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Investigating the Effect of PV Panel Mounting Orientation under Partial Shading Conditions: a Simulation-Based Study

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Abstract— **This study aims to investigate the effect of shading on the mounting orientation of PV panel and the availability or unavailability of bypass diodes on the performance of PV panel under partial shading conditions. In this study, for each PV panel mounting orientation, the number of PV cells that received shading was grouped into three categories: 9 cells, 18 cells and 27 cells respectively with the shading fixed vertically. The study also considers the presence or absence of bypass diodes. The simulation results show that with vertical shading partially covering the PV cells, the landscape mounting orientation is the best orientation for PV panels with bypass diodes to avoid the partial shading effect.**

Keywords*— *shading effect; PV mounting orientation; bypass diode.

I. Introduction

Over the last decade, solar energy technology has become less expensive and more efficient. Furthermore, it is a more environmentally benign energy source than traditional alternatives such as fossil fuels, coal, and nuclear energy. As a result, photovoltaic (PV) systems now account for a larger share of renewable energy sources. The PV system can be connected to the load directly as a stand-alone system or indirectly through the electric grid. When numerous sources of electricity are available, a grid-connected system is preferred [1]. The output power of a PV module depends on many factors such as solar radiation, wind speed, cell temperature, geographical location, module orientation, weather conditions, etc. [2].

PV systems operating under partial shading conditions (PSC) face challenges due to factors such as shadows from trees, clouds, dust, or buildings, leading to the PV modules receiving varying radiation levels [3]. The presence of multiple peaks in a PV array under partial shading makes it difficult to track the true peak power point accurately [4]. In such conditions, PV systems generate multiple peaks, including a global peak and several local peaks, affecting the overall power output [5]. Factors like partial shading, dust, temperature, solar radiation, and sand have a clear impact on PV system performance, with partial shading being a common issue that reduces sunlight reception and system efficiency [6], [7].

A number of studies have examined the quantification of the impact of partial shading [8], [9]. The study in [10] demonstrated the effect of partial shading on a PV system integrated into an electric vehicle. The experimental model employed to estimate shading losses on PV is discussed in [11]. Different shading patterns were tested, and multiple peaks were observed. The authors suggest an improvement in the MPPT algorithm to extract maximum power. The existing literature has highlighted various configurations of solar arrays to improve their performance under conditions of partial shading [12].

The previously mentioned studies have not specifically discussed how shadows affect the orientation of PV panel installation. Unlike previous studies that mainly analyzed shading effects on PV array

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configuration or MPPT algorithms, this study focuses on the combined impact of panel mounting orientation and bypass diode availability on PV performance under partial shading. To the best of our knowledge, few studies have simultaneously examined how these two factors interact to influence PV efficiency, especially using simulation-based analysis under controlled shading conditions. Therefore, this study aims to investigate how shading affects the installation orientation of PV panels and the presence or absence of bypass diodes on their performance.

II. PV Cells Configuration and Shading

In the literature [13], there are 6 PV configurations; parallel configuration, series parallel configuration, total cross tied configuration (CTC), bridge link configuration, and honey comb (HC) configuration. The following is an explanation of each configuration.

Modules connected in series provide the same current and increase voltage values. The primary disadvantage of series or parallel setups is the difficulty in attaining the expected current and voltage compared to the given value. Mismatch losses occur in series-connected PV cells due to their non-identical electrical properties [14].

Figure 1(a) and 1(b) show a single PV module and modules connected in series. Two PV series-connected modules produce a total voltage of 36.0 V and the same current of 5.56 A.

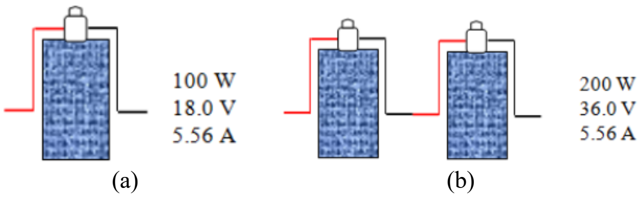

Figure 1. (a) Single module and (b) modules connected in series configuration [13].

In parallel configuration, the different PV modules are connected in parallel. They provide the same voltage and multiple current amounts. However, it is difficult to obtain the stated value due to various losses. Two modules connected in parallel provide multiple currents of 11.12 A and the same voltage of 18.0 V, as shown in Figure 2(a).

A number of researchers tested various parallel PV systems. Several of them are discussed here. The three PV modules are linked in parallel, and their I-V characteristics are anticipated using the common output voltage. The author also concluded that parallel coupled PV modules outperformed series and series-parallel modules [15].

In an PV panel arrangement, the various modules are series-connected first, followed by parallel-connected. In these arrangements, the current and voltage values are multiplied by the number of modules. Series parallel setups are increasingly popular among researchers. To maximize power output, the different PV modules are connected in series, parallel, and series-parallel configurations. Four modules connected in parallel create a multiple voltage of 36.0V and a current of 11.12A, as shown in Figure 2(b). According to a literature review, parallel linked PV modules perform better than modules connected in series and series-parallel combinations [15].

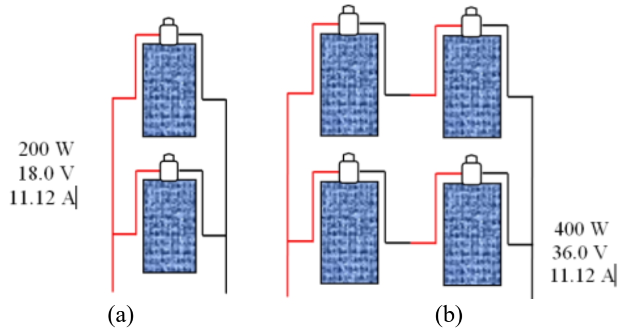

Figure 2. (a) Modules are connected in parallel configuration (b) Modules are connected in series-parallel configuration [13]

In PV systems, shading occurs when irradiance blocks energy from reaching the PV panels, as shown in Figure 3. When PV system is partial shading, then a converter's Global Maximum Power Point Tracking (GMPPT) action, aims to locate the greatest global energy generation value from the multiple I-V curves of the module arising from the various partial shading situations [16]. Partial shading increases mismatch losses and reduces the output of the solar photovoltaic system The output reduction in the partially shaded array is proportional to the shaded area, shaded panel's placement within the array, panel connections, shade geometry, etc. [17].

Cells in current modules are often connected in series, with cell counts of 36, 48, 60, or 72, resulting in MPP voltages of 18 to 36 V. Figure 3 illustrates a typical PV module with 36 cells and its corresponding characteristic curve. Similarly, one shaded cell causes a

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significant fall in power from MPP1 to MPP2. This loss is unacceptable, which is why so-called bypass diodes are inserted as additional components [18].

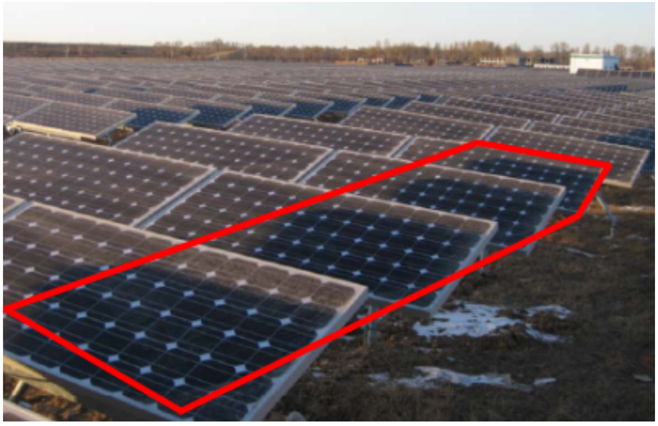

Figure 3. Shading on PV module [19]

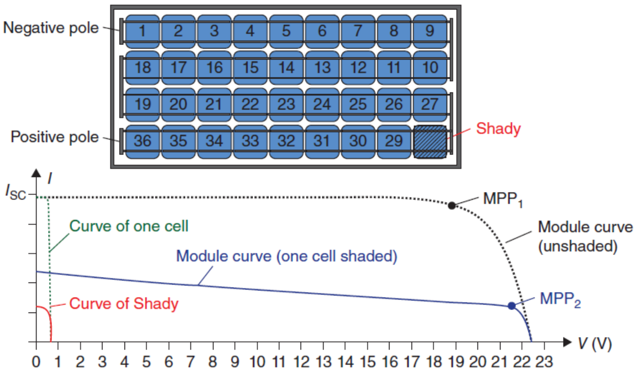

Figure 4. Solar module with 36 cells: When a single cell is shaded, the module power reduces dramatically [18].

This is shown in Figure 4 as an example of Figure 3: Each PV cell has an antiparallel bypass diode linked to it. Assuming no shading, all cells have a positive voltage. This voltage serves as a reverse voltage for the diodes, which conduct no current and cause no disturbance. If the shaded cell is now three-quarters covered by shade, then this cell will have a negative voltage. This signifies that the diode conducts and Shady are connected. The remaining 35 cells can so carry their full current. However, the bypass diode has a threshold voltage, V_{Th}, of about 0.7 V, which is roughly the open-circuit voltage of a solar cell. Only when the current drawn from outside the module is as tiny as the current that Shady can still give will Shady's voltage become positive again. As a result, the bypass diode blocks, and Shady can still supply some of the voltage (see the characteristic curve at the bottom right of Figure 5) [18].

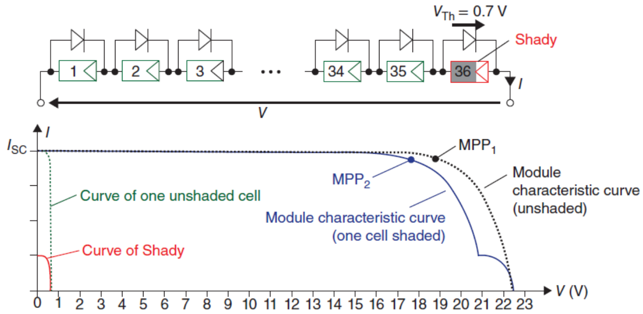

Figure 5. PV module with 36 cells and a bypass diode above each cell. When any cell is shaded, the power loss is kept to a minimum [18].

III. Research Methodology

A. PV Panel Specification under Study

The specifications of the PV panels used in this study are presented in Table 1. This PV panel uses monocrystal cells and the capacity is 100 Wp. The cell configuration on this PV panel is series, as presented in Figure 6.

Table 1. PV specification used in this study [20].

Parameters	Rating
Maximum power (Pmax)	100 W
Voltage at Pmax (Vmp)	20.90 V
Current at Pmax (lmp)	4.76 A
Open-circuit voltage (Voc)	25.52 V
Short-circuit current (Isc)	5.04 A
Module Efficiency	22 %
Temperature coefficient of Voc	-0.32 %/°C
Temperature coefficient of Isc	+0.06 %/°C
No. of cells and connections	36(4 x 9)

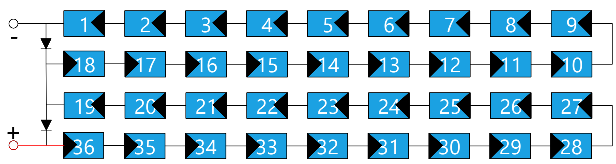

Figure 6. Connections PV cells under study.

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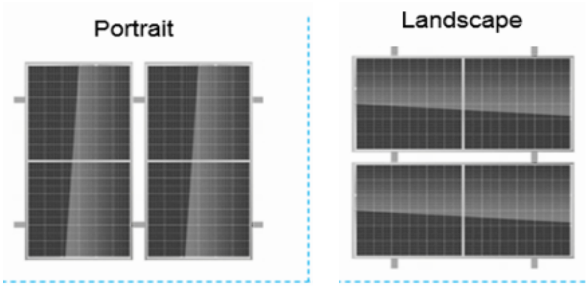

Figure 7. Installed orientation PV panel [21]

B. Simulation Procedure

This study used PSIM to simulate the effect of shading on PV panel installation orientation and the availability or unavailability of by-pass diodes on the performance of PV panel. The simulation procedure for analyzing the shading effects on photovoltaic (PV) cells was divided into two scenarios: portrait and landscape installation orientations of the PV panel. In this study, bypass diodes were connected across each PV cell. The shadows were kept fixed, and the PV cells were shaded vertically, with an equal number of shaded cells considered for both mounting orientations. The purpose is to evaluate performance loss due to shading under different configurations.

1. First Scenario

In this scenario, the PV panel installed orientation in a portrait orientation. The shading in this scenario are:

1. The PV cells covered by shading are cell numbers 7-11, 26-29 (see Figure 8a).
2. The PV cells covered by shading are cell numbers 5-14, 224-31 (see Figure 8b).
3. The PV cells covered by shading are cell numbers 3-16, 21-33 (see Figure 8c).

2. Second Scenario

In this scenario, the PV panel installed orientation in a landscape orientation. The shading in this scenario are:

1. The PV cells covered by shading are cell numbers 1-9 (see Figure 9a).
2. The PV cells covered by shading are cell numbers 1-18 (see Figure 9b).
3. The PV cells covered by shading are cell numbers 1-27 (see Figure 9c).

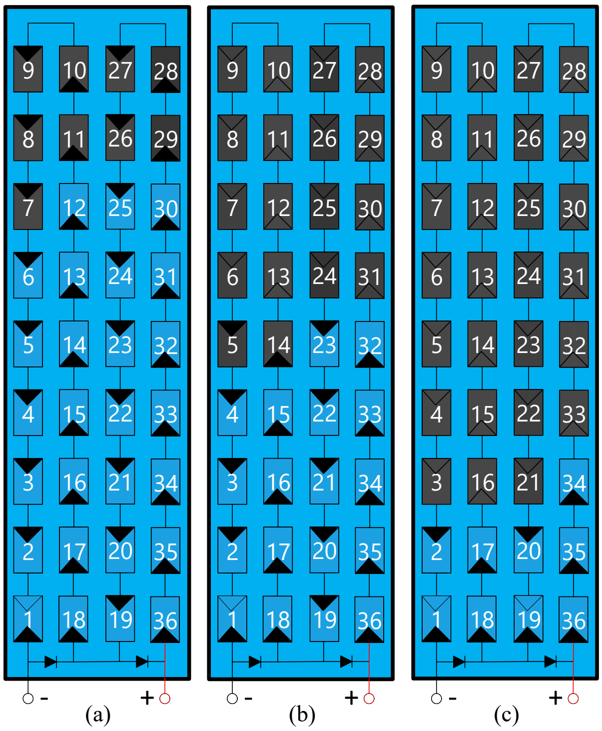

Figure 8. PV cell configuration, mounting orientation and PV cell shaded in the first scenario, (a) scenario I.1, (b) scenario I.2, and (c) scenario I.3.

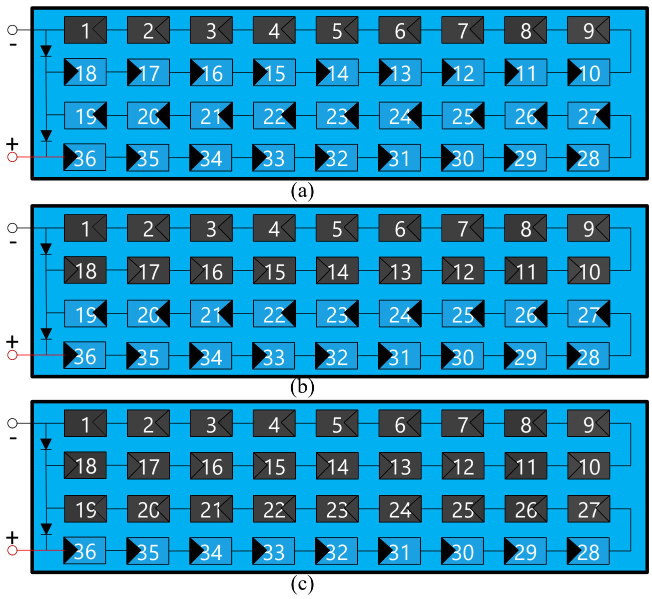

Figure 9. PV cell configuration, mounting orientation and PV cell shaded in the second scenario, (a) scenario II.1, (b) scenario II.2, and (c) scenario II.3.

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IV. Results and Discussion

The simulation results under the standard conditions of the 100-Wp PV panel used in this study are presented in Figure 10. The results of this simulation when

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compared with the data sheet (refer to Table 1), the level of accuracy can be seen in Table 2. Based on Table 2, the modeling results of this PV panel show high accuracy, due the MAPE is smaller than 1%, which is 0.73%.

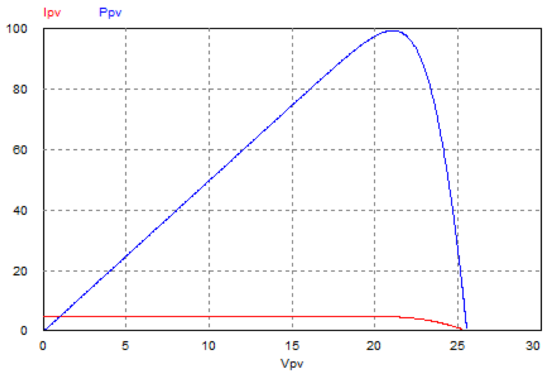


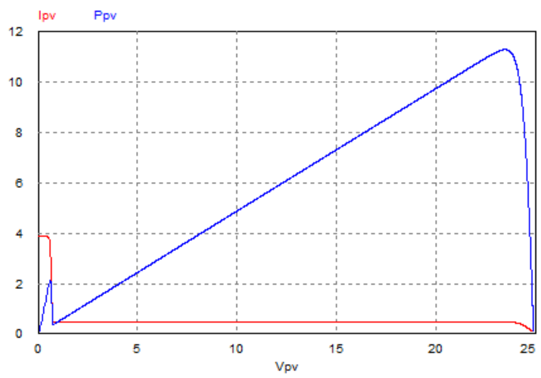
Figure 10. I-V and P-V curves of 100 Wp PV panel at standard conditions.

Table 2. Comparison of PV panel parameters between data sheet and simulation results.

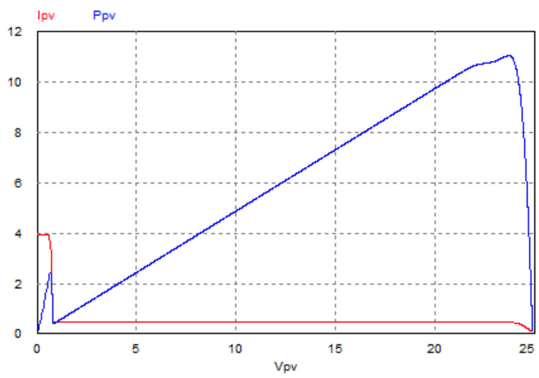
Parameters	Rating		Absolute Error (%)
	Data Sheet	Simulation	
Maximum power (Pmax)	100 W	99.51 W	0.49
Voltage at Pmax (Vmp)	20.90 V	21.08 V	0.86
Current at Pmax (Imp)	4.76 A	4.72 A	0.84
Mean Absolute Percentage Error (MAPE)			0.73

The simulation results for the first scenario are presented in Figure 11. In this scenario, a significant reduction in maximum power output (Pmax) occurs when partial shading is applied to some of the PV cells. The effect of shading can be observed by comparing Figure 10 with Figure 11a. In Figure 10, Pmax is 99.51 W, whereas in Figure 11a it decreases to 11.30 W, representing a reduction of 88.64%. When the number of shaded PV cells increases, Pmax does not decrease substantially. This behavior is illustrated by comparing Figures 11a, 11c, and 11d, where the Pmax values are 11.30 W, 10.64 W, and 9.94 W, corresponding to 9, 18, and 27 shaded cells, respectively. In this scenario, the presence of bypass diodes does not have a significant impact on Pmax. This can be further confirmed by comparing Figures 11a–b, 11c–d, and 11e–f. For example, Pmax in Figure 11a is 11.30 W, while in Figure 11b it is 11.06 W. Although the reduction in Pmax appears nonlinear, this nonlinearity is attributed to the configuration of PV cells and the distribution of shading, which affects certain series-connected strings more severely than others.

Figure 12 shows the I-V and P-V curves of the second scenario. Similar to the first scenario, in this scenario the shading of the PV cell has a very significant effect on reducing Pmax. This is clearly illustrated by comparing Figure 10 with Figure 12. Pmax in Figure 10 is 99.51 W, while in Figure 12a is 11.30 W. In this scenario, the increase in shadowed PV cells, Pmax does not experience a significant decrease. This can be seen by comparing Figure 12a, 12c and 12e.



(a)



(b)

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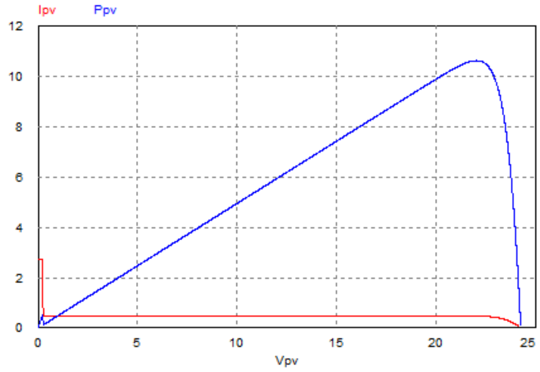

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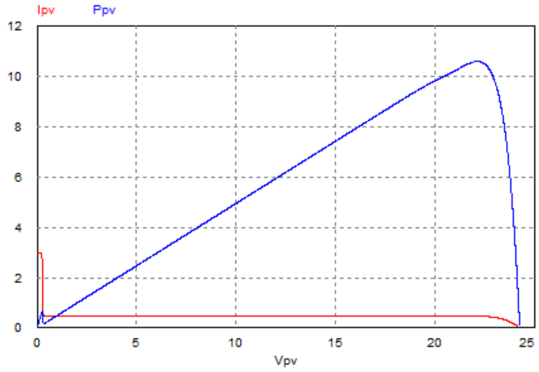
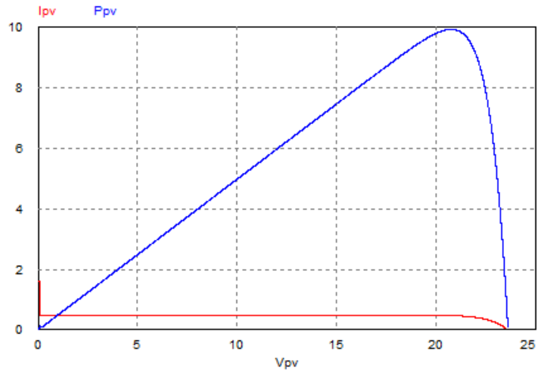
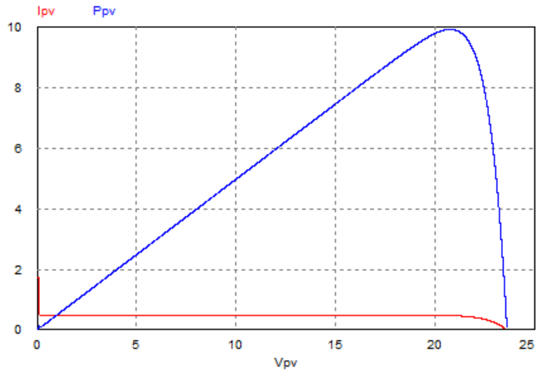


(d)

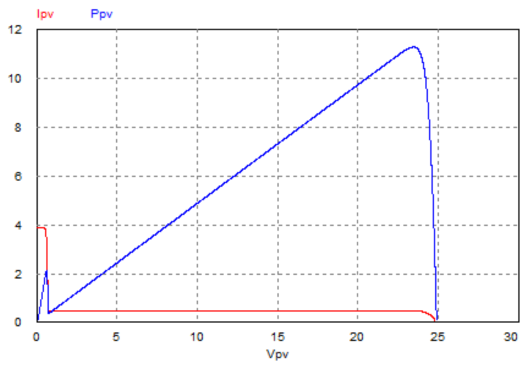


(e)

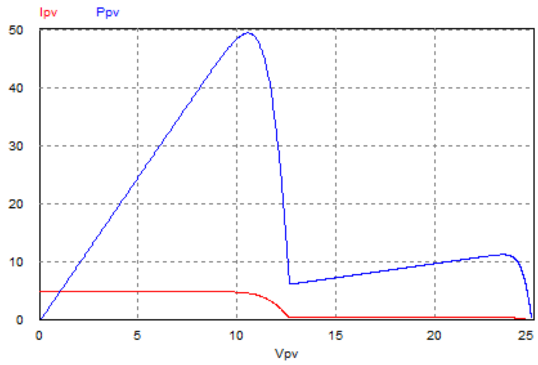


(f)

Figure 11. I-V and P-V curves, (a) scenario I.1 without Bypass Diodes, (b), scenario I.1 with Bypass Diodes, (c) scenario I.2 without Bypass Diodes, (d) scenario I.2 with Bypass Diodes, (e) scenario I.3 without Bypass Diodes, (f) scenario I.2 with Bypass Diodes



(a)



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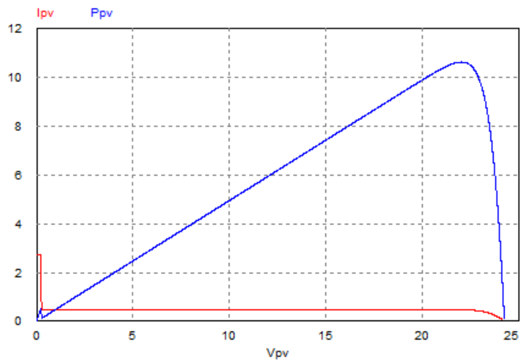

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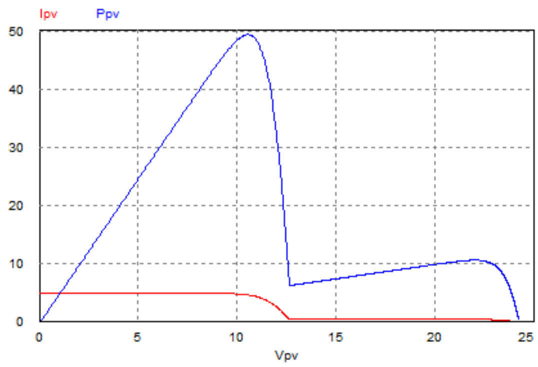

(d)

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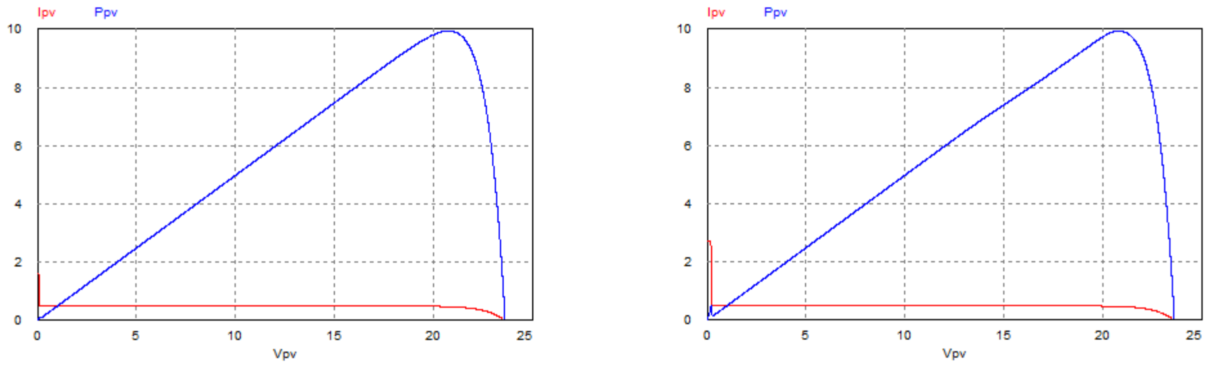

Figure 12. II-V and P-V curves, (a) scenario II.1 without Bypass Diodes, (b), scenario II.1 with Bypass Diodes, (c) scenario II.2 without Bypass Diodes, (d) scenario II.2 with Bypass Diodes, (e) scenario II.3 without Bypass Diodes, (f) scenario II.2 with Bypass Diodes.

In this second scenario, the bypass diode can increase the Pmax when there is a shading on the PV cell. This can be seen in Figure 12b and Figure 12d. Figure 12b is the I-V and P-V curves with PV cells that get shadows are 1-9 and Figure 12d is the I-V and P-V curves with PV cells that get shadows are 1-18. With this bypass diode, the Pmax becomes 49.35 W, while without the bypass diode it is only 11.30 W for the shadowed PV cells 1-7. Similarly, the shadowed PV cells are 1-18 with diode bypass Pmax becomes 49.35 W, while without diode bypass is 10.64 W. The interesting thing in this scenario is the condition of the shadowed PV cells are 1-27. In this condition the bypass diode cannot affect Pmax, as shown in Figure 12e and 12f.

Pmax, Vmp and Imp for both scenarios are presented in Table 3. Based on the table, Pmax and Imp for both scenarios in the condition without bypass diodes will experience a significant decrease with the presence of PV cells that get shadows, whether the number is small or large. Meanwhile, Vmp decreases slightly as the number of from Table 3, it can be seen that the first scenario with the presence of bypass diodes has no effect on the Pmax of PV panels. Whereas in the second scenario, the bypass diode has a significant effect on the Pmax of the PV Panel. For example, in scenario II.1 in the presence of bypass diodes can increase Pmax by 4.37 times from conditions without bypass diodes. Meanwhile, in scenario II.2, the presence of bypass diodes can increase pmax by 4.64 times from the condition without bypass diodes PV cells that get shadows increases.

Table 3. Comparison of Pmax, Vmp, and Imp between the first and second scenarios.

Scenario	**Without Bypass Diode**			**With Bypass Diode**		
	Pmax (W)	**Vmp (V)**	**Imp (A)**	**Pmax (W)**	**Vmp (V)**	**Imp (A)**
I.1	11.30	23.48	0.48	11.06	23.72	0.47
I.2	10.64	22.04	0.48	10.62	22.15	0.48
I.3	9.94	20.78	0.48	9.94	20.78	0.48
II.1	11.30	23.48	0.48	49.34	10.57	4.67
II.2	10.64	22.04	0.48	49.34	10.57	4.67
II.3	9.94	20.78	0.48	9.94	20.78	0.48

In conditions with bypass diodes, when compared to the two scenarios, the second scenario has slightly better performance. It can be seen in Table 3, the comparison of Pmax in scenario I.1 is higher than in scenario II.1, as well as scenario I.2 is higher than scenario II.2, except for scenario I.3 or scenario II.3.

V. Conclusion

The mounted orientation of PV panels has an important role in avoiding shading effects, as shading

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significantly reduces the Pmax of PV panels. For PV panels with bypass diodes, the most optimal mounting orientation is landscape. While without bypass diodes this mounting orientation is not recommended, the same is true for portrait orientation, with and without bypass diodes. It should be noted, however, that in this study the shading is kept fixed i.e. the shading encloses the PV cell vertically. In other words, to avoid the effect of shadows on the PV panels is to place them so that the shadows enclose the PV cells arranged lengthwise.

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