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Indoor Characterization At Production Scale: 200 kW_p Of CPV Solar Simulator Measurements

Juan Pablo Ferrer[1], María Martínez[1], Pablo Trujillo[1], Francisca Rubio[1], Steve Askins[2], César Domínguez[2], Rebeca Herrero[2] and Gabriel Sala[2]

[1]*ISFOC, +34 926.441.673, jpferrer@isfoc.com, Pol. Industrial La Nava III, c/Francia 7, Puertollano, Spain.*
[2]*Instituto de Energía Solar – Universidad Politécnica de Madrid, Avda. Complutense s/n, Madrid, Spain.*

Abstract. In order to complement ISFOC's characterization capabilities, a Helios 3198 CPV Solar Simulator was installed in summer 2010. This Solar Simulator, based on a parabolic mirror and a high-intensity, small area Xenon flash lamp was developed by the Instituto de Energía Solar in Madrid [1] and is manufactured and distributed by Soldaduras Avanzadas [2]. This simulator is used not only for R&D purposes, but as a quality control tool for incoming modules that are to be installed in ISFOC's CPV plants. In this paper we will discuss the results of recent measurements of close to 5000 modules, the entire production of modules corresponding to a small CPV power plant (200 kW_p). We scrutinize the resultant data for signs of drift in the measurements, and analyze the light quality before and after, to check for changes in spectrum or spatial uniformity.

Keywords: CPV solar simulator.
PACS: 88

INTRODUCTION

The characterization of a large-scale amount of CPV modules is a challenge for this solar simulator laboratory. Nevertheless, the equipment delivered by Soldaduras Avanzadas is prepared for this large-scale purpose. Some experiments related to the quality of the measurements (light homogeneity, spectrum) and their repeatability are conducted and analyzed.

The power measurements with this Solar Simulator use a mono-module (basic unit, receiver + optic, of the same technology to characterize) as a light sensor to determine the irradiance of the measurement. This mono-module is previously calibrated outdoor under an equivalent spectrum to the standard one (AM1.5D).

INITIAL TESTS

This section presents the tests that are carried out before any measurement in order to assure the best configuration of the equipment and characterize the uncertainty of the measurement of each technology. The light uniformity, the spectral distribution and the repeatability of the equipment is analyzed, because these parameters are technology dependent. The module area, acceptance angle or size of the optic are parameters that could influence in the accuracy of the results.

Light Uniformity

The solar simulator has to fulfill the requirement of providing a relative homogeneous light in terms of intensity for the whole area of module to characterize. The manufacturer assures a maximum range of non-uniformity of ±5%; this means that the intensity of reflected light by the parabolic mirror may differ up to 10%. This fact depends on the imperfections of the mirror's surface, on its curvature and also on the flash bulb used.

So, before beginning any characterization, a light uniformity test is carried out to determine this parameter for each technology. This test is carried out by repeating consecutive measurements of short-circuit current (I_{SC}) of the mono-module of the technology that is going to be later characterized, in some positions of the lenses of the module. This measurement of I_{SC} is proportional to the reflected irradiance.

In this case, the module to test is a CPV module of around 85x85 cm^2 with 25 lenses and an acceptance angle of ±0.77º for I_{SC}. 15 measurements were taken for the 15 lenses' positions of the module (only columns 1, 3 and 5), as represented in Figure 1, covering the same measurement plane than that of the module for its normal characterization.

	1	2	3	4	5
1	-0.93%		0.17%		-2.07%
2	0.64%		1.37%		-0.73%
3	-1.35%		-0.75%		0.27%
4	0.59%		-0.60%		2.39%
5	-0.57%		-0.12%		1.69%

FIGURE 1. Result of light uniformity test at the module's plane within a total area of around 85x85 cm^2. Each square corresponds to the position of a module's lens.

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The results for this specific measurement plane show relative low amplitude of non-uniformity: the relative deviation to the mean value of irradiance is lower than ±2.5%. This assures a relative good quality of the light used for the measurements of this technology in the characterized area.

Spectrum

The spectrum of the reflected light by the mirror at the measurement plane is analyzed by using isotype-component cells: top, middle and bottom, and a mono-module of a well known technology.

These 3 sub-cells correspond to those of the usual terrestrial CPV solar cells junctions. This set of 3 isotype-component cells were provided by Fraunhofer ISE and is named as "Set C", calibrated to AM1.5D low AOD spectrum at 1000W/m^2.

The calibration of the mono-module was taken outdoors under controlled conditions: *DNI*=913 W/m^2 and *SMR*=1.0 (see equation (2)).

The lamp's flash is analyzed in 2ms during the light pulse. The intensity is measured simultaneously by using the isotype-component cells and the mono-module. So, 3 signals of I_{SC} are monitored simultaneously: top, middle and mono-module. Only top and middle cells were considered in this experiment since only these 2 sub-cells may limit the photocurrent of a whole three-junctions CPV solar cell in general (there may be also CPV solar cells with different current mismatch between the 3 sub-cells, so another kind of sensor should be used).

Figure 2 shows the shape of the lamp's flash in terms of effective irradiance (when speaking of the isotype-component cells) and in terms of irradiance (when speaking of the mono-module or irradiance sensor). The light pulse decays exponentially after 0.2ms; I-V curves of simulator measurements are executed during this exponential decay. The effective irradiance of a sub-cell is defined as:

$$B_{eff}^{sub-cell} = \frac{I_{SC}^{sub-cell,measured}}{I_{SC}^{sub-cell,calibrated}} \times 1000(W/m^2) \quad (1)$$

where "sub-cell" corresponds to the top or the middle sub-cell. The factor of 1000W/m^2 is included because it is the irradiance at which the calibration of the isotype-component cells was carried out. The effective irradiance measured by the middle cell had a problem in terms of electromagnetic noise, but it is not crucial for this experiment.

Note that during the decay of the light intensity (the previous region is not of interest) there is an instant of time when both effective irradiance curves top and middle intersect. This corresponds to spectral conditions equivalent to the spectrum AM1.5D, since both cells proportionally produce the same photocurrent as by their calibration to the AM1.5D spectrum. The mono-module (irradiance sensor) provides an irradiance measurement of ca. 950W/m^2 for the instant of time when having this spectral conditions mentioned before. This value of irradiance is different than the value in which both isotype-cell's effective irradiances intersect because of: i) the spectrum outdoors is different than the indoors one, and ii) this difference in the spectrum may produce an impact on the mono-module's photocurrent due to the presence of the concentrating optics. Therefore the irradiance level is measured by the mono-module and the isotype-component cells are used to check how the spectrum during the measurements is.

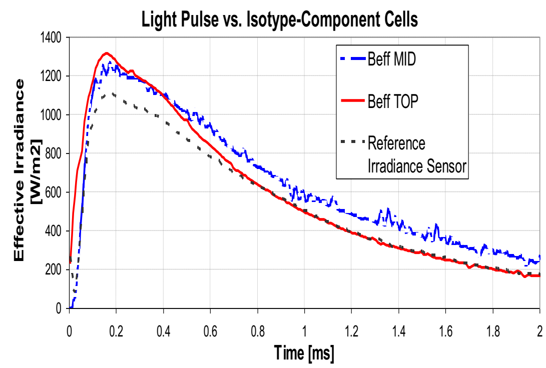
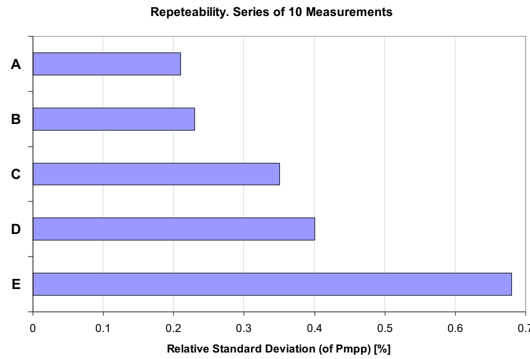


FIGURE 2. Light pulse as seen by the two isotype-component cells Top and Middle and by the reference irradiance sensor in terms of effective irradiance. The intersection between B_{eff}^{top} and B_{eff}^{mid} indicates the instant of time when the reflected light has equivalent spectral conditions to AM1.5D reference spectrum.

Repeteability

In order to know how repeatable the module's power indoor measurement is, a simple study of repeatability was conducted. A CPV technology with a relative low acceptance angle (ca. ±0.5º) was chosen for this experiment. The procedure consists of the repetition of 10 consecutive measurements while having controlled the surrounding conditions. Then, the relative standard deviation to the mean value on power is calculated. A diagram of this is presented in figure 3.

The first situation (A) represents the repeatability of the simulator, since no changes were introduced among the 10 measurements. For the situation B, the module was measured 10 times after 10 corresponding re-alignments to the continuous light of the simulator's model lamp. In situation C, the module was in a constant position but the mono-module was re-aligned 10 times. In situation D, both module and mono-module were re-aligned before each of the 10 measurements. In situation E, only the whole lamp's structure was re-aligned (both lamp and mono-module are mounted on the same support structure, which is different to that where the modules are mounted).



A. Simulator measurement repeatability
B. Re-aligning module
C. Re-aligning mono-module
D. Re-aligning both (module and mono-module)
E. Re-aligning both lamp and mono-module (same structure)

FIGURE 3. Five different experiments were made to calculate the repeatability of the solar simulator under different measurement procedures. In experiment E, please note that both, the lamp and the mono-module, are mounted on the same support structure different than that where the modules are mounted.

These results may approximately establish minimal values of deviations concerning the procedures needed to set up the solar simulator when characterizing a technology. Note that the simple action of re-aligning both module and mono-module (0.4% relative standard deviation) introduces a dispersion in the results double than the uncertainty of the solar simulator (0.2%, from the electronic acquisition).

PERIODIC TESTING

In order to study the measurement process of large-scale quantity of modules, a SPC (Statistical Control Process) analysis in terms of control charts was carried out. The objective is to control the conditions of the measurements by using a control module that it is measured periodically and the evolution in time of its power is analyzed.

Two different series, of two different technologies were analyzed. For both series, the 10 first measurements were used to calculate the corresponding control limits.

In the first series, around 4,500 module's measurements are analyzed. The control module was measured at least twice, once at the beginning and once again at the end of each day of work (in total there were around 60 days of measurements). Figure 4 shows the X-bar control chart for samples of the measurements of the control module. The most important problem found was to have points out of the control limits; some fixation problems were found in the support structure of the module.

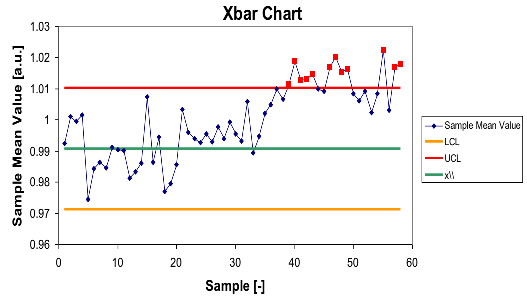


FIGURE 4. Xbar chart for groups of 2 measurements of a control module (technology A). The last group of measurements was out of the control limits probably due to misalignment reasons.

In Figure 5, a different technology was analyzed, in this case by individual measurements of the control module (taken in around 15 days time). The most important difference with respect to the previous experiment is the fact that the support structure used had a better fixation. In this case, all points are within the control limits. Nevertheless, there are some signs of non-random behavior, like having too many points at the upper side of the mean value, that are being analyzed.

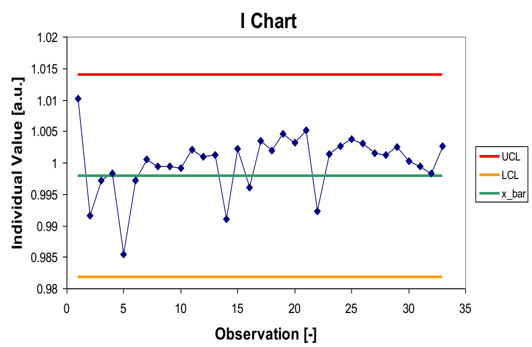


FIGURE 5. Chart of individual measurements of a control module (technology B). All points are within the control limits but there are still some signs of non-random behavior.

In this test, the results obtained are not related to the technology under test. This test is analyzing the rest of elements of the equipment that are involved in the measuring process, like the support structure of the module, mono-module and flash lamp.

LAMP AGING

After around 80,000 flashes (one I-V curve measurement needs around 15 flashes, so it means more than 5,300 modules measured), the flash bulb presented aging signs. These aging signs are visible as depositions in the inner side of the bulb near the electrodes (much more in the electrode at the right in figure 6).

FIGURE 6. Signs of degradation as depositions in the inner side of the bulb near the electrodes.

The aged lamp was compared with a new one in terms of Spectral Matching Ratio (*SMR*) relative to irradiance. *SMR* (non-dimensional parameter) is defined as the ratio between top and middle effective irradiances:

$$SMR = \frac{B_{eff}^{top}}{B_{eff}^{mid}} \qquad (2)$$

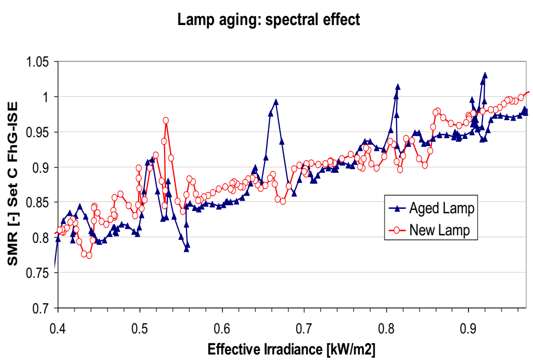


FIGURE 7. Spectral Matching Ratio (*SMR*) relative to irradiance for both aged and new lamp. Note that both curves have similar slope. *SMR* is reduced in 2-3% for high irradiance values for the aged lamp.

Figure 7 shows that both SMR curves (aged and new lamp) have similar behavior relative to the irradiance measured with a mono-module (irradiance sensor). Nevertheless, the aged lamp has ca. 2-3% less value of *SMR* at the highest values of irradiance, which implies 'red-richer' spectra produced.

This measurement is done in a light pulse of the flash lamp, where the mono-module indicates the irradiance of the measurement and in the same instant the photocurrent generated by the isotype-component cells is measured to calculate the SMR parameter.

CONCLUSIONS

Initial tests (light uniformity, spectral distribution) were executed and assured the quality of the measurements to the requirements of the IEC-62670 (draft) standard. Nevertheless, in large-scale measurements some non-random behavior was detected by analyzing the results of the measurements of control modules (using control charts). In the last series of large-scale measurements the module's alignment conditions were better controlled (by fixing properly the support structure) and no points (control module) were out of the control limits. The study of repeatability has relation to the study commented above, in the sense that around 0.7% of dispersion (relative standard deviation) may be consequence of usual alignment procedures taken place in the solar simulator when changing the locations of the key components (lamp, mono-module). For later works, it is a challenge to have large-scale measurements strictly under the rules of controlled processes.

As a consequence of those large-scale measurements the flash bulb presented visible signs of degradation as a deposition in the inner side of the bulb.

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REFERENCES

1. C. Domínguez, I. Antón, G. Sala, "Solar simulator for concentrator photovoltaic systems," Optics Express,16, pp. 14894-14901, 2008.
2. E. Agudo, et al., (2008). "First Commercial Single and Multijunction Cell CPV Module Tester". Proc. Of ICSC-5. Palm Desert, CA, USA.