UNDERSTANDING THE SUN'S ROLE AND ANALYZING PV SYSTEM PERFORMANCE

M Bhanu Prakash[1], Venkatesh Tadivalasa[2], Relli Pavani[3], S Bangari Naidu[4], P Varaprasad[5]

[2,3]Assistant Professor, Department of Electrical and Electronics Engineering, Satya Institute of Technology and Management, Vizianagaram, Andhra Pradesh, India

[1,4,5]B.tech Student , Department of Electrical and Electronics Engineering, Satya Institute of Technology and Management, Vizianagaram, Andhra Pradesh, India

Email: bhanumerugula@gmail.com[1]

***

Abstract - This paper aims to enhance the understanding of solar photovoltaic (PV) systems by conducting a detailed analysis under varied environmental conditions. While the base study focused on a singular scenario (1000 irradiance at 25 degrees Celsius), our project explores a broader spectrum. We systematically tested the system with different irradiances (1000, 900, 800, and 700) at a constant 25 degrees Celsius and diverse temperatures (25 and 30 degrees Celsius) to comprehensively evaluate its behavior. Leveraging Matlab/Simulink, we developed an intricate PV cell model, considering non-linear characteristics and the influence of temperature and irradiance. Simulink provided a simulated environment to emulate real-world conditions, incorporating factors such as temperature and irradiance sensors. Throughout testing, data logging in Simulink enabled the collection of crucial parameters, facilitating the calculation and analysis of PV and IV characteristics. Our project documentation will detail the modeling approach, assumptions, and insights gained from this extensive exploration, shedding light on the solar PV system's response to varying environmental factors.

Key Words: Solar cell, PV System, P&O, MPPT

1.INTRODUCTION

The pressing need to combat climate change has propelled the global transition towards cleaner energy sources. Among these, solar power stands out as a promising solution, leveraging the abundant and renewable energy of the Sun. In recent years, significant advancements have been made in solar energy technologies, enhancing their efficiency, affordability, and accessibility. This essay explores the evolution of solar power generation, focusing on innovative methods to maximize its output, the challenges faced, and the opportunities it presents in the global energy landscape.

1.1 Evolution of Solar Power Generation

Solar power, as a concept, has existed for centuries, with ancient civilizations harnessing sunlight for various purposes. However, it wasn't until the late 19th and early 20th centuries that significant strides were made in solar energy technology. The discovery of the photovoltaic effect laid the foundation for modern solar panels, allowing the direct conversion of sunlight into electricity. Since then, solar power has experienced exponential growth, driven by advances in materials science, engineering, and manufacturing processes.

1.2 The Rise of Renewable Energy

The 21st century has witnessed a surge in renewable energy adoption, spurred by concerns over climate change, energy security, and economic sustainability. Solar power, in particular, has emerged as a frontrunner in the renewable energy transition. Its inherent advantages, including inexhaustible supply, zero emissions, and versatility, have positioned it as a key player in the quest for a sustainable energy future.

1.3 Maximizing Solar Power Output

One of the critical challenges in solar power generation is maximizing energy output from photovoltaic (PV) panels. To address this challenge, researchers and engineers have developed various strategies aimed at optimizing the performance of solar energy systems. Among these, mechanical tracking systems play a pivotal role, ensuring that solar panels remain aligned with the Sun throughout the day to capture maximum sunlight. Additionally, sophisticated algorithms, such as the The Perturb and Observe (P&O) algorithm is utilized to continuously monitor and adjust solar panel parameters in order to accurately track the Maximum Power Point (MPP). This technique plays a pivotal role in optimizing solar panel efficiency.

1.4 Innovations in Solar Power Tracking

While mechanical tracking systems have been effective in improving solar power generation, they are not without limitations. Issues such as cost, complexity, and maintenance requirements have prompted the exploration of alternative tracking mechanisms. Recent innovations in solar tracking technology have focused on leveraging advanced materials, sensors, and control systems to develop more efficient and cost-effective tracking solutions. For example, novel approaches utilizing machine learning algorithms and artificial intelligence (AI) have shown promise in optimizing solar panel orientation in real-time, thereby maximizing energy output.

1.5 Challenges in Solar Power Optimization

Despite the progress made in maximizing solar power output, several challenges persist. One of the primary challenges is the intermittent nature of solar irradiance, which can lead to fluctuations in energy production. Additionally, factors such as shading, dust accumulation, and temperature variations can adversely affect the performance of solar panels, reducing their overall efficiency. Furthermore, the integration of solar power into existing energy grids poses technical and regulatory challenges, requiring robust infrastructure and policy frameworks to facilitate seamless integration.

1.6 Opportunities for Solar Power Integration

Despite these challenges, solar power integration presents significant opportunities for enhancing energy security, mitigating climate change, and driving economic growth. The decentralization of energy production through distributed solar systems can improve resilience and reliability, reducing reliance on centralized power plants. Moreover, solar energy has the potential to create new job opportunities, stimulate innovation, and spur investment in clean energy infrastructure. Furthermore, progress in energy storage technologies, such as batteries and pumped hydro storage, is enhancing grid flexibility, thereby easing the incorporation of intermittent renewable energy sources like solar power.

1.7 Policy and Economic Considerations

Government policies and economic incentives are pivotal in fostering the adoption and investment in solar power. Many nations have introduced measures such as feed-in tariffs, tax incentives, and renewable energy targets to promote the installation of solar energy systems. Furthermore, the declining cost of solar photovoltaic technology, driven by economies of scale and technological advancements, has made solar power increasingly competitive with conventional energy sources. Consequently, solar power has become economically competitive in numerous areas, further encouraging its widespread deployment.

2. MODELING PHOTOVOLTAIC PANELS

A typical representation of a solar cell employs a model comprising a current source alongside an inverted diode connected in parallel. This model effectively describes how the solar cell generates electrical current in response to sunlight exposure. Additionally, the cell possesses series and parallel resistances, each serving distinct purposes in the cell's operation.

The series resistance emerges due to impediments encountered by electrons during their journey from the n-type to the p-type junction within the cell. Conversely, the parallel resistance is attributed to leakage currents, which can occur due to various factors.

When solar irradiance strikes the surface of a photovoltaic (PV) cell, it initiates the generation of an electric field within the cell. This field facilitates the separation of positive and negative charge carriers within the cell's absorbing material, typically formed by the junction of n-type and p-type semiconductor layers.

As illustrated in Figure 3, this separation process enables the creation of a current within the cell, which can then be utilized in an external circuit. The generated current's magnitude varies directly with the incident radiation's intensity. Essentially, higher light intensity levels lead to more electrons being liberated from the cell's surface, consequently boosting current generation.

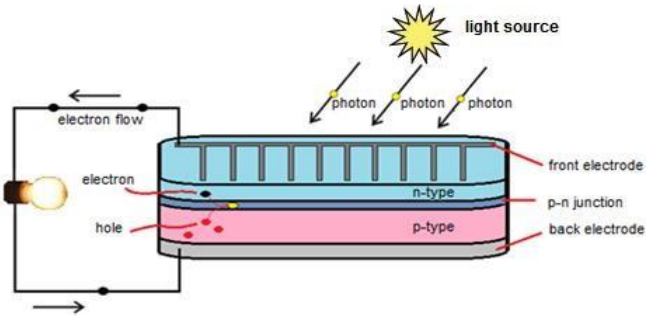

Fig 1. Schematic Cross-Section of a Typical Solar Cell

The precision of simulating photovoltaic (PV) systems greatly depends on the accuracy of the PV cell model. Modeling a PV cell involves precisely estimating its current-voltage (I-V) and power-voltage (P-V) characteristics to replicate real-world behavior under varying environmental conditions.

In an ideal situation, a solar cell is depicted as a current source connected in parallel with a diode. Nevertheless, real solar cells deviate from this ideal behavior, necessitating the inclusion of additional elements in the model. Figure 2 demonstrates this concept by integrating shunt and series resistances into the model.

These additional components account for practical factors affecting the performance of the PV cell. The series resistance reflects hindrances encountered by electron flow within the cell, while the shunt resistance represents leakage currents. Integrating these resistances into the model enables a more accurate depiction of the PV cell's behavior under diverse operating conditions.

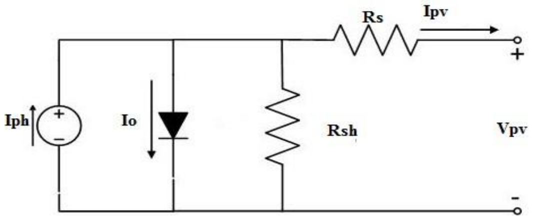

Fig 2. Equivalent Circuit of PV Cell

The current Ipv source within the model represents the photocurrent of the cell, while Rsh and Rs signify the inherent series and shunt resistance of the cell, respectively. Typically, Rsh has a significantly large value, while Rs has a very small value, making them negligible for simplifying analysis. As a result, the ideal voltage-current behavior of a photovoltaic cell can be described by the following equation and is illustrated in the accompanying figure.

I=Iph-ID

$$I = I_{ph} - I_0\left[\exp\left(\frac{q(V+R_s I)}{A k_B T}\right) - 1\right] - \frac{V+R_s I}{R_{sh}}$$

Where,

Iph = photocurrent,
ID = diode current,
I0 = saturation current,
A = ideality factor,
q = electronic charge 1.6x10-9,
kB = Boltzmann’s gas constant (1.38x10^-23),
T = cell temperature,
Rs = series resistance,
Rsh = shunt resistance,
I = cell current,
V = cell voltage

The power output of a solar cell is given by
PPV = VPV * IPV
Where,

IPV = Output current of solar cell (A).

VPV = Solar cell operating voltage (V).

PPV =Output power of solar cell (W).

Below is the power-voltage (P-V) characteristic of a photovoltaic module operating under standard conditions with an irradiance of 1000 W/m2 and a temperature of 25°C.

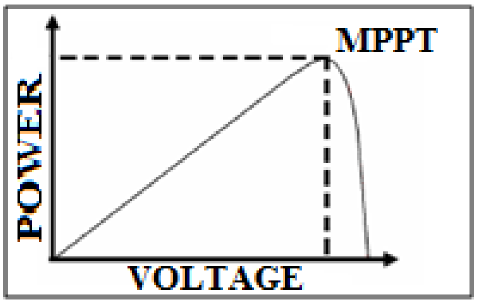

Fig 3. The Power-Voltage (PV) Characteristic of a Photovoltaic Module.

3. ALGORITHM FOR MAXIMIZING POWER POINT TRACKING

A standard solar panel typically transforms merely 30 to 40 percent of incoming solar radiation into electrical power. To enhance efficiency, Maximum Power Point Tracking (MPPT) technique is employed.

Per the Maximum Power Transfer theorem, the power output of a circuit reaches its maximum when the Thevenin impedance (source impedance) aligns with the load impedance. Hence, the task of tracking the maximum power point can be seen as a challenge of achieving impedance matching.

A boost converter is employed on the source side, linked to the solar panel, to elevate the output voltage for diverse applications like motor loads. By tuning the boost converter's duty cycle appropriately, the source impedance can be aligned with the load impedance.

3.1 Perturb and Observe

The Perturb and Observe (P&O) method stands out for its simplicity. It relies solely on one sensor, the voltage sensor, to monitor the PV array voltage. This results in reduced implementation costs and simplified setup. Although this algorithm has low time complexity, it tends to overshoot the MPP and continues perturbing in both directions when it gets very close to the MPP. To tackle this concern, one can establish suitable error thresholds or integrate a wait function, thereby elevating the algorithm's time complexity. However, P&O does not account for rapid changes in irradiation levels, erroneously interpreting them as changes in MPP due to perturbation. To mitigate this problem, the incremental conductance method can be employed.

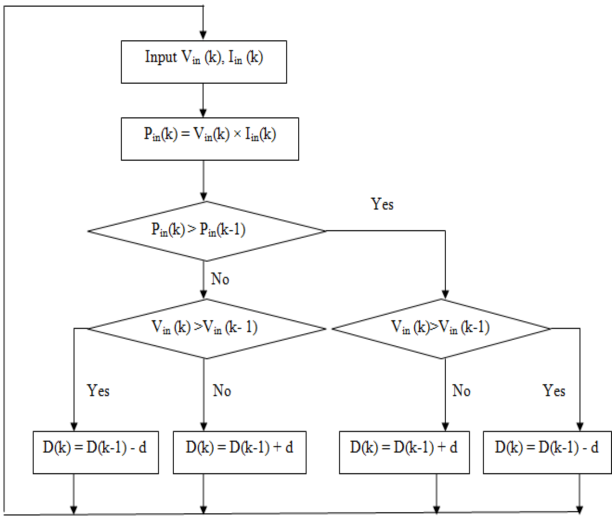

Figure 4. Flowchart of Perturb & Observe Algorithm

4. SIMULATION RESULTS

Construction of PV Module Using MATLAB

TABLE 1. Solar Cell Parameters [13]

Parameter	Variable	Specifications
Open Circuit Voltage	VOC	40.4 Volts
Short Circuit Current	ISC	10.11 Amps
Current at MPP (Calculated)	I_M	9.4614 Amps
Voltage at MPP (Calculated)	V_M	34.0013 Volts
Diode Saturation Current	Id	300 nano-Amp
Power at MPP (Calculated)	Pm	321 watts
Diode Ideality Factor	n	1.5
Number of solar PV cells in a panel	N	60
Thermal Voltage	V_t	0.0259 Volts

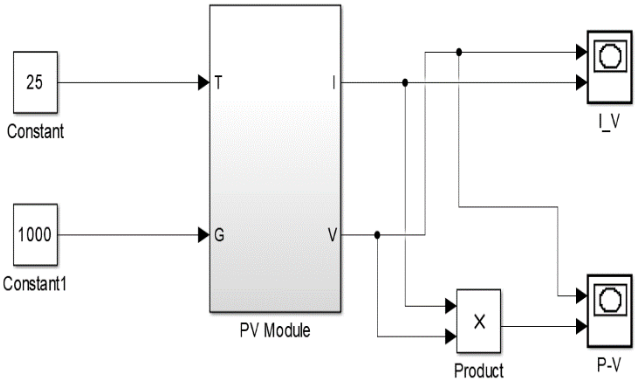

Fig-5: Construction of PV Module (Main Block) using MATLAB

Output at 1000W/m^2 Irradiance for 25^0

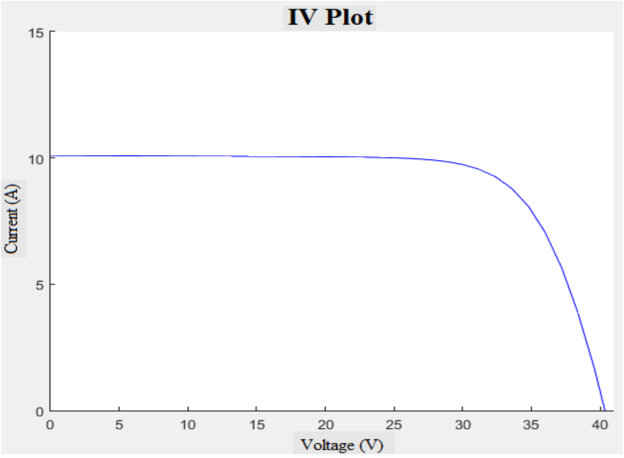

Fig-6: IV characteristics

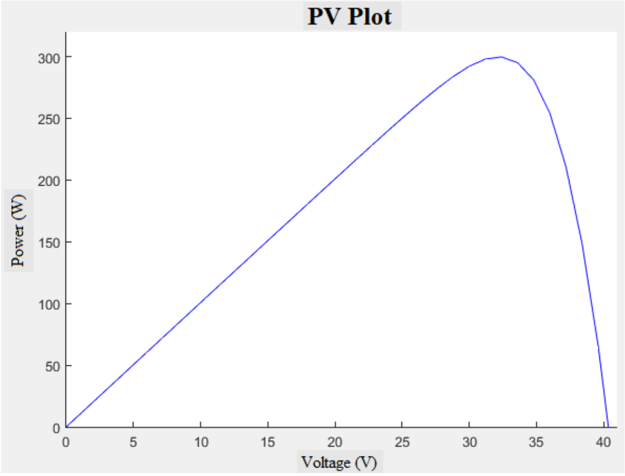

Fig-7: PV characteristics

In the depicted figure, the maximum power, reaching 305 W, is attained at 31V with a current of 10A.

Output at 800W/m^2 Irradiance for 25^0

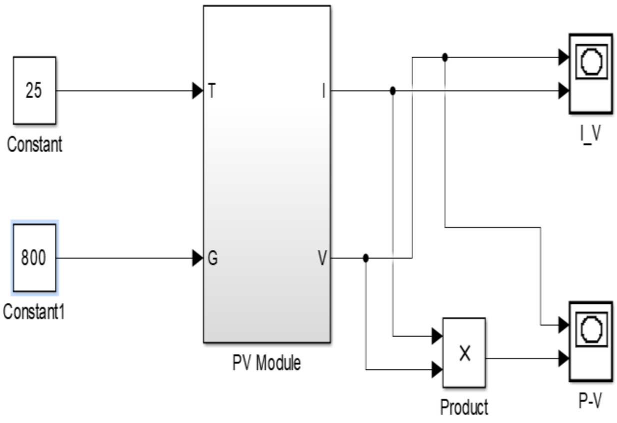

Fig. 8: Construction of PV Module for 800W/m^2 Irradiance

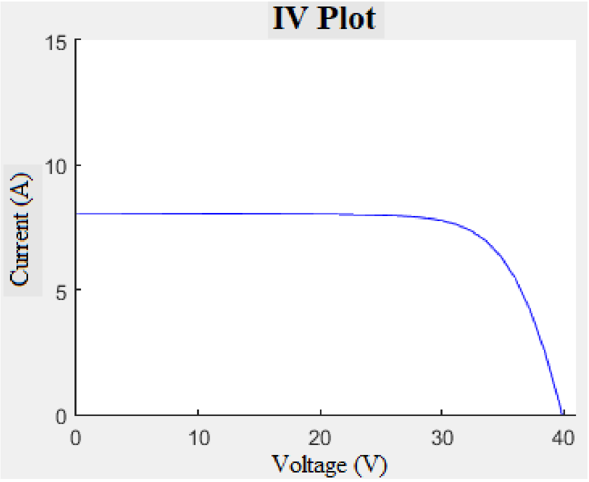

Fig-9: IV characteristics

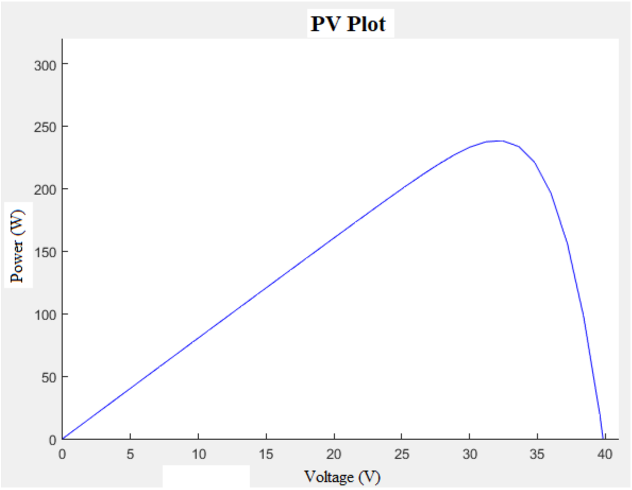

Fig-10: PV characteristics

From the above figure maximum power is 237 W which is obtained at 30.3V. The current is 7.7A

Output at 600W/m^2 Irradiance for 25^0

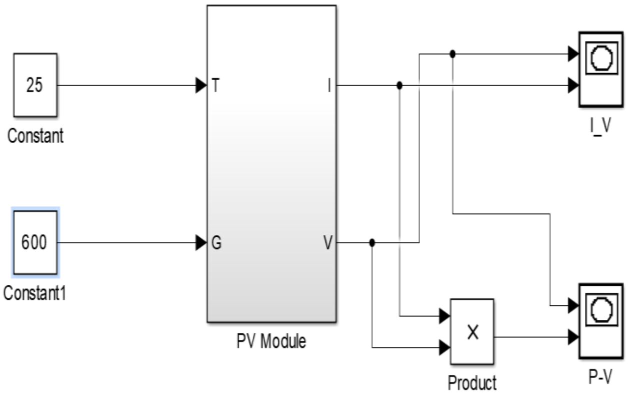

Fig-11: Construction of PV Module for 600W/m^2 Irradiance

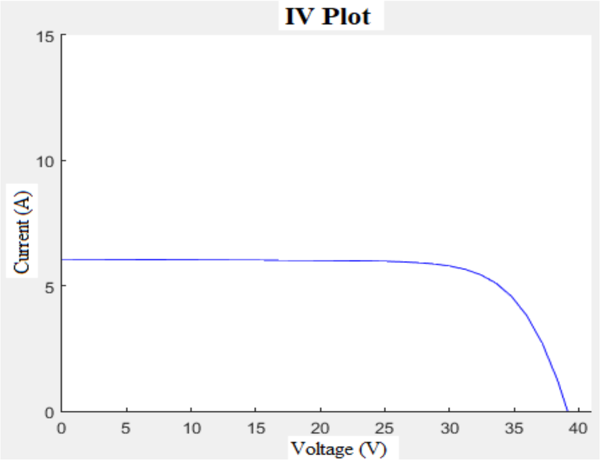

Fig-12: IV characteristics

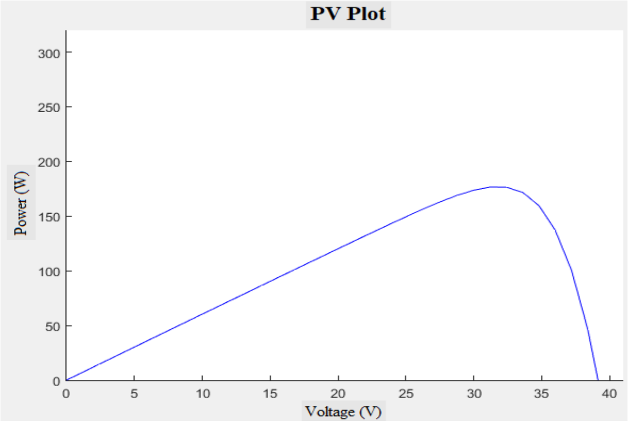

Fig-13: PV characteristics

From the above figure maximum power is 175 W which is obtained at 29V. The current is 6.017A

Table 2. Power, Voltage and Current values at 25 degrees Celsius

Irradiance (W/m^2)	Power (W)	Voltage (V)	Current (A)
1000	305	31	10
950	280	29.3	9.54
900	262.5	29	9.068
850	250	29.41	8.5
800	237	30.3	7.7
750	225	30.4	7.4
700	200	28.4	7.03
650	187	28.41	6.58
600	175	29	6.017

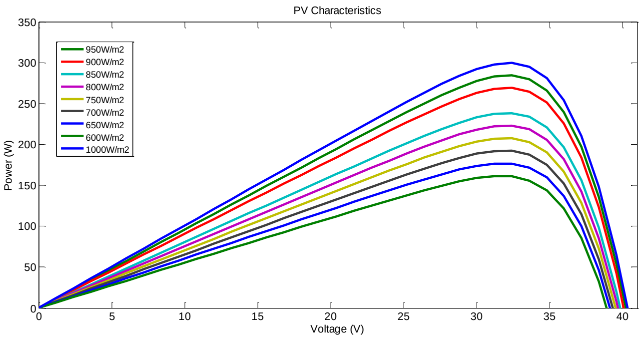

Fig-14: Influence of the various ambient irradiation on the PV cell (PV Plots)

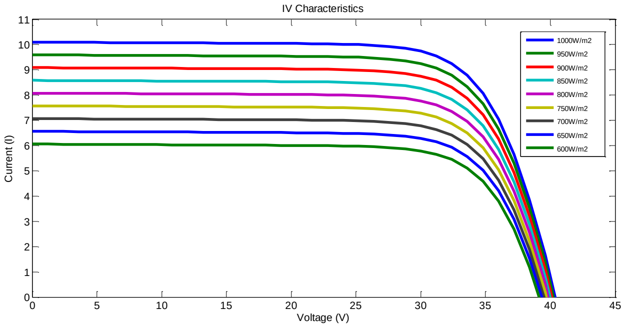

Fig-15: Influence of the various ambient irradiation on the PV cell (IV Plots)

Table 3. Power, Voltage and Current values at 30 degrees Celsius

Irradiance (W/m^2)	Power (W)	Voltage (V)	Current (A)
1000	290	29	10.1
950	270	28.42	9.5
900	250	27.7	9
850	230	27	8.5
800	210	26.25	8
750	190	25.3	7.5
700	170	24.28	7
650	160	24.61	6.5
600	150	25	6

Output at different Irradiance for 30^0

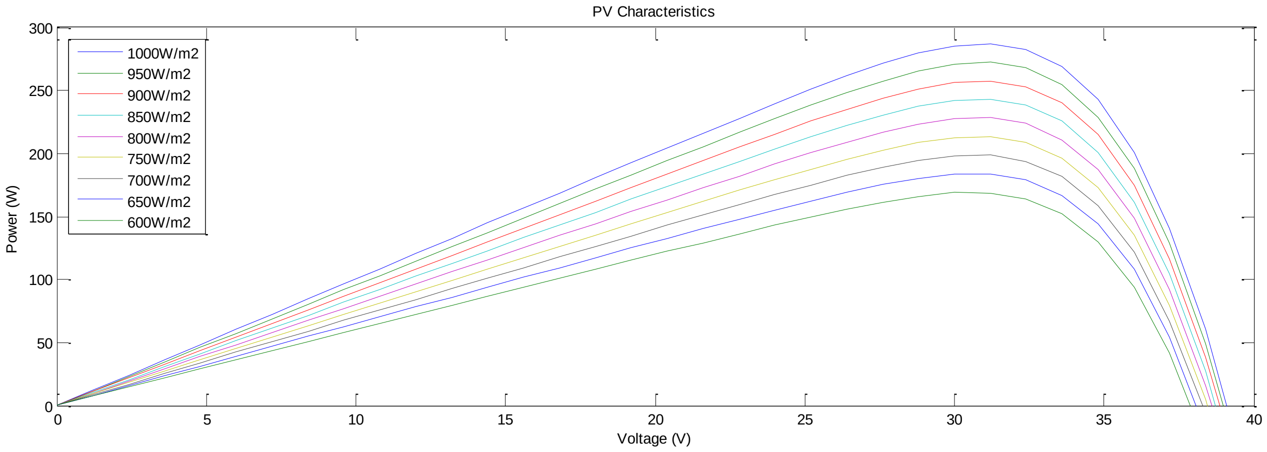

Fig-16: Influence of the various ambient irradiation on the PV cell (PV Plots)

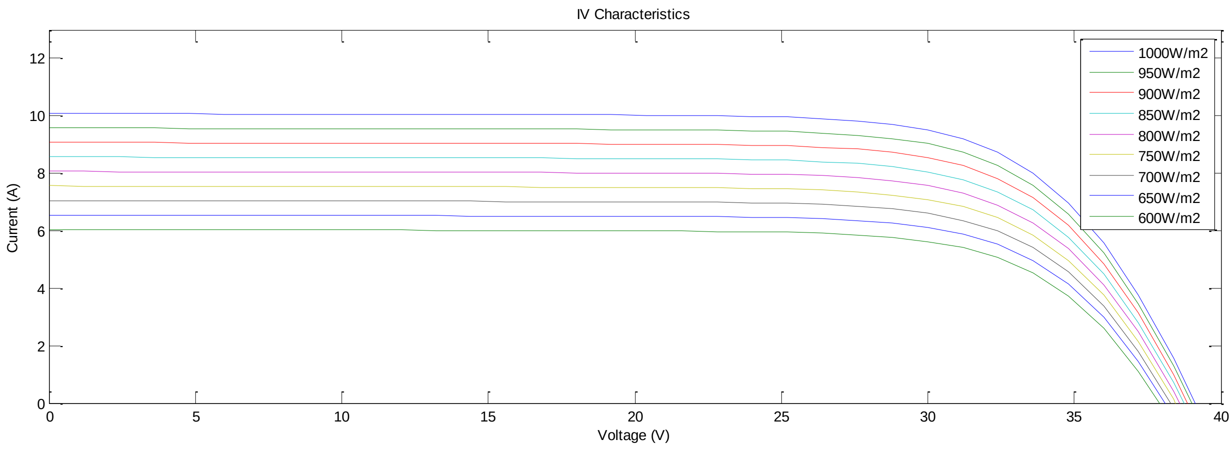

Fig-17: Influence of the various ambient irradiation on the PV cell (IV Plots)

5. CONCLUSION

Testing the PV panel under different temperature and irradiance conditions unveiled significant variations in power output. Specifically, at 25 degrees Celsius, the panel consistently exhibited higher power values across the range of irradiance levels tested (from 600W/m2 to 1000W/m2) compared to its performance at 30 degrees Celsius. This observation underscores the significant impact of temperature on the efficiency of PV panels, with higher temperatures generally leading to reduced power output due to increased internal resistance and decreased cell efficiency. The results suggest that temperature management is crucial for optimizing the performance of PV systems, particularly in environments where temperature fluctuations are significant. Therefore, strategies such as thermal management techniques or selecting suitable mounting locations to mitigate temperature effects should be considered to maximize the energy yield and overall efficiency of PV installations.

REFERENCES

[1] N. Pandiarajan and Ranganath Muth” Mathematical Modeling of Photovoltaic Module with Simulink” in 2011 1st International Conference on Electrical Energy Systems.

[2] Alpesh P. Parekh, Bhavarty N. Vaidya and Chirag T. Patel”Modeling and Simulation Based Approach of Photovoltaic System” in Global Research Analysis Volume 2 Issue 4 April 2013 • ISSN No 2277 – 8160.

[3] Pandiarajan N, Ramaprabha R and Ranganath Muthu” Application Of Circuit Model For Photovoltaic Energy Conversion System”.

[4] G. Venkateswarlu and Dr.P.Sangameswar Raju” Simscape Model Of Photovoltaic Cell” in International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering Vol. 2, Issue 5, May 2013.

[5] Vandana Khanna, Bijoy Kishore Das, Dinesh Bisht “MATLAB/SIMELECTRONICS Models Based Study of Solar Cells” in INTERNATIONAL JOURNAL of RENEWABLE ENERGY RESEARCH Vandana Khanna et al., Vol.3, No.1, 2013.

[6] Mihnea Rosu-Hamzescu, Sergiu Opera” Practical Guide to Implementing Solar Panel MPPT Algorithms”.

[7] P.Sathya, Dr.R.Natarajan” Design and Implementation of 12V/24V Closed loop Boost Converter for Solar Powered LED Lighting System “ in International Journal of Engineering and Technology (IJET) Volumeg No 1 Feb-Mar 2013.

[8] IEA (2019), "Solar Energy: Mapping the Road Ahead", IEA, Paris https://www.iea.org/reports/solar-energy-mapping-the-road-ahead.

[9] Whavale, S., and Dhavalikar, M. (2018). "A review of Adaptive solar tracking for performance enhancement of solar power plant." 2018 International Conference on Smart City and Emerging Technology (ICSCET).

[10] Elgendy, M. A., Zahawi, B., and Atkinson, D. J. (2012). "Evaluation of perturb and observe MPPT algorithm implementation techniques." 6th IET International Conference on Power Electronics, Machines and Drives (PEMD 2012).

[11] Hohm, D. P., and M. E_ Ropp. "Comparative study of maximum power point tracking algorithms." Progress in photovoltaics: Research and Applications 11.1 (2003): 47-62.

[12] Salas, V., Olias, E., Barrado, A., and Lazaro, A. (2006). "Review of the maximum power point tracking algorithms for stand-alone photovoltaic systems." Solar energy materials and solar cells, 90(11), 1555-1578.

[13] Xiao, Weidong, and William G. Dunford. "A modified adaptive hill climbing MPPT method for photovoltaic power systems." 2004 IEEE 35th annual power electronics specialists conference (IEEE Cat. No. 04CH37551). Vol. 3. Ieee, 2004.

[14] Pandey, Ashish, Nivedita Dasgupta, and Ashok Kumar Mukerjee. "High-performance algorithms for drift avoidance and fast tracking in solar MPPT

system." IEEE Transactions on Energy Conversion 23.2 (2008): 681-689.

[15] Dinesh, L., Sesham, H., & Manoj, V. (2012, December). Simulation of D-Statcom with hysteresis current controller for harmonic reduction. In *2012 International Conference on Emerging Trends in Electrical Engineering and Energy Management (ICETEEEM)* (pp. 104-108). IEEE

[16] J. Huang and K. A. Corzine, "Extended operation of flying capacitor multilevel inverter," *IEEE Trans. Power Electron.*, vol. 21, no. 1, pp. 140–147, Jan. 2006.

[17] Manoj, V. (2016). Sensorless Control of Induction Motor Based on Model Reference Adaptive System (MRAS). *International Journal For Research In Electronics & Electrical Engineering*, *2*(5), 01-06.

[18] J. I. Leon, S. Vazquez, S. Kouro, L. G. Franquelo, J. M. Carrasco, and J. Rodriguez, "Unidimensional modulation technique for cascaded multilevel converters," *IEEE Trans. Ind. Electron.*, vol. 49, no. 5, pp. 1058–1064, Oct. 2002.

[19] V. B. Venkateswaran and V. Manoj, "State estimation of power system containing FACTS Controller and PMU," 2015 IEEE 9th International Conference on Intelligent Systems and Control (ISCO), 2015, pp. 1-6, doi: 10.1109/ISCO.2015.7282281.

[20] Manohar, K., Durga, B., Manoj, V., & Chaitanya, D. K. (2011). Design Of Fuzzy Logic Controller In DC Link To Reduce Switching Losses In VSC Using MATLAB-SIMULINK. *Journal Of Research in Recent Trends*.

[21] Manoj, V., Manohar, K., & Prasad, B. D. (2012). Reduction of switching losses in VSC using DC link fuzzy logic controller *Innovative Systems Design and Engineering ISSN*, 2222-1727.

[22] G. Ceglia, V. Guzman, C. Sanchez, F. Ibanez, J. Walter, and M. I. Gimanez, "A new simplified multilevel inverter topology for DC–AC conversion," *IEEE Trans. Power Electron.*, vol. 21, no. 5, pp. 1311–1319, Sep. 2006.

[23] N. A. Rahim and J. Selvaraj, "Multi-string five-level inverter with novel PWM control scheme for PV application," *IEEE Trans. Ind. Electron.*, vol. 57, no. 6, pp.2111–2121, Jun. 2010.

[24] Dinesh, L., Harish, S., & Manoj, V. (2015). Simulation of UPQC-IG with adaptive neuro fuzzy controller (ANFIS) for power quality improvement. *Int J Electr Eng*, *10*, 249-268.

[25] E. Villanueva, P. Correa, J. Rodríguez, and M. Pacas, "Control of a single phase cascaded H-bridge multilevel inverter for grid-connected photovoltaic systems," *IEEE Trans. Ind. Electron.*, vol. 56, no. 11, pp. 4399–4406, Nov. 2009.

[26] "Modeling and Simulation of Photovoltaic module using MATLAB/Simulink", *International Journal of Chemical and Environmental Engineering*, Volume 2, No.5 , October 2011.

[27] "Mathematical Modeling and Simulation of Photovoltaic Cell using Matlab-Simulink Environment", *International Journal of Electrical and Computer Engineering (IJECE)*,Vol. 2, No. 1, February 2012