The Study of Partial Shading on Mono and Poly Crystalline Photovoltaic Modules in Southern Rajasthan

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Abstract: ***In this modern world energy has become an integral part of our daily life. Research is going on for creating a proper way to get power from non - conventional sources which are harmless to environment and human society. The performance of PV panel is affected by shading effect due to trees, passing of clouds, neighbouring buildings and any other medium. Partial shading of solar cells can have detrimental effects on the overall efficiency and performance of a solar panel. When some cells within a panel are shaded, they generate less electricity than the un - shaded cells, creating an imbalance in power output. This imbalance can lead to hotspots, where the shaded cells can experience higher temperatures due to reduced electrical generation. Hotspots not only reduce the efficiency of the solar cells but can also lead to long - term damage, affecting the overall lifespan of the solar panel. Bhilwara is situated in the semi - arid lands of southern Rajasthan of India, experiences abundant sunlight throughout the year, making it an ideal location for solar energy generation. However, the efficiency of solar panels can be significantly impacted by shading, especially in densely populated areas or regions with uneven terrain. In this research paper we explore the shading effect on both mono crystalline and poly crystalline solar modules in the context on environmental and climatic condition of Bhilwara. It is observed that partial shading affects both mono crystalline and poly crystalline solar modules similarly; however, their responses to shading differ. Mono crystalline modules typically perform slightly better in low - light conditions, thereby handling partial shading more efficiently. In contrast, poly crystalline modules may experience a somewhat greater reduction in efficiency under the same conditions.***

Keywords: solar cell, shading, hot spot, efficiency, performance

1. Introduction

India is blessed with a large amount of sunlight and this solar energy is one of the promising sources using photovoltaic technology to generate electricity to fulfill the requirement of the nation. [1 - 3]

Mono crystalline and polycrystalline solar modules are the two most common types of solar panels used in Bhilwara and worldwide. Mono crystalline panels are made from single - crystal silicon, offering higher efficiency and better performance in low - light conditions compared to polycrystalline panels, which are composed of multiple silicon crystals. However, mono crystalline panels are more sensitive to shading than polycrystalline panels due to their design and electrical properties.

In Bhilwara, where sunlight is abundant, even partial shading can have a significant impact on mono crystalline and poly crystalline panels, leading to hotspots, reduced power output, and potential long - term damage to the shaded cells.

Poly crystalline solar cells are less affected by shading as compared to mono crystalline cells due to their uneven crystal structure. While polycrystalline panels are more tolerant to shading, they still experience some loss in energy output, albeit to a lesser extent than mono crystalline panels.

Furthermore, partial shading can trigger a phenomenon known as the "multiple power point tracking problem. " Solar panels are typically connected in series to form a string, and when shaded, the output of the entire string is limited by the lowest - performing cell. These results in a non - linear power - voltage curve, making it challenging for traditional solar inverters to find the optimal operating point, further decreasing overall efficiency.

Partial shading of a solar module can lead to significant changes in its electrical parameters, affecting the overall performance and efficiency of the photovoltaic system. Electrical parameters, such as short circuit current, open circuit voltage, maximum power and module efficiency are influenced by partial shading. This further leads to reduction in power and drastic changes in current - voltage characteristics. In this study, experimental results are presented under different partial conditions. Different shading patterns have been investigated on series and parallel connected photovoltaic modules.

When partial shading occurs, the shaded cells receive less sunlight, resulting in a reduction in their voltage output. This creates a voltage mismatch among the cells within the solar module or string, leading to a lower overall voltage for the entire module. The voltage drop can be severe, especially if a significant portion of the module is shaded.

Shaded cells produce less current compared to un - shaded cells, as they receive reduced sunlight and generate fewer electrons. This reduction in current contributes to an overall reduction in the current flowing out of the solar panel or array. The difference in current between shaded and un - shaded cells can create imbalances within the system.

The power output of a solar module is the product of voltage and current (P = V * I). Partial shading affects both voltage and current, leading to a more substantial decrease in power output. Hotspots may also form due to the mismatch, potentially causing long - term damage and further reducing the overall power manufacture of solar panels.

How well a solar module turns sunshine into electricity is determined by its fill factor, which is the maximum power to open - circuit voltage (Pmax) divided by the product of Isc and Voc. Partial shading typically reduces the fill factor due to the imbalance in voltage and current, leading to non - uniform power production across the module.

The Maximum Power Point (MPP) is the point on the current - voltage (I - V) curve where the solar module generates the maximum power output. Partial shading can shift the MPP, making it challenging for traditional solar inverters to track and operate efficiently. Advanced Maximum Power Point Tracking (MPPT) algorithms are crucial to adapt to changing conditions and optimize the power output.

Partial shading can also contribute to localized heating in shaded cells, affecting the overall temperature of the solar module. Elevated temperatures have a multiplicative effect on the detrimental effects on electrical parameters since they reduce cell efficiency.

Partial shading of photovoltaic module is a common phenomenon in all kinds of solar cells. In many case PV array get shadowed, completely or partially by passing clouds, neighboring buildings, towers, trees, leaves, bird dropping, cable or the shadow of one array on the other etc. The objective of this paper is to clarify the impact of shading on mono crystalline and poly crystalline solar cells comparatively. We will discuss impacts of partial shading on I - V curves and PV curves of both technologies.

The most commonly used circuit model to describe the electrical behavior of a PV cell is a single diode model as shown in figure.

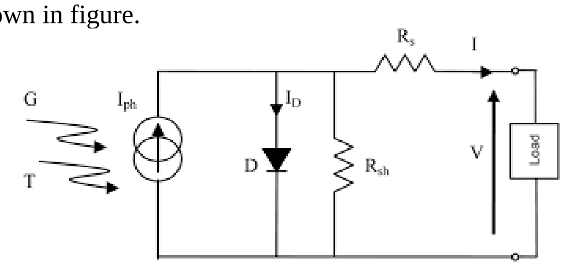

Figure 1: Equalant circuit of solar cell

The current generated by cell is expressed by

$$I = I_{ph} - I_0\left(e^{V+IR_S/N_S Vt} - 1\right) - \frac{V + IR_S}{R_{SH}}$$

Where the junction thermal voltage v_t is defined by

$$Vt = \frac{Akt}{q}$$

Whether solar cells are linked in series or parallel, partial shade affects the power output and efficiency of a solar module.

Shading in a series succession of solar cells

Solar photovoltaic modules linked in series the efficiency is badly affected if all the cells are not getting same amount of illumination. Shading effects are estimated by steady experimental study of how shading is perceived on the power output, fill factor and efficiency.

Even if a small number of shaded cells reduce the system's photon current and performance, all of the cells in a series array carry the same amount of current. The shaded cells are reverse biased and act as a resistance tool which consumes some power from the illuminated cell's current. It may be hot spot problem. [4 - 5]

Connecting solar cells in series result in an increase in voltage, even when the current passing through each cell remains constant. If a single cell in a series is partially shaded, the total current will be restricted to that cell. The power output of the whole series - connected module is decided by the lowest - performing cell; hence this might cause a large decrease in that output.

A bottleneck effect, which reduces the module's efficiency, is caused by shaded cells in a series - connected design. The darkened cell causes a current mismatch, which in turn reduces the module's overall efficiency since it prevents it from reaching its maximum power point. Hotspots may also form in the shaded cells, further reducing efficiency and potentially causing long - term damage.

Shading of Parallel - Connected Cells

While the voltage between individual cells stays constant in a parallel arrangement, the currents added together do. While shading one cell in a parallel setup does impact its output, it has no effect on the other cells' performance. Nevertheless, due to the shaded cell's lower current contribution, the overall power output of the module is still decreased.

Parallel - connected cells are less affected by shading compared to series - connected cells. The impact on efficiency is localized to the shaded cell, and the other cells continue to operate at their maximum power points. This configuration is more resilient to partial shading, and the reduction in efficiency is typically less severe than in series - connected cells.

A photovoltaic PV system consists of series and parallel combination called array using photovoltaic cells to convert solar energy into electricity.

A PV module's efficiency is specified as the ratio of peak power output to the input solar power.

$$\eta = \frac{Vmax*Imax}{I*A}$$

Where Vmax is the voltage at peak power, Imax is the current at peak power, I is solar intensity and A is area of panel on which radiation falls.

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One may find the fill factor using

$$F.F. = \frac{Vmax*Imax}{Isc*Voc}$$

and it is an important performance indicator. In this paper the effect of homogeneous and non - uniform shading regarding the efficiency of both single - and multi - crystalline PV panel is examined and investigated in Bhilwara.

The present work was curied out to experimentally investigate the effect of different shadow as single cell; two series connected cells, two parallel connected cell, wire, leaves and building shad on the electrical performance of the solar PV panel.

2. Literature Review

Quaschring and Hanitsch (1996) [6] came up with the issue of partial shading. A solar array is a collection of photovoltaic modules linked in series and parallel to generate electricity. Inadequate illumination of any one cell in a string of solar cells reduces the efficiency of the whole string. Shade from nearby buildings, trees, leaves, birds, and other natural phenomena may cover some solar cells in an array.

Although the current flowing through a series of interconnected cells is constant, there are a small number of darkened cells that, although producing less current, are still compelled to transport the same current as the other, fully - illuminated cells in the string. As burdens, the darkened cells might drain electricity from the fully lighted ones. Inadequate system configuration might lead to hot spot problems and permanent system damage. In many applications the PV photovoltaic array is non - uniformly illuminated due to partial shading. Solar cells are vulnerable to damage from small hotspots in shadowed areas of PV arrays. [7]

Ramaprabha and Badrinath (2009) [8] focuses on harmful effect of partial concealing in an equal and series connection by considering power dissipation and uses bypass diodes in antiparallel to partially solve the problem of power reduction due to partial shadow. Parallel cell concealing might cause numerous neighborhood maxima's, so it becomes more difficult to get optimum power output.

Smita and Pankaj (2012) [9] fostered a mat lab program giving the worldwide greatest power highlight increment the power yield. It is very clear that solar panels should be placed in such a way that it absorbs maximum solar radiation during the day time when the sun is at highest as shading supersedes this, when it comes to dominance. [10] Shadow affects solar panel performance considerably. [11] Partial shadow or full shadow both affects the amount of solar radiation received by cell. When shaded by tree branch, building or module dust, a cell's output declines. [12] The result diminishes in relation to how much is the overshadowing. So contingent upon the region of the cell that is shed, the power creating limit of cell will go down. [13] Hence there will be drop in energy result of the sunlight based cell.

The weakness of a series association of cells is that one cell will influence the presentation of entire solar array. For completely opaque objects like a leaf, the decrease of the cell current output is proportional to the amount of cell area that is obscured.

The results show that the electrical performance of solar panel is significantly affected because of shadows. [14] Efficiency also decreases with shadowing. [15 - 23]

Wu et al. [23] studied that for a mono crystalline panel, shadow result in average energy reduction of 3.92%.

Saavedra et al. [22] using mono crystalline PV panel find that bypass diode enhances the power compared with the shaded module.

Dimich et al. [21] find that under shaded conditions power and efficiency is diminished and using current limiter it can be enhanced by 15% when compared to that without the current limiter. In the study work of Sisodia and Mathur, the effect of various dust particles from western Rajasthan on solar electrical characteristics has been examined. In their study they concluded that seasonal bird dropping play a crucial role in reduction of power generation capacity of PV module under western Rajasthan climatic conditions. [24]An experiment has been conducted Tulsi Panwar and R K Mathur to analyze the effect of irradiance and temperature in Ajmer region in India on 20 Watt poly crystalline solar module and found that temperature is a negative factor that reduces the efficiency of module and can be reduced by various cooling arrangements. They also found that short circuit current of the module increases with irradiance while open circuit voltage was least affected. [25] Mathur R K *et al*. in their study found that, with the increasing thermal non - uniformities, the reduction in the open circuit voltage and conversion efficiency of the cell becomes more severe whereas short circuit current shows an increase. The temperature gradient increases as the non - uniformities of illumination is increased. [26]In the study of solar cells, Dhariwal and Mathur proposed a parameter model to account for the effect of partial illumination on the open circuit voltage of solar cell and also reported that, cells may have lower Voc due to non - optimized structure, lower quality material with increased SRH recombination, additional shunt paths or non - uniform illumination. [27]

Figure 2: Concealing of two series associated cells

Figure 3: Tree leaves shading

Figure 4: Card board shading for two parallel cells

3. Experiment and Methodology

To create a partial shadowing condition, two cells belonging to the same sub module were covered with a sheet of cardboard, which makes the shadowing close to 100% i. e. zero solar irradiation on the covered area. The measurement results shown in figure below show a good agreement with the predicted curves.

A mono crystalline and polycrystalline solar panel, having following parameters are used to examine the impact of concealing and we fix the panel at 22.4° inclination due south.

Table 1: Manufacturer's characteristic specifications

Particulars	Mono - crystalline	Poly - crystalline
Module dimensions	640 mm x 320 mm	640 mm x 320 mm
Cell dimensions	160mmx80mm	160 mm x 80 mm
No. of cells	12	12
Total cell area	0.2048m^2	0.2048m^2

Table 2: Rated values of modules at STC

Electrical parameters	symbols	Mono - crystalline	Poly – crystalline
Max power	Pmax [W]	50	40
Max current	Imax [A]	2.50	2.30
Max voltage	Vmax [V]	20	18
Short circuit current	Isc [I]	2.60	2.50
Open circuit voltage	Voc [V]	23.5	22.6
Fill factor	FF	0.7864	0.7686

For testing uniform and non - uniform shading, we use tree leaves, cable wire, card board and building shade etc. We use card board for cloud testing. I - V measurement was taken in each case using different irradiance levels. Each experiment repeated to get constant reading and average value noted. We calculate power output and efficiency for every experiment.

The figure shows I - V characteristics of PV panel subjected to card board shading of one cell or (cells in series and parallel), leaf, wire and building shed. The impact of non - uniform concealing on PV board on power and voltage are displayed in charts.

An important result noticed due to non - uniform shading and efficiency depend on experiment is that fill factor and the efficiency depend on effective cell illumination obtained by non - uniform shading. When shades cover a significant area of the cell then a huge drop in efficiency as well as fill factor occurred. This is because of the reality that shades of leaves or pipe covers limited area, on the other hand building wall result in high drop in efficiency. Cell that get lower insolation will act as a load and behave as the reversed biased condition. This leads reduction in circuit power and efficiency, further this condition may convert into hot spot in the panel and cause drop in power and efficiency or can lead to permanent damage.

Experiment using solar panels partially obstructed with different types of shadow pattern under natural outdoor conditions. The experiment is performed on a clean solar PV panel without any shadow. The same set of analysis is repeated with different type of shadow pattern. The impact of shadow was concentrated on in view of the rate decrease in power and proficiency of the sun oriented PV module.

Power output of PV module = Vmax*Imax

Electrical efficiency of PV module

$$\eta = \frac{Vmax*Imax}{I*A}$$

% Reduction in power =

(Power $_{\text{clean panel}}$ - Power $_{\text{shadowed panel}}$/ Power $_{\text{clean panel}}$) *100

% Reduction in Efficiency= (Efficiency $_{\text{clean panel}}$ - Efficiency $_{\text{shadowed panel}}$/ Efficiency $_{\text{clean panel}}$) *100

A few presumptions are made during the review the experiment was done on clear sky day in which climatic conditions are assumed to be similar. The analysis of power and efficiency were evaluated for different irradiance conditions from 9am to 5pm at each irradiation level. We analyze the effect of different shading patterns on mono crystalline and poly crystalline solar modules.

The following table represents the solar irradiation, ambient temperature and module temperature throughout the daytime in February month 2024. It is submitted that it increases initially from 730 W/m^2 at 9 am to 1040W/m^2 at 11 am then it decreases gradually till 5pm in evening. The irradiation level is found out 752W/m^2 at 5 pm.

Table 3: Solar irradiation, ambient temperature and module temperature

Time	9 am	10 am	11 am	12 pm	1 pm	2 pm	3 pm	4 pm	5 pm
Solar insolation	730	910	1040	981	972	961	832	801	752
Ambient Temperature	15.2	18.1	20.2	22.0	23.5	23.1	22.2	20.4	19.2
Module Temperature	28.6	39.4	48.1	51.0	33.1	37.7	31.0	21.8	18.3

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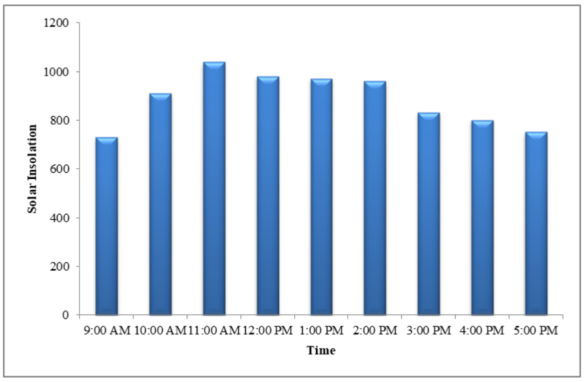

Figure 5: Solar Insolation verses day time

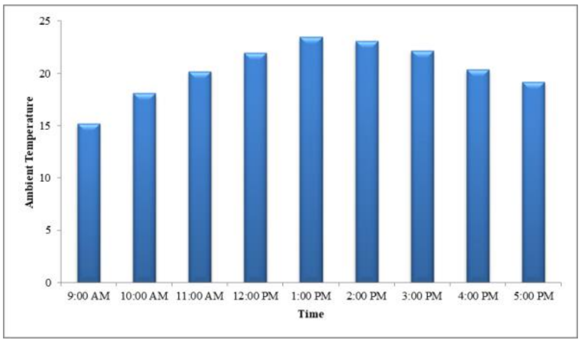

Figure 6: Ambient Temperature verses day time

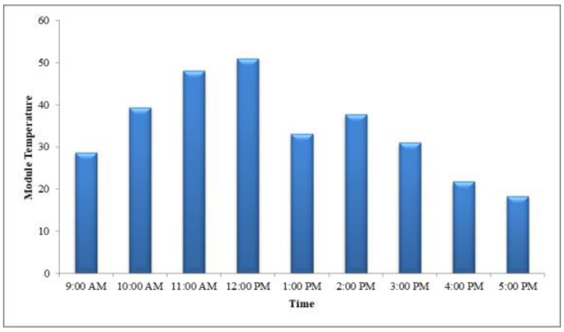

Figure 7: Module Temperature verses day time

4. Result and Discussion

This research presented the impact of shading on the I - V and P - V curves of solar cell panel and clarifies the basic mechanisms that estimate the reduction in output power. Such degradation in power and execution relies upon the concealed region as well as design of the sub module and the inherent bypass diode for short circuit current. The analysis was confirmed by experimental procedure. This study is useful for solar panel designers when attempting to minimize the impact of shading on solar panels.

It is concluded that there is a substantial power loss due to non - uniform illumination of series connected panels. The power generated by highly illuminated cell is wasted as heat in the poorly illuminated cells. Non uniform shade caused by building wall affected the efficiency to a great extent whereas cable or leaves dropping affected the least. The cells that received lower radiation than the rest, acted as a loads and caused drop in current, power and efficiency. So care should be taken to see all cells connected in series receive same illumination under different pattern of shading and non - uniform shading must be avoided. Such a care will give a better protection to the array and at the same time the efficiency and power out will also be higher.

Figure shows comparison of current of clean panel and shadowed panel.

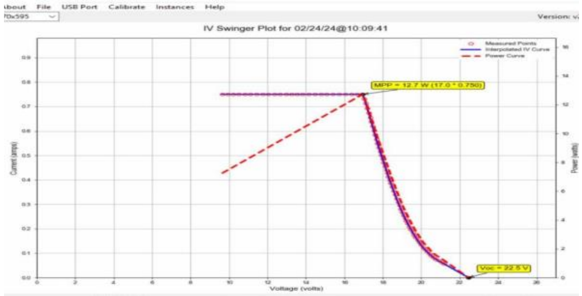

Figure 8: I - V characteristic of no shading (mono crystalline)

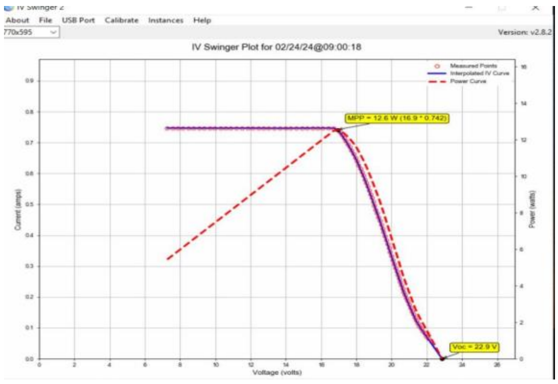

Figure 9: I - V Characteristic of one cell blocked shading (mono crystalline)

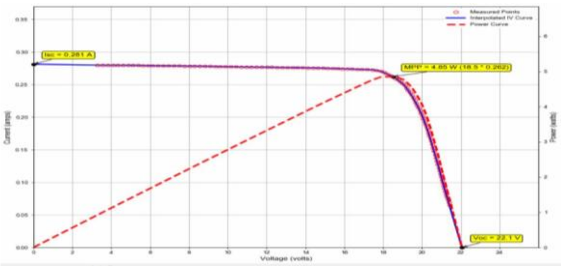

Figure 10: I - V characteristic building shading (mono crystalline)

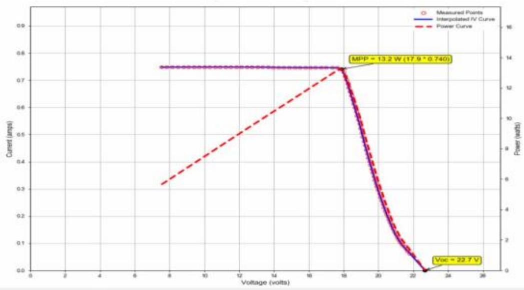

Figure 11: I - V characteristic of leave shading (mono crystalline)

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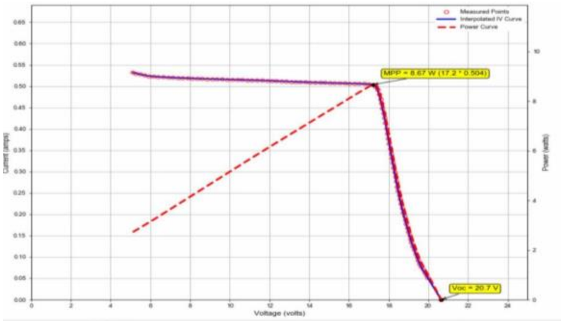

Figure: 12: I - V characteristic one cell shaded (poly crystalline)

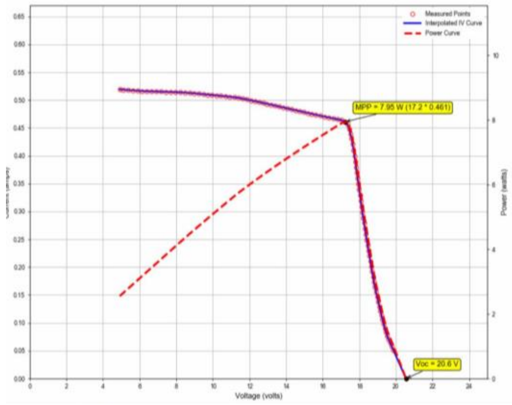

Figure 13: I - V characteristic parallel cell shading (poly crystalline)

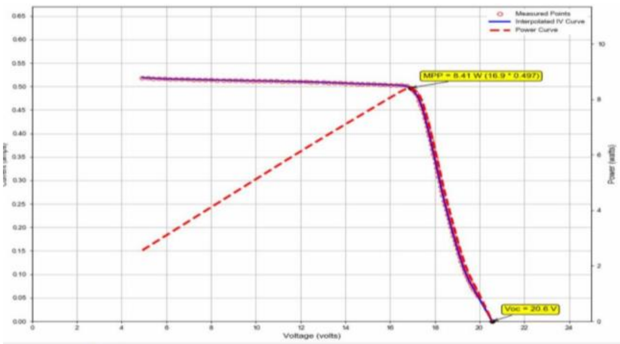

Figure 14: I - V characteristic series cells shading (poly crystalline)

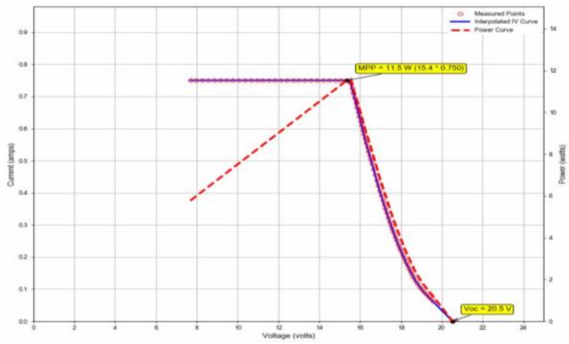

Figure 15: I - V characteristic of leave shading (poly crystalline)

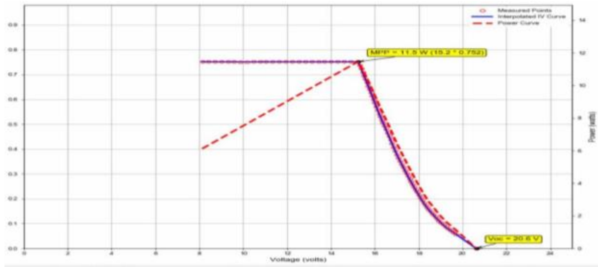

Figure 16: I - V characteristic of wire shading (poly crystalline)

* **Voltage and current variation in shaded condition**

The analysis was completed in natural environment of Bhilwara region. Execution boundaries, for example, voltage, current flow, electrical power and electrical effectiveness were estimated with and without shadow at various insolations.

We examine the current and voltage for mono crystalline solar module. We analyze open circuit voltage Voc at 10 am, we see that open circuit voltage has maximum value 22.5 volt without any shading and this value decreases with different type of shading pattern. The value of Voc is found to be 22.3, 22.2 and 22.2 for single cell shading, two series connected shaded cells and two parallel connected shaded cells. Apart from this open circuit voltage is 21.1V for building shading which is maximum reduction as compared to other shading elements. In summery we analyzed that voltage over open circuits do not change much by shading effect. A minor adjustment has been made in Voc, we have found so far except building shed.

In the same way, we find the value of short circuit current at 10 am is maximum 0.750A without any shading. and this value decreases with different type of shading pattern accordingly. The value of Isc is found to be 0.623A, 0.656A and 0.606A for single cell shading, two series connected shaded cells and two parallel connected shaded cells. This current in a short circuit is separate from is 0.238A for building shading which is maximum reduction as compared to other shading elements. In summery we analyzed that short circuit current change much by shading and there is appreciable change in Isc, we have found so far. Building shed creates higher reduction in short circuit current. We find a little change in short circuit current and open circuit voltage for wire and leaves shad.

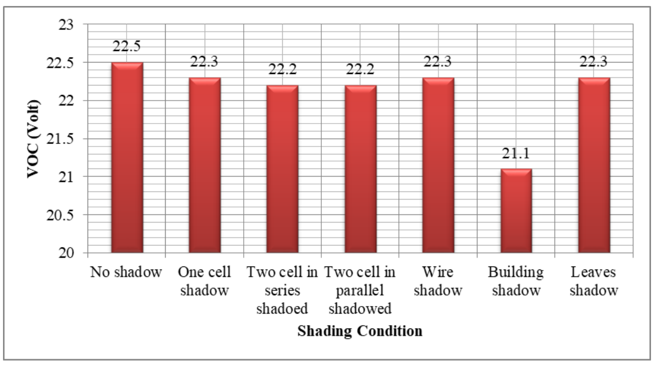

Figure 17: Open Circuit voltage verses shading pattern in mono crystalline

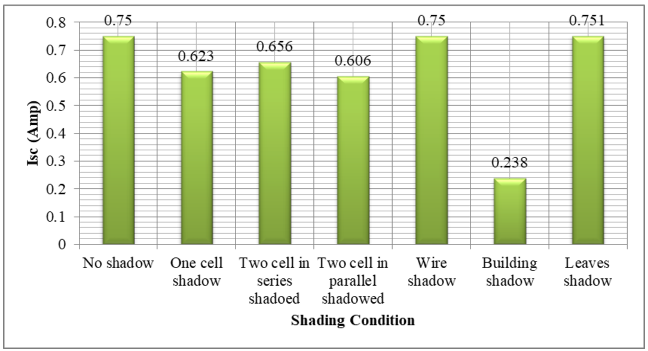

Figure 18: Short Circuit Current verses shading pattern in mono crystalline

We examine the current and voltage for poly crystalline solar module. If we analyze open circuit voltage Voc at 10 am, the voltage at the open circuit has maximum value 20.5 volt without any shading and this value decreases with different type of shading pattern. The value of Voc is found to be 20.4V for single cell shading, two series connected shaded cells and two parallel connected shaded cells. Apart from this open circuit voltage is 19.5 for building shading which is maximum reduction as compared to other shading elements. In summery we analyzed that open circuit voltage do not change much by shading effect. There is a little change in Voc, we have found so far except building shed. There is no appreciable change in open circuit voltage by shading implemented by wire and leaves.

In the same way, we find the value of short circuit current at 10 am is maximum 0.751A without any shading and this value decreases with different type of shading pattern accordingly.0.581A, 0.590A, and 0.558A are the determined values of Isc for single cell shading, two series connected shaded cells and two parallel connected shaded cells. Aside from this short out current is 0.0.283A for building shading which is maximum reduction as compared to other shading elements. In summery we analyzed that short circuit current change much by shading and there is appreciable change in Isc, we have found so far. Building shed creates higher reduction in short circuit current. We find a little change in short circuit current and open circuit voltage for wire and leaves shad for poly crystalline cell also.

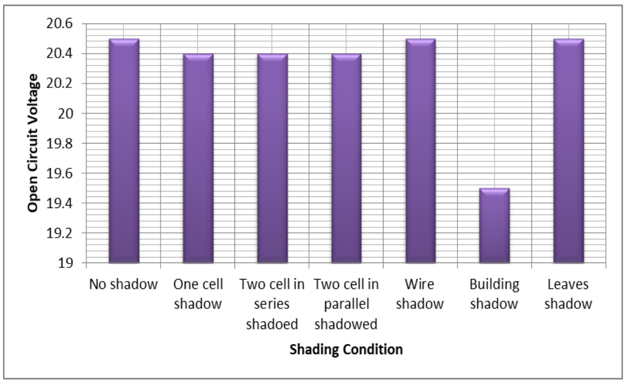

Figure 19: Open Circuit voltage verses shading pattern in poly crystalline

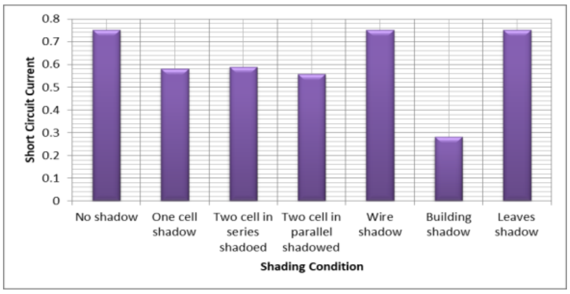

Figure 20: Short Circuit Current verses shading pattern in poly crystalline

As solar insolation increases, the change in Voc and Isc due to shading decreases. Due to the effect of shading at 11 o'clock, the change in electrical parameters is quite less. From noon to evening onwards, solar insulation decreases. Voc and Isc values start decreasing more and becoming less. And due to shading, from the comparative study of mono crystalline and poly crystalline, we come to know that both Voc and Isc have negative effects by shading, yet reduction in mono crystalline solar module is found higher than the comparison to poly crystalline module or we can say that mono crystalline solar cells shading are more sensitive toward shading impact.

Variation in power output

You can see the difference in power between the clean panel and the panel with various shadows in the figure. The power output was reduced to 60% of the maximum power that could be achieved by using building shadows compared to when no shadows were present. Shadow has a substantial impact on the electrical performance of the panel, as shown by the results. Variation at various solar insolations is also compared.

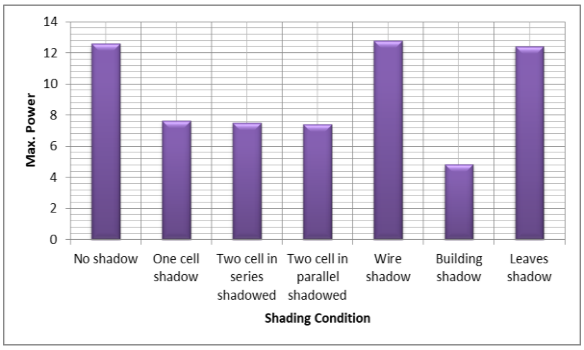

Figure 21: Maximum Power verses shading pattern in mono crystalline

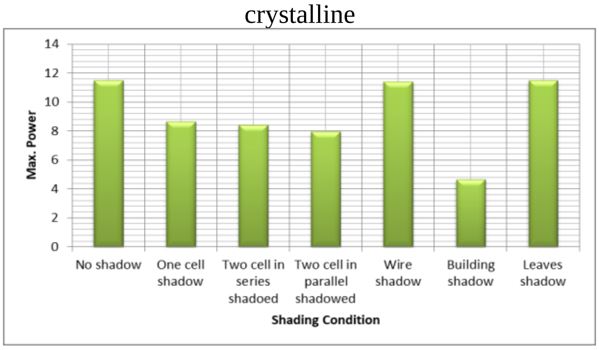

Figure 22: Maximum Power verses shading pattern in poly crystalline

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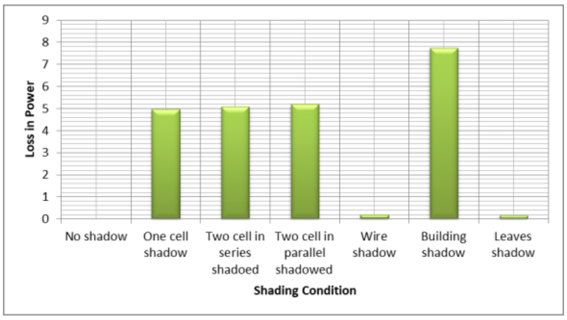

Figure 23: Power loss verses shading pattern in mono crystalline

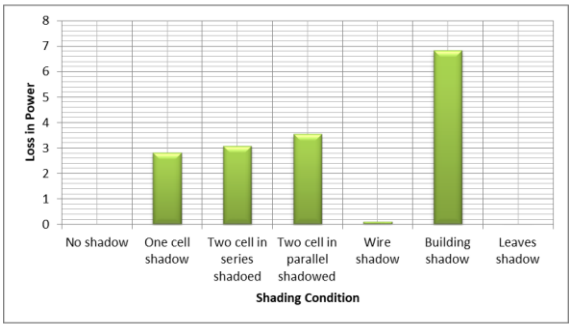

Figure 24: Power loss verses shading pattern in poly crystalline

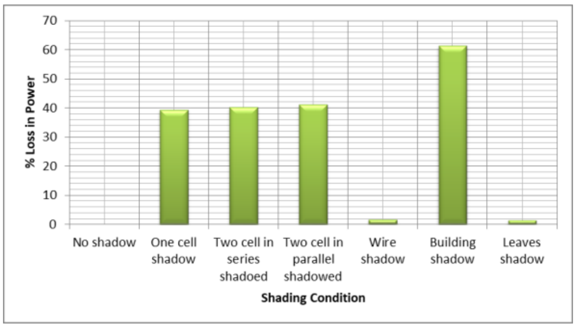

Figure 25: % Power loss verses shading pattern in mono crystalline

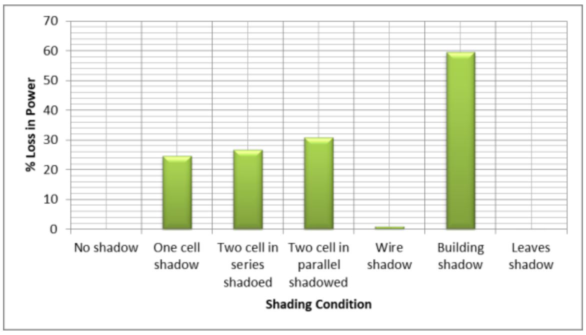

Figure 26: % Power loss verses shading pattern in ploy crystalline

According to observation at 9 am, power of mono crystalline solar module was 12.6W and power output for poly crystalline module was 11.5W without any shading. At this time solar insolation was 730 W/m^2. According to different shading patterns, one cell, two shaded cells in series, two shaded cells in parallel, wire, building and leaves shadows, power output loss for mono crystalline was found 39.44%, 40.31%, 41.2%, 1.50%, 61.50%, and 1.34%respectively. While we did not find a significant drop in power output when the leaves were shaded, we did find that the solar cell's output was significantly reduced when the building shadow was in the way. Power loss is more due to shading in parallel arrangement compared to series one. Similarly, power loss of poly crystalline solar cell at 9 o'clock without any shading was 11.5 Volt. Different shading of one cell, two shaded cells in series, two shaded cells in parallel, wire , building shad and leaves shad, power output loss was 24.60%, 26.80%.30.56% 0.869%, 56.47% and 0% respectively. That is, like mono crystalline solar cell, there is power loss due to shading but comparatively in mono crystalline power loss is relatively higher. The percentage of power loss changes from day to evening with the flow of solar insolation, that is, the shading effect in the morning and evening is dominant and during the day the shading effect gets weakened. Power loss due to shading is higher in parallel shaded cells rather than in two shaded cells in series. The effect is as same as we find in theoretical model i. e. in the parallel arrangements, reduction power loss is greater.

Efficiency fluctuation of modules due to shading

Compared to the clean panel that did not have any shadow, the efficiency in shaded one was lower. Shadow reduces power output and efficiency, two key metrics for any system's performance study, as is evident from the aforementioned attribute.

The impact of various shadows has been investigated by analyzing the performance of PV modules under genuine experimental conditions.

When comparing mono crystalline solar modules with and without building shadows, researchers found that electrical power output decreased by 61.50%, by 1.34% for leaf shadows, by 1.58% for cable wire shadows, and by 39.44% for one cell shadows. Compared to the panel free of any shadow in the poly crystalline solar module, electrical power generation was found to be 61.50% lower with building shadow, 0% lower with leaf shadow, 0.869% lower with cable wire shadow, and 24.60% lower with one cell shadow.

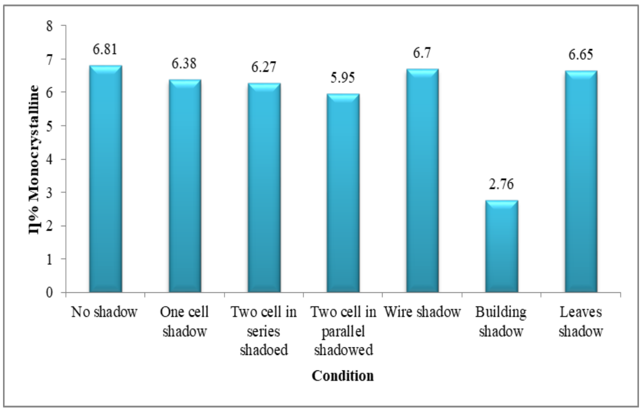

Figure 27: Efficiency verses shading pattern in mono crystalline

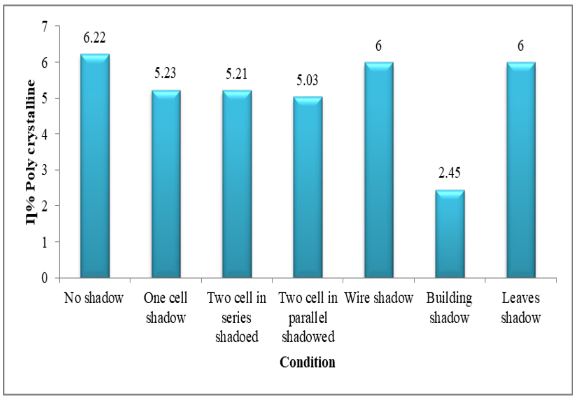

Figure 28: Efficiency verses shading pattern in poly crystalline

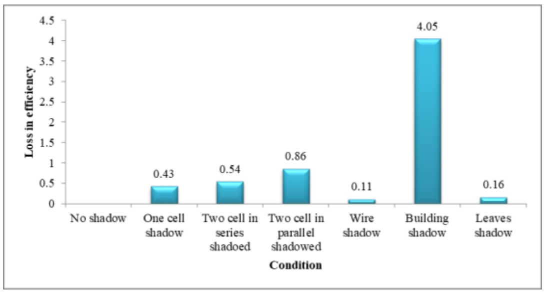

Figure 29: Loss in Efficiency verses shading pattern in mono crystalline

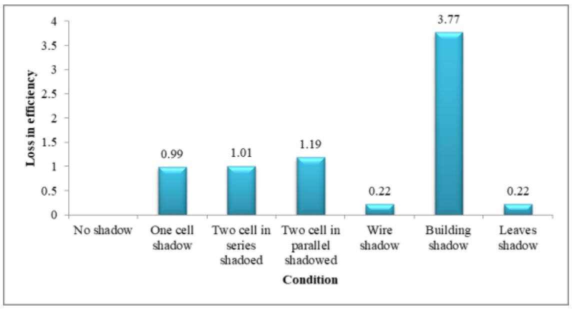

Figure: 30 Loss in Efficiency verses shading pattern in poly crystalline

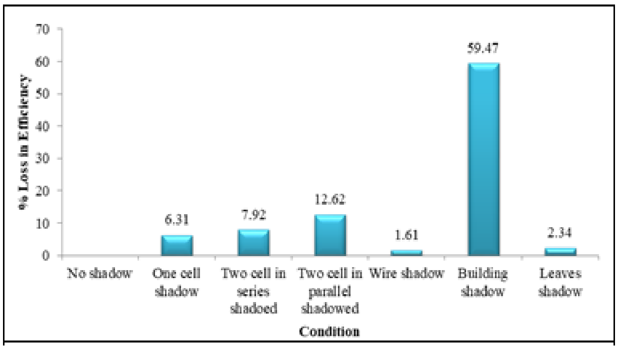

Figure: 31 %Loss in Efficiency verses shading pattern in mono crystalline

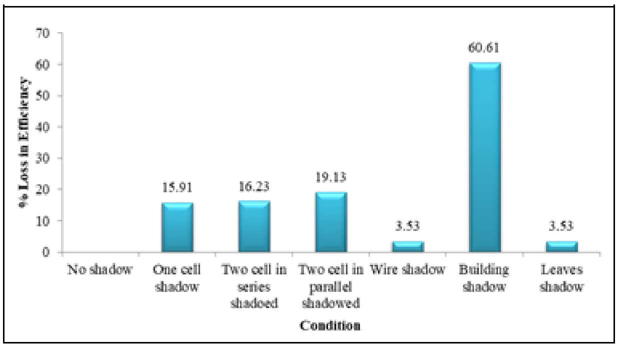

Figure: 32 % Loss in Efficiency verses shading pattern in poly crystalline

According to observation at 10am, efficiency of mono crystalline solar module was 6.81 and efficiency for poly crystalline module was 6.22 without any shading. At this time solar insolation was 910 W/m^2. According to different shading patterns, one cell, two shaded cells in series, two shaded cells in parallel, wire, building and leaves shadows, efficiency loss for mono crystalline was found 6.31%, 7.92%, 12.62%, 1.61%, 59.47%, and 2.34%respectively. We observed that when the leaves shaded the panel, although there is a little decrease in efficiency, the building's shade significantly reduces the solar cell's performance. Efficiency loss is more due to shading in parallel arrangement compared to series one. Similarly, efficiency of poly crystalline solar cell at 10o'clock without any shading was 6.22%. Different shading of one cell, two shaded cells in series, two shaded cells in parallel, wire, building and leaves, efficiency loss was 15.91%, 16.23%.19.13% 3.53%, 60.61% and 3.53% respectively. That is, like mono crystalline solar cell, there is efficiency loss due to shading but comparatively in polycrystalline efficiency loss is relatively higher. The percentage of power loss changes from day to evening with the flow of solar insolation, that is, the shading effect in the morning and evening is dominant and during the day the shading effect gets weakened. Efficiency loss due to shading is higher in parallel shaded cells rather than in two shaded cells in series. The effect is as same as we find in theoretical model i. e. in the parallel arrangements, reduction efficiency loss is greater.

According to the results of the experiments, the solar panel's efficiency is affected by even a little amount of shadow, as opposed to only dust.

It is critical to find and choose a standard that allows solar PV to operate in the absence of shadows. Additionally, it is crucial to ensure that the PV is free from shadows and that regular maintenance is carried out, since solar PV technologies are being used more and more in Building Integrated photovoltaic (BIPV). It is now clear how critical it is to keep the PV panel clean and out of shadows.

Wire shading may refer to shading caused by wires or any other physical obstruction on the surface of solar modules. In this case, the solar cells may not get enough light if the cables create a shadow on them, again resulting in reduced power output. Buildings can cast shadows on solar panels, especially during certain times of the day. This shading can be dynamic, changing with the position of the sun. If not carefully planned, it can lead to intermittent shading on the solar modules and reduce overall efficiency.

5. Conclusion and Future Aspects

Partial shading in a solar module can have different effects depending on whether the solar cells are connected in series or in parallel. We have examined the impact in both scenarios by observation we have taken for mono and poly crystalline solar modules.

In a series configuration, the solar cells are connected end - to - end, forming a string. The current flowing through the entire string is limited by the cell with the lowest illumination. When one cell in a series string is shaded, its output voltage drops significantly. This is because the current through the string is determined by the shaded cell, and the voltage across the string is the sum of the voltages of all the cells. The shaded cell acts as a bottleneck, reducing the overall voltage of the string. The shaded cell can act as a resistor, leading to localized heating known as a "hot spot. " This can potentially damage the shaded cell and affect the overall performance and reliability of the solar module.

The whole series - connected string's power output drops as a result of the lower voltage and possible hot spot problems. In the long run, this can affect the solar module's ability to collect energy.

Each branch of a solar cell module in a parallel arrangement adds to the module's total current output. Partial shading of one cell affects only the current output of its respective branch. Other branches continue to produce current unaffected by the shading. On the other hand, if the currents generated by the various branches aren't balanced, the solar module's total current output will be reduced. In contrast to a series arrangement, the voltage across branches connected in parallel is very constant. When one branch is shaded, the voltage on the remaining branches is little affected.

To reduce the impact of shade, bypass diodes are a common component of solar panels. Bypass diodes provide an alternative path for the current to bypass a shaded cell, preventing the entire module from being dragged down by the shaded cell.

In conclusion, both series and parallel shading have negative impacts on solar module performance, but the nature of the impact differs. Manufacturers often use bypass diodes and other technologies to minimize these effects and improve the overall reliability of solar modules in shaded conditions.

In conclusion, shading, regardless of the source (Leaf, wires, or buildings), can negatively impact solar module performance, and it's essential to consider shading effects in the design and installation of solar systems.

In observation we find that partial shading has similar effects on both mono crystalline and polycrystalline solar modules, nevertheless, the responses of mono crystalline and polycrystalline solar cells to shading are distinct. Within the scope of this research, we investigate the comparative influence of partial shadowing on mono crystalline and polycrystalline modules.

*Mono crystalline solar cells typically have higher efficiency and better performance in low - light conditions. The series - connected cells' overall performance is impacted when partial shading occurs because of the substantial voltage drop in the shaded portion.

Because of the lower voltage, hot spot problems may develop, which might lead to localized heating in the cells that are shadowed. Polycrystalline solar cells generally have slightly lower efficiency compared to mono crystalline cells. The voltage drop in a shaded area of polycrystalline modules is also significant, impacting the overall module performance. Hot spot issues can occur, similar to mono crystalline modules, when a cell is shaded.

*The use of bypass diodes in mono crystalline modules helps mitigate shading effects. Bypass diodes provide an alternative path for current to bypass the shaded cells, preventing a significant reduction in the overall module output. Polycrystalline modules also utilize bypass diodes to minimize the impact of shading. The effectiveness of these diodes depends on their quality and how well they can handle shading events.

*****Mono crystalline cells are generally more sensitive to temperature changes than polycrystalline cells. This characteristic can be an advantage in mitigating temperature - related issues associated with shading. Polycrystalline cells are less temperature - sensitive than mono crystalline cells. Shading - induced temperature increases can exacerbate the negative effects on performance.

* Mono crystalline modules tend to perform slightly better in low - light conditions, increasing their efficiency in handling partial shading. Polycrystalline modules may experience a slightly greater reduction in efficiency in low - light conditions compared to mono crystalline modules.

*Mono crystalline technology has seen more significant advancements in recent years, with many manufacturers focusing on producing high - efficiency mono crystalline modules. Particularly in contexts where price is of the essence, polycrystalline modules continue to see extensive use. Manufacturers continue to refine polycrystalline technology, but efficiency improvements may not be as rapid as in mono crystalline technology.

In summary, both mono crystalline and polycrystalline modules are susceptible to the negative effects of partial shading. Mono crystalline modules for the most part enjoy a slight benefit concerning effectiveness and low - light execution; however the decision between the two relies upon different variables, including cost contemplations and explicit application prerequisites. Mitigation strategies, such as the use of bypass diodes, are critical for optimizing the performance of both types of modules in shaded conditions.

Overall, individual reactions to partial shading may vary, but in general, decreased generation, greater recombination, and perhaps poorer carrier mobility are seen in shaded regions of both mono crystalline and polycrystalline solar cells. To reduce these impacts and maintain solar cells' overall performance under shadowing situations, bypass diodes, are still an important tool to have on hand.

The photovoltaic community is always working to find solutions to the problems caused by partial shadowing of solar cells. To improve solar systems' overall performance and lessen the impact of shadowing, researchers are looking at a number of potential future directions. It is important to keep in mind the following:

Advanced Bypass Diode Technologies: Research is focused on developing more advanced bypass diode technologies. Improved diode characteristics, such as faster response times and lower voltage drops, can enhance the effectiveness of these diodes in minimizing the effect of incomplete overshadowing.

Smart Inverters and Maximum Power Point Tracking (MPPT) Algorithms: Advancements in inverter technologies and MPPT algorithms are crucial. Smart inverters equipped with advanced MPPT algorithms can dynamically adapt to changing environmental conditions, including partial shading, optimizing energy harvesting from the solar array.

Module - Level Power Electronics: Module - level power electronics, such as micro inverters and DC - DC converters, are being integrated directly into solar panels. This allows for individual panel optimization, reducing the impact of shading on the overall system.

Advanced Panel Designs: Future solar panel designs may incorporate innovative materials and structures to minimize the effects of shading. For instance, bifacial solar panels capture sunlight from both the front and rear sides, reducing the impact of shading on the overall system efficiency.

Machine Learning and Predictive Analytics: The use of machine learning algorithms and predictive analytics is gaining traction for optimizing solar system performance. These technologies can anticipate shading events based on weather patterns and other factors, allowing for proactive adjustments to minimize energy losses.

Energy Storage Integration: The integration of energy storage solutions, such as batteries, can help store excess energy during periods of low shading and release it when shading occurs. This can contribute to maintaining more stable energy output and grid integration.

Flexible and Tandem Solar Cells: Flexible solar cells and tandem solar cell configurations are being explored to enhance the adaptability of solar panels to different environmental conditions, including partial shading. Energy harvesting and system efficiency may both be enhanced by these solutions.

Urban Planning and Design Considerations: Urban planning and solar system design considering shading patterns are becoming more critical. Proper placement of solar panels and understanding local shading conditions can help optimize energy production in urban environments.

As the solar industry continues to grow and mature, Maximizing the efficiency and dependability of solar power systems is anticipated to be greatly impacted by resolving the issues associated with partial shade. Ongoing research and technological advancements will likely lead to more resilient and adaptive solar technologies in the future.

In summary, series - connected cells are more susceptible to the negative effects of partial shading, as shading one cell affects the entire series. Parallel - connected cells offer better resilience, with the impact localized to the shaded cell. Bypass diodes and maximum power point tracking (MPPT) technologies may lessen these impacts, making solar modules more efficient and dependable even when partial shadowing is present.

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