The Need for a New Parameter on PV Modules Datasheet
Shading Tolerability

Ziar, Hesan; Mishra, Sandeep; Isabella, Olindo; Zeman, Miro

DOI
10.1109/PVSC.2018.8548194

Publication date
2018

Document Version
Accepted author manuscript

Published in
2018 IEEE 7th World Conference on Photovoltaic Energy Conversion, WCPEC 2018 - A Joint Conference of 45th IEEE PVSC, 28th PVSEC and 34th EU PVSEC

Citation (APA)
Ziar, H., Mishra, S., Isabella, O., & Zeman, M. (2018). The Need for a New Parameter on PV Modules Datasheet: Shading Tolerability. In A. Freundlich, M. Topic, & A. Yamada (Eds.), *2018 IEEE 7th World Conference on Photovoltaic Energy Conversion, WCPEC 2018 - A Joint Conference of 45th IEEE PVSC, 28th PVSEC and 34th EU PVSEC* (pp. 664-667). [8548194] Institute of Electrical and Electronics Engineers (IEEE). https://doi.org/10.1109/PVSC.2018.8548194

The Need for a New Parameter on PV Modules Datasheet: Shading Tolerability

Hesan Ziar, Sandeep Mishra, Olindo Isabella, and Miro Zeman

Delft University of Technology, PVMD Laboratory, EKL, P.O. Box 5053, 2600 GB Delft, the Netherlands

***Abstract* — This paper suggests a measurable parameter, the so-called Shading Tolerability (ST), to be added on PV modules datasheet. Using this parameter, PV modules can be compared and classified regarding the ability to oppose shading effects. The parameter is extracted based on mathematical and probability analysis, then measured using a Large Area Steady State Solar (LASSS) simulator. Outdoor measurements proved a correlation between ST and Performance Ratio (PR) of PV modules. ST was also found to be independent of the ambient temperature, which indicates that it is a characteristic parameter of a PV module. Finally, a selection map for PV module installation at different climate conditions based on ST and temperature coefficient for maximum power (γ) is presented.**

***Index Terms*— Photovoltaic (PV) module, shading tolerability (ST), partial shading, temperature coefficient, selection map**

I. Introduction

As the goal of the PV industry is to push forward the mindset of the energy society to the concept of "PV everywhere" [1], PV modules are going to be increasingly installed in urban areas. In such a situation, next to moving clouds, PV modules will be more frequently subjected to shades projected by any possible object such as side trees, chimneys, flying birds, and so on. How can a PV designer or installer company distinguish the better performing PV module under non-uniform irradiation condition?

Most PV module manufacturer claim the superior performance of their products in shading condition by qualitative terms. Terms such as: better shading response [2], outstanding low light behavior [3], etc., are being used in PV modules datasheet. However, these general qualitative terms may not help the designer or installer to select the most suitable module for a specific location. On the other hand, a quantified parameter, a number, which classifies PV modules in terms of shading tolerability (ST), can be more meaningful. Therefore, we believe that there is a need for a new parameter on PV modules datasheet to address this issue. The establishment of such a parameter is the goal of this contribution.

II. Theoretical Definition of Shading Tolerability

After decades of research on PV systems [4], the random nature of shading profile on PV systems has been the major obstacle in the quantification of shading tolerability. Therefore, in a framework of probability laws, the following formula is suggested for PV module shading tolerability [5]:

$$ST_{(i,c)} = \frac{1}{P_{mod\_mpp}} \sum_{k=1}^{k=i^c} P_k \left(\frac{1}{i^c}\right) \qquad (1)$$

where $ST_{(i,c)}$ stands for shading tolerability. ***c*** and ***i*** are the total number of PV cells (within the module) and irradiation levels, respectively. P_k corresponds to the MPP at each shading profile (in W), while P_{mod_mpp} is the maximum power of PV module (in W). P_{mod_mpp} normalizes the value of mathematical expectation and makes it possible to compare PV modules with different rated powers. Mathematically, the PV module which gains higher value from (1), acts better at shading.

One of the remarkable outcomes of this analysis is that ST of a PV module is inversely proportional to the factor of ***(n+1)***, where ***n*** is the number of series connected PV cells in a module. Besides, the shading vulnerability is independent from number of PV cell parallel strings within the module. Results can also be extended to array level.

III. Experimental Results

To validate our study, long-term experiments were accomplished both indoors and outdoors. For covering a wide range of PV markets, various PV modules were selected and tested indoor using an EternalSun Large Area Steady State Solar (LASSS) AAA-class simulator and each module was tested under 64 shading profiles (see Fig. 1). Studies proved that these 64 shading profiles are decent representatives of all possible shading conditions. Thirteen PV modules have been tested so far in the PVMD laboratory. Table I shows the results of indoor test, the corresponding measured ST values, and the suggested shading classes. Results showed that the number of bypass diodes, cells size and shape, and technology of a module are not always a valid measure for shading tolerability.

From Table I, PV modules #3, #6, and #10 belonging to different ST classes were evaluated outdoor. Modules were separated into two identical groups and installed on two locations as close as possible. One location was mostly sunny during day-time while the other one was frequently shaded by side objects. Performance Ratio (PR) of the modules were measured for 12 days. Results showed that modules which had performed better at indoor ST test kept on providing higher output at on-field outdoor measurements. Moreover, the ratio of differences of the measured outdoor PR values are surprisingly close to the ratio of differences of the obtained indoor ST values.

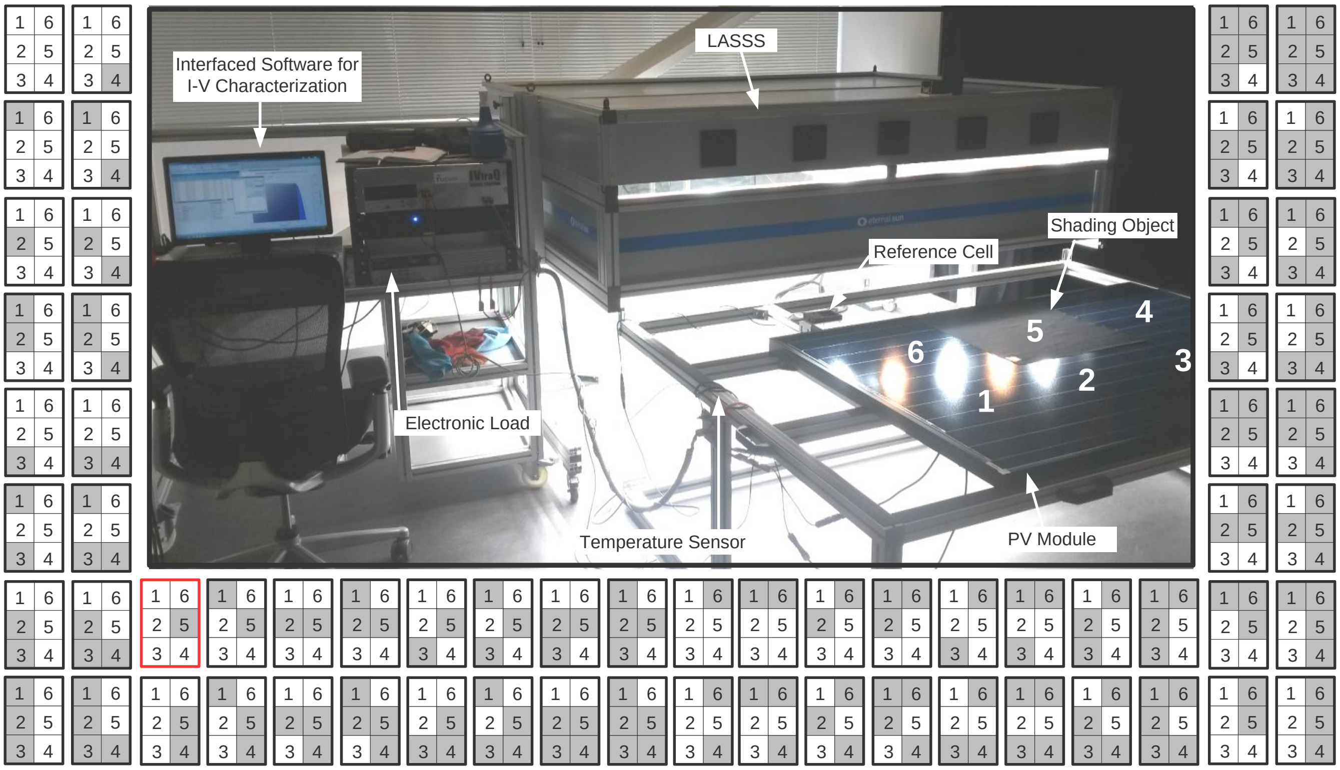

Fig. 1. Indoor experimental setup for testing shading tolerability along with 64 shading profile codes from 000000 to 111111. The depicted module under test (#4, see Table I) has 54 cells and is divided into 6 sections. The shading profile with code 010000 is shown in the picture (red-highlighted rectangle). In this respect, sections 1, 2, 3, 4, and 6 are about to receive rated irradiation (1000 W/m^2) while section 5 is shaded and receives 250 W/m^2. The shading object for this specific module shades simultaneously 9 cells [5].

Furthermore, four different PV modules of different technologies were tested for its ST at three different ambient temperatures (see Fig. 2). It was found that the change in ST with temperature was not much significant. On an average, the percentage deviation of the ST at higher ambient temperatures from that at 25 °C was only 1.14%. The average change in ST with temperature was 0.07 %ST/°C. Therefore, it can be concluded that the ST of a PV module is independent of the ambient temperature and can be treated as its characteristic parameter.

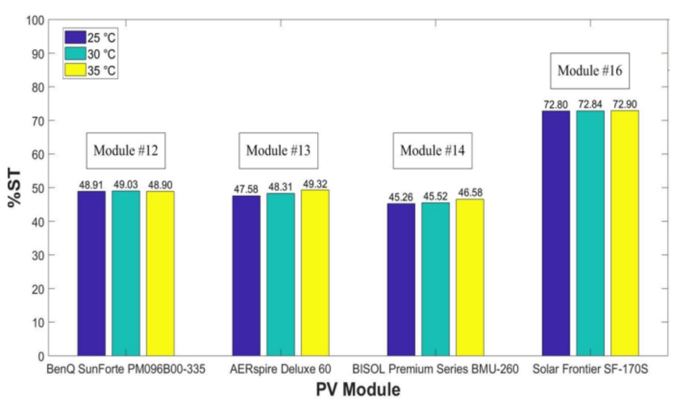

Fig. 2. Indoor experimental results for shading tolerability at ambient temperatures of 25 °C, 30 °C and 35 °C. The module number in the figure correspond to the number of PV module as shown in Table 1.

III. Discussion on The Significance of The Shading Tolerability Parameter

The defined shading tolerability ST could be very useful in PV engineering. Our previously published paper [5], theoretically and experimentally proved that the indoor measurement of ST is enough to know and compare the performance of modules in outdoor shading conditions. Therefore, the randomness of the shade and its profiles is not an issue anymore and module manufacturers can have their modules tested using this explained measurement procedure.

For each tested PV module, shading tolerability was manually determined in less than 6 hours. Consequently, it is industrially feasible to perform ST test on a single or couple of modules which are randomly selected from an identical group of modules. In this way, for a small amount of energy consumed within six hours (or much less), a substantial extra energy will be extracted from the sun during the PV system lifetime by selecting correct PV modules. It is thus suggested to add ST on photovoltaic modules datasheet as a benchmark to distinguish PV modules regarding shading tolerability.

Here it has been experimentally proven that the new defined parameter, ST, is independent from measurement temperature. In other words, ST and temperature coefficient (γ) are independent, making possible to categorize PV modules in a ST-γ map for appropriate selection (see Fig. 3).

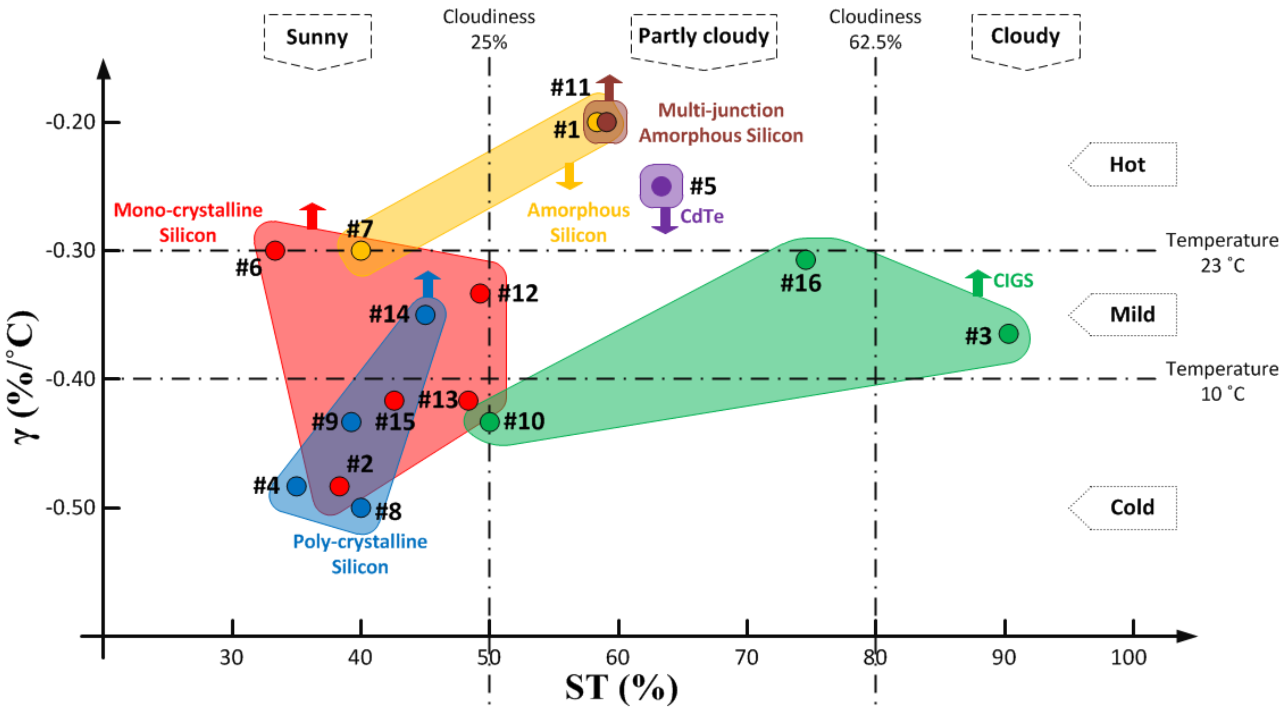

Fig. 3. Selection map for different technologies of PV modules based on their Shading Tolerability and Temperature Coefficient. The vertical dash-dotted lines correlate cloudiness to ST values. The horizontal dash-dotted lines suggest climate boundaries compatible with PV modules temperature coefficient values. The numbers in the figure correspond to the number of the PV modules as shown in Table I.

ST, together with γ of the PV modules, can significantly help designers to select the best module for different installation locations. Along with the shade classes discussed above, the selection map also makes use of temperature classes for PV modules. This was based on the datasheet information of several PV modules of different technologies that are currently available in the market and are under production. The boundaries for cloudiness and temperature conditions for a given location were based on climate classification systems used in meteorology [6, 7]. Thus, it is possible to select an optimal module for a PV system simply by knowing the technical specifications of the PV module along with the meteorological conditions of the installation locations.

V. Summary

PV modules are being installed everywhere and are prone to shading more frequently. Currently, there is no quantitative way to compare PV modules in terms of shading tolerability. Therefore, we suggest ST which is a new measureable parameter for photovoltaic modules datasheet and has the potential to be industrially applicable. Using this parameter, PV modules can be compared and rated based on their performance at shading. Moreover, the established selection map can help designers to increase the yield of their system and, subsequently, reduce the cost of electricity which would help to accelerate the growth of the PV industry.

Disclaimer

Results presented in this work strictly concern the individual photovoltaic modules available and tested in the PV Laboratory of the PVMD group of TU Delft. The performance of such modules might not reflect that of similar or updated modules from the same brand and/or under different circumstances.

References

[1] A. Smets, Closing session speech at EUPVSEC, Amsterdam, The Netherlands, 2017.
[2] "First solar technology advantage brochure," First Solar, Tempe,AZ, USA, 2015, pp. 1–7.
[3] "Multisol P6-54 series datasheet," Scheuten, The Netherlands, 2010, pp. 1–2.
[4] G.K. Singh, "Solar power generation by PV (photovoltaic) technology: A review," *Energy*, 53 pp. 1-13, 2013.
[5] H. Ziar, et. al., "Quantification of Shading Tolerability for Photovoltaic Modules." *IEEE J. Photovolt.*, vol. 7, no. 5, pp. 1390–1399, Sep. 2017.
[6] World Weather Organization, "Definition of Oktas." 2018.
[7] M. Belda et. al., "Climate classification revisited: From Koppen to Trewartha." *Climate Research*, vol. 59, no. 1, pp. 1-13, 2014.

TABLE I
DETAILED SPECIFICATION OF TESTED PV MODULES AND CORRESPONDING MEASUREMENT RESULTS

	Company/ Commercial Name	Technology	Electrical specification	Mechanical size Weight Flexibility	Notes on module's datasheet regarding shading tolerance	Percentage value of $ST^{(\sharp)}$	Suggested Shading Class Symbol
1	Neste Module PV A12	a-Si	MPP=7.5 W Bypass diodes: None Total 29 cells-one string	614×309×22 mm^3 3.0 kg (Rigid)	None	58%	◑ Partly-cloudy
2	Victron Energy SPM30-12	Mono c-Si	MPP= 30 W Bypass: One silicon p-n diode Total 36 cells-one string	450×540×25 mm^3 2.5 kg (Rigid)	None	38%	○ Sunny
3	Wurth Solar GeneCIS module 80W	CIS	MPP=80 W Bypass: One silicon p-n diode Total 132 cells- two parallel strings	605×1205×35 mm^3 12.7 kg (Rigid)	*Optimum energy yield through outstanding temperature and low light behavior*	91%	● Cloudy
4	Scheuten Multisol P6-54 series 200	Poly c-Si	MPP=200 W Bypass: Three Schottky diodes Total 54 cells-one string	1500×1000×42 mm^3 20.0 kg (Rigid)	*Junction box with patented connection system and 3 bypass diodes*	35%	○ Sunny
5	Calyxo CX3-77 Thin film solar module	CdTe/CdS	MPP=77.5 W Bypass diodes: None Total 156 cells-two parallel strings	1200×600×6.9 mm^3 12.0 kg (Rigid)	None	63%	◑ Partly-cloudy
6	SunPower SPR X20 327-BLK	Mono c-Si	MPP=327 W Bypass: Three silicon p-n diodes Total 96 cells-one string	1559×1046×46 mm^3 18.6 kg (Rigid)	*Designed to deliver the most energy in partial shade and hot rooftop temperatures*	33%	○ Sunny
7	Masdar PV MPV-T	Tandem a-Si/a-Si	MPP=109.81 W Bypass: One silicon p-n diode Total 636 cells-three parallel strings	1300×100×7 mm^3 29.5 kg (Rigid)	*Excellent energy output even during diffuse or low light conditions*	40%	○ Sunny
8	IKS Photovoltaik STA14 10W SolarTrainer	Poly c-Si	MPP=10 W Bypass: One silicon p-n diode Total 36 cells-one string	345×294×23 mm^3 Not specified (Rigid)	None	40%	○ Sunny
9	Solland SunWeb module 235 W_p	Poly c-Si	MPP=235 W Bypass: Three Schottky diodes Total 60 cells- one string	1613×984×35 mm^3 22 kg (Rigid)	None	39%	○ Sunny
10	Hanergy PowerFlex 90W	CIGS	MPP=90 W Bypass: Diodes at each cell; one at j-box. Total 36 cells-one string	2017×494×3 mm^3 3.3 kg (Flexible)	*Shade tolerant*	50%	◑ Partly-cloudy
11	Uni-Solar PowerBond ePVL	Multi-junction a- Si	MPP=27.4 W Bypass: Diodes at each cell Total 5 cells-one string	1325×373×3 mm^3 1.8kg (Flexible)	*Excellent performance even when partially shaded*	59%	◑ Partly-cloudy
12	BenQ SunForte PM096B00-335	Mono c-Si	MPP=335 W Bypass: Three diodes Total 96 cells-one string	1559×1046×46 mm^3 18.6 kg (Rigid)	None	49%	○ Sunny
13	AERspire Deluxe 60	Mono c-Si	MPP=250 W Bypass: Three diodes Total 60 cells-one string	1720×1035×40 mm^3 24 kg (Rigid)	None	48%	○ Sunny
14	BISOL Premium Series BMU-260	Poly c-Si	MPP = 260 W Bypass: Three diodes Total 60 cells-one string	1649×991×40 mm^3 18.5 kg (Rigid)	*High efficiency at low irradiation*	45%	○ Sunny
15	JA Solar JAM6-60-270 (BK)	Mono c-Si	MPP = 270 W Bypass: Three diodes Total 60 cells-one string	1650×991×40 mm^3 18.2 kg (Rigid)	None	43%	○ Sunny
16	Solar Frontier SF170-S	CIS	MPP = 170 W Bypass: One diode Total 170 cells-one string	1257×977×35 mm^3 20.0 kg (Rigid)	*Efficiency reduction of maximum power from an irradiance of 1000 W/m^2 to 200 W/m^2 at 25 °C is typically 2.0%*	73%	◑ Partly-cloudy

(♯) ST and %ST values are rounded to the closest integer. To obtain %ST, defined as the percentage value of ST, measured ST is divided by the maximum theoretical value of ST (for the measurement criteria).