# Experimental Analysis of Different Parameters on the Performance of Solar Photovoltaic Modules

V.V.M.R. Srinivasulu Reddy (MTech), Vaibhav Tripathi (MTech), Yogender Singh Pal (MTech), Yatharth Kumar (MTech), Martin Veny (MTech)
Department of Sustainable Energy Engineering, Indian Institute of Technology, Kanpur

***Abstract* - Solar energy has become one of the most promising energy sources which has the potential to replace fossil fuels. Nowadays electricity generated from solar energy is much less compared to fossil fuels, and even amongst other renewable energy sources. Solar PV module converts solar energy into electrical energy. This energy is used in various applications. The biggest challenge in solar PV modules is their energy conversion efficiency. Energy conversion depends on various parameters such as solar radiation intensity incident on the solar PV module, the tilt angle of a module, shading of the modules caused during the nighttime, rainfall, cloudy sky, dust, etc., and change in module temperature. Considering all these parameters, an experimental study of solar PV modules is conducted inside a laboratory with artificial sunlight using halogen lights. Analysis of Current-Voltage (I-V) and Power-Voltage (P-V) characteristics under different conditions of radiations, tilt angle, and temperature, and in different module arrangements (series and parallel arrangement) was carried out. The results revealed that with an increase in radiation intensity, there is an increase in power output, voltage, and current. Increasing the tilt angle reduces the power output, and maximum power output was observed at $0^o$ tilt angle where the module is perpendicular to the incident radiation. An increase in module temperature results in a reduction in power output and efficiency. Shading one module connected in series with the second module decreases the voltage and power output. These parameters will be optimized to extract maximum power and efficiency under different conditions. The finding of this study will result in increasing electricity generation, reducing dependency on fossil fuels resulting in a decrease in greenhouse gas emissions, energy security, and cost reduction.***

***Keywords*- Solar cell, solar PV module, I-V characteristics, P-V characteristics, radiation intensity, tilt angle, shading, module temperature, open-circuit voltage ($V_{oc}$), short-circuit current ($I_{sc}$).***

## I. Introduction

Energy generation using fossil fuels has created huge environmental and health impacts. Changes such as the melting of glaciers, increase in sea level, forest fires, cyclones, drought, heavy rainfall, etc. are observed all over the world [1,2]. The use of fossil fuels has increased the concentration of carbon dioxide ($CO_2$) in the atmosphere which has given rise to global warming which then increases the global average temperature. The global average temperature has increased to 1.11 °C compared to the pre-industrial revolution [3]. If the use of fossil fuels increases continuously the global average temperature is projected to exceed 2 °C. This will lead to extreme weather conditions, loss of species, impact on human health and food production, etc. [3]. To prevent these disasters, countries have adopted many policies and mitigation measures [4]. One of these policies is to increase the installed capacity of renewable energy sources to generate electricity. Renewable energy sources emit very little to no emissions. An increase in renewable energy will help reduce greenhouse gas emissions [5]. Many countries have taken steps to increase their installed capacity of renewable energy.

India's renewable energy installed capacity as of January 2024 is 135116.36 MW excluding large hydropower [6]. India has announced many goals at the Conference of the Parties (COP26) which includes an increase in installed capacity to 500 GW of renewable energy sources and 50 percent electricity generation from non-fossil fuel sources by 2030. India also announced their target to achieve net-zero emissions by 2070 at COP26 [7]. To achieve these goals solar energy will play a very important role unlike other renewable energy sources, installation of solar photovoltaic (PV) systems at the site or on the rooftops is easy and safe compared to other renewable sources. The government has announced various policies to subsidize the installation of solar PV systems on the rooftops [8,9].

Solar photovoltaic (PV) cells are an important part of solar energy conversion systems. Solar PV cells convert solar energy into electrical energy. They are made of semiconductor materials and work as a P-N junction diode [10]. Several solar PV cells are connected in series and parallel combinations to form a solar PV module and several solar PV modules are connected to form a solar PV panel. The series and parallel combinations of solar cells in a solar PV module are based on the output requirements. One solar cell produces 0.5 to 0.6 V therefore, to get the desired voltage several solar cells are connected in series, and to get the desired current solar cells are connected in parallel.

The objective of this study is to analyze the Current-Voltage (I-V) and Power-Voltage (P-V) characteristics of solar PV modules under different radiation intensities and in series and parallel combinations. Study the effects of other parameters like tilt angle, shading, and temperature on the solar PV modules. Conducting these tests helps better understand the effects of different parameters on the solar PV modules and optimize these parameters to extract the best voltage, current, power output, and efficiency combination to generate electricity. General, I-V and P-V characteristics of a solar PV module are shown in figure 1 and figure 2 [11] respectively. Optimizing the parametric performance of solar PV modules helps India to achieve its goals by 2030, its target of net-zero emissions by 2070.

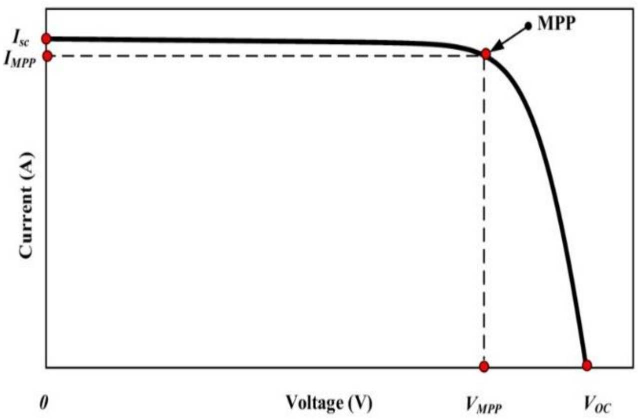


**Fig.1.** Current-Voltage (I-V) characteristics

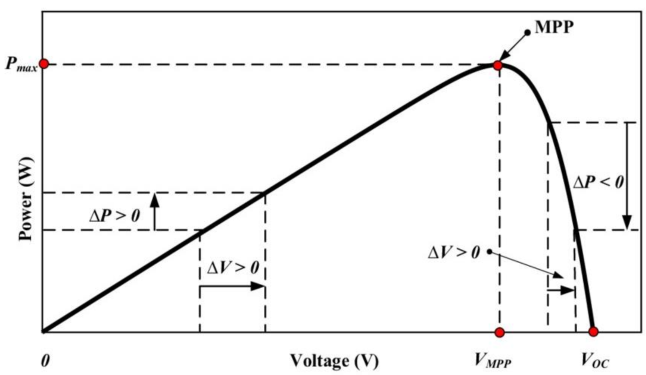


**Fig.2.** Power-Voltage (P-V) characteristics

## II. Methodology

### A. Setup description

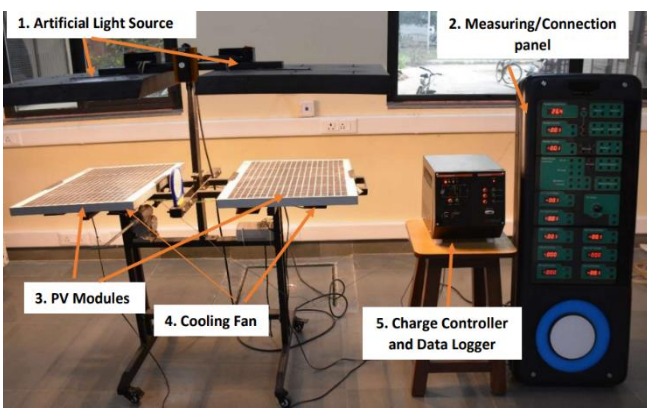


**Fig.3.** Experimental setup

This setup is a small-scale model of an actual solar PV power plant and is adapted to be used indoors. The setup includes 12 halogen lights of 150W each with a total power rating of 1800W and generates a maximum light intensity of 550W/m$^2$ to simulate sunlight, two batteries rating 4.5Ah, 12V each, two solar PV modules rating 40W each made of polycrystalline material, cooling fans used to cool the panels, data logger and charge controller unit. The PV modules are connected to a panel where the different plug-in units can be connected. For taking the reading of voltage and current values, ECOSENSE's solar PV training and research system is used via the data logger.

This study proposes five experiments which include understanding the effect of radiation, tilt angle, and temperature on the solar PV module characteristics, the effect of series and parallel connection of the module, and the use of a bypass diode in case of shading. For each experiment, the parameters such as radiation intensity, tilt angle, temperature, and load, are monitored and measured with the help of a pyranometer, an inclinometer, a thermocouple, and a potentiometer respectively.

TABLE I: Specification of measurement devices

| Sr. No. | Measuring device | Unit | Least Count |
|---|---|---|---|
| 1 | Ammeter (DC) | A | 0.001 |
| 2 | Voltmeter (DC) | V | 0.1 |
| 3 | Ammeter (AC) | A | 0.001 |
| 4 | Voltmeter (AC) | V | 1 |
| 5 | K- Type Thermocouple | °C | 0.1 |
| 6 | Pyranometer | W/m$^2$ | 0.01 |
| 7 | Inclinometer | degree ($^0$) | 1 |
| 8 | Potentiometer | Ω | 30 Counts |

### B. Experimental Procedure

In this study, the radiation is set at different values by using the radiation intensity regulator and measuring the intensity at the top, middle, and bottom, and taking the average of these 3 locations the intensities are set at approximate values of 110, 220, and 330 W/m$^2$. Except in experiment 3, the tilt angle is kept at zero degrees in all other experiments.

*1) Effect of radiation on I-V and P-V characteristics*

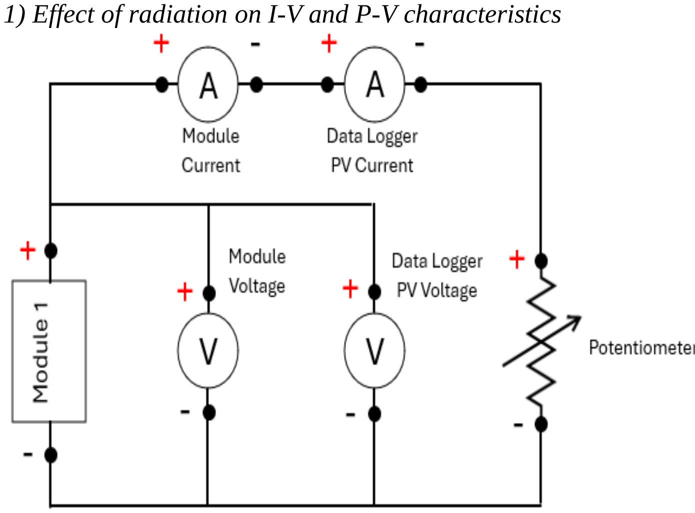


**Fig.4.** Circuit diagram for the evaluation of I-V and P-V characteristics

The I-V curve is generated by varying the load resistance from maximum to zero and recording the current and voltage of the module, as shown in figure 4. This curve is used to determine key parameters such as the short-circuit current ($I_{sc}$), open-circuit voltage ($V_{oc}$), maximum power current ($I_{mp}$), and voltage ($V_{mp}$). The P-V curve is generated by multiplying the current and voltage obtained at various load resistances and plotting the results against the voltage. To measure the impact of radiation on the module, the I-V and P-V curves are plotted at radiation levels of 106.33, 223.33, and 332.66 W/m².

*2) Interconnection of solar PV modules*

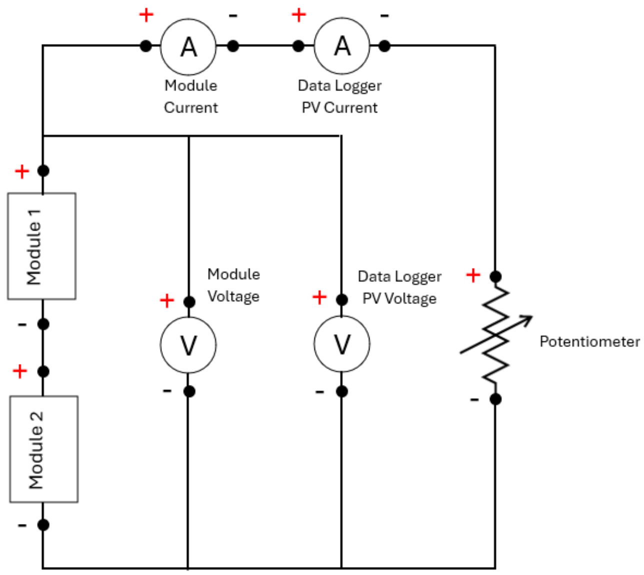


**Fig.5.** Circuit diagram for series connection

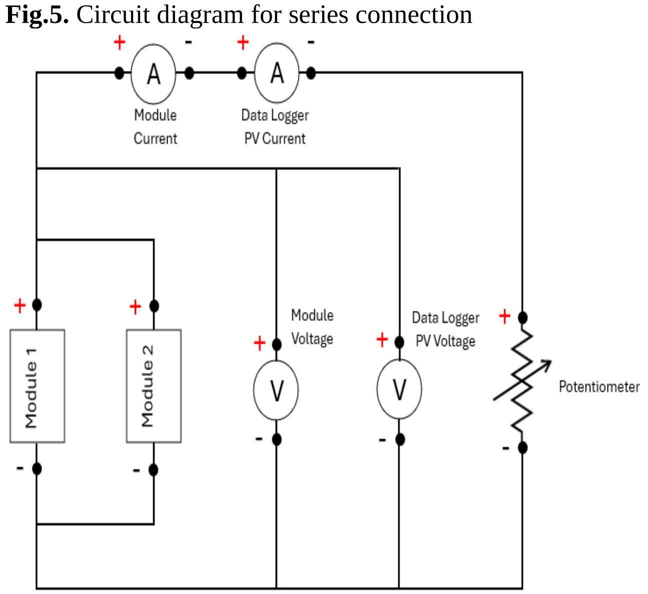


**Fig.6.** Circuit diagram for parallel connection

In this experiment, solar PV modules are configured in both series and parallel connections as shown in figures 5 and 6 respectively to observe the effect of radiation on I-V and P-V characteristics for each setup. The I-V curve is plotted with the same process as discussed in the previous experiment, where the load resistance is varied, and the current and voltage across the interconnection are observed. The P-V curve is also generated by multiplying the current and voltage measured, and the two curves are measured under different radiation intensities of 109.66, 222.66, and 332.66 W/m².

*3. Effect of tilt angle on the power output*

The solar PV module is connected to the setup, as shown in figure 7. By adjusting the tilt angle of the solar module for every 5 degrees from 0 to 35 degrees, readings of voltage and current were noted. Throughout the experiment, the radiation intensity and load resistance were kept constant.

*4) Effect of shading and working of bypass diode*

To determine the impact of shading for modules connected in series. The experiment was carried out for constant radiation intensity (332.66 W/m$^2$) and load resistance. Reading was noted by first shading one module without the bypass diode as shown in figure 8, and then by connecting the bypass diode as shown in figure 9.

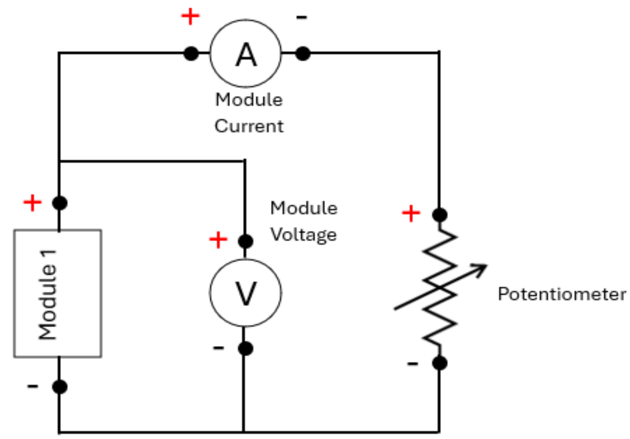


**Fig.7.** Circuit diagram to determine the effect of tilt angle

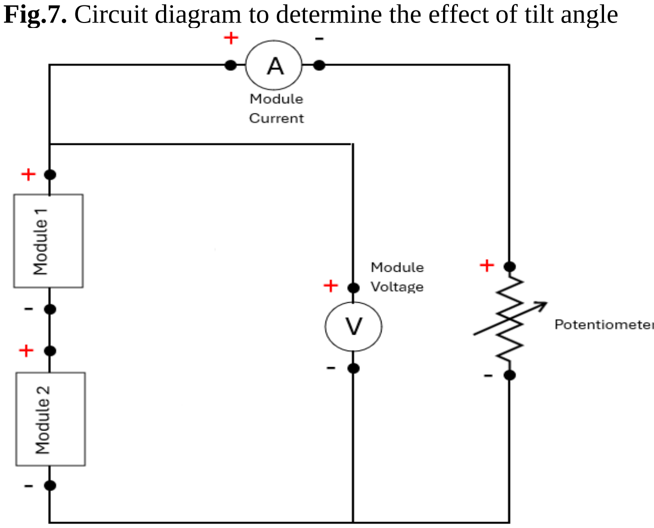


**Fig.8.** Circuit diagram without bypass diodes

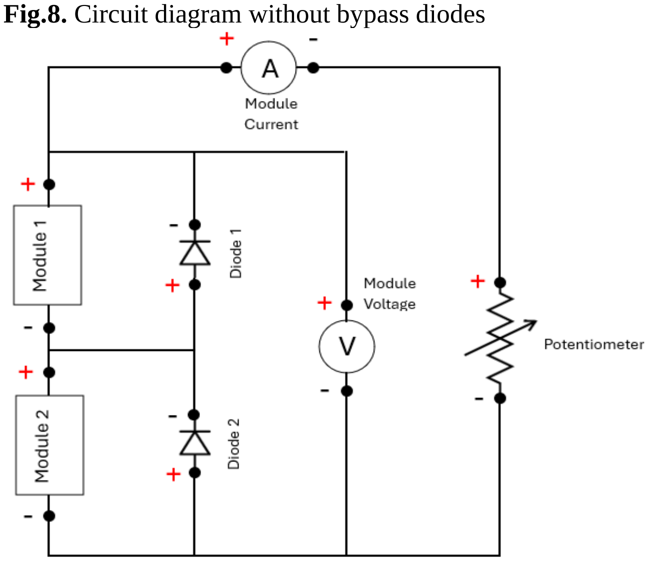


**Fig.9.** Circuit diagram with bypass diodes

*5) Effect of temperature on the efficiency of the module*

The solar module was connected as shown in figure 10. The radiation intensity is set at 332.66 W/m$^2$. The experiment kept load resistance, tilt angle, and radiation intensity constant. The module temperature increases with time and readings were noted for every 1 °C change. The module's power output is calculated, and the graph is plotted against temperature.

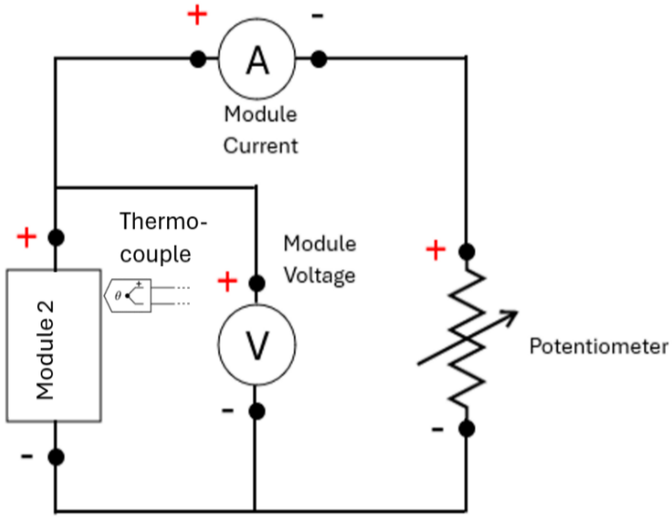


**Fig.10.** Circuit diagram to determine the effect of temperature

## III. Result and Discussion

The performance of solar PV modules under various parameters has been studied. Using this study, the effect of these parameters at different conditions on the solar PV module was observed. These observations are broken down into different sections for easy understanding.

*3.1) Current – Voltage (I-V) characteristics at different radiation levels*

Plotting the current against voltage in a graph represents the I-V characteristics. The results show that with an increase in radiation intensity, the short-circuit current ($I_{sc}$) and open-circuit voltage ($V_{oc}$) increase.

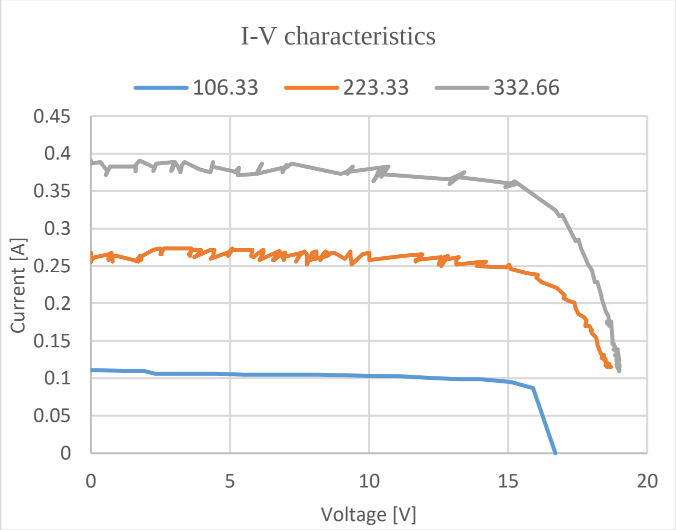


**Fig.11.** I-V characteristics for a single module

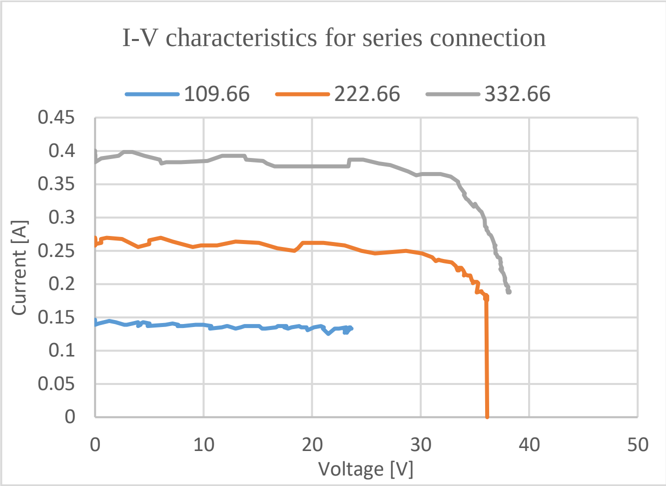


**Fig.12.** I-V characteristics for a series connection

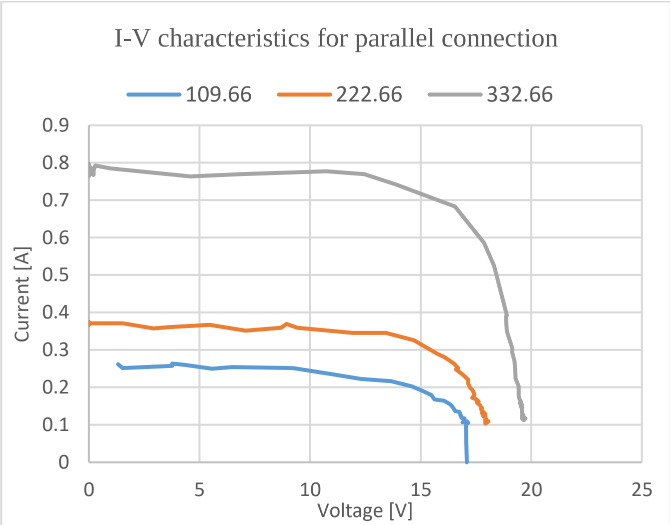


**Fig.13.** I-V characteristics for a parallel connection

The $I_{sc}$ is the current that passes through the module when the voltage across the cell is zero (both terminals are shorted out). The $V_{oc}$ is the potential difference between the two terminals of an electronic device when no load is connected. $I_{sc}$ increases linearly with an increase in radiation level [12,13]. Because as the radiation increases more charge carriers get excited. Figure 11 shows the variation in the current and voltage of a single solar PV module at different radiation intensities.

I-V characteristics for the series and parallel connection of two solar PV modules are shown in figures 12 and 13. In the series configuration, the potential difference between each module combines to provide almost twice the voltage compared to a single module and the current in the circuit remains the same as it was in a single module. In the parallel configuration, the potential difference between the two modules will remain the same, and the current in this case becomes twice as compared to a single module. The series configuration is used to obtain the required voltage for a constant current and the parallel configuration is used to obtain the required current for the same potential difference across the terminals. The required voltage and current vary with various applications and the series and parallel configuration depends on these applications.

### *3.2) Power – Voltage (P-V) characteristics at different radiation levels*

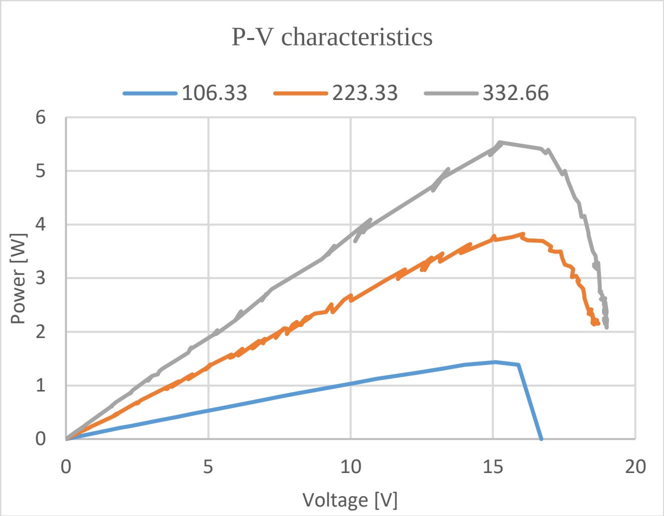


**Fig.14.** P-V characteristics for a single module

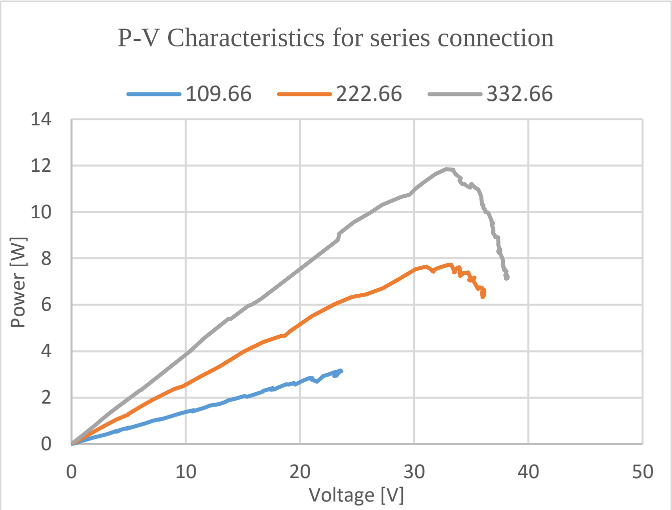


**Fig.15.** P-V characteristics for a series connection

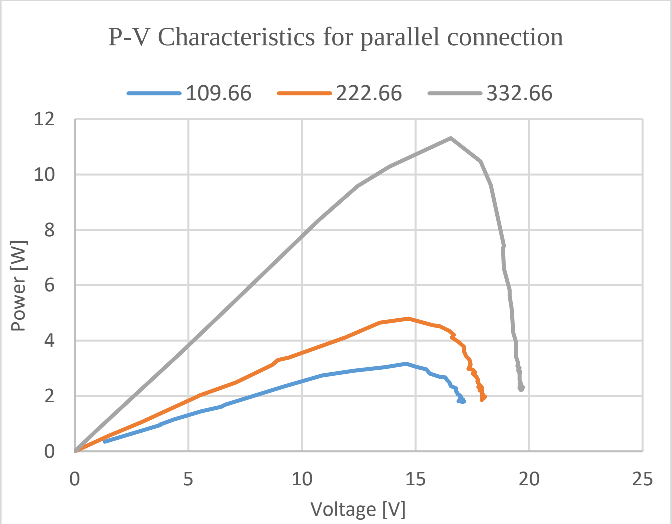


**Fig.16.** P-V characteristics for a parallel connection

Power and voltage are plotted in the graphs as shown in figure 14. This graph represents the P-V characteristics of a single module at different radiation intensities. The power output of a module depends on various parameters such as short-circuit current ($I_{sc}$), open-circuit voltage ($V_{oc}$), fill factor, etc. Figures 15 and 16 represent the P-V characteristics for series configuration and parallel configuration respectively. It is observed that the power output in the series and parallel configuration is almost twice compared to the power output of a single module. However, the power output in the series configuration is higher than the power output in the parallel configuration. This difference in power output is because the current in parallel configuration is high and due to this fact, the losses have increased, reducing the power output.

### *3.3) Variation in open-circuit voltage ($V_{oc}$) under different radiation levels*

It is observed that the open-circuit voltage ($V_{oc}$) has increased with an increase in radiation intensities. But at higher radiation intensities, the increase in the open-circuit voltage ($V_{oc}$) is smaller as shown in figure 17, this is because, at higher radiation, temperature plays an important role, and the excess energy which is supposed to increase the $V_{oc}$ is wasted in the form of heat [14].

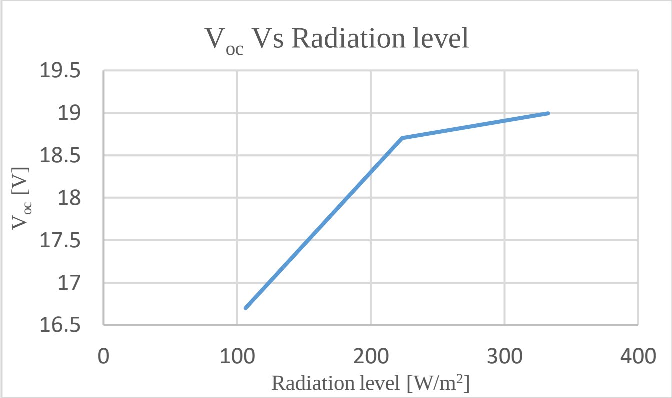


**Fig.17.** Effect of different radiation intensities on $V_{oc}$

### *3.4) Variation in short-circuit current ($I_{sc}$) under different radiation levels*

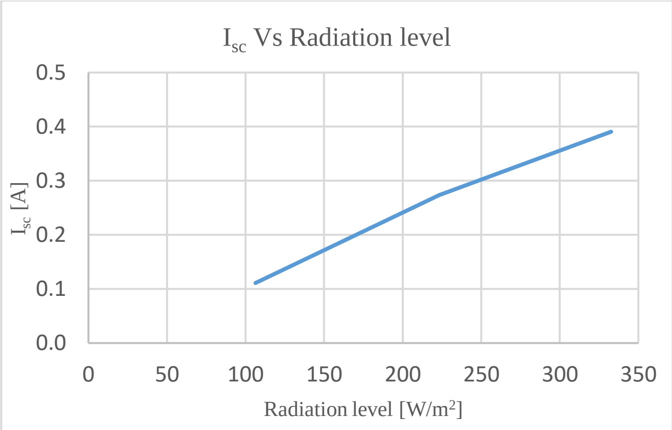


**Fig.18.** Effect of different radiation intensities on $I_{sc}$

The short-circuit current ($I_{sc}$) increases almost linearly with an increase in radiation intensities as shown in figure 18. At high radiation levels, the number of photons incident on the solar PV module increases, exciting more electrons to pass through the circuit, and in this process increases the current in the circuit [14].

*3.5) Variation in power output under different radiation levels*

The power output of a solar module is defined as the product of the fill factor, short-circuit current ($I_{sc}$), and open-circuit voltage ($V_{oc}$). In this study, it is observed that the power output varies almost linearly with the radiation intensity as shown in figure 19. It is seen that the effect of short-circuit current ($I_{sc}$) on the power output is more compared to the other two factors. The change in $V_{oc}$ and fill factor are less compared to $I_{sc}$.

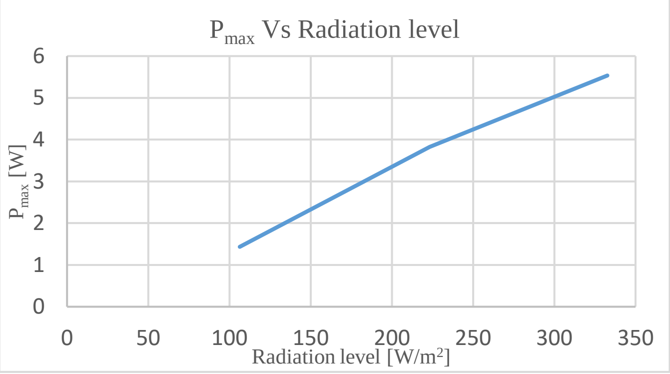


**Fig.19.** Effect of different radiation intensities on power output

*3.6) Variation in fill factor under different radiation levels*

The fill factor (FF) is an important factor in determining the performance of the solar PV module. It is defined as the ratio of maximum power output to the product of $I_{sc}$ and $V_{oc.}$ The fill factor determines the "rectangle" shape of the I-V curve. In this study, it is observed that as the radiation level increases the fill factor decreases. At high radiation levels, the series resistance increases which causes a slight decrease in the fill factor as shown in figure 20. In addition to power output, $V_{oc,}$ and $I_{sc,}$ the fill factor also depends on the series and shunt resistance [14,15], temperature, material properties, and design of the solar PV module. The fill factor will vary depending on these factors.

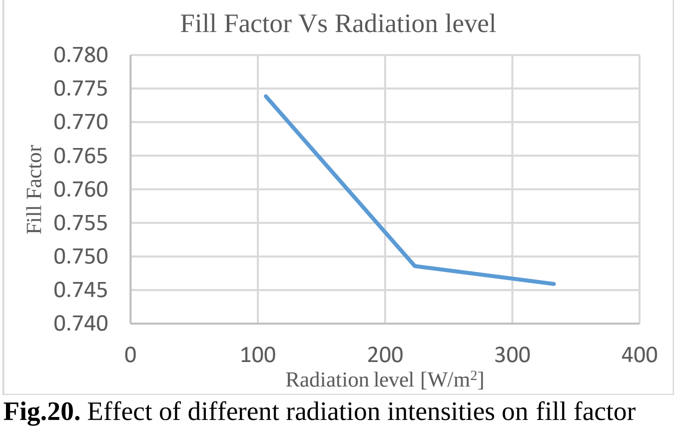


**Fig.20.** Effect of different radiation intensities on fill factor

*3.7) Variation in efficiency under different radiation levels*

Conversion efficiency or efficiency of a solar module is defined as the ratio of electrical energy generated to the solar energy incident on the solar module. The efficiency of a solar module depends on solar radiation, power output, area of the solar module, temperature, shading, etc. [14]. The solar module's efficiency increases with an increase in radiation, but it is observed that the efficiency is almost constant after 223.33 W/m$^2$. At higher radiation, the module temperature increases which negatively affects the efficiency of the solar module which is seen in Figure 21.

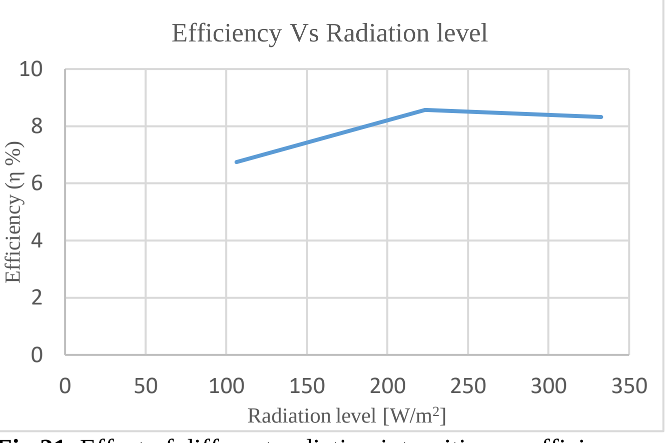


**Fig.21.** Effect of different radiation intensities on efficiency

*3.8) Effect of tilt angle on the power output at a constant radiation level*

The power output is maximum when the solar radiation falls perpendicular to the solar PV module. Increasing the tilt angle of the solar module creates an uneven distribution of the incident solar radiation. Some solar cells receive more solar radiation while others receive less solar radiation. The solar cells in the module are connected in series to get a higher voltage, but due to uneven distribution, the output current decreases because the current output of the solar module is governed by the weakest cell receiving less solar radiation. As the tilt angle increases, the power output keeps on decreasing as shown in figure 22.

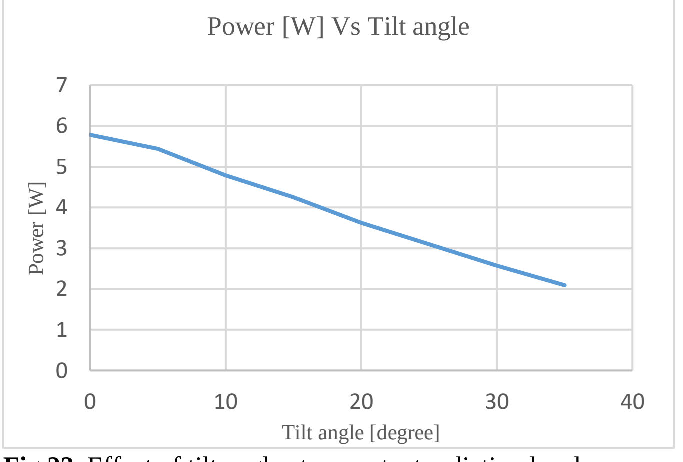


**Fig.22**. Effect of tilt angle at a constant radiation level

To extract maximum power output from a solar module the orientation and tilt angle should be optimized. For a particular latitude, the optimum tilt angle is different for each month [16,17]. By optimizing the orientation and tilt angle for each month one can extract maximum power output. Using a sun tracker, a larger amount of power can be extracted, but it is not economically feasible for small-scale plants [18].

### *3.9) Effect of temperature on the power output at a constant radiation level*

The effect of temperature is observed at high solar radiation. With the increase in solar radiation, the module temperature also increases negatively affecting the performance of the solar module [13]. It is seen that as the temperature of the module increases, the power output decreases as shown in figure 23. As the temperature increases the charge carrier increases, which increases the saturation current and decreases the bandgap of the depletion layer causing a decrease in the open-circuit voltage ($V_{oc}$). In this study, the source (halogen lights) is kept close to the solar module which increases the module's temperature at a faster rate than normal.

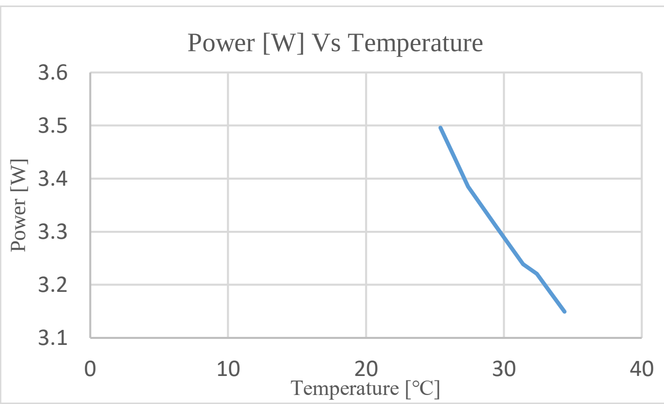


**Fig.23**. Effect of temperature at a constant radiation level

### *3.10) Effect of shading on the power output at a constant radiation level*

Shading of the module is an important problem in large solar generation plants. Shading occurs due to trees, buildings, walls, cloud cover, dust, and in the nighttime [19,20]. Dust is an important factor and gets settled on the solar module, blocking the solar radiation from entering the module, and causing a reduction in current generation, power output, and efficiency. Compared to the unshaded module, a shaded module absorbs less radiation causing less current to be produced [20]. As discussed, the current passing through the circuit depends on the weakest cell. Likewise current generated by the weakest module is passed through the entire circuit reducing the overall power output.

This problem can be solved by adding a bypass diode across each module. The bypass diode creates an alternate path for the current to flow through the circuit and the current will treat the weakest module as an open circuit maintaining a constant current throughout. Using this approach, the weakest module is separated from the rest of the configuration. An alternative solution for this problem can be cleaning the solar PV modules frequently either manually or using computer-controlled cleaning technology [21,22].

## IV. Conclusion

A parametric analysis of solar PV modules using artificial sunlight is presented in this study. This study helps us to understand the basic physics of solar PV modules which include I-V and P-V characteristics, fill factor, and efficiency. These parameters are very important to understand the basic functionality of a PV module. Experiment results show power output and efficiency of the module increase with an increase in radiation level. The effect of tilt angle, shading, and temperature show a negative impact on the power output of the module. Results show that maximum power is obtained when the radiation falls normally on the surface, as the angle of tilt is increased, the power output of the module decreases. Temperature and shading are also important parameters in PV module performance. As the module temperature increases power output decreases. Shading also reduces the power output of the module. So, the performance of the PV module mainly depends upon these four factors radiation level, tilt angle, temperature, and shading. This study also shows that the configuration of the module is optimized according to the power requirement of the load. The parallel combination of modules increases the output current while the series combination increases the output voltage.

While conducting the experiments significant care has been taken even though some errors cannot be ignored. The sensitivity of the radiation intensity regulator was very high which caused fluctuation in incident radiation. The accuracy of the pyranometer, potentiometer, voltmeter, and Ammeter is not up to the mark which limits the accuracy of values available.

In an actual scenario, the radiation level depends upon the latitude of the installation site. However, the power output of the modules can be increased by taking an optimized tilt angle and orientation. The sun tracking technology can be used for large-scale PV plants. For a small PV plant, optimizing the tilt angle of modules for each location and for each month, and manual adjustments reduces initial, operational, and maintenance costs. To minimize the effect of shading, cleaning of the module can be done from time to time either manually or using a computer-controlled technique. All these findings are important for designing and optimizing the performance of solar PV modules.

## V. Acknowledgements

The authors would like to thank the Department of Sustainable Energy Engineering for establishing the experimental setup in our laboratory. Special thanks to Professor Sudarshan Narayana and Professor Jishnu Bhattacharya for their invaluable insights throughout the study, as well as Ms. Rajbala Purnima Priya for her guidance during the process. Thanks to Mr. Ajay Singh Chauhan and Mr. Chandan Kumar for setting up the laboratory equipments and for their invaluable guidance.

## VI. REFERENCES

[1] F. BARBIR, T. N. VEZIROGLU, and H. J. PLASS, JR, *ENVIRONMENTAL DAMAGE DUE TO FOSSIL FUELS USE*, p.11, 1990. https://www.sciencedirect.com/science/article/pii/036031999090005J/pdf?md5=f4f8eaa015b89c07f7f62b41ccd7a97f&pid=1-s2.0-036031999090005J-main.pdf

[2] Columbia Center for Children's Environmental Health, Department of Environmental Health Sciences, Mailman School of Public Health, Columbia University, "International Journal of Environmental Research and Public Health", *Pollution from Fossil-Fuel Combustion is the Leading Environmental Threat to Global Pediatric Health and Equity: Solutions Exist*, p.17, 2017. http://dx.doi.org/10.3390/ijerph15010016

[3] IPCC, 2023: Summary for Policymakers. In: *Climate Change 2023: Synthesis Report*. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, H. Lee and J. Romero (eds.)]. IPCC, Geneva, Switzerland, pp. 1-34, doi: 10.59327/IPCC/AR6-9789291691647.001 https://www.ipcc.ch/report/ar6/syr/downloads/report/IPCC_AR6_SYR_SPM.pdf

[4] IPCC, 2022: Summary for Policymakers. In: *Climate Change 2022: Mitigation of Climate Change*. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926.001. https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_SPM.pdf

[5] Moomaw, W., F. Yamba, M. Kamimoto, L. Maurice, J. Nyboer, K. Urama, T. Weir, 2011: Introduction. In IPCC Special Report on *Renewable Energy Sources and Climate Change Mitigation* [O. Edenhofer, R. Pichs-Madruga, Y. Sokona, K. Seyboth, P. Matschoss, S. Kadner, T. Zwickel, P. Eickemeier, G. Hansen, S. Schlömer, C.von Stechow (eds)], Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA. https://www.ipcc.ch/site/assets/uploads/2018/03/Chapter-1-Renewable-Energy-and-Climate-Change-1.pdf

[6] Ministry of New and Renewable Energy (MNRE), *Renewable energy-installed capacity*. https://mnre.gov.in/physical-progress/

[7] Jean Chateau, Geetika Dang, Margaux MacDonald, John Spray, and Sneha Thube, "International Monetary Fund (IMF)", *A Framework for Climate Change Mitigation in India*, p.49, 2023. https://www.imf.org/en/Publications/WP/Issues/2023/10/20/A-Framework-for-Climate-Change-Mitigation-in-India-535854

[8] Ministry of New and Renewable Energy (MNRE), Grid connected Rooftop Solar Programme. https://mnre.gov.in/grid-connected-solar-rooftop-programme/

[9] Ministry of New and Renewable Energy (MNRE), Policies and Schemes. https://mnre.gov.in/policies-and-regulations/schemes-and-guidelines/schemes/

[10] Jama Adam Salah, "Research Gate", *Basics of solar PV system*, p.33, 2019. http://dx.doi.org/10.13140/RG.2.2.10829.59363

[11] Hamdan, I., Maghraby, A. & Noureldeen, O. *Stability improvement and control of grid-connected photovoltaic system during faults using supercapacitor*. *SN Appl. Sci.* **1**, 1687 (2019). https://doi.org/10.1007/s42452-019-1743-2

[12] Abass, Khaleel & Al-Asadi, Kadhem. (2019). *Solar Panel's Current-Voltage Characteristics*, p.6, 2019. Solar Panel's Current-Voltage Characteristics (researchgate.net)

[13] Maan J B Buni, Ali A. K. Al-Walie, and Kadhem A. N. Al-Asadi, "International Research Journal of Advanced Engineering and Science", *Effect of solar radiation on photovoltaic cell*, Volume 3, Issue 3, pp. 47-51, 2018. Effect of solar radiation on photovoltaic cell (researchgate.net)

[14] M. Chegaar, A. Hamzaoui, A. Namoda, P. Petit, M. Aillerie, A. Herguth, "ScienceDirect", *Effect of illumination intensity on solar cells parameters*, p.8, 2013. https://doi.org/10.1016/j.egypro.2013.07.084

[15] Abhishiktha Tummala, Effect of Series Resistance *Increase on Fill Factor of PV Cells Extracted from Field Aged Modules of Different Climates*, p.81, 2016. https://core.ac.uk/download/pdf/79586847.pdf

[16] George and R. Anto, "*Analytical and experimental analysis of optimal tilt angle of solar photovoltaic systems*," 2012 International Conference on Green Technologies (ICGT), Trivandrum, India, 2012, pp. 234-239, doi: 10.1109/ICGT.2012.6477978. https://ieeexplore.ieee.org/abstract/document/6477978

[17] M.A.A. Mamun, M.M. Islam, M. Hasanuzzaman, Jeyraj Selvaraj, "Energy and Built Environment", *Effect of tilt angle on the performance and electrical parameters of a PV module: Comparative indoor and outdoor experimental investigation*, p.13, 2022. https://doi.org/10.1016/j.enbenv.2021.02.001

[18] Omer Gonul, Fatih Yazar, A. Can Duman, Onder Guler, "Renewable and Sustainable Energy Reviews", A comparative techno-economic assessment of manually adjustable tilt mechanisms and automatic solar trackers for behind-the-meter PV applications, p.14, 2022. https://doi.org/10.1016/j.rser.2022.112770

[19] Abdelaziz, Gharbi & Hichem, Hamdi & Gharbi, Rached. (2022). *Shading effect on the performance of a photovoltaic panel*. http://dx.doi.org/10.1109/SCC53769.2021.9768356

[20] Tareq Salamah, Ahmad Ramahi, Kadhim Alamara, Adel Juaidi, Ramez Abdallah, Mohammad Ali Abdelkareem, El-Cheikh Amer, Abdul Ghani Olabi, *Effect of dust and methods of cleaning on the performance of solar PV module for different climate regions: Comprehensive review, Science of The Total Environment*, Volume 827, 2022. https://doi.org/10.1016/j.scitotenv.2022.154050

[21] Habib, Md & Tanvir, Md Shahnewaz & Suhan, Ahmed & Vadher, Abhishek & Alam, Sanim & Tashrif, Tahsina & Ahmed, Koushik & Alrashed, Abdelrhman. (2021). *Automatic Solar Panel Cleaning System Based on Arduino for Dust Removal*. 1555-1558. 10.1109/ICAIS50930.2021.9395937. http://dx.doi.org/10.1109/ICAIS50930.2021.9395937

[22] Haya Aljaghoub, Farah Abumadi, Maryam Nooman AlMallahi, Khaled Obaideen, Abdul Hai Alami, *Solar PV cleaning techniques contribute to Sustainable Development Goals (SDGs) using Multi-criteria decision-making (MCDM): Assessment and review*, International Journal of Thermofluids, Volume 16, 2022, 100233, ISSN 2666-2027, https://doi.org/10.1016/j.ijft.2022.100233.