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Performance Analysis of Partial Shading Effect on PV Plant

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Abstract - **Partial shading of PV plants mitigate the maximum power generation of solar modules. As a result, the power output is lower than expected. It is affected not only by the number of shaded modules but also by the shaded patterns. This paper examined a PV plant rated at 15 kW connected in series-parallel for various shading patterns, such as row-wise and column-wise partial shading. This solar plant's behavior is also investigated under various irradiation levels and degrees of shading. The number of solar modules required for this plant was also evaluated. The performance results of solar modules under partial shading conditions, such as power, voltage, and current, are revealed by using the Matlab/Simulik model. From the analysis, the result shows that the column-wise shading condition generates more power output than the row-wise shading condition.**

Keywords— Shading effect, Solar module, Row wise, Column wise, Partial shading

I. INTRODUCTION

One of the energy sources that produces the necessary electricity is renewable energy. Solar energy is now widely used throughout the world. Yet, irradiance levels affect how much power solar modules can produce. When the modules are shaded, no electricity is generated that is needed. Many different things, including buildings, trees, passing clouds, structures, and dust, can create partial shadowing conditions on solar modules [1]. Many researchers focus on improving the performance of photovoltaics (PV) systems under shading conditions. In order to generate the maximum power under shading conditions, PV array reconfiguration is carried out. This method increases not only power output but also the cost and complexity of the PV system [2]. Partial shading conditions significantly reduce the power production of PV systems. For optimum power extraction, the researchers analyzed the best PV configuration under various shading patterns [3, 4]. Several configurations, including SP, TCT, BL, HC, and A-TCT-BL, are modeled and analyzed using nine different shading patterns, including center, diagonal, corner, L-shaped, short narrow, short wide, and long narrow [5]. The author investigated the performance of a PV array under various partial shading scenarios using a voltage versus current curve and a power versus voltage curve. The effect of the by-pass diode on the PV array is also investigated using Matlab and Simulink. By-pass diodes play an important role in partial shading. Many researchers have explored the performance of various configurations in different shading patterns. This paper investigates the performance of a 15 kW solar plant connected in series-parallel configuration under row-wise and column-wise partial shading conditions. This paper is divided into five sections. The first section presents an introduction to the basic concept of PV systems as well as literature reviews. Section II is concerned with the Matlab/Simulink modeling of a PV module based on a single diode model. Section III includes a case study of a solar plant for evaluating solar module design. Section IV investigated the simulation results for a solar plant under partial shading. Finally, the conclusion is presented.

II. MODELLING OF SOLAR MODULE

In this study, a Matlab/Simulink model was used to analyze the performance of a PV plant. Using this model, the solar plant's performance parameters, such as maximum power, voltage, and current of the PV strings, are evaluated and compared under various

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shading conditions. Figure 1 depicts the Simulink model for a 250 W solar module.

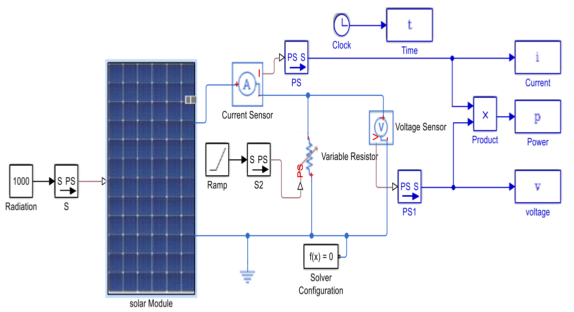

Fig. 1. Simulink model for 250W solar module.

Figure 2 depicts the voltage-current curve of a 250 W solar module under normal condition. According to this graph, the short-circuit current is proportional to the irradiance level. The value of the short circuit decreases as the irradiance level decreases. However, when the solar irradiance changes, the voltage of the solar module does not change significantly.

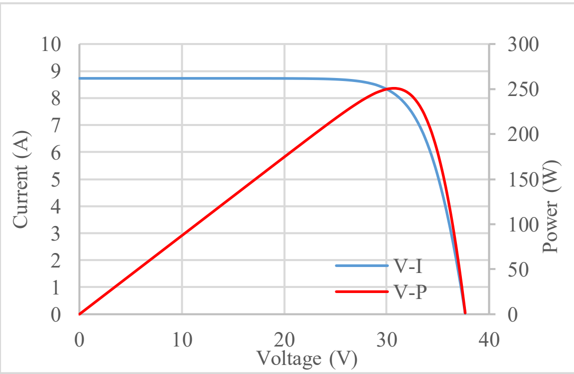

Fig. 2. V-I curve and V-P curve for 250W solar module.

III. CASE STUDY

This paper investigates the performance of a 15 kW solar array installed at the West Yangon Technological University in Yangon, Myanmar, under various partial shading conditions (row- and column-wise). Due to the practical difficulty of conducting experiments, a generalized MATLAB simulation has been developed.

A. Solar Module Design Calculation

PV modules should be designed to meet the energy needs of battery banks [6]. Total load energy per day was calculated to determine the number of modules required for system reliability. The total load energy per day of this solar plant is 41 kWhr/day. A 250-watt solar module is used in this solar power plant. The system voltage for this solar power plant is 150 volts. Table I shows the solar module specifications. The number of solar modules required to generate the required power is calculated using the following mathematical equations. Assume the inverter has an efficiency of 0.9, the battery has an efficiency of 0.85, and the charge controller has an efficiency of 0.8 [6].

Table I. Solar module specification.

Model number	LXP-3J250WA1
Maximum Power (P_{max})	250 W
Voltage at P_{max} (V_{mp})	30.2 V
Current at P_{max} (I_{mp})	8.28 A
Short -circuit current (I_{sc})	8.73 A
Open-circuit current (V_{oc})	37.3 V

$$\text{Solar plant energy} = \frac{\text{Total energy demand per day}}{\begin{matrix}\text{inverter} \\ \text{efficiency}\end{matrix} \times \begin{matrix}\text{battery} \\ \text{efficiency}\end{matrix} \times \begin{matrix}\text{charge controller} \\ \text{efficiency}\end{matrix}} \quad (1)$$

$$\text{Solar plant power} = \frac{\text{Solar plant energy}}{\text{Sun hour per day}} \quad (2)$$

The number of sun hours per day varies depending on the climate of the site [6]. In this solar plant, it is assumed to be 4.5 hr. Therefore, solar power from this system generates at least 15 kW to meet the electrical demand. After calculating the required power to supply the system, the total number of modules required for this system is calculated by using these equations:

$$\text{Number of series module} = \frac{\text{System voltage}}{\text{Solar module voltage}} \quad (3)$$

$$\text{Solar panel current} = \frac{\text{Solar plant power}}{\text{System voltage}} \quad (4)$$

$$\text{Number of parallel module} = \frac{\text{Solar panel current}}{\text{Solar module current}} \quad (5)$$

$$\text{Total no. of solar module} = \begin{matrix}\text{No. of series} \\ \text{module}\end{matrix} \times \begin{matrix}\text{No.of parallel} \\ \text{module}\end{matrix} \quad (6)$$

According to the evaluation, this system requires at least sixty modules to generate the required power. To start, five modules are connected in series to form a string, and twelve strings are connected in parallel to obtain the required voltage and current.

B. Partial Shading Effect on Solar Module

In this study, the performance of solar modules under partial shading conditions is investigated with different irradiance levels and shading patterns that are row-wise and column-wise. Different percentages of irradiance levels (20%, 40%, 60%) are carried out in sixty modules. 12, 24, and 36 modules are shaded, respectively. In this research, unshaded solar modules are considered at 1000 W/m^2. The insolation of a shaded solar module is provided at 800 W/m^2 to 200 W/m^2, depending on the shading condition. However, simulation results show only four irradiance levels (200 W/m^2, 400 W/m^2, 600 W/m^2, and 800 W/m^2). The V-I curve and the P-V curve for normal conditions are shown in Fig. 3.

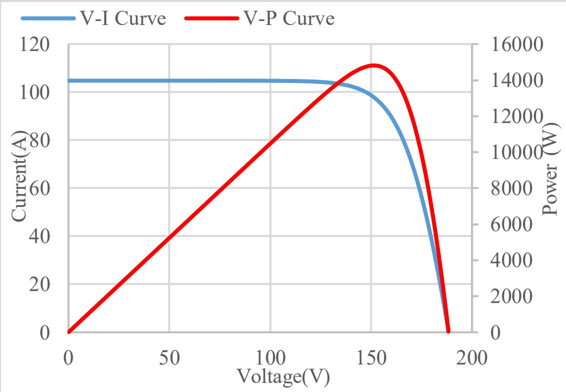

Fig. 3. V-I curve and V-P curve under normal condition.

According to the figure, maximum power is approximately 15 kW, and maximum voltage and maximum current are about 151.1 volts and 98.01 amps, respectively, under normal conditions. The Matlab model for a sixty-module configuration is built as shown in Fig. 4. The performance results of the shading condition are mentioned in Section IV.

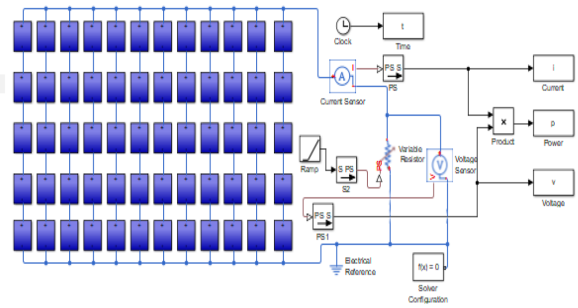

Fig. 4. Simulink model for 5×12 size solar plant.

IV. RESULT AND DISCUSSION

In this paper, row-wise partial shading is first used to collect power, voltage, and current performance by varying the shading level and irradiance. As shown in Table II, three case studies are investigated in a row-wise partial shading condition with varying irradiance levels. In a column-wise shading condition, Cases IV to VI are investigated in Table III.

Table II. Row wise partial shading condition.

Shading Pattern	Shading Level	Irradiance (W/m²)
Case I	20%	200 to 800
Case II	40%	200 to 800
Case III	60%	200 to 800

Table III. Column wise partial shading condition.

Shading Pattern	Shading Level	Irradiance (W/m²)
Case IV	20%	200 to 800
Case V	40%	200 to 800
Case VI	60%	200 to 800

Case I investigates the shaded condition of twelve modules in the first row with varying irradiance levels (200 W/m², 400 W/m², 600 W/m², and 800 W/m²), but the P-V curve is only shown for Cases I to III, as shown in Fig. 5. Case II investigates the shaded condition for twenty-four modules in a row (first and second row shaded conditions). Case III includes 36 shaded modules arranged in three rows. According to performance results, the lower the irradiation level, the lower the maximum power. The maximum output power decreases as the number of shaded modules increases, as illustrated in Fig. 5. Table IV summarizes the findings.

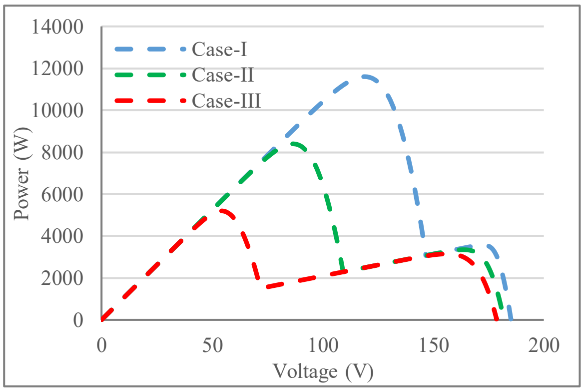

Fig. 5. V-P curve for row wise shading condition in 200 W/m² (Case I to Case III).

Table IV. Performance results of solar module in row wise shading effect with different irradiance levels.

Shading Pattern	Irradiance (W/m²)	Row Wise Shading		
		P_{max}(kW)	V_{max} (V)	I_{max} (A)
Case-I	200	11.6	119.5	97.1
	400	11.65	120.5	96.69
	600	11.7	120.4	97.19
	800	13.11	158.8	82.56
Case-II	200	8.397	86.25	97.35
	400	8.499	87.25	97.41
	600	9.815	160.4	61.18
	800	12.71	156.3	81.29
Case-III	200	5.198	54.42	95.51
	400	6.339	157	40.38
	600	9.442	155.9	60.56
	800	12.37	154.8	79.95

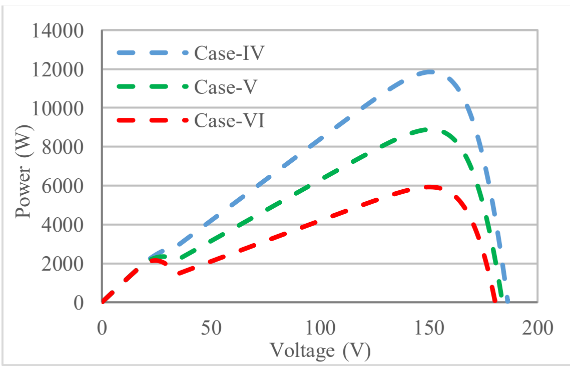

Fig. 6. V-P curve for column wise shading condition in 200W/m² (Case IV to Case IV).

Figure 6 depicts the partial shading condition simulation results for each column. The line graph compares the maximum power and output voltage for column-wise shading conditions at 200 W/m^2 for Cases IV to VI. Maximum power is reduced to 11.84 kW in a column-wise shading condition with 200 W/m^2, and 8.887 kW in a 40% shading condition (Case-V). The power drops dramatically to 5.926 kW at 200 W/m^2 in Case-VI (60% shading), as shown in Fig. 6. Table V summarizes the performance of column-wise shading conditions with varying irradiance levels (200 W/m^2, 400 W/m^2, 600 W/m^2, and 800 W/m^2). The amount of shading increases as the outpower decreases.

Table V. Performance results of solar module in column wise shading effect with different irradiance levels.

Shading Pattern	Irradiance (W/m^2)	Row Wise Shading		
		P_{max}(kW)	V_{max} (V)	I_{max} (A)
Case-IV	200	11.84	150	78.96
	400	12.62	151.2	83.47
	600	13.38	151	88.64
	800	14.06	151.9	92.6
Case-V	200	8.887	150.9	58.89
	400	10.43	151.3	68.95
	600	11.96	152.6	78.39
	800	13.32	150.3	88.62
Case-VI	200	5.926	150.9	39.26
	400	8.244	152.1	54.22
	600	10.53	153.3	68.71
	800	12.57	150.3	83.64

Table VI displays the comparison results for all conditions. Maximum power generation under row-wise shading conditions is less than that under column-wise shading conditions. When the radiance value is lower, the maximum power generation under row- and column-wise shading conditions differs slightly. However, when the amount of irradiance levels is increased, the maximum power generation of the column-wise shading condition is significantly greater than that of the row-wise shading condition.

Table VI. Performance results comparison for row wise and column wise shading condition.

Shading Pattern	Irradiation (W/m^2)	Module Shaded 20%	Module Shaded 40%	Module Shaded 60%
		P_{max} (kW)		
Row Wise	200	11.6	8.397	5.198
Column Wise		11.84	8.887	5.926
Row Wise	400	11.65	8.499	6.339
Column Wise		12.62	10.43	8.244
Row Wise	600	11.7	9.815	9.442
Column Wise		13.38	11.96	10.53
Row Wise	800	13.11	12.71	12.37
Column Wise		14.06	13.32	12.57

V. CONCLUSION

The investigation of a PV plant under row-wise and column-wise partial shading conditions for different irradiance levels and degrees of shading is examined. It can be seen that the power generated was affected by partial shading patterns. This analysis shows that the maximum power generation of the row-wise shading condition differs slightly from the column-wise shading condition at lower irradiance levels. However, column-wise shading outperforms row-wise shading.

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