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Investigation of the Trail Environment to Enhance the Efficiency of the Solar Cell through Pre-Installation Study

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This research investigates the performance of solar photovoltaic modules in real-world climatic conditions at various locations in India using MATLAB simulation. The study utilizes a single-diode model and a detailed simulation of a solar PV module to analyze the P-V and I-V characteristics of the module on a monthly basis. The month-wise power output is evaluated in relation to temperature and solar irradiance under various weather conditions. To model the PV module, the input parameters such as solar irradiance and temperature were first determined, and an appropriate PV panel model was selected based on the complexity and accuracy required. The PV panel model was then set up in MATLAB and run to generate the output data. The simulated results were compared to the verified data sheet of the JAM60S10-350/MR module, demonstrating that the simulation accurately represents the PV solar module's performance curve. The study aims to identify the most efficient locations for installing solar PV modules for optimal efficiency. Different models such as single-diode, two-diode, and PV system model can be used to model PV panels depending on the specific conditions being simulated and the level of accuracy required.

Keywords: Irradiance, MATLAB modeling, Renewable energy, Solar photovoltaic, Solar simulation

Introduction

Sustainable energy sources play a vital role in developing any nation, and solar energy is one of the best affordable options. India is the country that has plans to produce large amounts of renewable energy through solar cells. Since the mid-twentieth century, people have been dependent on a conventional energy source that releases an enormous amount of gaseous pollutants.[1,2] In the early 1980s, India became the first country to establish a Ministry of New and Renewable Energy (MNRE) and the Solar Energy Corporation of India, which is responsible for developing the solar energy industry in India.[3] The solar energy industry in India is proliferating. The country's installed solar capacity was 40.01 GW as of March 31, 2021.[(4)] The Indian government plans to install an additional 40 GW of rooftop solar projects, including roof-to-roof systems. Wind or solar PV systems combined with four-hour energy storage systems are currently cost-competitive and unmatched sources of energy when compared to new coal and gas-fired power plants.[5] India recently surpassed Italy to reach fourth place on the world stage for solar power deployment.[6] In the last six years, solar power installed capacity has risen from 6.8 GW in 2016 to 61.97 GW as on 30st November, 2022.[(7)]

Over the past decade, numerous studies in next-generation solar cells like Dye-sensitized solar cells, Perovskite solar cells, new materials for solar cell technologies, quantum dot solar cells, theoretical modelling, researchers have carried out bilayer organic photovoltaic cells.[8–15] Some authors conducted the experimental verification on the model that calculated the PV module's current, voltage, and cell temperature and presented two diode models to represent the solar PV cell.[16,17] The main focus of the recent research work is to enhance the efficiency of the solar cells, new materials for solar cells, and P-V & I-V modelling of different PV modules, etc. Various software like C-program, Excel, MATLAB, Simulink, toolboxes, and neural network techniques are being cast-off to model and simulate the solar PV modules and enhance solar irradiation.[18,19] There are so many articles on the fabrication of hybrid models of multiple quanta well solar cells and synthesis of nanoparticle doped photoanode to study the I-V characteristics, impedance, and refraction index to improve the efficiency of photovoltaic solar cells.[20] Several articles use MATLAB software to investigate solar panels for I-V and P-V properties. From 2005 to date, researchers have used different methods to study

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the temperature and irradiance effect on I-V and P-V graphs. People used MATLAB to estimate the electric behavior of the cell concerning changes in environmental temperature and irradiance parameters and prepared solar PV modules using empirical data and a curve-fitting tool.[21] The work of Md. Hafizur Rahman and his team demonstrates the variation in efficiency between single diode and two diode photovoltaic models as simulated through MATLAB.[22] Vandana Jha presents a comprehensive MATLAB simulation of a photovoltaic module, considering both uniform irradiance and partial shading scenarios.[23] The research conducted by Samik Kumar Das and colleagues concentrates on the development and simulation of a double-stage photovoltaic system that connects to the electrical grid and provides a power output of 100 KW. The goal is to anticipate the dynamic performance of the grid-linked photovoltaic system under varying temperatures and irradiance conditions, and the simulations were executed using the MATLAB/ Simulink version R2021a software.[24] In their study, Mohsin Ali Koondhar and his colleagues employed a straightforward MATLAB simulation to compare the characteristics of a Photovoltaic Module (PVM) as outlined in its technical datasheet.[25] Various PV system models using MATLAB/Simulink application and compare the data with standard datasheet.[26] These measurements predict the operational and responses characteristics of PV setups and examine the experimental outcomes with its simulation results efficiently and demonstrated in MATLAB, a circuit-based solar PV model was created and simulated for various radiation and temperature parameters.[27,28] The authors have used MATLAB to model a solar PV module and simulated it in real-world climatic circumstances in Tetouan, Morocco, although they do not explain the precise modeling of the PV model in the study.[29] The PV module's MATLAB/Simulink model is used to determine the characteristics curve by changing the irradiance and temperature conditions.[30,31] The solar irradiance is affected by weather conditions, and varies with geographical locations. Accurate PV power output forecasting is essential for the planning and scheduling alternate sources of conventional power.[32] There are numerous studies on photovoltaic cell modeling using MATLAB, however, to the best of our knowledge, no paper presented the detailed study on the solar photovoltaic at different locations in India before installation so far. This study has vital importance in the developing country like India, which may lead to save time, money and human resources. In this paper, we report a study that is required before the installation of the solar panels at different locations in India with the help of MATLAB. The present study is based on the real metrological data and demographic positions of Tezpur, Assam; Phalodi, Rajasthan; Gurugram, Haryana; Chennai, Tamil Nadu; Gwalior, Madhya Pradesh. The obtained results are compared with the reference model parameters and the relative percentage error has also been calculated. The block diagram of the MATLAB model of a photovoltaic (PV) module using the single diode equation is illustrated in Fig. 1. There are some steps given below which can elaborate the working of this model.

1. Determine the input parameters for the simulation, including the solar irradiance, temperature, and other environmental factors that can affect the performance of the PV panel.
2. Define the model equations using the single-diode model equation, including the diode current (I_D), reverse saturation current (I_{RS}), Thermal voltage (V_{TC}), quality factor (A), series resistance (R_S), output current (I), diode voltage (V), Number of cells in series (N_S), Number of cells in parallel (N_P).
3. Set up the input and output variables for the simulation, including the voltage (V) and current (I) through the PV panel.
4. Specify the simulation conditions, including the range of voltage values to be simulated and the time step for the simulation.

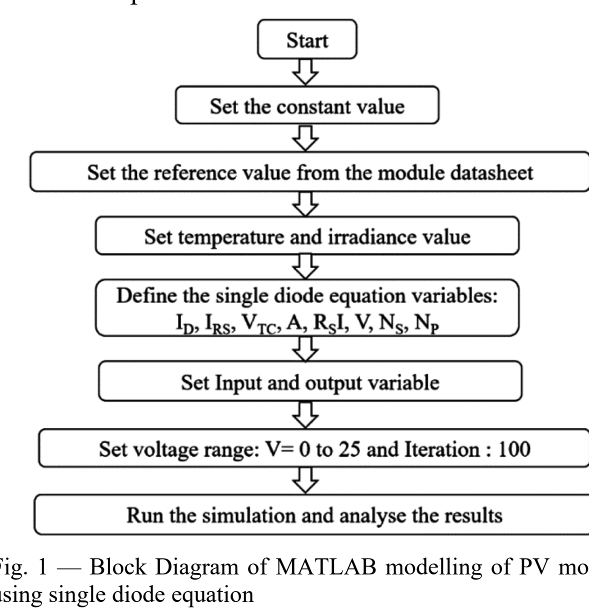

Fig. 1 — Block Diagram of MATLAB modelling of PV module using single diode equation

5. Run the simulation using a loop to iterate over the voltage values and solve the single-diode model equation at each iteration using the input parameters and model equations.
6. Analyse the results of the simulation to understand the performance of the PV panel under different conditions and identify potential issues or areas for improvement.
7. Optimize the model as needed by modifying the input parameters or model equations to improve the accuracy of the simulation. Repeat steps 5 and 6 until the desired level of accuracy is achieved.

Methodology

The single diode model (an ideal diode with a parallel and series resistance) has been used to model the solar cell.[33] This model is composed of a current source that generates light in parallel with an ideal diode and series and parallel resistance. The circuit is described by Eqs (1–3),

$$I = I_l - I_D - I_{SH} \quad \ldots (1)$$

$$V_D = V + R_S I \quad \ldots (2)$$

$$I_{SH} = \frac{V + R_S I}{R_{SH}} \quad \ldots (3)$$

where, I = output current, I_l = Light current, I_D= Diode current, I_{SH} = Shunt current, V_D = Diode voltage, R_{SH} = Shunt resistance, R_S = Series resistance.

When considering an actual solar cell model, we must consider parasitic resistance. R_S, series resistance introduced due to bulk resistance, and R_{SH} is shunt resistance due to leakage along the p-n junction.[34]

An array of solar cells is made up of photovoltaic panels that are connected together in both series and parallel circuits to produce electricity. The composition of a solar cell array, consisting of N_S cells connected in series and N_P cells connected in parallel, is displayed in Fig. 2. If we assume that all the connected cells are identical and experiencing the same lighting and temperature conditions, Eqs (1) & (3) can be simplified to:

$$I = N_P I_L - I_D N_P - I_{SH} \quad \ldots (4)$$

$$N_S V_D = V + R_S I \times \frac{N_S}{N_p} \quad \ldots (5)$$

$$I_{SH} = \frac{V + \frac{N_S}{N_P} \times R_S I}{\frac{N_S}{N_P} \times R_{SH}} = \frac{V \times N_P + N_S \times R_S I}{N_S} \quad \ldots (6)$$

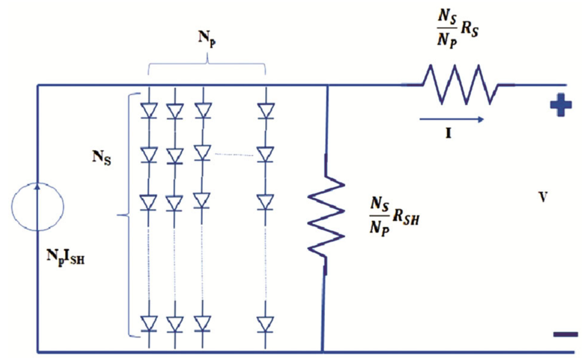

Fig. 2 — Equivalent circuit of a solar cell array

where, N_S = The number of cells in a series of a photovoltaic module, N_P = The number of cells in parallel within a photovoltaic module

For an ideal cell, R_S = 0 and R_{SH} = ∞, it means there is no loss of voltage in series resistance, and there is no current leakage via the shunt resistance.[33] When an output is short-circuited (V = 0), omit the leakage current across R_{SH} and current of ideal diode, so,

$$I_L = I_{SC} \quad \ldots (7)$$

where, I_{SC} = Short circuit current

When the solar cell is overcast, it behaves like a diode, and the I_D current is shown by Shockley in Eqs (8), altered by diode quality factor A,[35]

$$I_D = I_{RS}\left\{\exp\left[\frac{1}{AV_{TC}}\left(\frac{V}{N_S} - \frac{R_S I}{N_P}\right)\right] - 1\right\} \quad \ldots (8)$$

where, V_{TC} = Thermal voltage, A = Quality Factor, I_{RS} = Reverse saturation current

The parameter "A" ranges from 1 to 2, and it depends on the fabrication process of the solar cell.

$$V_{TC} = \frac{q}{kT_c};$$

where, k = Boltzmann's constant (1.38×10^{-23}) (J/K); q = charge of electron (1.6×10^{-19}); T_C = Absolute temperature

From Eqs (4), (6) & (8), the I-V equation of solar cell array is,

$$I = N_P P_L - N_P I_{RS}\left\{\exp\left[\frac{1}{AV_{TC}}\left(\frac{V}{N_S} + \frac{IR_S}{N_P}\right) - 1\right]\right\} \frac{N_P V + N_S I R_S}{N_S R_{SH}} \quad \ldots (9)$$

Thus, we can compute the power by Eq. (10),

$$P = V \times I \quad \ldots (10)$$

where, V and I are voltage and current, respectively.

Temperature and Irradiation Dependence of Solar Cell Matrix

When the output circuit is open (I = 0), there is no leakage current across the series resistance, then $I_L = I_D$

with this assumption, from Eqs (7) & (8), the short circuit current I_{SC} can be computed:[36]

$$I_{SC} = I_{RS}\{\exp(\frac{V_{OC}}{AV_{TC}N_S}) - 1\} \quad \ldots (11)$$

where, V_{OC} = Open circuit voltage

As a result, the short-circuit current is proportional to solar radiation since it is analogous to the photocurrent.

$$I_{SC} = I_{SC}^{*} \times \frac{\phi}{\phi^{*}}[1 + \alpha I_{SC}(T_C - T_C^{*})] \quad \ldots (12)$$

where, I_{SC}^{*}= Reference short circuit current, Φ = Irradiance (W/m^2), Φ* = Reference irradiance (1000 W/m^2 is used in the study), T^*_C = Reference temperature (25°C), αI_{SC} = Temperature coefficient of short circuit current

The open-circuit voltage (V_{OC}) of a solar cell is affected by its temperature –

$$V_{OC} = V_{OC}^{*}[1 + \beta V_{OC}(T_C - T_C^{*})] \quad \ldots (13)$$

where, V^*_{OC} = Reference open circuit voltage, βV_{OC} = Temperature coefficient of open circuit voltage

At reference cell temperature T_C^{*}, the value of the reference reverse saturation current is:

$$I_{RS}^{*} = I_{SC}^{*}[\exp\left(\frac{V_{OC}^{*}}{AN_S V_{T_C^{*}}}\right) - 1]^{-1} \quad \ldots (14)$$

where, I_{RS}^{*}= Reference reverse saturation current

The reverse saturation current (I_{RS}) can be calculated based on its value at a reference condition I_{RS}^{*},[36]

$$I_{RS} = I_{RS}^{*}(\frac{T_C}{T_C^{*}})^3 \exp[\frac{qN_S E_G}{AK}(\frac{I}{T_C^{*}} - \frac{1}{T_C})] \quad \ldots (15)$$

where, E_G = Energy band gap.

By selecting a specific model, we can obtain the values of E_G and A from the manufacturer of that model.

Results and Discussion

The development of a solar photovoltaic model through the utilization of MATLAB technology represents a major advancement in the realm of renewable energy. The circuit-based model was created and simulated for a variety of irradiance and temperature conditions[27,28], with a focus on understanding how the intensity of solar irradiance can be impacted by environmental factors such as weather and geographical location.[32] With the ability to produce accurate predictions of photovoltaic power output, the MATLAB model is a crucial tool for effectively planning and coordinating the use of conventional power sources. The utilization of the previously described solar cell mathematical formulae provides a comprehensive and accurate representation of the photovoltaic performance. The reference module, JAM60S10-350/MR, listed in Table 1, serves as a benchmark for the comparison of the simulated model's parameters with its corresponding datasheet. The comparison of the parameters across various locations in India provides a thorough understanding of the photovoltaic performance in different conditions.

Impact of Temperature and Irradiance on PV Solar Modules

The output performance curves of PV solar modules are considerably affected by temperature and irradiance. The plot between current & voltage (I-V) and power & voltage (P-V) with the variation of temperature (25°C to 75°C) at a constant irradiance (1000 W/m^2) are shown in Fig. 3 (a & b). If we keep the irradiance intensity constant at 1000 W/m^2, the current remains unchanged or exhibits only minor variations, as shown in the plots. In contrast, the voltage decreases with the increase in the temperature (from 25°C to 75°C). Similarly, solar cell power increases when the temperature drops. Thus, it can be concluded that the solar cell's performance decreases with increasing temperature. The impact of irradiance on the I-V and P-V characteristics curves of a solar photovoltaic system is demonstrated in Fig. 4 (a & b). The curves were recorded at a constant temperature of 25°C, with the irradiance intensity varying from 100 W/m^2 to 1000 W/m^2. When continuously exposed to solar irradiation, the current has been observed to

Table 1 — Datasheet of reference model JAM60S10-350/MR

Parameters	Reference Datasheet
P_{max} (W)	350
V_{oc} (V)	42.02
I_{sc} (A)	10.62
V_{mp} (V)	35.25
I_{mp} (A)	9.93

P_{max} = Maximum power at STC, V_{mp} = Maximum power voltage, I_{mp} = Maximum power current remain constant with voltage until 15 V and then decrease thereafter.

Additionally, it has been noticed that the current increases as the irradiance intensity increases. This indicates that irradiance has a significant impact on the short circuit current, while only slightly affecting the open-circuit voltage. As the intensity of solar irradiance increases, the power generation by the solar PV also increases, as shown in Fig. 4(b).

The solar PV module has been designed and simulated using monthly average irradiance and ambient temperature for different demographic regions of Solar Radiation Resource Assessment (SRRA) for the year 2019.(37) We randomly selected five different sites from the East, West, North, South, and Central parts of India and compared their results. We have chosen Tezpur University, Tezpur, Assam (Station ID: 2611) from East, 220 KV GSS – RRVPNL, Phalodi, Rajasthan (Station ID: 1806) from West, National Institute of Solar Energy, Gurugram, Haryana (Station ID: 2548) from North, National Institute of Wind Energy, Chennai, Tamil Nadu (Station ID: 1791) from South and College of Agriculture, Gwalior, Madhya Pradesh, (Station ID: 1945) from the central part of India. The Ministry of New and Renewable Energy (MNRE) under the Government of India established the previously mentioned centers/sites. Detail's demographic locations are listed in Table 2, and monthly average values of solar irradiance and temperature of these sites are listed in Table 3. In the case of Sonitpur, Assam, the irradiance changes from a minimum of 603.3 W/m^2 (in January) to a maximum of 831.5 W/m^2 (in February), and the temperature varies from a minimum of 18.2°C (in January) to a maximum of 30.6°C (in August). For Jodhpur, Rajasthan, the monthly average values of the irradiance change from a minimum of 758 W/m^2 (in June) to a maximum of

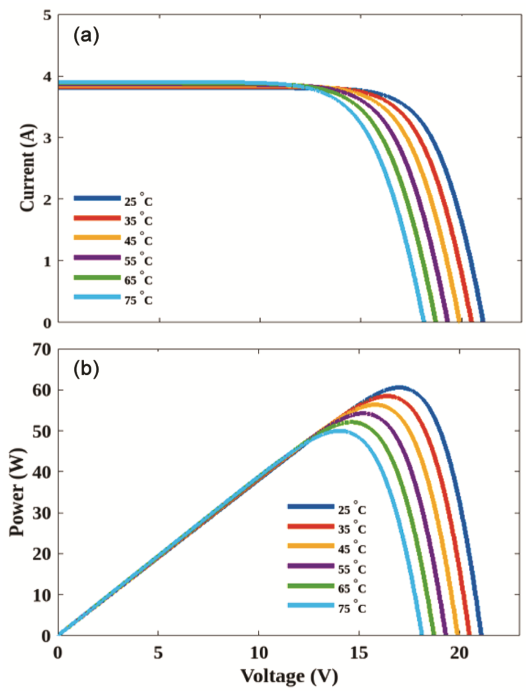

Fig. 3 — (a) I-V & (b) P-V characteristics with the variation of temperature at constant irradiance (1000 W/m^2)

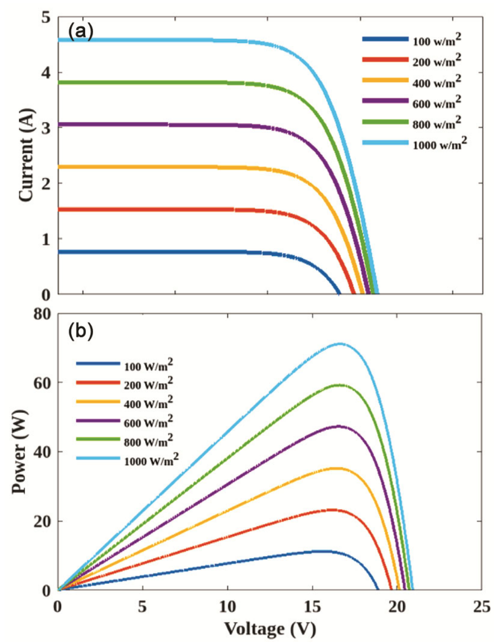

Fig. 4 — (a) I-V & (b) P-V characteristics with the variation of irradiance at constant temperature (25°C) Interpretation of Solar Photovoltaic Module in Different Locations through Basic Metrological Measures

Table 2 — Demographic position of the selected locations[37]

Location & (Station ID)	Station, Dist., State	Co-ordinates (°N & °E)	Elevation (m AMSL)
Tezpur University (2611)	Tezpur; Sonitpur; Assam	26.699 & 92.833	83
220KV GSS – RRVPNL (1806)	Phalodi; Jodhpur; Rajasthsn	27.118 & 72.345	242
National Institute of Solar Energy (2548)	Gurugram; Gurugram; Haryana	28.425 & 77.155	259
National Institute of Wind Energy (1791)	Chennai; Chennai; Tamil Nadu	12.956 & 80.217	1
College of Agriculture (1945)	Gwalior; Gwalior; Madhya Pradesh	26.223 & 78.19	210

Table 3 — Solar PV model input parameter of different areas for the year 2019

	Input Parameters									
	Sonitpur, Assam		Jodhpur, Rajasthan		Gurugram, Haryana		Chennai, Tamil Nadu		Gwalior, Madhya Pradesh	
Months	AVI (W/m^2)	AVT (°C)	AVI (W/m^2)	AVT (°C)	AVI (W/m^2)	AVT (°C)	AVI (W/m^2)	AVT (°C)	AVI (W/m^2)	AVT (°C)
January	603.3	18.2	806.5	17.3	802.5	12.8	539.8	29.6	780.4	15.0
February	831.5	20.2	830.8	18.9	832.4	15.3	571.9	32.2	832.2	18.1
March	804.2	23.3	797.6	25.1	803.1	20.5	818.0	35.2	803.1	23.3
April	820.1	25.0	812.9	32.5	811.3	28.7	765.0	36.8	807.8	31.0
May	823.6	25.2	824.2	34.1	823.0	30.9	799.2	39.2	796.1	33.8
June	768.0	29.3	758	36.4	760.7	34.2	542.9	39.7	760.6	35.3
July	763.3	28.3	771.6	33.1	770.7	31.4	593.8	36.1	768.0	30.9
August	799.3	30.6	803.0	30.2	800.6	30.5	672.1	34.7	800.6	28.9
September	788.8	28.7	801.5	30.7	800.2	30.7	616.5	33.4	803.9	28.2
October	796.7	26.7	798.0	28.0	797.0	25.7	615.8	32.0	796.7	25.6
November	791.6	24.4	797.8	24.1	798.9	20.3	574.3	31.7	799.1	21.8
December	787.3	18.6	789.4	17.9	789.5	11.4	613.3	29.7	763.0	14.2

AVI = Avg. value of irradiance; AVT = Avg. value of temperature

830.8 W/m^2 (in February), and temperature vary from a minimum of 17.3°C (in January) to a maximum of 36.4°C (in June). For Gurugram, Haryana, the irradiance changes from a minimum of 760.7 W/m^2 (in June) to a maximum of 832.4 W/m^2 (in February), and temperature vary from a minimum of 11.4°C (in December) to a maximum of 34.2°C (in June). In Chennai, Tamil Nadu, the irradiance changes from a minimum of 539.8 W/m^2 (in January) to a maximum of 818 W/m^2 (in March), and temperature vary from a minimum of 29.6°C (in January) to a maximum of 39.7°C (in June). For Gwalior, Madhya Pradesh, the irradiance changes from a minimum of 760.6 W/m^2 (in June) to a maximum of 832.2 W/m^2 (in February), and temperature varies from a minimum of 14.2°C (in December) to a maximum of 35.3°C (in June).

Inference of Monthly Characteristics Graph for Various States

Monthly evaluation of I-V and P-V graphs from January to December 2019 for Sonitpur, Assam are simulated for solar PV model and depicted in Fig. 5(a). The maximum current (12.46 A) and power (136.68 W) were observed in February, and the minimum current (9.03 A) and power (88.60 W) have been observed in January. The I-V and P-V graphs for Jodhpur, Rajasthan are shown in Fig. 5(b). The maximum current (12.63A) and power (138.83W) were observed in February, and the minimum current (11.36 A) and power (119.05 W) have been observed in June. I-V and P-V graphs from January to December 2019 for Gurugram, Haryana are simulated for the solar PV model and depicted in Fig. 5(c). The maximum current (12.47 A) and power (135.17 W) were observed in February, and the minimum current (11.57 A) and power (120.36 W) were observed in June. For Chennai, Tamilnadu (Fig. 5(d), the maximum current (12.27 A) and power (128.68 W) have been observed in March, and minimum power (73.45W) and current (7.26 A) have been observed in November. The I-V and P-V plots for Gwalior, Madhya Pradesh are shown in Fig. 5(e); the maximum and minimum power and current are 135.84 W, 120.60 W and 12.46 A, 11.43 A, respectively in February and June.

Assessing Monthly Energy Output of Various Locations

The month-wise solar module power output of Sonitpur, Jodhpur, Gurugram, Chennai, and Gwalior are shown in Fig. 6 with different color histograms. The minimum output power was 88.60 W in January 2019, and the maximum output power was 136.68 W in February 2019 at Sonitpur, Assam. The minimum output power was 119.05 W in June 2019, and the maximum output power was 138.83 W in February 2019 at Jodhpur. The minimum output power was 120.36 W in June 2019, and the maximum output power was 135.17 W in February 2019 at Gurugram. The minimum output power was 73.45 W in November 2019, and the maximum output power was 128.68 W in March 2019 at Chennai. The minimum output power was 120.6 W in June 2019, and the maximum output power was 135.84 W in February 2019 at Gwalior.

It has been observed that less power is produced in June, which is a hot summer session in India, almost all places in India, except Eastern India. Less power is generated due to high temperature and low solar irradiance, as observed from I-V and P-V plots with the variation of temperature and irradiance (Figs 3

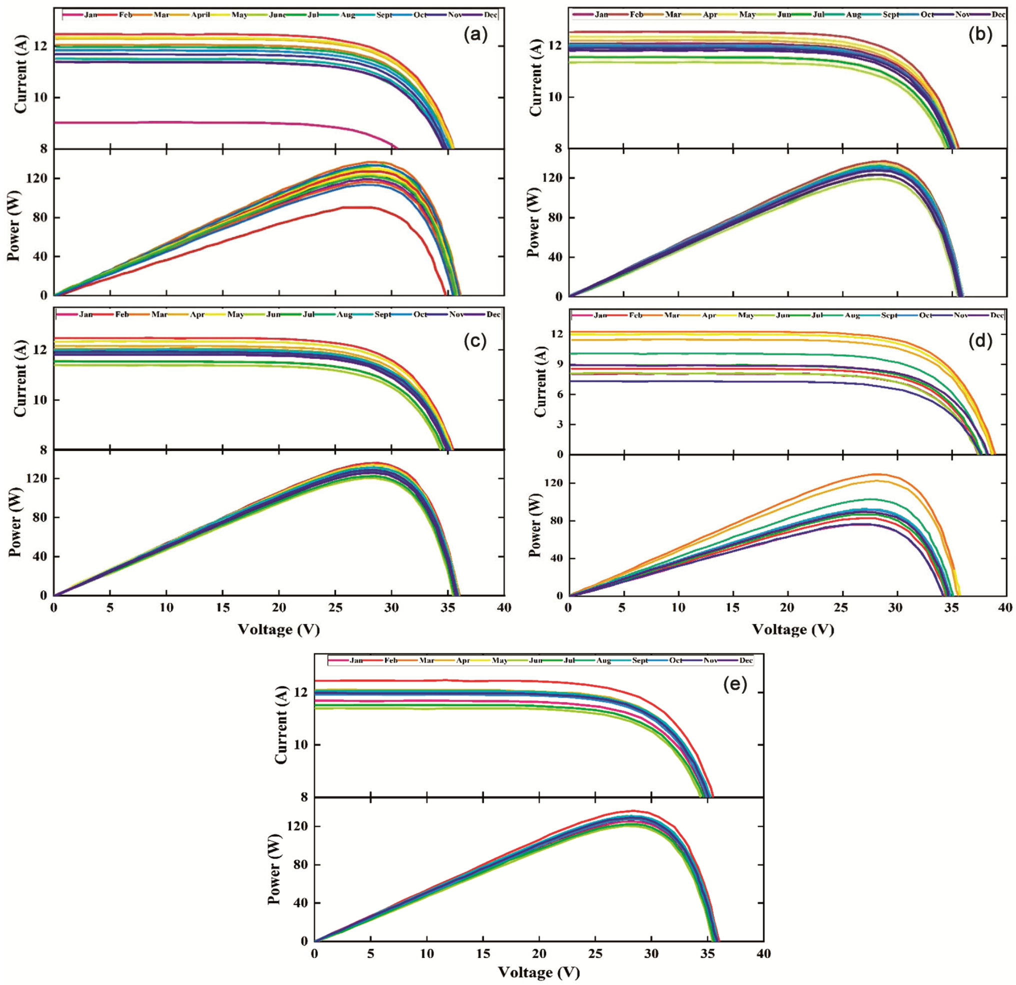

Fig. 5 — I-V & P-V graph for the month of Jan to Dec 2019 for: (a) Sonitpur, Assam; (b) Jodhpur, Rajasthan; (c) Gurugram, Haryana; (d) Chennai, Tamilnadu; (e) Madhya Pradesh

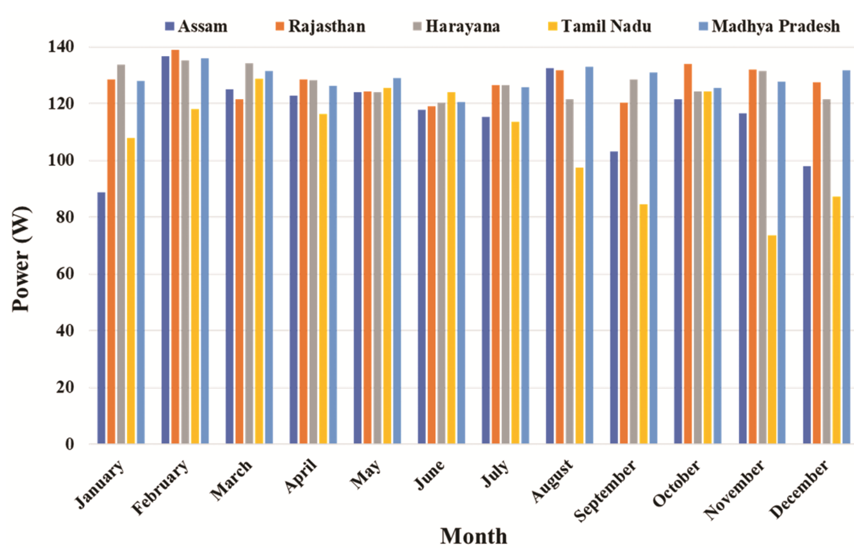

Fig. 6 — Month-wise Power output in Solar PV module of different states

Table 4 — Comparison of evaluated results with the reference model JAM60S10-350/MR Datasheet

Area	P_{max} (W)	V_{OC} (V)	I_{SC} (A)	V_{mp} (V)	I_{mp} (A)	Efficiency (η %)
Reference Model	350	42.02	10.62	35.25	9.93	20.8
Sonitpur, Assam Relative Error (%)	348.16 ± 1.84	39 ± 3.02	12.47 ± 1.85	32 ± 3.25	10.88 ± 0.95	14.30 ± 6.5
Jodhpur, Rajasthan Relative Error (%)	350.4 ± 0.4	39 ± 3.02	12.55 ± 1.95	32 ± 3.25	10.95 ± 1.02	14.39 ± 6.42
Gurugram, Haryana Relative Error (%)	348.60 ± 1.4	39 ± 3.02	12.48 ± 1.86	32 ± 3.25	10.89 ± 0.96	14.32 ± 6.48
Chennai,Tamil Nadu Relative Error (%)	341.44 ± 8.65	39 ± 3.02	12.27 ± 1.65	32 ± 3.25	10.67 ± 0.74	14.03 ± 6.77
Gwalior, Madhya Pradesh Relative Error (%)	348.18 ± 1.52	39 ± 3.02	12.48 ± 1.86	32 ± 3.25	10.89 ± 0.96	14.31 ± 6.49

and 4). The low value of solar irradiance may be due to cloudy weather. Whereas in Sonitpur, Assam, low power in January is due to the low value of solar irradiance; however, the temperature is appropriate this month. It has also been observed that the maximum power is produced in February; however, in the case of Chennai, it is March. The maximum power is generated due to good solar irradiance and appropriate environment temperature. January to March is the winter session in India. Hence, a general inference can be drawn from the results that more power can be produced in the winter session compared to the summer session. The proposed model is the generic model that can be implemented at any location in the world. In the present work, the data has been analyzed at different locations in India. Present analysis may be helpful in the determination of the time spam when the maintenance of the installed solar module can be done. The present analysis shows that the summer is the best suitable time for maintenance in India, in general. The analysis may also be useful in the determination of installation time.

The comparison of the reference model values, which were calculated under standard test conditions, with the simulated model values is presented in Table 4. The relative percentage error between the two is also included in the table. According to this data, the lowest relative error (Power Output) has been observed at Jodhpur, Rajasthan, and the highest relative error (Power Output) has been observed at Chennai, Tamil Nadu. The climate of Chennai is hot and humid, and torrential rains arrive during the northeast monsoon season. Chennai belongs to the thermal equator and is also a coastal region that prohibits extreme fluctuations of seasonal temperature. Most of the year, it's hot and moist. The most dominant winds at Chennai are southwest between late May to late September and northeast during the rest of the year. Hence, Chennai has the highest error.

Conclusions

The study presented in this paper developed a mathematical model to analyze the performance of a single-cell solar PV module under different temperatures and irradiance conditions in various locations in India. The results showed that the voltage and power increase with a decrease in temperature, while the current and power increase with an increase in solar irradiance. The study found that the summer season is the best time for maintenance and installation of solar panels in India, and that the location of Jodhpur, Rajasthan had the lowest relative error and is therefore the best place for solar panel installation. In terms of future scope, this study can be extended to analyze the performance of multi-cell solar PV modules or to investigate the effects of different weather conditions on solar panel performance. Additionally, the findings of this study can have practical applications in the selection and optimization of solar panel installations in various locations, particularly in developing countries like India, where it can help save time, money, and resources.

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