CLIMA 2016 - proceedings of the 12th REHVA World Congress

volume 3

Heiselberg, Per Kvols

Publication date:
2016

Document Version
Publisher's PDF, also known as Version of record

Characteristics of Power Losses in Photovoltaic Module depending on Shading Patterns and Solar Irradiance

Eun-Jin Moon[#1], Jae-Han Lim[*2], Yoon-Bok Seong[#3], Kwang-Woo Kim[**4]

[#] *Korea Conformity Laboratories*

199, Gasan digital 1-ro, Geumcheon-gu, Seoul, 08503 Korea

[1]ejmoon@kcl.re.kr

[3]ybseong@kcl.re.kr

[*] *Division of Architecture, Ewha Womans University*

11-1 Daehyun-dong, Seodaemun-gu, Seoul, 120-750 Korea

[2]limit0@ewha.ac.kr

[**] *Division of Architecture, Seoul National University*

599 Gwanak-ro, Gwanak-gu, Seoul, 151-744 Korea

[4]snukkw@snu.ac.kr

Abstract

This study investigates the characteristics of power losses in a photovoltaic module under different partial shading patterns and solar irradiance that cause abnormal voltage–current responses. To analyze the effects of both loss factors, i.e., shading patterns and irradiance, several tests were conducted in a laboratory. Results show that in the case of a module with bypass diodes, reduction in power generation was affected more by circuit configurations than shading patterns. Moreover, the performance of the entire module was proportional to the solar intensity. The analysis of this experiment can be applied to improve the accuracy of performance estimations when designing photovoltaic systems and mathematical models.

Keywords - Photovoltaic Module; Power Loss Factor; Partial Shading; Solar Irradiance

1. Introduction

Power generation of photovoltaic systems is significantly influenced by external and internal loss factors. Therefore, the design process of photovoltaic systems requires information on performance characteristics under various environmental conditions for estimating real power generation. The study of power loss effects is important to foresee the working point of a system. Nevertheless, there is still a lack of information related to the behavior of photovoltaic cells operating under various environmental conditions.

This study investigates the characteristics of power losses in a photovoltaic module under different partial shading patterns and solar irradiance that cause abnormal voltage–current responses. To analyze the effects of both loss factors, i.e., shading patterns and irradiance, several tests were conducted in a laboratory.

2. Characteristics of Solar Cell and Bypass Diode Operation

2.1 Electrical Output Properties and Maximum Power Delivery

As shown in Fig. 1, the properties of a solar cell are defined as current versus voltage. An ideal characteristic would be rectangular in shape. The point where the graph intercepts the current axis represents zero voltage and is the short-circuit current (I_{sc}). The point where the graph intercepts the voltage axis represents zero current and is the open-circuit voltage (V_{oc}).

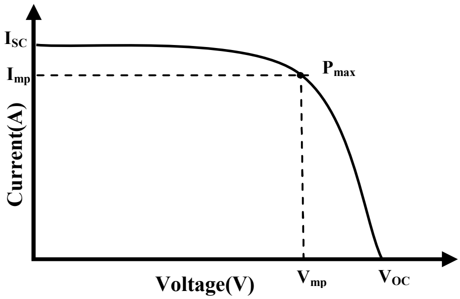


Fig. 1. I–V Characteristic of Typical Solar Cell

For the typical characteristic shown in Fig. 1, the maximum power point (P_{max}) lies in the region of the knee of the curve. This point is calculated by the multiplication of the operating current (I_{mp}) and operating voltage (V_{mp}):

$$P_{\max} = I_{mp} V_{mp} . \tag{1}$$

Fill factor (FF) is defined as the ratio of the maximum power from a solar cell to the product of V_{oc} and I_{sc}:

$$FF = \frac{I_{mp} \times V_{mp}}{I_{sc} \times V_{oc}} \times 100(\%) . \tag{2}$$

The efficiency (η) of a solar cell is determined as the fraction of the incident power that is converted to electricity:

$$\eta = \frac{P_{max}}{P_{input}} = \frac{I_{mp} \times V_{mp}}{P_{input}} = \frac{I_{sc} \times V_{oc}}{P_{input}} \times FF \tag{3}$$

2.2 Operation Characteristics of Bypass Diodes

Mismatch caused by partial shading occurs on all types of PV installations; nearby shade obstructions such as buildings, trees, and telephone poles as well as self-shading from adjacent PV modules occur. If shading occurs to the series connection PV module, the output current is limited to the current of the shaded PV module. In this case, a solar cell that has a relatively lower current would initiate reverse voltage, which causes hot-spot heating and power degradation.

Normally, to minimize the power loss and prevent hot-spot heating, a bypass diode is installed. This bypass diode allows the current from good solar cells to flow in an external circuit. The bypass diode is connected in parallel with substrings in a reverse bias condition and starts working when it obtains the reverse voltage. When the current of a solar cell is reduced while the shading is generated, current mismatch with other solar cells that are connected in series occurs and substrings are under reverse bias [1, 2].

The effect of a bypass diode on an I–V curve can be determined by first finding the I–V curve of one solar cell with a bypass diode and then combining this curve with the curves of other solar cells. The combined I–V curve is shown in Fig. 2 [3].

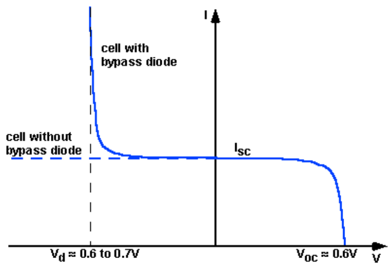


Fig. 2. I–V Curve of Solar Cell with Bypass Diode

3. Experimental Conditions and Purpose

3.1 Experimental Conditions and Specifications of the Module

A conventional PV module has been prepared for laboratory tests; the module consisted of 60 single-crystalline silicon (c-Si) cells. Each substring consisted of 20 cells connected in series.

Laboratory experimental conditions are as follows: irradiance of 1000 W/m2, standard AM 1.5 spectrum, and temperature of 25°C. A reference I–V curve of the module was obtained under standard test conditions (STCs). Main parameters are presented in Table 1.

Table 1. Module specifications

Material	Single-crystalline silicon
Module size	1619 mm × 979 mm (60 cells)
Bypass diodes	CASE1(-), CASE2(3ea)
Rated maximum power (P_{max})	250 W
Short-circuit current (I_{sc})	8.9 A
Open-circuit voltage (V_{oc})	37.7 V
Rated current (I_{mp})	8.1 A
Rated voltage (V_{mp})	31.1 V
Cell voltage	0.6 V

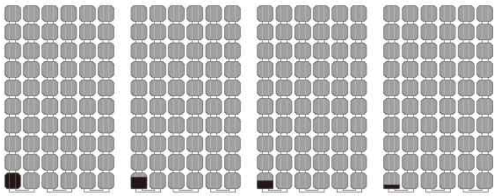
3.2 Experimental Procedure and Purpose

Several tests were conducted in a laboratory to investigate the characteristics of power losses in a photovoltaic module under different partial shading patterns and solar irradiance. Shade impact depends not only on the shading pattern and shading ratio but also on the bypass diode placement and string configuration. Therefore, an experiment was conducted on two PV modules: one without bypass diodes (Module A) and another with bypass diodes (Module B). For analyzing the shadow patterns of surrounding buildings through virtual simulation, the position of the shadow was moved from left to right. The shape of the shadow can be represented as a combination of cell shading and substring shading. Experimental cases are as follows:

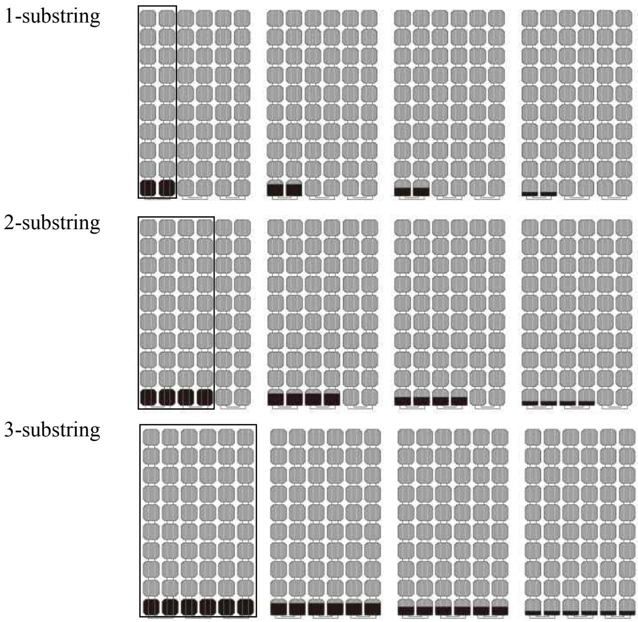
- Shading of one cell, increasing the shaded area from 25% to 100%, as illustrated in Fig. 3-(a)
- Shading of substring from left-to-right, increasing the shaded area from 2 to 6 strings, as illustrated in Fig. 3-(b)
- Reducing solar irradiance from 1000 W/m2 to 200 W/m2, as illustrated in Fig. 3-(c)

Objectives of the experiment are as follows:

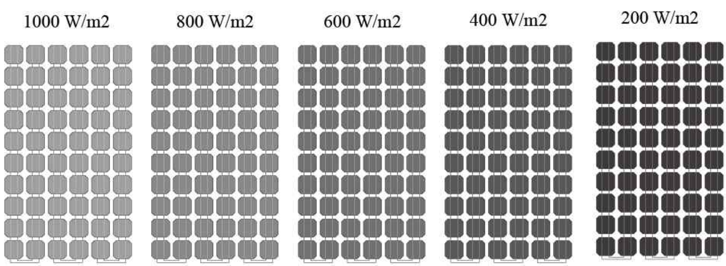
- Deriving generalized operating characteristics of a PV module under various environmental conditions to construct a PV performance estimation model
- Evaluation of shading effects on I–V characteristics
- Documentation of the working point of each module (A, B) when a module is partially shaded
- Influence of solar intensity on power loss



(a) Shading pattern of one cell



(b) Shading pattern of substring



(c) Solar irradiance variation

Fig. 3. Experimental Cases

4. Experimental Results

4.1 Module without Bypass Diodes

When a cell or part of a cell is shaded, it becomes reverse biased and then acts as a load instead of a generator. It is clear that cell shading significantly reduces module performance. The maximum module power decreases from 250 W (STCs) to 50.05 W (shading of one cell), i.e., a reduction by approximately 80% when only 1.7% of the module is shaded. As shown in Fig. 4, the output current is limited to the current of the shaded cell; thus, the maximum power decreases. If a cell is partially shaded, some of the current from good cells can flow in a low voltage range. It is interpreted to be because of a relatively small resistance. Moreover, because the resistance of the cell increases in accordance with an increasing shading ratio, a large current mismatch occurs, and the slope of the I–V curve changes.

Shading patterns were extended from unit cells to substrings. As shown in Fig. 5, current, voltage, and power change trends were similar to unit cell experimental results, except that the current was not generated in a low voltage range.

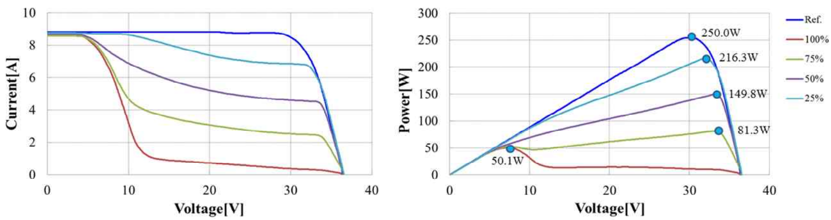


Fig. 4. Experimental results of a unit solar cell under partial shading (without a bypass diode)

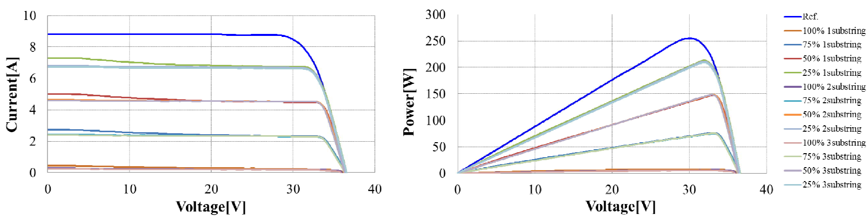


Fig. 5. Experimental results of a substring under partial shading (without a bypass diode)

4.2 Module with Bypass Diodes

As illustrated in Fig. 6, the generated current of a bad cell decreases as the shading ratio is varied between 0% and 100%. The higher the shading ratio of a cell, the higher will be the voltage across diode groups; that is, when the reverse bias voltage is larger than that of a bypass diode, the diode starts to operate.

For a 100% shaded cell, 20 series-connected cells of the substring by shadowing were short-circuited by a bypass diode, and thus, only 2/3 of the module was productive. When shading occurs, a significant reduction of the output power is recorded, and two peak points appear on the power–voltage curve. However, because real power generation occurs at the maximum power point, the operating power point was maintained at 175.12 W with approximately 40% shading.

The results of extended shading patterns from a unit cell to substring displayed the same behavior as that shown in the former case in Fig. 7. The horizontal shading of the module influences all three substrings. The generated current critically decreases until it becomes zero when an entire horizontal line of cells is shaded.

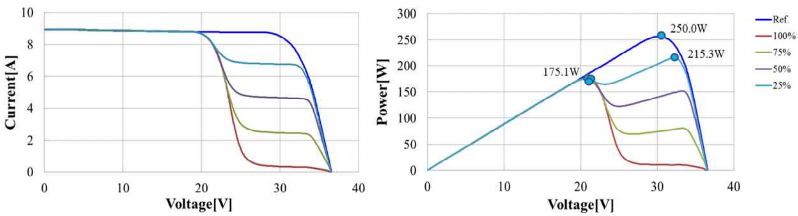


Fig. 6. Experimental results of a unit solar cell under partial shading (with bypass diodes)

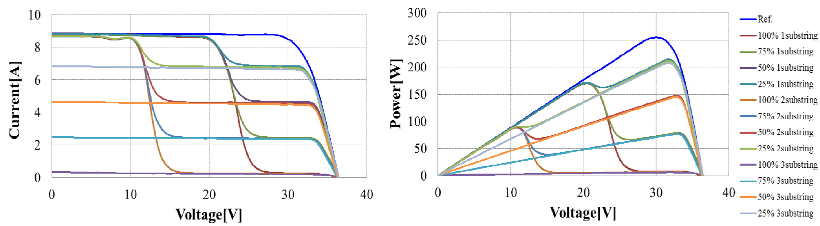


Fig. 7. Experimental results of a substring under partial shading (with bypass diodes)

4.3 Power Losses depending on the Variation of Solar Irradiance

A change in the solar intensity on a solar cell affects all solar cell parameters, including the short-circuit current, open-circuit voltage, efficiency, and resistances. As illustrated in Fig. 8, the short-circuit current decreases proportionally to the intensity of irradiance, and the open-circuit voltage changed slightly. This led to power loss. The results can be interpreted by the fact that the current generated by a light source reduces when solar irradiance decreases.

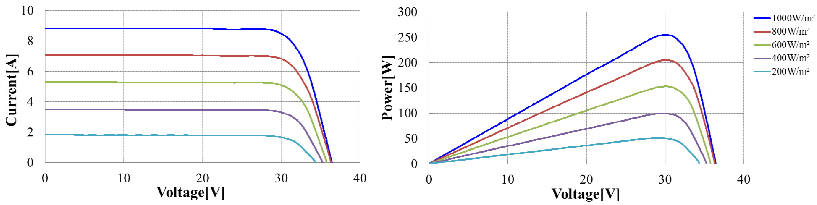


Fig. 8. Experimental results of the variation of solar irradiance

5. Conclusion

In this study, the effects of partial shading on a photovoltaic module were analyzed. The effects of shadow on main electrical characteristics of two types of PV modules (with and without bypass diodes) were investigated via experimental tests. The results show a large difference in the performances of the two PV modules.

The performance of a module significantly reduced in accordance with cell shading. In the case of the module without bypass diodes, the generated current almost proportionally decreased with increased shading rate. However, in single-cell unit shading, the current was generated in a low voltage range, unlike the case where more than 2 cells are shaded.

A bypass diode was operated at 100% shading of one cell. Bypass diodes allowed dividing in several sections each module as substrings, limiting the production’s decrease caused by the shading. Therefore, the reduction in power generation was affected more by the circuit configuration (bypass diode) than shading patterns. The performance of the entire module was proportional to the solar intensity.

The results show that the shading effect on the module’s power generation critically depended not only on shading patterns but also on bypass diode’s existence. Namely, PV performance data about substring unit shading need to be provided to consumers for estimating real power generation. Moreover, since the performance of PV module in accordance with solar irradiance change proportionally, solar irradiance from simulation tool could be used for estimating real power generation. The analysis of this experiment can be applied to improve the accuracy of performance estimation when designing photovoltaic systems and mathematical models.

Acknowledgment

This research was supported by a grant (15CTAP-C098006-01) from Technology Advancement Research Program funded by the Ministry of Land, Infrastructure and Transport of Korean government.

References

[1] S. T. Kim, C. H. Park, G. H. Kang, W. C. K. Lawrence, H. K. Ahn, G. J. Yu, D. Y. Han. Operation Characteristics of Bypass Diode for PV Module. Journal of KIEEME. 21(2007) 12.
[2] A. Abete, F. Cane, C. Rizzitano, M. Tarantino, R. Rommasini. Performance testing procedures for photovoltaic modules in mismatching conditions. in Proceedings of the 22nd IEEE Photovoltaic Specialists Conference (1991).
[3] PV CDROM. http://pveducation.org. (accessed 13 Jan 2015).
[4] J. W. Bishop. Computer simulatin of the effects of electrical mismatches in photovoltaic cell interconnection circuits. Solar Cells. 25(1988) 73-89.
[5] A. Dolara, G. C. Lazaroiu, S. Leva, G. Manzolini. Experimental investigation of partial shading scenarios on PV(photovoltaic) modules. Energy. 55 (2013) 466-475.
[6] M. C. Alonso-Garcia, J. M. Ruiz, F. Chenlo. Experimental study of mismatch and shading effects in the I–V characteristic of a photovoltaic module. Solar Energy Materials & Solar Cells. 90(2006) 329-340.