Communications on Applied Nonlinear Analysis
ISSN: 1074-133X
Vol 32 No. 10s (2025)

Complex Modeling and Data Analysis of Single Diode Photovoltaic Characteristics at Different Temperature Variations

[1] Munir Iliyasu Abdullahi, [2] Anas Muktar, [3]Praveen Kumar Yadaw, [4] Manoj Nigam Kumar, [5]Kabiru Salisu Bawa, [6] *Mubarak Musa Umar*

[1]Department of Electrical Engineering, Kalinga University Naya Raipur C.G. India
munirilyasu98@gmail.com

[2] Department of Electrical Engineering, Kalinga University Naya Raipur C.G. India
muktaranas5@gmail.com

[3]Department of Electrical Engineering, Kalinga University, Chhattisgarh, India, 492015 0000-0003-1922-5827

[4]Department of Electrical Engineering, Kalinga University, Chhattisgarh, India, 492015

[5]Department of Electrical Engineering, Kalinga University, Chhattisgarh, India,

492015ksalisubawa@gmail.com

[6]Department of Electrical Engineering, Kalinga university , Chhattisgharh, India,

492015musamubarak63@gmail.com

Article History:

Received: 12-01-2025

Revised: 15-02-2025

Accepted: 01-03-2025

Abstract: Simulations are becoming increasingly popular among researchers because of their ease of data processing and parameter estimation. A single-diode equivalent circuit is used in this study. To examine the characteristics (PV) modules. The weather conditions of Naya Raipur and Chhattisgarh were used to parametrize and apply this model. The characteristics of PV module I (current voltage) and P-V (power-voltage) were examined using MATLAB/Simulink. The simulations used actual meteorological data such as solar temperature and irradiance to ensure robust geographical validation. Owing to its simplicity and capacity to accurately characterize the fundamental electrical characteristics of PV modules, a single diode type was selected. There were very few differences between the simulated data and the theoretical predictions, indicating that the simulation results were very accurate. The study also demonstrates how the model can predict the PV module performance under a range of climatic conditions, which is essential for system optimization using solar energy.

Keywords: Single Diode, MATLAB, Simulink, Photovoltaic Module, I-V & P-V curve, Meteorological Data.

1. INTRODUCTION

Access to inexpensive and sustainable electricity is essential for economic development, industrial advancement, and societal development. The demand for electricity in India is gradually rising as a result of ongoing industrialization and urbanization. Since independence, India's connected electricity bulk consumption increased dramatically As of March 31, 2017, 326.849 GW, up from 1.362 GW in 1947. Traditionally, coal- and lignite-based power generation has been the primary source of electricity in India. However, these traditional power plants significantly contribute to environmental pollution by emitting massive amounts of heavy metals and polluting gases into the atmosphere, resulting in serious health consequences [1-3]. This environmental dilemma highlights the need for cleaner and more sustainable alternatives.[1]

Modeling and evaluating the single-diode solar cell characteristics in Naya Raipur, Chhattisgarh, necessitates consideration of India's overall energy landscape. India's total installed capacity for producing power was 331.117 GW, as of October 31, 2017. Thermal power accounted for 66.27% of this capacity, and renewable energy sources accounted for 18.17%. Nuclear energy accounts for 2.05% of the total capacity, whereas 13.52% is made up of hydro energy (Central Electricity Authority, 2017b).[2]

The hybridization of diverse renewable energy sources together with energy storage technology can drastically reduce reliance on traditional energy sources. These technologies are crucial for managing power uncertainty and guaranteeing steady energy supply [5]. Within the current energy landscape, energy storage is viewed as a critical element in each country's power distribution system. Energy storage can increase system effectiveness, grid stability, and permeation of renewable energy. Furthermore, it helps alleviate health and the environment risks by preserving fossil fuels. [3-7]

It is estimated that this form of energy will account for at least 42% of the production by 2050, with applications in both energy generation and desalination processes [4-10]. Government measures, together with a more than 40% drop in photovoltaic module costs, have greatly helped the global adoption of photovoltaic solar systems (PV), with the photovoltaic panels serving as the primary component [10-15]. An array of photovoltaic cells acts as a generator, transforming solar energy converted into electrical power. These results are highly reliant on the expected solar irradiation [8]. ambient temperatures [9]. The panel consisted of several solar cells connected in both series and parallel. The precision of these solar cells in a PV system was evaluated using a precise model developed by measuring current and voltage [11]. To precisely mimic the electrical behavior of PV solar cells, an adequate mathematical model that is relevant in all scenarios is required. The literature provides a variety of models for this purpose, with a diode commonly serving as the central component. The electrical modeling of PV cells employs three major circuits:

The single diode model (SDM) was introduced, and more recently, the three-diode model (TDM) was introduced for industrial applications. [9-15]

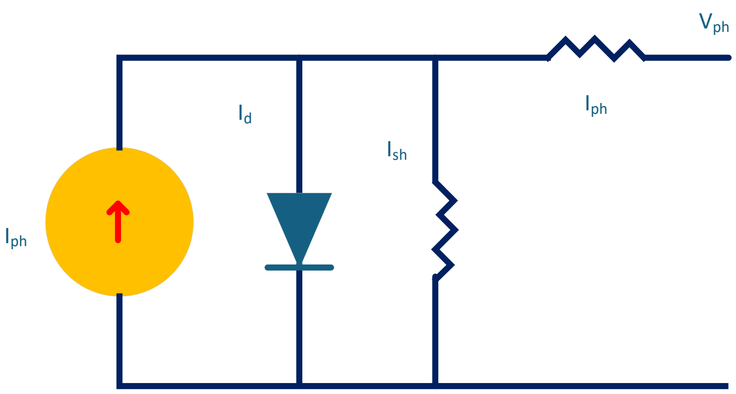

Figure 1 One Diode Model representation and Modelling

The double diode model (DDM) and the three-diode model (TDM) are regarded as the most effective because of their detailed and precise performance, particularly under low-irradiance situations [15-21]. However, these models have significant flaws, notably in the identification of model parameters. It is critical to determine these parameters accurately to obtain the highest possible model accuracy. This process is usually handled as an optimization issue, which necessitates the development of an objective function to minimize. The complexity of this topic results in a complex multivariate search space. Conventional approaches frequently struggle with speed and precision, particularly given the number of unidentified characteristics grows [21-27].

Table 1: **Electrical Parameters of the JAP6-72-320/4BB Solar PV Module (*Source: JAP6-72-320/4BB Data Sheet, JA Solar)***

S/N0	Parameters	Variables	Values
1	Maximum power at STC (Pm)	Pm	320W
2	Maximum power current (Imp)	I'm	8.56A
3	Maximum power voltage (Vmp)	Vm	37.38V
4	Short-circuit current (Isc)	Isc	9.06A
5	Open circuit voltage (Voc)	Voc	46.22V
6	Total series cells	Ns	72
7	Ideality factor of diode	n	1.3
8	Cell short circuit current temperature coefficient of Isc	Ki	0.058%^{0}C
9	Reference temperature	Tref	25^{0}C
10	Solar Irradiance	Gref	1000 at STC

The solar Photo Voltaic device is like an ideal solar cell by a current source (I_{ph}) parallel with a ideal diode.

$$I = Iph - Id \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

According to semiconductor theory, the essential mathematical equation that embodies the I-V properties of a photovoltaic solar cell is "Shockley's diode" current equation, given in Equation (2).

$$Id = Is\left[\exp\left(\frac{qVoc}{Ns.KnT}\right) - 1\right] \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Substituting Id into (1) yields the output current I of a perfect solar cell, as specified in (3):

$$I = Iph - Io\left[\exp\left(q\left(\frac{V + IRs}{nkNsT}\right)\right) - 1\right] - Ish \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

This more realistic model requires identifying five key parameters: photocurrent (Iph), ideality factor (n), diode saturation current (Io), series resistance (Rs), and shunt resistance (Rsh). The equation for this model is as follows:

$$Io = Irs\left(\frac{T}{Tn}\right)^3 \exp\left[\frac{qEgo\left(\frac{1}{Tn}-\frac{1}{T}\right)}{nk}\right] \quad \text{.....................................(4)}$$

$$Ish = \left(\frac{v+IRs}{Rsh}\right) \quad \text{....................................... (5)}$$

$$Iph = \left[Isc + Ki\left(T-298\right)\right]\frac{G}{1000} \quad \text{....................................... (6)}$$

$$Irs = \frac{Isc}{\exp\left(\frac{qVoc}{nNs.KT}\right)} - 1 \quad \text{....................................... (7)}$$

The solar PV modeling process comprises several detailed steps. First, temperature values are converted from degrees Celsius to Kelvin to ensure accurate PV modeling, as illustrated in Step 1 and Figure 7. In Step 2, a Simulink product model for NsKnTo was created to calculate the operating temperature in Kelvin, functioning as a subsystem in the final PV model. Step 3 involves developing the PV photocurrent model using Equation (6) in Simulink, where the photocurrent is linearly related to sun irradiance and affected by temperature, as shown in Figure 3. In Step 4, the reverse saturation current model is implemented in Simulink based on Equation (7) and the manufacturer datasheet parameters, as shown in Figure 6. Step 5 focuses on the saturation current model (Is), which varies with the cell temperature, and is built in Simulink using Equation (4), utilizing inputs such as the energy bandgap, electron charge, and operational temperature, as illustrated in Figure 4 and further examined in Figure 11. Step 6 creates the output current model, as specified by Equation (3) in Simulink, investigating the relationship between the output current, voltage, irradiance, and temperature, as shown in Figure 7. In Step 7, all subsystem models from Steps to 1-6 are combined into a cohesive linked model in Simulink, as shown in Figure 8. Step 8 results in the creation of the final PV module model, which integrates irradiance (G) and temperature (To) as inputs, producing current (I) and voltage (V) outputs, as illustrated in Figure 8.

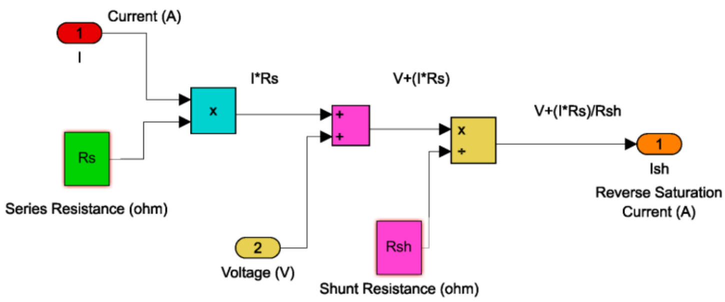

Figure 2 Depicts the complete Simulink model of shunt current

Communications on Applied Nonlinear Analysis
ISSN: 1074-133X
Vol 32 No. 10s (2025)

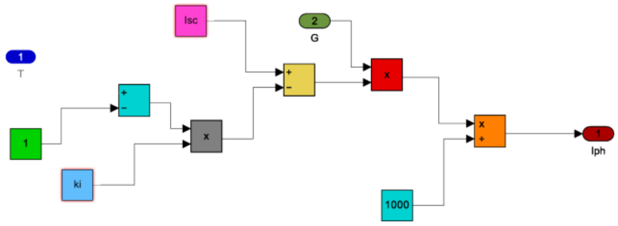

Figure 3 Depicts the complete Simulink model of Photocurrent

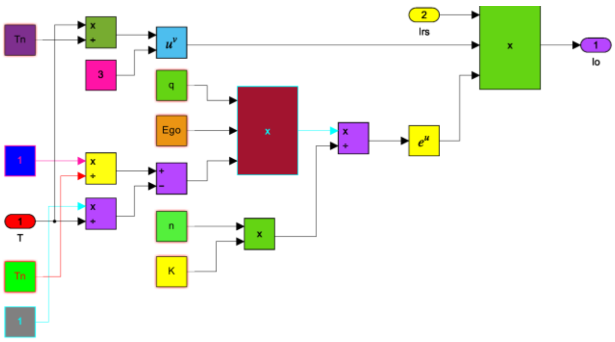

Figure 4 Depicts the complete Simulink model of Saturation current

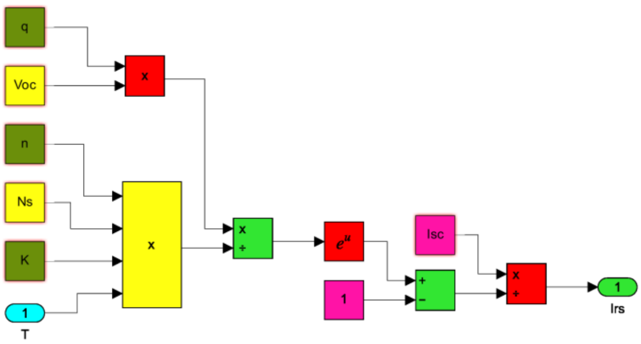

Figure 5 Depicts the complete Simulink model of Reverse saturation current

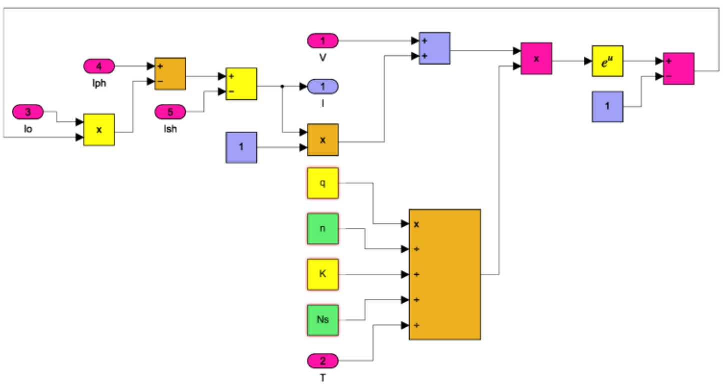

Figure 6 Depicts the complete Simulink model of Output Current

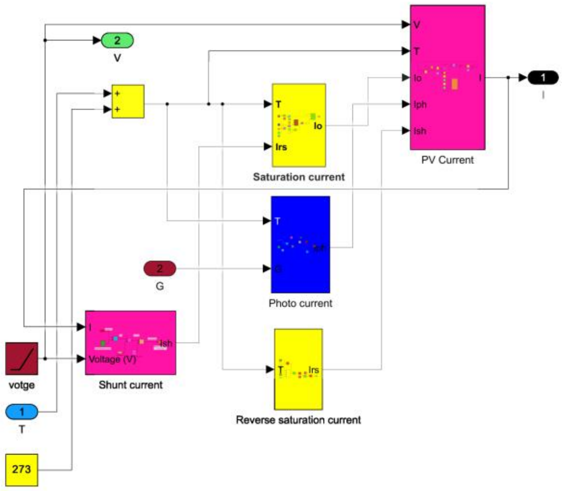

Figure 7 Depicts the complete Simulink model as Linked model subsystems

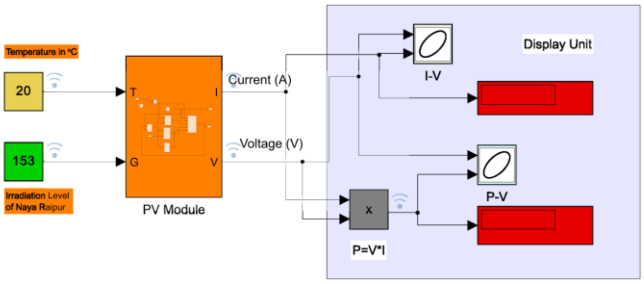

Figure 8 Depicts the complete Simulink model of Final PV Model

4. Simulation findings and discussion.

The solar PV module model was created using the MATLAB/Simulink environment and was based on the mathematical formulae for solar cells presented previously. The simulation block model incorporated parameters from the manufacturer's datasheet for The JAP6-72/320/4BB module functions as the reference module. Figure 14 depicts the final solar PV model, which was simulated to provide output results for current, voltage, and power, utilizing radiation and temperature fluctuations as input parameters.

4.1.1 The effects of irradiance on PV solar modules Figures 15 and 16 show how shifting irradiance affects the I-V and P-V curves of the solar PV model. The curves were created by adjusting the irradiance intensity from 200 to 1000 W/m², while maintaining a constant temperature of 25°C. The current is generally steady as the voltage increases up to 30 V, after which it begins to decline. In addition, an increase in irradiance intensity causes an increase in the current, demonstrating that irradiance has a major effect on short-circuit currents. In contrast, the open-circuit voltage remains relatively low, as illustrated in Figure 15. The power performance curves clearly show the effect of irradiance on the power generation. As seen in Figure 16.

4.1.2 The Impact of Temperature on PV Solar Modules

When the irradiance intensity remains constant at 1000 W/m², the temperature has a substantial impact on the output performance of PV solar modules. As illustrated in Figure 17, the current varies minimally when the temperature increases from 10°C to 70°C. However, as the air temperature drops, the voltage rises on the I-V performance curve.

Furthermore, as shown in Figure 18, the solar cell produces more electricity when the temperature drops. This demonstrates an inverse link between solar cell performance and temperature, with lower temperatures increasing both the voltage and the power output of the solar module.

4.2. Validation of the solar PV model

The accuracy of the solar PV model was determined by comparing its simulated results with those from the manufacturer's datasheet under Standard Test Conditions. Table 3 shows the percentage relative error (RE) for each parameter, which was typically less than 1.70 percent. This indicates a good level of consistency between the manufacturer's specifications and the simulated PV solar model results. The relative error for all parameters was less than 2% when comparing the simulated solar PV model with the manufacturer's data. Furthermore, the percentage error in maximum power production varied between 0.1% and 6.76% across fifteen various types of PV connections (Hashim and Khazaal, 2017). The difference between the simulated results and the manufacturer datasheet values was less than ten percent.

Table2: Solar PV model output parameters based on real-world climate data for 2024.

Months	**Time**	**Temperature (^{0}C)**	**Irradiance (W/m^2)**	**Current (A)**	**Voltage (V)**	**Power (W)**
15thJuly	7:00	18^{0}C	75	0.85	20.5	17.4
	8:00	30^{0}C	100	1.67	24.0	40.08
	9:00	31^{0}C	226	2.15	25.6	55.04
17thJuly	10:00	31^{0}C	228	2.20	26.2	57.6
	11:00	31^{0}C	230	2.3	27.0	62.1
	12:00	30^{0}C	229	2.26	26.8	60.5
20thJuly	13:00	30^{0}C	236	2.23	27.2	63.1
	14:00	29^{0}C	231	2.15	27.0	58.0
	15:00	27^{0}C	198	1.67	24.6	41.0
25thJuly	16:00	24^{0}C	178	0.95	17.8	16.9
	17:00	20^{0}C	153	0.65	13.6	8.84
	18:00	18^{0}C	142	0.55	12.3	6.7

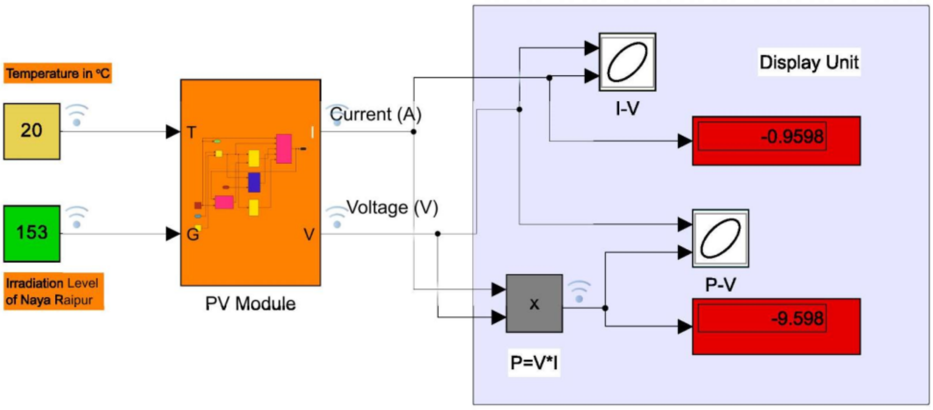

Figure 9 The Analysis of PV Panel in context to Naya Raipur

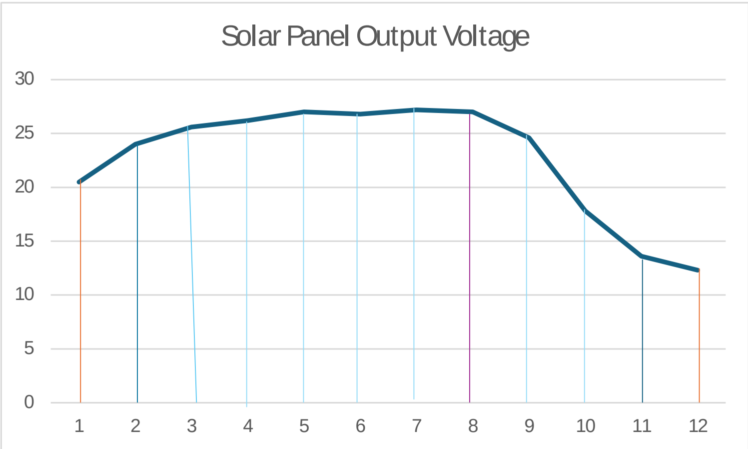

Figure 10 Depicts the complete Simulink model of Solar PV module output voltage

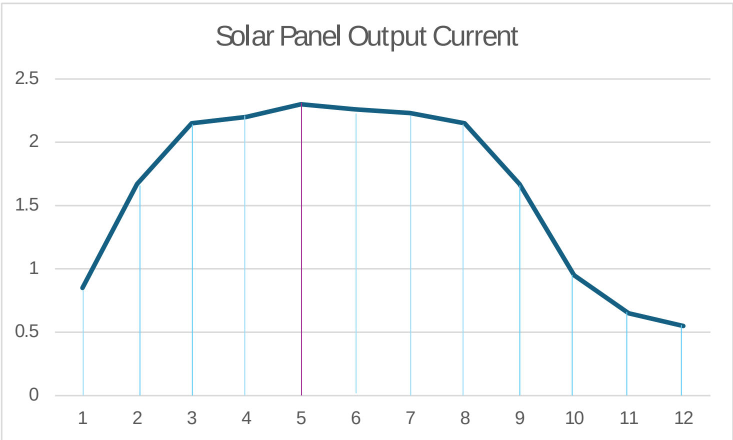

Figure 11 Depicts the complete Simulink model of Solar PV module output Current

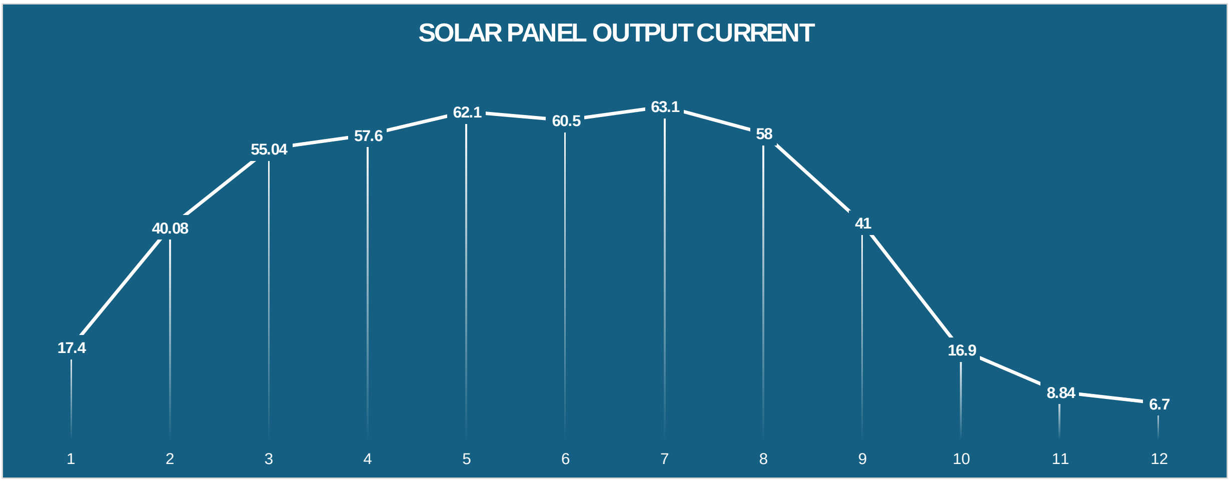

Figure 12 Depicts the complete Simulink model of Solar PV module output Power

Evaluation and Results of Solar PV Modules Based on Real Meteorological Data This section presents the evaluation and findings from an investigation of solar PV modules using real meteorological data as part of a wider endeavor to collect comprehensive solar energy data across India. Naya Raipur, a greenfield smart city, promises to improve people' quality of life and promote economic development. The Solar Radiation Resource Assessment (SRRA) station in Naya Raipur, Chhattisgarh, significantly contributes to this effort by combining sophisticated technology with sustainable practices. The SRRA station collects useful meteorological data, such as solar irradiance and temperature, which are critical for determining the viability and performance of PV systems in the region.

Table 2 shows the output values from the solar PV model for July 2024 calculated using the monthly average irradiance (G) and temperature (T) parameters. The irradiance varies from 75 W/m² to 236 W/m², with temperatures ranging from 18.45°C to 31°C. Figures 20-22 show the I-V and P-V characteristics of the solar PV model using the July 2024 data. These figures show strong constancy in the current, voltage, and power across all major locations when the irradiance and temperature change. There is a direct correlation between the current and irradiance intensity; as irradiance increases, so does the current in the solar PV model.

Figure 19 shows the minimum output power of 6.7 W in July 2024 and the maximum output power of 62 W in July 2024. Between July 17th and July 20th, there was a substantial link between the power output and increasing irradiance intensity. However, the power output decreased in May because of the lower irradiance intensity and the highest average temperature recorded during this month. The power output falls from July 25th, when it rises owing to increased irradiance intensity. This demonstrates that when irradiance increases, so does the output current, resulting in a higher power output from the solar PV module.

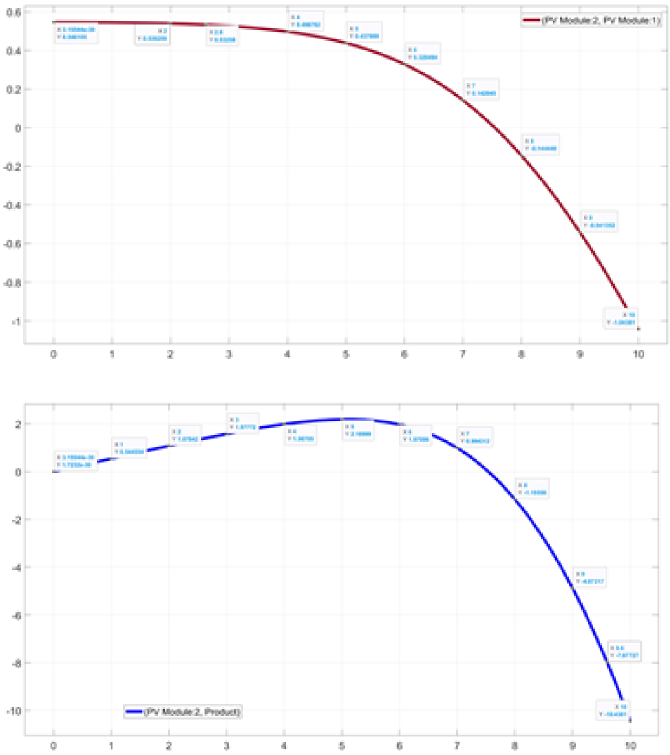

Figure 13 Depicts the complete Simulink model of I–V and P–V graphs for the month of Jan. at 18^{0}C and 75W/m^{s}

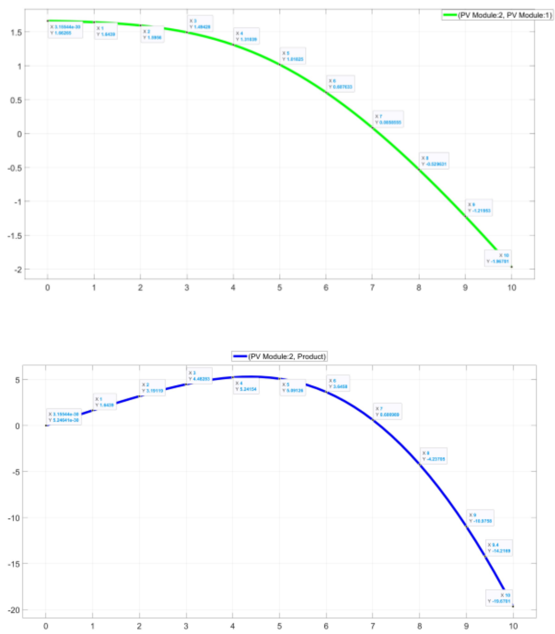

Figure 14 Depicts the complete Simulink model of I–V and P–V graphs for the month of Jan. at 310C and 230W/ms

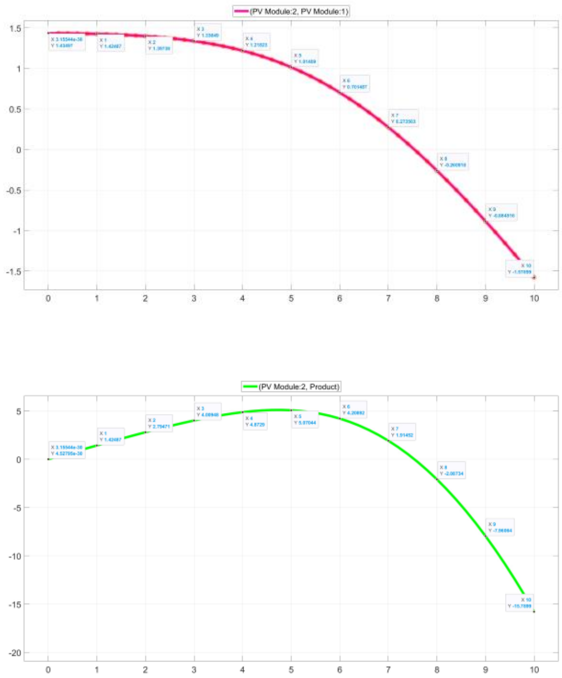

Figure 15 Depicts the complete Simulink model of I–V and P–V graphs for the month of Jan. at 270C and 198W/ms

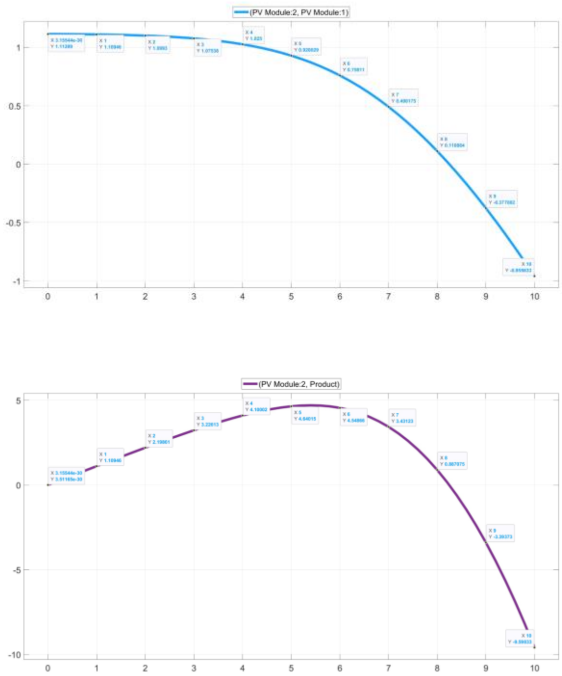

Figure 16 I–V and P–V graphs for the month of Jan. at 200C and 153W/ms

6. Conclusions

In this study, we describe a precise single-diode equivalent circuit model. for photovoltaic (PV) solar modules, as well as a step-by-step procedure for simulating these modules using MATLAB/Simulink.

This modeling approach is intended to help academics, manufacturers, and users understand the characteristics of PV solar modules. The simulation results show a maximum comparative fault of 1.65%, suggesting a strong arrangement with the manufacturer values and supporting the accuracy of the characteristic curves and performance estimates. The model also showed good performance based on meteorological data (irradiance and temperature) from February to October. It also serves as a reliable tool for evaluating the performance of solar cells and modules under various meteorological conditions, thereby boosting the "Make in India" effort in the photovoltaic manufacturing sector.

References

1: AbdelHady, R. (2017). Modelling and simulation of a microgrid-connected solar PV system. Water Sci. 31(1), 1–10. http://dx.doi.org/10.1016/j.wsj.2017.04.001. Abdulkadir, M.; Samosir, A.S.; Yatim, A.H.M. (2012). Modelling and simulation of solar systems using Simulink. J. Eng. Appl. Sci. (ARPN), 7(5), 616–623.

2**:** Abdullahi, N.; Saha, C.; Jinks, R. (2017). Modelling and performance study for a silicon PV module. J. Renew. Sustain. Energy, 9(3), 1–11. Reference: http://dx.doi.org/10.1063/1.4982744.

3: Adamo F., Attivissimo F., Di Nisio A., & Spadavecchia M., 2011. Developed and tested a tool for modelling solar panels. IEEE Trans. Instrum. Meas. 60(5), 1613–1622. http://dx.doi.org/10.1109/TIM.2011.2105051.

4: Altas, I.H., and Sharaf, A.M. 2007. A photovoltaic array simulation model for Matlab- Simulink's GUI environment. Clean Electrical Power, 2007. ICCEP. IEEE. pp. 341-345. https://doi.org/10.1109/ICCEP.2007.384234.

5: Amrani, O. & Rekioua, D. (2006). Investigation and identification of several solar electrical models. International Conference on Electrical and Computer Engineering (ICEA), Volume 6.

6: Amrouche, S.O., D. Rekioua, T. Rekioua, and S. Bacha (2016). An overview of energy storage in renewable energy systems. International Journal of Hydrogen Energy, 41(45), 20914-20927. https://doi.org/10.1016/j.ijhydene.2016.06.243.

7: Aneke, M., and Wang, M. 2016. A cutting-edge examination of energy storage technologies and their real-world applications. Applied Energy, 179, 350–377. https://doi.org/10.1016/j.apenergy.2016.06.097.

8: Aoun N., Chenni R., Nahman B., & Bouchouicha K. (2014). The evaluation and validation of an equivalent five-parameter model for solar panels using just reference data. Energy Power Engineering, vol. 6, no. 9, 235. https://doi.org/10.4236/epe.2014.69021.

9: Banu, I.V., Istrate, M. (2012). Modelling and simulation of photovoltaic systems. Bul. AGIR 3, 161-166; http://www.buletinulagir.agir.ro/articol.php?id=1378. Bellini A., Bifaretti S., Iacovone V., & Cornaro C. 2009. A simplified model of a solar module. Applied Electronics, IEEE, pp. 47–51.

10: Central Electricity Authority (2017a. Growth of India's electrical sector from 1947 to 2017 (pp. 1-83). Link: http://www.cea.nic.in/reports/others/planning/pdm/growth_2017.pdf.

11: Central Electricity Authority (2017b. Power station installed capacity across India (pp. 1-7). Visit www.cea.nic.in/reports/monthly/installedcapacity/2017/installed_capacity-10.pdf.

12: Dewagan, P.K., Goswami, A., and Dewangan, S.K. (2015). Mathematical model of 72W Cosmic Module using Matlab/Simulink. SSRG International Journal of Electrical and Electronic Engineering (SSRGIJEEE), 2(5), 15-21.

13: Fara, L., and Craciunescu, D., 2017. Output analysis for stand-alone PV systems: modelling, simulation, and control. Energy Procedia, 112, 595–605. https://doi.org/10.1016/j.egypro.2017.03.1125.

14: Geonka, D. and Guttikunda, S. (2012). Coal Kills: An estimate of the death and sickness caused by India's most polluting energy source. Urban Emissions, in collaboration with the Conservation Action Trust and Greenpeace India. http://www.greenpeace.org/india/Global/india/report/Coal_Kills.pdf.

15: Gould, T. (2015). World Energy Outlook Special Report 2015. Paris: OECD/International Energy Agency; International Energy Agency, pp. 1- 19. https://www.iea.org/publications/freepublications/publication/IndiaEnergyOutlook_WEO2015.pdf

16: Hamdi, R. T. A. 2017. Solar cell system simulation with Matlab-Simulink. Kurdistan Journal of Applied Research, 2(1), 45–51. https://doi.org/10.24017/science.2017.1.4.

17:Hashim, E. T., and Khazaal, S. Q., 2017. Modelling and evaluating the output power of photovoltaic modules in series and parallel. International Journal of Computer Applications, 158(8), 35–46. https://doi.org/10.5120/ijca2017912846.

18:Hemmati, R. 2018. Optimal design and operation of energy storage systems and generators in wind turbine networks, with practical storage unit parameters used as design variables. Journal of Cleaner Production, 185, 680–693. https://doi.org/10.1016/j.jclepro.2018.03.062.

19:Hemmati, R. and Saboori, H. (2016). A study of the emerging hybrid energy storage devices in renewable energy and transportation applications. Renewable and Sustainable Energy Reviews, 65: 11–23. https://doi.org/10.1016/j.rser.2016.06.029.

20- Kanchan, S., & Kumarankandath, A., 2015. The Indian power sector: Need for sustainable energy access. *IPPAI Knowledge Report*, pp. 126–140. http://cdn.cseindia.org/attachments/0.61046700_1505884602_The-Indian-Power-Sector.pdf.

21- Kharb, R.K., Shimi, S.L., & Chatterji, S., 2013. Improved maximum power point tracking for solar PV modules using ANFIS. *International Journal of Current Engineering and Technology*, 3(5), 1878–1885.

22- Kim, H., & Jung, T.Y., 2018. Independent solar photovoltaic systems with energy storage for rural electrification in Myanmar. *Renewable and Sustainable Energy Reviews*, 82, 1187–1194. https://doi.org/10.1016/j.rser.2017.09.037.

23- Kirmani, S., Jamil, M., & Rizwan, M., 2015. Empirical correlation for estimating global solar radiation using meteorological parameters. *International Journal of Sustainable Energy*, 34(5), 327–339. https://doi.org/10.1080/14786451.2013.826222.

24- Krismadinata, Rahim, N.A., Ping, H.W., & Selvaraj, J., 2013. Photovoltaic module modeling using Simulink/Matlab. *Procedia Environmental Sciences*, 17, 537–546. https://doi.org/10.1016/j.proenv.2013.02.069.

25- Lyden, S., Haque, M.E., Gargoom, A., Negnevitsky, M., & Muoka, P.I., 2012. Modeling and parameter estimation of photovoltaic cells. In *Power Engineering Conference, AUPEC*. IEEE, pp. 1–6.
26- Meflah, A., Rahmoun, K., Mahrane, A., & Chikh, M., 2017. Outdoor performance modeling of three different silicon photovoltaic module technologies. *International Journal of Energy and Environmental Engineering*, 8(2), 143–152. https://doi.org/10.1007/s40095-017-0228-6.
27- Mendalek, N., & Al-Haddad, K., 2017. Photovoltaic system modeling and simulation. In *Industrial Technology, ICIT*. IEEE, pp. 1522–1527. https://doi.org/10.1109/ICIT.2017.791592.
28- Ministry of New and Renewable Energy (MNRE), 2017. Annual Report MNRE 2016-2017, pp. 1–224. http://mnre.gov.in/file-manager/annual-report/2016-2017/EN/index.html.
29- Mohammedi, A., Rekioua, D., & Mezzai, N., 2013. Experimental study of a PV water pumping system. *Journal of Electrical Systems*, 9(2), 212–222.
30- Nathan, H.S.K., 2014. Solar energy for rural electricity in India: A misplaced emphasis. *Economic and Political Weekly*, 49(50), 60–67. http://eprints.nias.res.in/921/1/2015-Kristle%20Nathan-EPW.pdf.
31- Pandiarajan, N., & Muthu, R., 2011. Mathematical modeling of photovoltaic modules using Simulink. In *Electrical Energy Systems, ICEES*. IEEE, pp. 258–263. https://doi.org/10.1109/ICEES.2011.5725339.
32- Patel, J., & Sharma, G., 2013. Modeling and simulation of a solar photovoltaic module using Matlab/Simulink. *International Journal of Research in Engineering and Technology*, 2(3), 225–228.
33- Pendem, S.R., & Mikkili, S., 2018. Modeling, simulation, and performance analysis of solar PV array configurations (Series, Series-Parallel, and Honey-Comb) for maximum power extraction under partial shading conditions. *Energy Reports*, 4, 274–287. https://doi.org/10.1016/j.egyr.2018.03.003.
34- Qi, C., & Ming, Z., 2012. Photovoltaic module Simulink model for a stand-alone PV system. *Physics Procedia*, 24, 94–100.
35- Rahman, S.A., Varma, R.K., & Vanderheide, T., 2014. Generalized model of a photovoltaic panel. *IET Renewable Power Generation*, 8(3), 217–229. https://doi.org/10.1049/iet-rpg.2013.0094.
36- Rekioua, D., & Matagne, E., 2012. *Optimization of Photovoltaic Power Systems: Modeling, Simulation and Control*. Springer Science & Business Media. https://doi.org/10.1007/978-1-4471-2403-0.
37- Saboori, H., Hemmati, R., Ghiasi, S.M.S., & Dehghan, S., 2017. Energy storage planning in electric power distribution networks: A state-of-the-art review. *Renewable and Sustainable Energy Reviews*, 79, 1108–1121. https://doi.org/10.1016/j.rser.2017.05.171.
38- Salem, F.A., 2014. Modeling and simulation issues in photovoltaic systems for mechatronics design of solar electric applications. *IPASJ International Journal of Mechanical Engineering (IIJME)*, 2(8), 24–47.
39- Sera, D., Teodorescu, R., & Rodriguez, P., 2007. PV panel model based on datasheet values. In *Industrial Electronics*. IEEE, pp. 2392–2396. https://doi.org/10.1109/ISIE.2007 .4374981.