK T_K} \right) - 1 \right]}{-1 - \dfrac{N_p I_o q R_S \left[\exp\left(\frac{q\left(V_{pv} + I_{pv} R_S\right)}{N_S AK T_K} \right) - 1 \right]}{N_S AK T_K}} \tag{13}$$

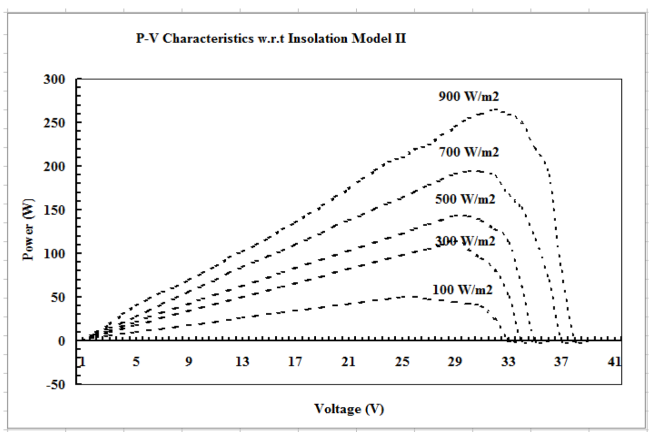


Figure 7 Iterative based contracting P-V aspects regarding Insolation

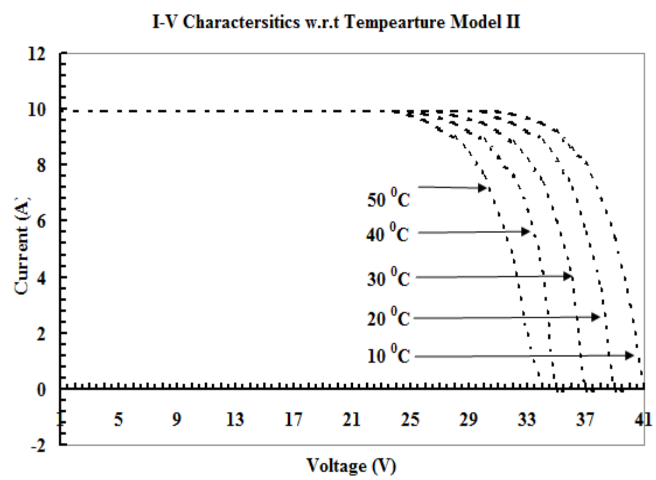


Figure 8 Iterative based contracting I-V aspects regarding Temperature

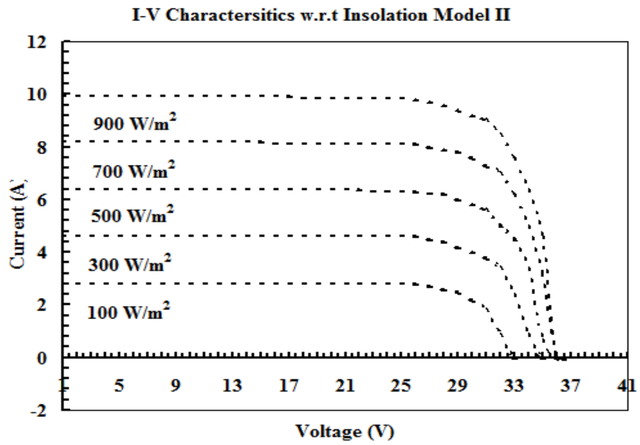


Figure 9 Iterative based contracting I-V aspects regarding Insolation

MATLAB results of the second model and the comparison with the observed outcomes, it can be seen that the sustainability of these outcomes of the model is consistent in the straight region, consistent in the nonlinear region, but not in the saturated region. For the observation outcomes in the I-V aspects under distinct saturation and temperature situations, the observed value in the saturated region is lower than the model value. On the other hand, the characteristics of PV, under different saturation conditions, the observed value is smaller than the model value, but under different temperature conditions, in the saturation region and vice versa.

By applying iteration technique Figures 6 to 9 illustrates that the response of PV, IV slightly occured in the non-linear and linear region but not in saturation region due to the effects of temperature and insolation at different levels.

4.0 COMPARISON OF PERFORMANCE

The proposed Newton Raphson's technique with ORSM based approaches has been compared with related approaches in the literature. In Table 2, the comparative results are presented. In [1, 2, 47-49] have extracted only a few features using the data of temperature and insolation. The result comparison shows that the proposed strategy of Newton Raphson's is efficient than ORSM.

The insolation is directly proportional to ambient temperature in this model the active cooling has been used to maintained the temperature and due to this the efficiency is boosted up to 5% and effieciency is calculated by [59, 60]:

$$\eta = \frac{P_{\max}}{A \times G} \times 100$$

Where,
η = Efficiency
Pmax = Maximum power
A= Area of PV cell
G= Insolation

Table 2 Comparative Analysis

References	Insolation (W/m2)	Temp:	P_{max}	Efficiency
Proposed Method	900	25	270	5%
[1, 2]	1150	44.85	200	3%
[47]	1268	85	250	4%
[48]	1000	40	82	1%
[49]	1000	75	60	1%

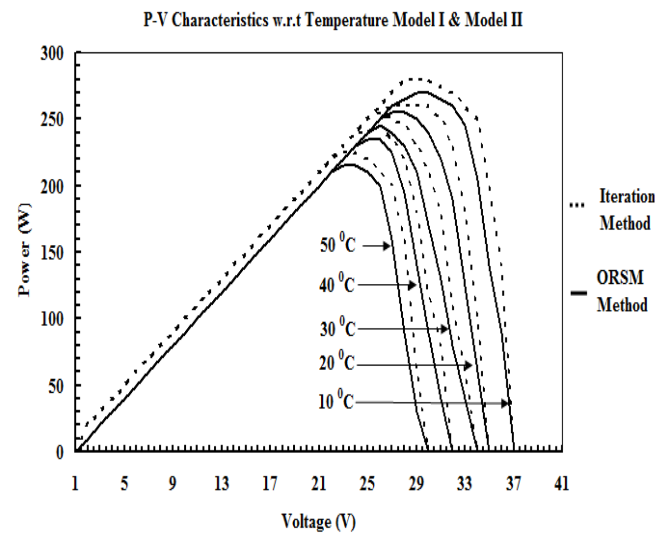


Figure 10 Comparison b/w Iteration ORSM based contracting of P-V aspects regarding Temperature

Figures 10, 11, 12, and 13 have been illustrated satisfactory b/w the ORSM and iteration based achieved I-V, P-V characteristics of temperature and irradiance of the PVM. Hence, the parameters bring out by the Newton-Raphson method were be used to compare the results at a different level of temperature with the ORSM method to adjust the parameters of SDM for covering the temperature and irradiance.

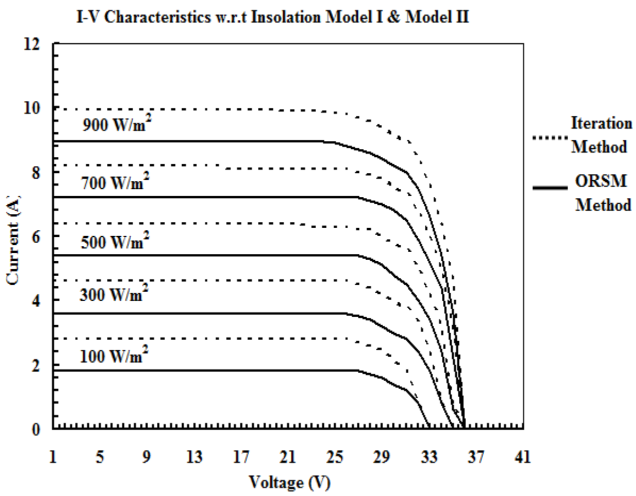


Figure 11 Comparison b/w Iteration ORSM based contracting of I-V aspects regarding Insolation

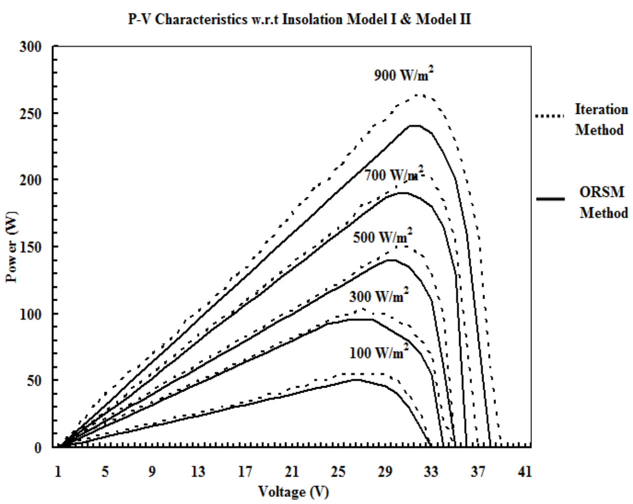


Figure 12 Comparison b/w Iteration ORSM based contracting of P-V aspects regarding Insolation

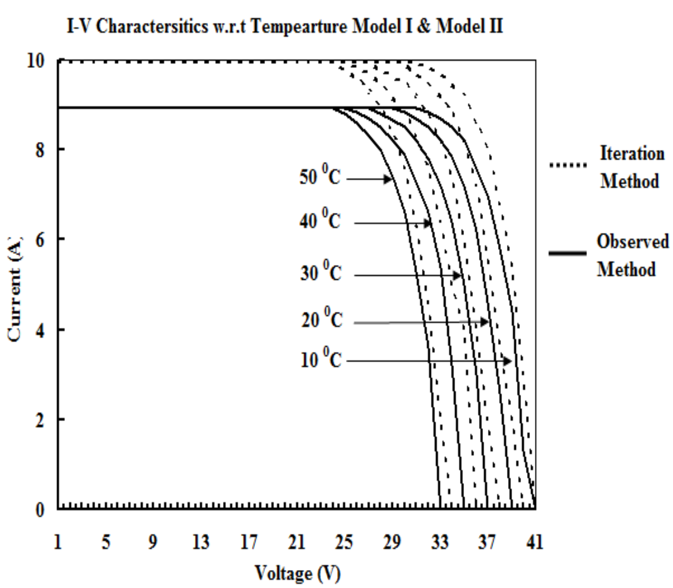


Figure 13 Comparison b/w Iteration ORSM based contracting of I-V aspects regarding Temperature

Table 3, reveals that the NR method has superior accuracy and error as compared to the ORSM method, unusually for higher values of insolation. This is because the NR method extracts the non-linear impact of insolation on the current. Normally, the entire error between these methods is a comparably little provision that the exact value of a has been used. Different values of the measured value of current and insolation have been used from which at 900 W/m^2 and 10 amperes the error and accuracy were 8.7% and 91.3% respectively in ORSM method whereas, in NR method error and accuracy were 1.01% 100%.

Table 3 Comparative Analysis of Error and Accuracy at different Insolation Levels

Insolation (W/m^2)	900	700	500	300	100
Measured Current	10	8.5	7	5	3
ORSM Method (Error %) (Accuracy)	9.2 (8.7%) (91.3%)	7.3 (16.43%) (83.57%)	5.5 (27.27%) (72.72%)	3.9 (28.2%) (71.8%)	1.9 (57.9%) (42.1%)
NR Method (Error %) (Accuracy)	9.9 (1.01%) (98.9%)	8 (6.25%) (93.7%)	6.2 (12.9%) (87.1%)	4.8 (4.16%) (95.8%)	2.9 (3.45%) (96.5%)

Table 4 manifested that the different levels of temperature from 10 ^{0}C to 50 ^{0}C at different values of measured current from which it can be seen that as the effect of temperature was decreases the error and accuracy of PV module increases. At 900 W/m^2 insolation and 10 A error and accuracy in the ORSM method were 5.1% and 95% whereas in the NR method the error and accuracy were 0% and 100 % due to low temperature.

Table 4 Comparative Analysis Analysis of Error and Accuracy at different Temperature Levels

Temperatur e (^{0}C)	10	20	30	40	50
Measured Current	41	39	38	36	35
ORSM Method (Error %) (Accuracy)	39 (5.1%) (95%)	37 (5.4%) (94.6%)	36 (5.5%) (94.5%)	34 (5.9%) (94.1%)	33 (6.1%) (93.9%)
NR Method (Error %) (Accuracy)	4 (0%) (100)	38 (2.6%) (97.4)	37 (2.7%) (97.3)	35 (2.8%) (97.2)	34 (2.9%) (97.1)

5.0 CONCLUSION

This article describes numerous techniques for modifying the SDM parameters of the model for different radiation intensities and temperatures. The virtual precision of these techniques was evaluated by evaluating the adjusted parameter values with the available measurement data in the datasheet. The short circuit current (I_{SC}) changes non-linearly with radiation and its contrast with temperature are very low, which is a function of the temperature coefficient. The forecast of photocurrent by different techniques shows that the difference in temperature and radiation is alike to the difference in short-circuits current. To find the reliance of the open-circuit voltage (V_{OC}) on temperature and radiation, it was initiated that these monitoring techniques gave good outcomes due to their less rounding and because of the consequences of temperature and radiation at the same time.

By considering the non-linear effects of temperature and radiation, the accuracy of open-circuit voltage determination is improved. To predict the saturation current, the Newton Raphson method is mainly precise when the effects of temperature and radiation change. The change of shunt resistance (Rsh) with irradiance is a lot greater than that shown by the series impedance. These two resistors are almost insensitive to temperature changes. A power loss in PV is due to the low Rsh, which provides another path for high generating current. The amount of current through PV decreased by making such deviation and causes a reduction in voltage of PV.

References

[1] Vicente, E. M., dos Santos Vicente, P., Moreno, R. L., & Ribeiro, E. R. 2020. High-efficiency MPPT Method based on Irradiance and Temperature Measurements. *IET Renewable Power Generation*. 14(6): 986-995.

[2] Goodrich, A., James, T., & Woodhouse, M. 2012. Residential, Commercial, and Utility-scale Photovoltaic (PV) System Prices in the United States: Current Drivers and Cost-reduction Opportunities (No. NREL/TP-6A20-53347). National Renewable Energy Lab.(NREL), Golden, CO (United States).

[3] Karthikeyan, V., Sirisamphanwong, C., Sukchai, S., Sahoo, S. K., & Wongwuttanasatian, T. 2020. Reducing PV Module Temperature with Radiation based PV Module Incorporating Composite Phase Change Material. *Journal of Energy Storage*. 29: 101346.

[4] Lindsey, R. and Dahlman, Lu. A. 2018. Climate Change: Global Temperature. https://www.climate.gov/news-features/understanding-climate/climate-change-global-temperature.

[5] Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Farahani, E., Kadner, S., & Seyboth, K. 2014. *Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom and New York, NY.

[6] Change, I. C. 2014. Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, 1454.

[7] Alami, A. H. 2014. Effects of Evaporative Cooling on Efficiency of Photovoltaic Modules. *Energy Conversion and Management*. 77: 668-679.

[8] Moshksar, E., & Ghanbari, T. 2018. Real-time Estimation Of Solar Irradiance and Module Temperature from Maximum Power Point Condition. *IET Science, Measurement & Technology*. 12(6): 807-815.

[9] Barukčić, M., Ćorluka, V., & Miklošević, K. 2015. The Irradiance and Temperature Dependent Mathematical Model for Estimation of Photovoltaic Panel Performances. *Energy Conversion and Management*. 101: 229-238.

[10] Attivissimo, F., Di Nisio, A., Savino, M., & Spadavecchia, M. 2012. Uncertainty Analysis in Photovoltaic Cell Parameter Estimation. *IEEE Transactions on Instrumentation and Measurement*. 61(5): 1334-1342.

[11] Abdulrazzaq, A. K., Bognár, G., & Plesz, B. 2020. Accurate Method for PV Solar Cells and Modules Parameters Extraction using I–V Curves. *Journal of King Saud University-Engineering Sciences*. Article in Press. https://doi.org/10.1016/j.jksues.2020.07.008.

[12] Das, A. K. 2011. An explicit J–V Model of a Solar Cell for Simple Fill Factor Calculation. *Solar Energy*. 85(9): 1906-1909.

[13] Das, A. K. 2013. An Explicit J–V Model of a Solar Cell using Equivalent Rational Function Form for Simple Estimation of Maximum Power Point Voltage. *Solar Energy*. 98: 400-403.

[14] Akbaba, M. 1995. Performance Analysis of Solar Cell Arrays Loaded with Passive Loads. *Applied Energy*. 52(2-3): 209-218.

[15] Chan, D. S., & Phang, J. C. 1987. Analytical Methods for the Extraction of Solar-cell Single-and Double-diode Model Parameters from IV Characteristics. *IEEE Transactions on Electron Devices*. 34(2): 286-293.

[16] Hejri, M., Mokhtari, H., Azizian, M. R., Ghandhari, M., & Söder, L. 2014. On the Parameter Extraction of a Five-parameter Double-diode Model of Photovoltaic Cells and Modules. *IEEE Journal of Photovoltaics*. 4(3): 915-923.

[17] Sandrolini, L., Artioli, M., & Reggiani, U. 2010. Numerical Method for the Extraction of Photovoltaic Module Double-diode Model Parameters through Cluster Analysis. *Applied Energy*. 87(2): 442-451.

[18] Lun, S. X., Wang, S., Yang, G. H., & Guo, T. T. 2015. A New Explicit Double-diode Modeling Method based on Lambert W-function for Photovoltaic Arrays. *Solar Energy*. 116: 69-82.

[19] Di Piazza, M. C., Luna, M., Petrone, G., & Spagnuolo, G. 2017. Translation of the Single-diode PV Model Parameters Identified by using Explicit Formulas. *IEEE Journal of Photovoltaics*. 7(4): 1009-1016.

[20] Di Piazza, M. C., Luna, M., Petrone, G., & Spagnuolo, G. 2017. Parameter Translation for Single-diode PV Models Based on Explicit Identification. *IEEE International Conference on Environment and Electrical Engineering and IEEE Industrial and Commercial Power Systems Europe (EEEIC/I&CPS Europe)*. 1-5.

[21] Ghani, F., Rosengarten, G., Duke, M., & Carson, J. K. 2014. The Numerical Calculation of Single-diode Solar-cell Modelling Parameters. *Renewable Energy*. 72: 105-112.

[22] Rhouma, M. B., Gastli, A., Brahim, L. B., Touati, F., & Benammar, M. 2017. A simple Method for Extracting the Parameters of the PV Cell Single-diode Model. *Renewable Energy*. 113: 885-894.

[23] Farivar, G., & Asaei, B. 2010. Photovoltaic Module Single Diode Model Parameters Extraction based on Manufacturer Datasheet Parameters. *2010 IEEE International Conference on Power and Energy*. 929-934.

[24] Toledo, F. J., & Blanes, J. M. 2016. Analytical and Quasi-explicit Four Arbitrary Point Method for Extraction of Solar Cell Single-diode Model Parameters. *Renewable Energy*. 92: 346-356.

[25] Bonkoungou, D., Koalaga, Z., & Njomo, D. 2013. Modelling and Simulation of Photovoltaic Module Considering Single-diode Equivalent Circuit Model in MATLAB. *International Journal of Emerging Technology and Advanced Engineering*. 3(3): 493-502.

[26] Ayodele, T. R., Ogunjuyigbe, A. S. O., & Ekoh, E. E. 2016. Evaluation of Numerical Algorithms Used in Extracting the Parameters of a Single-diode Photovoltaic Model. *Sustainable Energy Technologies and Assessments*. 13: 51-59.

[27] Azzouzi, M., Popescu, D., & Bouchahdane, M. 2016. Modeling of Electrical Characteristics of Photovoltaic Cell

Considering Single-diode Model. *Journal of Clean Energy Technologies.* 4(6): 414-20.

[28] Bastidas-Rodriguez, J. D., Petrone, G., Ramos-Paja, C. A., & Spagnuolo, G. 2017. A Genetic Algorithm for Identifying the Single Diode Model Parameters of a Photovoltaic Panel. *Mathematics and Computers in Simulation.* 131: 38-54.

[29] Farivar, G., & Asaei, B. 2010. Photovoltaic Module Single Diode Model Parameters Extraction based on Manufacturer Datasheet Parameters. *2010 IEEE International Conference on Power and Energy.* 929-934.

[30] Jadli, U., Thakur, P., & Shukla, R. D. 2017. A New Parameter Estimation Method of Solar Photovoltaic. *IEEE Journal of Photovoltaics.* 8(1): 239-247.

[31] Hosseini, S., Taheri, S., Farzaneh, M., Taheri, H., & Narimani, M. 2018. Determination of Photovoltaic Characteristics in Real Field Conditions. *IEEE Journal of Photovoltaics.* 8(2): 572-580.

[32] Mehta, H. K., Warke, H., Kukadiya, K., & Panchal, A. K. 2019. Accurate Expressions for Single-diode-model Solar Cell Parameterization. *IEEE Journal of Photovoltaics.* 9(3): 803-810.

[33] Silva, E. A., Bradaschia, F., Cavalcanti, M. C., & Nascimento, A. J. 2015. Parameter Estimation Method to Improve the Accuracy of Photovoltaic Electrical Model. *IEEE Journal of Photovoltaics*. 6(1): 278-285.

[34] Silva, E. A., Bradaschia, F., Cavalcanti, M. C., Nascimento, A. J., Michels, L., & Pietta, L. P. 2017. An Eight-parameter Adaptive Model for the Single Diode Equivalent Circuit Based on the Photovoltaic Module's Physics. *IEEE Journal of Photovoltaics.* 7(4): 1115-1123.

[35] Cubas, J., Pindado, S., & De Manuel, C. 2014. Explicit Expressions for Solar Panel Equivalent Circuit Parameters Based on Analytical Formulation and the Lambert W-function. *Energies.* 7(7): 4098-4115.

[36] Das, A. K. 2013. Analytical Expression of the Physical Parameters of an Illuminated Solar Cell using Explicit J–V model. *Renewable Energy*. 52: 95-98.

[37] Saetre, T. O., Midtgård, O. M., & Yordanov, G. H. 2011. A New Analytical Solar Cell I–V Curve Model. *Renewable Energy.* 36(8): 2171-2176.

[38] Et-Torabi, K., Nassar-Eddine, I., Obbadi, A., Errami, Y., Rmaily, R., Sahnoun, S., & Agunaou, M. 2017. Parameters Estimation of the Single and Double Diode Photovoltaic Models Using a Gauss–seidel Algorithm and Analytical Method: A Comparative Study. *Energy Conversion and Management.* 148: 1041-1054.

[39] Bourdoucen, H., & Gastli, A. 2007. Analytical Modelling and Simulation of Photovoltaic Panels and Arrays. *The Journal of Engineering Research [TJER]*. 4(1): 75-81.

[40] Ibrahim, H., & Anani, N. 2017. Evaluation of Analytical Methods for Parameter Extraction of PV Modules. *Energy Procedia*. 134: 69-78.

[41] Vergura, S. 2016. A Complete and Simplified Datasheet-based Model of PV Cells in Variable Environmental Conditions for Circuit Simulation. *Energies*. 9(5): 326.

[42] Can, H., & Ickilli, D. 2014. Parameter Estimation In Modeling of Photovoltaic Panels based on Datasheet Values. *Journal of Solar Energy Engineering.* 136(2).

[43] Sera, D., Teodorescu, R., & Rodriguez, P. 2007. PV Panel Model based on Datasheet Values. *2007 IEEE International Symposium on Industrial Electronics* (pp. 2392-2396). IEEE.

[44] Brano, V. L., & Ciulla, G. 2013. An Efficient Analytical Approach for Obtaining a Five Parameters Model of Photovoltaic Modules Using Only Reference Data. *Applied Energy.* 111: 894-903.

[45] Chikh, A., & Chandra, A. 2015. An Optimal Maximum Power Point Tracking Algorithm for PV Systems with Climatic Parameters Estimation. *IEEE Transactions on Sustainable Energy*. 6(2): 644-652.

[46] Suthar, M., Singh, G. K., & Saini, R. P. 2013. Comparison of Mathematical Models of Photo-voltaic (PV) Module and Effect of Various Parameters on Its Performance. *2013 IEEE International Conference on Energy Efficient Technologies for Sustainability.* 1354-1359.

[47] Abdulrazzaq, A. K., Bognár, G., & Plesz, B. 2020. Accurate Method for PV Solar Cells and Modules Parameters Extraction using I–V curves. *Journal of King Saud University-Engineering Sciences.* Article in Press. https://doi.org/10.1016/j.jksues.2020.07.008

[48] Reddy, G. S., Reddy, T. B., & Kumar, M. V. 2017. A MATLAB based PV Module Models Analysis under Conditions of Nonuniform Irradiance. *Energy Procedia.* 117: 974-983.

[49] Chaibi, Y., Allouhi, A., Malvoni, M., Salhi, M., & Saadani, R. 2019. Solar Irradiance and Temperature Influence on the Photovoltaic Cell Equivalent-circuit Models. *Solar Energy.* 188: 1102-1110.

[50] Zdyb, A., and Gulkowski, S. 2020. Performance Assessment of Four Different Photovoltaic Technologies in Poland. *Energies.* 13(1): 196.

[51] Zhu, H., *et al.* 2017. Online Modelling and Calculation for Operating Temperature of Silicon-based PV Modules based on BP-ANN. *International Journal of Photoenergy.* Hindawi. 2017: 1-13 https://doi.org/10.1155/2017/6759295

[52] Sharadga, H., Hajimirza, S. and Cari, E.P. 2020. A Fast and Accurate Single-diode Model for Photovoltaic Design. *IEEE Journal of Emerging and Selected Topics in Power Electronics.* 9(3): 3030-3043.

[53] Prakash, R. and Singh, S. 2016. Designing and Modelling of Solar Photovoltaic Cell and Array. *IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)*. 11(2): 35-40.

[54] Abdullahi, N., Saha, C. and Jinks, R. 2017. Modelling and Performance Analysis of a Silicon PV Module. *Journal of Renewable and Sustainable Energy.* 9(3): 033501.

[55] Anani, N. and Ibrahim, H. 2020. Adjusting the Single-diode Model Parameters of a Photovoltaic Module with Irradiance and Temperature. *Energies.* 13(12): 3226.

[56] Salem, F. A. 2014. Modeling and Simulation Issues on Photovoltaic Systems, for Mechatronics Design of Solar Electric Applications. *IPASJ International Journal of Mechanical Engineering IIJME.* 2(8): 24-47.

[57] Reis, L. R. D., Camacho, J. R. and Novacki, D. F. 2017. The Newton Raphson Method in the Extraction of Parameters of PV Modules. *Proceedings of the International Conference on Renewable Energies and Power Quality, Malaga, Spain.* 4-6.

[58] Oi, A. 2005. Design and Simulation of Photovoltaic Water Pumping System. PhD thesis California Polytechnic State University.

[59] Jamali, M. I., Bhutto, G. M., Saand, A. S., Koondhar, M. A., Tunio, A. Q. 2020. Dust Deposition Effect on Solar Photovoltaic Modules Performance: A Review. *Journal of Applied and Emerging Sciences.* 10(2), 117-125.

[60] Idoko, L., Anaya-Lara, O. and McDonald, A. 2018. Enhancing PV Modules Efficiency and Power Output Using Multi-concept Cooling Technique. *Energy Reports.* 4: 357-369.