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Simulation based analysis of the partial shading at different locations on polycrystalline PV array

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Abstract

Photovoltaic (PV) technologies have definite environmental advantages over other power generation techniques. No matter many technologies are used, PV power generation emits no emissions. Solar cells and PV modules are produced using a variety of manufacturing techniques, and as with any energy source or product, there are no dangers to the environment, human health, and safety associated with these processes. Like any other device, even PV cells and modules go under degradation due numerous reasons. Shading is one such mode of degradations which directly impact the output of a PV system. Along with that the output power drastically get impacted. There is a drop in the output power and the electrical characteristics gets distorted. During shading condition the characteristics curves,Power - Voltage and Current-Voltage curve are seen with unusual peaks which is the exact reason for the presence of shading in the module. The paper presents the various impact on the curves which confirm the presence of power loss due to shading.

Keywords: Photovoltaic; Shading; MATLAB; Renewable Energy; Hotspot; Efficiency

1. Introduction

Population expansion and country economic growth, particularly in developing nations, are the two main factors driving the increase in global energy demand. The primary energy sources are nuclear, hydropower, and conventional fossil fuels which are extensively used likedcoals, oil, and gas.The burning of fossil fuels, which are finite resources, contributes to the release of massive volumes of CO_2 dropped into the living surroundings, which worsens the global warming effect and lowers air quality. Hydroelectricity raises environmental concerns because it necessitates flooding a huge region, impacting both community life and wildlife. Additionally, this energy source relies on rainfall to keep the reservoirs full. Concerns about the energy sources presently available and the need to diversify the global energy system led to the expansion of renewable energy sources comprising biomass, wind, solar and many other The utility of electrical energy and its demand are both increasing more quickly today. However, the supply of fossil fuels as traditional energy sources is running out. Hence, boosting the practice of non-conventional sources incorporating Geo-thermal heat, Biomass, Solar, Wind, and Tidal power. The most common and well-liked energy source overall is solar photovoltaic (PV) electricity. However, the nonlinear PV output characteristics primarily depend on temperature and irradiance. The most common and well-liked energy source overall is solar photovoltaic (PV) electricity. However, the nonlinear PV output characteristics primarily depend on temperature and irradiance. The requirement of studying the Solar PV system is so required because of following reasons:

- To comprehend the root causes of degradation in solar PV System.

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- Hotspot due resulting because of shadowing is identified as one of the prominent reasons for degradations in a PV system. Hence it become significant to understand the concept how shadowing impacting the output of the system.
- It is crucial to educate vendors and clients on foreseeable technological variations usual in the crystalline silicon (c-Si) grounded solar business.
- The thesis's goal is to highlight the need for improvement among the PV community, to create future requirements, and to promote the creation of comprehensive solutions through these means rather than to recommend specific technical fixes for identified problem areas.
- The current study will provide a brief understanding of the degradation in solar photovoltaic modules for producers of poly-Si, wafers, c-Si solar cells, modules, PV apparatus, and construction materials as well as various research institutes and consultants in PV sector.
- The current article includes a review of the literature on shadowing and how it affects solar photovoltaic technology.
- Important metrics and discussions on new trends in the PV sector are provided in order to comprehend PV systems.
- Due to ongoing PERC capacity expansions, it is anticipated that the worldwide conventional c-Si cell and PV module manufacture capacity will have expanded to around 200 GWp by the end of 2019.
- It is assumed that the global shares position of c-Si nearly 95% and for thin-film technologies is nearly 5% will continue stable
- The Reliable Supply of Energy is again one of the motivations for selection of the research work.

One factor contributing to climate change and global warming is CO_2 greenhouse gas. To understand the concept of degradations in a solar module and promote research to increase the performance of PV panel in different environmental factors working as a factor to impact the performance parameter. Boost module area effectiveness without materially raising processing costs. The first argument means that in order to increase module area efficiency, cell efficiency improvements must be put into practice concurrently with new module concepts. To maximize capital expenditures and enable cost-effective manufacturing, this must be done using lean procedures. In order to increase the installed production capacity's overall equipment efficiency (OEE), Si and non-Si materials must be used more effectively. Due to its clean production, convenience on-site, and absence of greenhouse gas emissions, renewable energy has recently drawn more research attention. A basic Photo-Voltaic cells, which are typically encompassed of semiconductor recast the energy of sunlight is transformed into DC electricity. A module of commonly 36, 60, or 72 PV cells is created by linking the cells in series. The modules are then associated together in a variety of arrangements of series connections and parallel connections to obtain the required electrical output. Before supplying to local loads or fed into grids, the output of a PV array is conditioned by controllers based on power electronics. But, two factor which are solar irradiation and cell temperature do affect how the PV arrays produce energy. However, partial shade brought on by the shadows created by advancing clouds, neighboring trees, or nearby structures may result in uneven solar irradiation on a particular array. The features of PV arrays in partial shade conditions have been extensively researched.

2. Types of solar cell technology

The top most main PV cell technologies type that rule the global market are

- Monocrystalline silicon,
- Polycrystalline silicon
- Thin film

Being expensive, advanced efficiency PV technologies for instance gallium arsenide or multi-junction cells are fewer in general application but impeccable for usage in space and concentrated solar systems applications. A variety. of novel PV cell technologies being established for example Perovskite cells (PVC), the novel Organic Solar Cells(OSC),the innovative Dye-Sensitized Solar Sells, and very new quantum dots solar cells.

At the moment, around 90% of the photovoltaics used in the globe and a similar percentage of household solar panel systems use some form of silicon. For monocrystalline and polycrystalline cells, crystalline silicon serves as the foundation. Solar cells' silicon can be found in a wide variety of shapes. The quality of the silicon, though, is what really counts. The reason for this is that it directly influences how effective it is. In this context, purity refers to the arrangement of silicon molecules. Purity of the resultant silicon increases with alignment quality. As a result, sunlight is converted into power more effectively. With silicon accountancy for over 95% of the solar modules now available for sale, the element silicon most widespread semiconductor material cast-off in solar cells. It also has an advantage of being. one of the abundant constituent on Earth and the maximum extensively manufactured semiconductor in computer chips. The most conventional type second generation solar cell is Amorphous silicon (a-si) also well known material used in thin film solar cell. It is manufactured with new technology by placing amorphous silicon on a base or substrate which can be glass or plastic. This procedure make use of less than 1 % of silicon in the manufacturing of the thin film type of solar cell which fully justify the name of the solar cell. This type of construction make it flexible than usual silicon sola cell. Secondly these solar cell are very cheaper than the usual silicon solar cell as it requires less silicon in manufacturing. The new or the third generation of solar cells, which also comprises of the Tandem PV, Perovskite PVis, Dye-sensitized, Organic, and Emerging concepts are the few variety of solar cells ranging from inexpensive but low-efficiency systems such as dye-sensitized, organic solar cells to expensive but better in efficiency III-V multi-junction cells incorporated in from building incorporation to space applications. Even though some of the third-generation photovoltaic cells have been researched for more than 25 years, they are frequently denoted to as "emerging concepts" owing to their bad market penetration. The less well-known commercial "emerging" technologies of third-generation inventive cells include.

3. Different types of degradation

For the photovoltaic (PV) business to expand, it is essential to be able to estimate power delivery with accuracy over time. The efficiency of solar energy conversion and how this relationship evolves over time are two major cost factors. It is imperative for all parties involved, including utility companies, integrators, investors, and academics, to estimate power loss over time, also known as degradation rate, precisely. Considering financially, a PV module's or system's weakening is correspondingly noteworthy because a advanced degradation rate proximately associates to less power production, which lowers future cash flows. Additionally, inaccurately calculated degradation rates directly raise the financial risk. Technically, it's crucial to comprehend how degradation mechanisms work because they might finally result in failure.

Improvements in lifetime may result directly from the discovery of the fundamental degradation method through research and demonstrating. Basically at least for two reasons: Primarily it is the normal employed environment for PV systems and secondly only possible way to match the results of test performed indoor accelerated testing to the consequences of outdoor field testing in order to predict field performance. Climate, module type, and racking system, among other things, affect the solar panels' useful life and their ability to produce electricity over time. Degradation is the term used to describe the gradual decrease in solar panel output. According to a report by NREL which is a famous laboratory,the installations rooftop systems where the climate is hotter have observed degradation rates found higher than the median rate of 0.5% per year in the solar panel.Various kind of degradation observed in the PV modules are :

- Hotspot
- Crack
- Packaging Material Degradation
- Loss of adhesion
- Interconnect Degradation
- Moisture Intrusion
- Discoloration
- LID
- PID
- Corrosion
- Bubbles

4. Literature review of shadowing impact on solar PV

Photovoltaic (PV) arrays are prone to varying irradiance levels under partial shade conditions because of nonuniform shading. A mismatch among the modules, a reduces the total of power produced, and most likely hotspot will develop as a consequence. One method to lessen mismatch losses is to reconfigure the total-cross-tied array in dynamic and static versions, where better performance can be attained by more effective shade distribution due to bigger dimensions. For partially shadowed solar panels, a mathematical model is created in the MATLAB environment and experimentally confirmed. Additionally, a Simulink model using the Sim Power Systems block set is created to simulate the PV array under the same circumstances. Under conditions of partial shade, artificial neural networks (ANN) are used to estimate the I-V properties. In contrast to normal operation, the P-V curve under partial shade has numerous peaks, the number of which depends on the array design. This makes process of maximum power point tracking extra problematic.

A exclusive power modification and MPPT control method for PV arrays operating in challenging non-uniform illumination circumstances is given. By monitoring the dynamic resistance and voltage of the PV modules, the suggested system is based on forward biassing bypass diodes of shaded modules.

Using a multi-stage buck-boost chopper circuit and accounting for shading effects, novel MPPT is developed. It suggests a brand-new MPPT algorithm to increase power output under any conditions of ambient/junction temperature and solar radiation. Early automatic diagnosis of PV arrays with prompt and effective actions is crucial, and this topic has been extensively researched. Since quick calculation, correctness, and easiness are vital concerns in this type of study, ANN, an intelligent strategy, can be a leading remedy. For monitoring and supervision reasons as well as the application of suitable model predictive control MPPT algorithms, partial shading must be detected and evaluated. To monitor the equivalent thermal voltage and identify partial shading on small areas, a condensed expression could be utilized. Through the corresponding rise in series resistance of partially shaded cells, fuzzy inference methods are used to identify partial shading.

Photovoltaic (PV) module output power is influenced by sun irradiation along with cell temperature conditions. On exposure of PV module to homogeneous irradiance, the generation of electricity by each module is comparable, therefore leading to equal total output power from each module separately. On the other side, if the system is partially shaded, the irradiance is not uniform, which results in power losses. The partial shadowing may be brought on by nearby components like vegetation (trees), nearby structures, and soil. Other factors that can sometimes result in partial shadowing include wind, tilt angle, and dust, which all have an impact on the effectiveness of PV systems. It's essential to evaluate shadows on PV systems in order to prevent or lessen their effects and to increase production estimation and performance. The majority of research studies in the literature concentrate on methods for estimating shading fractions, tracking maximum power points, estimating and detecting shading, and rearranging the module, array, and inverter to reduce these impacts.

The Author built a yield model that took the shading impact into account. The author built a plug-in for SketchUp to evaluate the methodology and proposed a way to determine the shade fraction and irradiation in a three-dimensional model.The author examined the effects of the PV module reconfiguration on energy and cost for three scenarios with various shadow patterns. They examined the traditional topology as well as the U-type and I-type snake topologies. Both topologies result in energy gain when there is partial shadowing, but the reconfiguration of the modules results in additional expenditures. They came to the conclusion that the cost-benefit of module reconfiguration depends on additional criteria, including the energy gain, installation location, and power price, and is only profitable for installations under partial shadowing situations. Additionally, switching from series to parallel cell connections in the module arrangement reduces shading losses. Additionally, a single bypass diode is commonly linked in anti-parallel to a collection of series cells; however, variations to the bypass circuit have also been presented in the literature.Using Matlab/Simulink, the author investigated the effects of partial shade on three array topologies (3 *3 array): series-parallel (SP), bridge-linked (BL), and total cross-tied. (TCT). They recognized with shading area of a module below 50%, the two configurations BL and TCT are more appropriate. If the shading is larger, these arrangements improved the power by up to 5%. The analysis comparison made on different configurations like S, P, SP, BL, TCT, and Honey-Comb (HC) configurations on 6* 4 array for different shadow patterns.

It was observed through study that either by static or dynamic change in configuration of the PV array, the shading impact can be reduced. In contrast to static reconfigurations, which change the physical location, dynamic reconfigurations change the electrical connections. Hotspots on PV modules are said to be caused by partial shadowing or an uneven distribution of light intensity. A phenomena of hot-spot is defined by the localised over heating location in a solar cell or photovoltaic module this make it obvious that the rea will generate a lesser power than compared to other that are connected in series. Due to hotspots, the performance of partially shaded solar cells and PV modules would be significantly reduced, or they might even result in PV modules suffering irreparable damage like tedlar delamination or a fire disaster.

5. Mathematical modelling specification for a PV cell

In the Matlab environment, a mathematical model is created from experimental data. Early and fast programmed diagnosis of PV arrays with quick and real actions is vital, and this topic has been extensively researched Figure 1 represent theiequivalent model of single diode model of PV Cell.

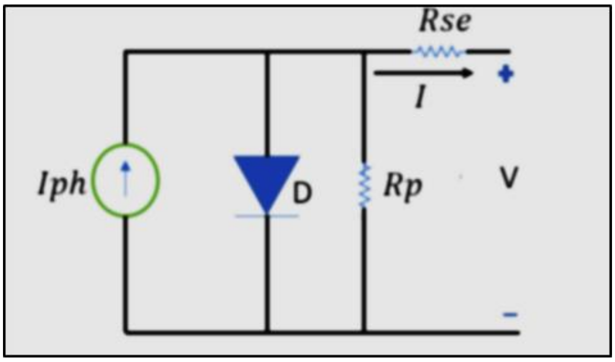


Figure 1 A Equivalent model of single PV cell

$$I = I_{pho} - I_{satur}\left[\exp\left(\frac{q}{kT_oA}(\,Vo + IR_{se}\,)\right) - 1\right] - \frac{(V+IR_{ser})}{R_{pa}} \text{ .... (1)}$$

$$I_{pho} = \left(I_{sh} + K_{Tshr}\left(T_o - T_{ref}\right)\right)\frac{G_s}{G_{STC}} \text{ ....(2)}$$

Equation 1 prompts the association between output Voltage represent by V volts – Current, I amperes of a photovoltaic cell.

The various parameters included in the equation 1, 2 and 3 are :

- Ipho described to be photogenerated current.
- I_{satur} described to be PVscell dark saturation current.
- T_o described PV cell operating temperature in Kelvin.
- k described to be Boltzmannsconstant and is equal to value of 1.381×10^{-23} J/K
- q is electron charge.
- A is theeconstant value known to be as diode ideality constant.
- Rpa , R_{ser} signifies the ashunt and series eresistances respectively.
- I_{sh} denotes sshort circuit current of theacell at standard testincondition (STC), at 25^0C and 1000 watts/$m^{2.}$
- K_{Tshr} is described as shortvcircuit temperature coefficient of the PV cell.
- T_{ref} is the references temperature of the cell.
- G_s is the solar irradiationn.
- G_{STC} is thessolar irradiation atSSTC

$$I_{sat} = I_{rsat}\left[\frac{T_{ref}}{T_o}\right]^3 exp\left[\frac{qE_G}{kA}\left(\frac{1}{T_r} - \frac{1}{T_o}\right)\right] \text{ ....(3)}$$

Where,

- I_{rsat} described reverse saturation current of photovoltaic current at ai reference solar irradiation and temperature.
- E_G is the band-gap energy of semiconductor is given by photovoltaic cell is manufactured.

The electrical current-voltage curve of the PV array is directly obtained by incorporating of the above-mentioned formulae. It is clear that, particularly at condition of the short-circuit point, the influence of irradiation on the0output curves is significantly greater than that of temperature. However, temperature has a marginally more significant impact on the array's open-circuit voltage than does irradiation

5.1. Simulation result

The core power conversion constituent of a PV generating system is the well known photovoltaic (PV) array, which is nothing but combination of modules. The functioning curves of the PV array under numerous operating conditions must be obtained, which is highly expensive and time-consuming due to the nonlinear properties of the PV array. Common and straightforward solar panel models have been created and implemented into a variety of engineering software packages, including Matlab/Simulink, to help solve these challenges. However, because these models need flexible modification of a few system parameters and are difficult for readers to utilize independently, they are not suitable for applications requiring hybrid energy systems. As a result, this study provides a procedure wise tutorial for simulating PV modules using tools in Matlab/Simulink. As a benchmark, KD solar 20013A2 solar panel is used. Additionally, a variety of operational situations and physical parameters are examined in order to better comprehend how aPV array operates. The polycrystalline KD Solar KD20013A2 modules used in our simulation model are shown in figure 2. The stimulus of shading making use of the I-V & P-V characteristics has previously been examined in numerous studies due to its simplicity and ease of understanding. Our study presents the MATLAB simulation of PV array representing areal time system used in small function such as micro pumping in farms. A we can see in the model given below there are two strings each carrying a 3 PV module in each string. Each block is given two constant block, one is for temperature and the other one is for solar irradiance.

The diagrammatic simulation model a PV array is shown in figure 2. By keeping the tract of the variations in theII-V and P-V curves and analyzing the simulation results, the functioning of solar arrays under varying solar irradiance and shading locations is investigated.

Three distinct kinds of shadowing conditions are produced for PV modules employing solar radiation of 1000, 700, and 400 watts/m2.Solar irradiations of 700 (W/m^2) represent light shading of the modules and 400 (W/m^2) represent severe shading. Partial shading of irradiance of 700 watts/m^2 and 400 watts/m^2 is applied to the modules at various string locations. The results show that shading PV modules with number of shading scheme causes output power to be reduced. It takes two steps to model a solar array operating with partial shading. Using Eqs. (1), (2) and (3) two distinct I-V curves are generated in the first phase for PV modules operating at various sun irradiation levels.The PV array's unshaded modules receive a particular degree of solar radiation during partial shading operation, but the shaded modules receive less. The number of shaded modules and the shading factor define the partial shading operating state.

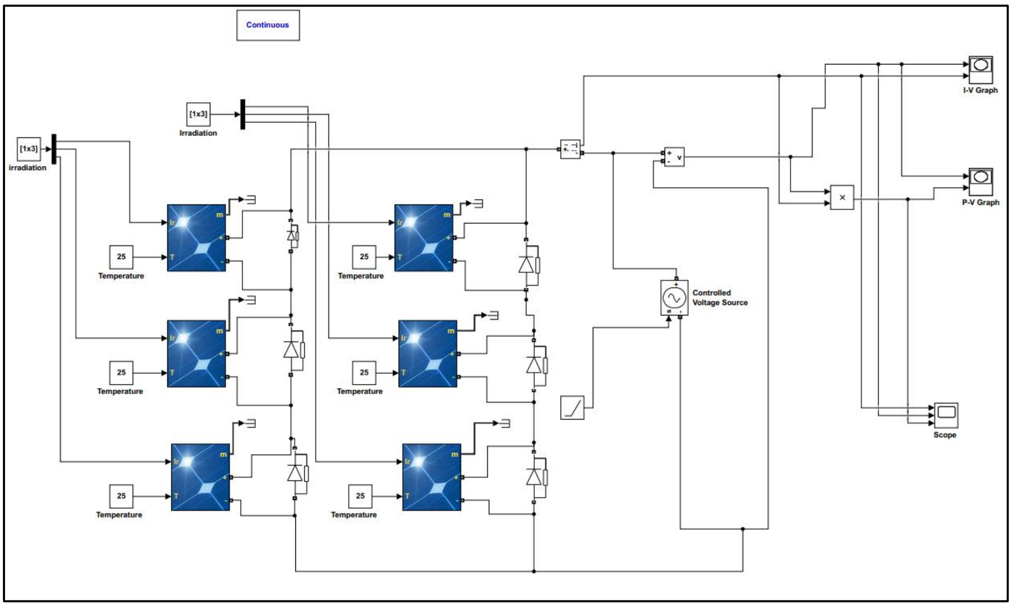


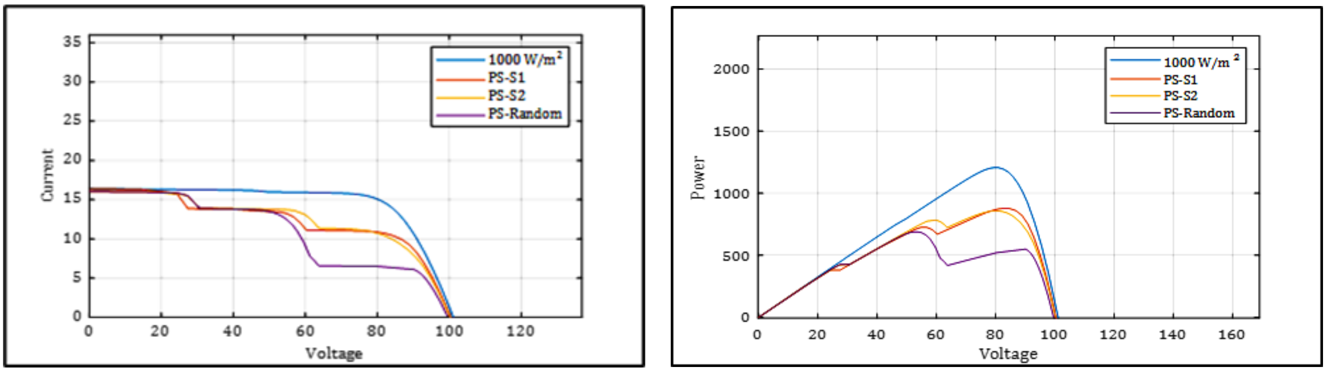
Figure 2 MATLAB /Simulation model of PV Array under study

6. Results

A change in the array's output power could be caused by partial shading or irradiation that affects all of the modules. Due to the abrupt and unpredictable nature of the irradiation change, it takes some time for the MPPT controller to react to the occurring disturbance and find the new maximum power. Changes in the array's output power may result from uniform changes in temperature or irradiation across the entire array or from partial shade, where some modules receive less irradiation than others. Consequently, the brief modification of the curves are as shown in figure 3.TThe simulation results, which showed the occurrence of local maxima and global maxima in theII-V &PP-V graphs. Similar to what we did in our study, many scholars also look at the use of analytical modelling in C/MATLAB to understand the principles of partial shading.The four different conditions are

- The PV array's string S1 and S2 modules are all exposed to homogeneous illumination of 10000 watts/m^2 at a temperature of225^{0}C.(1000 W/m^2)
- The 1st PV moduleMM11 and the string S2 continue to perceive irradiation of 10000 watts/m^2 at a temperature of225^{0}C, the PV modulesMM12 andMM13 of first-stringSS1 are partially shaded with irradiation of7700 watts/m^2 and 400 watts/m^2, respectively (PS-S1)
- The 1stPPV moduleMM21 and the parallel string S1 continue to perceive irradiation of11000 Watts/m^2 at a temperature of 25^{0}C, the PV modulesMM22 andMM23 of first-string S2 are partially shaded with irradiation of 700 watts/m^2 and4400 watts/m^2, respectively (PS-S2).
- Analysis of the PV array's partial shading scenario under various shading with arbitrarily selected shaded modules in both of the strings and varying solar irradiation. In string S1, the randomly chosen module M12 is exposed to an irradiation of 400 watts/m^2, and in string S2, the modulesMM22 andMM23 are exposed to4400 watts/m^2 and7700 watts/m^2, respectively.(PS-Random)

The respective results of the four conditions are seen in the figure 3: It can be seen in figure 3 that both the curves are dropping. Also in figure 3 b, the generated power which was near about 1200 watts dropped along with changes in the shape of curve. The curves in figure 3 have multiple peaks which completely supports the literature available.



(a) I-V Curve (b) P-V Curve

Figure 3 (a) and (b) the comparative graphs outputs of PV arrays under four different cases of partial shading

7. Conclusion

To investigate the effects of shade on a two-string photovoltaic (PV) array, simulation work was done. The MATLAB/Simulink model was used to examine the electrical properties of the PV panel. The impact of a module's entire cell shading was investigated through simulation research and supported by theoretical modelling and existing literature. For each scenario, the I-V and P-V curves were recorded in order to look at the impact of shading losses. Our investigation covered all of the ways that shade might affect photovoltaic systems. It is crucial to talk about this specific issue because photovoltaic cells greatly rely on the amount of radiation they receive in order to gain energy. Due to its significance in the study of PV panels, it was chosen to introduce the most important variables.

The results of the original research and simulations carried out specifically for the purpose of this article were added to the analyzed problems. Analysis of PV installation shading is a challenging issue. It can be challenging to forecast or assess its consequences. To reduce the likelihood of different types of shade and their potentially harmful impacts on the performance of the installation, each installation should be examined for the possibility of each type of shading. Shade and its consequences can be avoided in a variety of ways.

In the current work, the electrical properties of the PV array are discussed, and the shapes of curves that clearly illustrate the PV array's behavior are investigated. Our study came to the following conclusions: - Our research demonstrates that shading any array module would reduce output power and alter electrical properties, both of which are blatant signs of degradation. Additionally, as the module is shaded, it is visible that maximum power generation also alters. The curves are descending and the original contour of the graph is noticeably shifting, which is a blatant sign of degradation. As a result, under constant voltage, the operating point changes vertically and the array's P-V curve descends. A power loss is thus noted in the output characteristics.

Compliance with ethical standards

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Disclosure of conflict of interest

All manuscripts for articles, original research reports, editorials, comments, reviews, book reviews, and letters that are submitted to the journal must be accompanied by a conflict-of-interest disclosure statement or a declaration by the authors that they do not have any conflicts of interest to declare. All articles that are published in the journal must be accompanied by this conflict-of-interest disclosure statement or a statement that the authors have replied that they have no conflicts of interest to declare. If a journal prints unsigned editorials, they should not have been written by anyone with a conflict of interest.

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