COMPARISON OF BIFACIAL MODULE LABORATORY TESTING METHODS

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ABSTRACT: Bifacial modules, capable of additional power generation from the rear side, are a promising technology for increased energy yield compared to standard PV (monofacial) modules and with a low added cost. In order to provide customers and end-users confidence in the bifacial products now available on the market a clear laboratory test is needed that is both accurate and feasible with the current characterization equipment. A draft bifacial standard test has been proposed and suggests options for both full laboratory testing and characterization for modules from a manufacturing line. The authors conducted a survey of various parties in the PV value chain including institutes, module manufacturers, and equipment suppliers, gathering more information about the advantages and disadvantages of different test protocols and to use as a guide for recommendation for best practices after future laboratory evaluation.

Keywords: bifacial modules, characterization, LCOE

1 INTRODUCTION

Many module manufacturers are now offering bifacial modules, capable of additional power generation and annual energy yield due to light falling on the rear side, in addition to the standard monofacial modules. This is due to the increased production of p-PERC and n-PERT cell technologies that are amenable to bifacial applications. The new bifacial modules can be manufactured for similar costs as the monofacial variety but offer increased energy yield and therefore potential for lower levelized cost of electricity (LCOE) [2]. However, an official standard for characterizing and reporting performance for bifacial modules is not yet available although a draft standard has been proposed (IEC 60904) [1]. More uniform test definitions and conditions is of great importance for certification and comparison between laboratories and manufacturing locations. However, the added complexity of bifacial module testing and the attempt to simulate the outdoor environment in the laboratory space is a key challenge to widespread adoption of bifacial modules.

A bifacial module test standard should fulfil a number of useful criteria. It should be accepted by the community as an accessible and standardized way to measure performance of modules in a laboratory environment; it should measure the necessary parameters for quantifiable comparison between modules; it should result in parameters necessary for input for accurate energy yield modelling; and have a predictable relationship to outdoor performance in common applications (neglecting degradation). The purpose of this work is to evaluate various methods of indoor standardized testing of bifacial modules based on (1) community acceptance and opinions, (2) accuracy and ease of testing methods, and (3) utility for energy yield modelling and outdoor performance. In this contribution, we report on the first part, a survey conducted with participants from along the PV value chain to gather information about the community opinions on what is feasible, economic, and reasonable for bifacial module characterization. Further evaluations in the laboratory and outdoor will be reported in future publications.

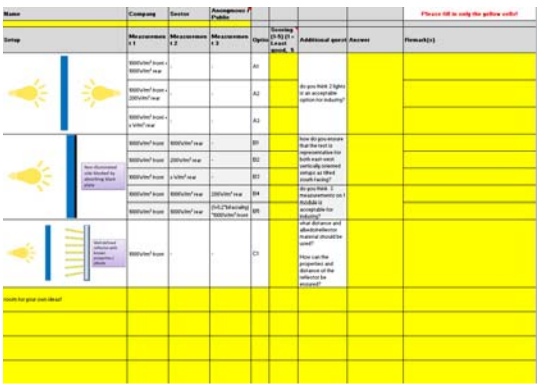

Figure 1: Screen shot of survey on bifacial module testing sent to various representatives of the PV valuechain.

2 BIFACIAL TESTING SURVEY

To gather input we surveyed various parties along the PV module value chain. We divided these parties into three types: module manufacturers, research institutes, and equipment suppliers. Many of the module manufacturers are also playing the role of system developers for many bifacial module systems today. While this end user group is not specifically included in this survey due to the technical nature of the testing methods, their opinions are also of significant value.

The survey is arranged as a worksheet with 3 basic equipment setups and variations of measurements that can be made with each of these equipment setups, resulting in nine specific test configurations. A screen shot of the survey is shown in Figure 1. The participants are asked to rate each proposed method on a scale of 1-5 with 5 as the best. In addition a few specific questions are also asked regarding the specific test setups. There was also space for the respondent to write-in other ideas and methods for bifacial testing. We received 13 responses from the survey with five representatives each from institutes and module manufacturers and three from equipment suppliers. In the following sections, we describe each of three equipment setups and the general responses and comments received.

2.1 Setup A: Two Light Sources

The first equipment setup requires two light sources that are flashed simultaneously (Figure 2). One will be on the front of the module and the other illuminating the rear

Figure 2: Schematic of Setup A, with two light sources illuminating the front and rear simultaneously. One measurement can be sufficient.

of the module. This setup has the benefit that it requires only one measurement but the logistics of timing two flashes, controlling the reflection of the environment, and the added cost of more equipment make it difficult. Industry commented that the current equipment is not suitable for this setup and requires significant and potentially expensive modifications. One respondent pointed out that the rear illumination could potentially be of lower quality in order to ease costs. Another drawback identified was the possible physical footprint of the test setup for uniform illumination.

There were three specific test setups that were rated as described in Table 1 . The general feedback was that method A1 would result in irrelevant values as a module would never be in this situation outside. Method A2 was considered a reasonable test but all respondents believed that tuning a flash tester to such low power might cause problems. Method A3 was favored among the first equipment setup with the idea that the rear illumination source would not be fixed in power but rather could vary from 100 W/m^2 to 300 W/m^2 to evaluate linearity and also provide useful input for annual yield modelling.

Table 1: Setup A proposed methods. All methods are a single measurement with simultaneous front and rear side illumination. XX indicates a tunable or variable value where respondents could enter a suggested value.

	Front Source Power	Rear Source Power
A1	1000 W/m^2	1000 W/m^2
A2	1000 W/m^2	200 W/m^2
A3	1000 W/m^2	XX W/m^2

2.2 Setup B: Single Light Source and Multiple Measurements

The second equipment setup, shown in Figure 3, consists of only one illumination source making it more compatible with standard monofacial module testing apparatus most common today. In this setup, the non-illuminated side of the module, during any specific measurement is covered by a black absorbing material, such that all measurements are effectively monofacial. Therefore, bifacial data collection requires multiple measurements.

Different series of multiple measurements were proposed as summarized in Table 2. For B1, B4, and B5, the bifaciality factor (BF) can be calculated after the first two measurements M1 and M2, such that,

$$BF = P_{mpp}(M2)/P_{mpp}(M1).$$

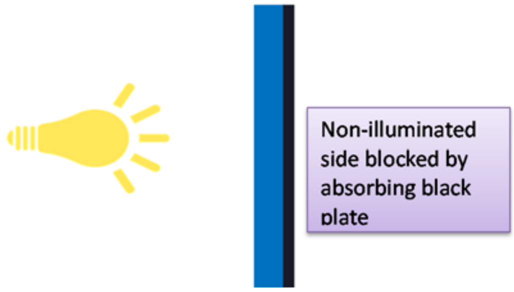

Figure 3: Schematic of Setup B with one light source and a non-reflecting black absorbing material is placed against the module on the non-illuminated side. Multiple measurements are necessary.

The bifaciality factor here is calculated in terms of maximum power, but a similar term can be calculated from measurements M1 and M2 for each of the module parameters of short-circuit current, open-circuit voltage, and fill factor. Each of these calculations could also be provided on a module specification sheet or used as input for modelling.

Overall, Setup B was preferred by many research institutions as it gives the most amount of data. However, the need for multiple measurements for each module made it impractical for most module manufacturers. Test B1 was somewhat more practical with fewer measurements and can be used to calculate performance in various installation configurations, such as fixed tilt (south), vertical east-west, or even tracking. However, the impact of higher current density in the module is not well characterized with B1. Therefore the results for half-cell modules would probably be more representative than the results for full-cell modules due to interconnection series resistance.

B2 and B4 both offer more realistic characterization of the rear side performance with diffuse albedo light, but suffer the issue identified in A2, in that it is difficult to get a uniform distribution and good spectrum at the low intensity of 200 W/m^2. For B3, various intensities were suggested ranging from 100 – 300 W/m^2.

Test setup B5 was identified as one of the best methods for testing (and is similar to the draft standard) but many module manufacturers suggested that three measurements on a single module is too many. An equipment supplier mentioned the fact that some module test equipment could do both measurements M1 and M3 at the same time.

Table 2: Series of multiple measurements proposed for Setup B. Illumination intensity and illumination side (F – front, R – rear) is indicated. The bifaciality factor (BF), calculated from the ratio of M2 to M1, is used to determing illumination intesity in B5.

	Measurement		
	M1	M2	M3
B1	1 kW/m^2 –F	1 kW/m^2-R	-
B2	1 kW/m^2 –F	200 W/m^2-R	-
B3	1 kW/m^2 –F	XX W/m^2-R	-
B4	1 kW/m^2 –F	1 kW/m^2-R	200 W/m^2-R
B5	1 kW/m^2-F	1 kW/m^2-R	(1+0.2*BF)* 1 kW/m^2-F

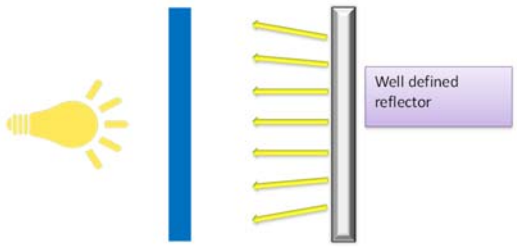

Figure 4: Schematic of Setup C with one light source illuminating the front of the module and a well-defined diffuse reflector behind the module at some distance.

Setup B also does not sufficiently account for self-shading on the rear of the module such as, large or misplaced junction boxes. In this case, the rear measurements and bifaciality factor would not reflect the real performance of the module. A significant shade on the rear of a bifacial module only contributes as a much smaller partial shade for the whole module when illuminated from the front under real outdoor conditions. In these cases, simulations of energy yield would likely be very inaccurate if based upon Setup B test results.

2.3 Setup C: Single Light Source and Defined Reflector

The third equipment setup consists of a single measurement from the front of the module with a diffuse reflector placed a specific distance behind the module with a known reflectivity, as shown in Figure 4. In this Setup, light that does not illuminate the module directly, or passes through the inactive and transparent areas of the module is reflected diffusely by the reflector behind and illuminates the rear side of the module at the same time as the front side and with only one measurement. This method was praised by respondents for potentially simulating the real outdoor environment of direct light, albedo, and self-shading. But it was also recognized that that ensuring uniformity of illumination, specifications of the reflector, and measurement setup would result in a difficult implantation and limit the useful comparison between various measurements on different setups. This would pose a large challenge to Setup C.

2.4 Write-in Suggestions

In addition to the scoring of the proposed tests A-C, the respondents were also asked for any other ideas. Many module manufacturers suggested that for each module bill of materials (including specific cell types and bifaciality), only one B1 or B5 type measurement should be made. For all following modules, a simple standard monofacial flash test could be used to predict module performance in

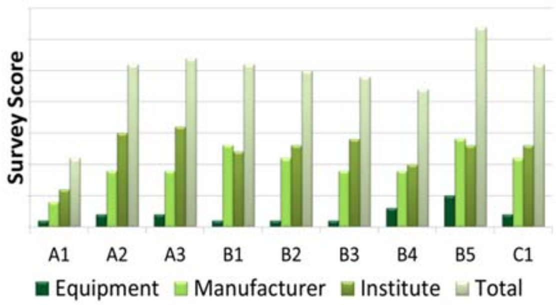

Figure 5: Histogram of survey results by respondent type and in total.

bifacial conditions. For institutions, it was suggested that a B5 test should include a 4th measurement (M4) at lower illumination intensities, i.e. approximately 800 W/m^2 in order to establish the module characteristics with less than one sun. A third suggestion was also made that multiple measurements with equipment arranged in Setup C with varying distances between the module and reflector to simulate different installation and albedo intensity conditions.

3 RESULTS AND CONCLUSIONS

A histogram of the responses from each sector and total is seen in Figure 5. Test setup B5 is preferred for almost all sectors and overall as it provides the most information. Research institutes also indicated a preference for A2 and A3, despite the measurement difficulty of two light sources as it would clearly mimic the outdoor performance in the most controlled way. Research institutes also scored Setup C highly as a possible way to clearly mimic real-world conditions. Manufacturers preferred B1 for a reduced number of measurements and B5 in order to gather more module performance parameters.

4 RECOMMENDATIONS AND OUTLOOK

It is crucial for the large-scale adoption of bifacial modules that a well demonstrated standardized test procedure is defined such that it is indicative of real world performance. It should also be a relatively simple test procedure that provides quantitative information for energy yield modelling and calculations. Finally, it should also be a relatively simple test procedure that can be reproduced at various institutions for comparison purposes.

Based on the survey results, the overall PV community is still uncertain of what test will be sufficient to address the various needs of each part of the value chain. For the end user and systems developers, the gain or value for bifacial modules is still often unclear [3]. LG has published a bifacial users guide explaining how different module characteristics and installation choices such as distance from the ground, albedo light of rear surfaces, orientation, and inverter or optimizer choice will impact the peformance in a bifacial system [4]. Module manufacturers prefer to use fewer measurements and then calculate peformance while institutes prefer either multiple measurements or methods that illuminates both sides of the module at the same time, most closely related to real-world applications. Overall, it is clear however that tracking the behavior of modules with various illumination intensities, including lower light behavior, is preferred by all respondents to verify the assumed linear response.

The results of the community survey for bifacial module characterization reported in this paper will provide a basis for a laboratory experiment to compare the highest ranked testing procedures as outlined above along with the proposed standard test method IEC 60904, Parts 1-2 Draft A [1]. Further, outcomes of these tests will be used for annual yield and performance modelling of bifacial systems [5]. These simulations and laboratory tests will be compared with outdoor bifacial module data in order to establish an empirical justification and to provide a clear recommendation for practical bifacial module and characterization in both industry and research.

5 REFERENCES

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