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Helios 3198 Solar Simulator Adaptation for the Characterization of LCPV Prototypes

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Abstract. This paper covers the adaptation and experimental verification that has been carried out to the Helios 3198 solar simulator to use it in the characterization of a LCPV prototype. The challenge is to deal with the diffuse light that can distort the measurement of a LCPV prototype because of the larger acceptance angle. A deflector chamber for the flash lamp has been designed and implemented to capture this diffuse light. The experimental verification has proven the reliability of the solution, demonstrating that the inclusion of this element in the equipment is not modifying the spatial uniformity and the angular distribution of the light at the receiver plane. Therefore, this work demonstrates that the Helios 3198 solar simulator, including a deflector chamber for the lamp, can be used for the characterization of a LCPV prototype.

INTRODUCTION

The Helios 3198 solar simulator was developed by IES-UPM in collaboration with the company Solar Added Value for the indoor characterization of high-concentration photovoltaic (HCPV). This equipment has been extensively described and validated in the past [1,2]. ISFOC has a Helios 3198 solar simulator installed in its laboratory that has been widely used in different characterization works and projects [3] but always related with HCPV. In fact, there are several works in the community [4,5] that cover the characterization of the solar simulator equipment but always when measuring HCPV.

This paper describes all the works and the experimental verification that has been carried out to this equipment for the characterization of the low-concentration photovoltaic (LCPV) system that it is being developed by Abengoa Solar in collaboration with IES-UPM within the Spanish project "THESEUS" (RTC-2014-2304-3).

First, the structure that ISFOC usually uses in the characterization of HCPV modules cannot be used to work with LCPV. Therefore, Abengoa Solar together with ISFOC has prepared a special structure to mount a LCPV prototype adapted to the solar simulator room. Figure. 1(a) shows a scheme of the structure and Fig. 1(b) shows the LCPV prototype installed in the laboratory. In this case, because of the huge dimensions of the prototype, the measurements have to be done always using the off-axis topology of the equipment [1,2]. Figure. 1(c) shows the layout of the off-axis measurement including the LCPV prototype. This structure has to be versatile enough to carry out different characterization works; therefore it permits the alignment of the concentrator as a whole and also between its different elements (receiver and primary optic).

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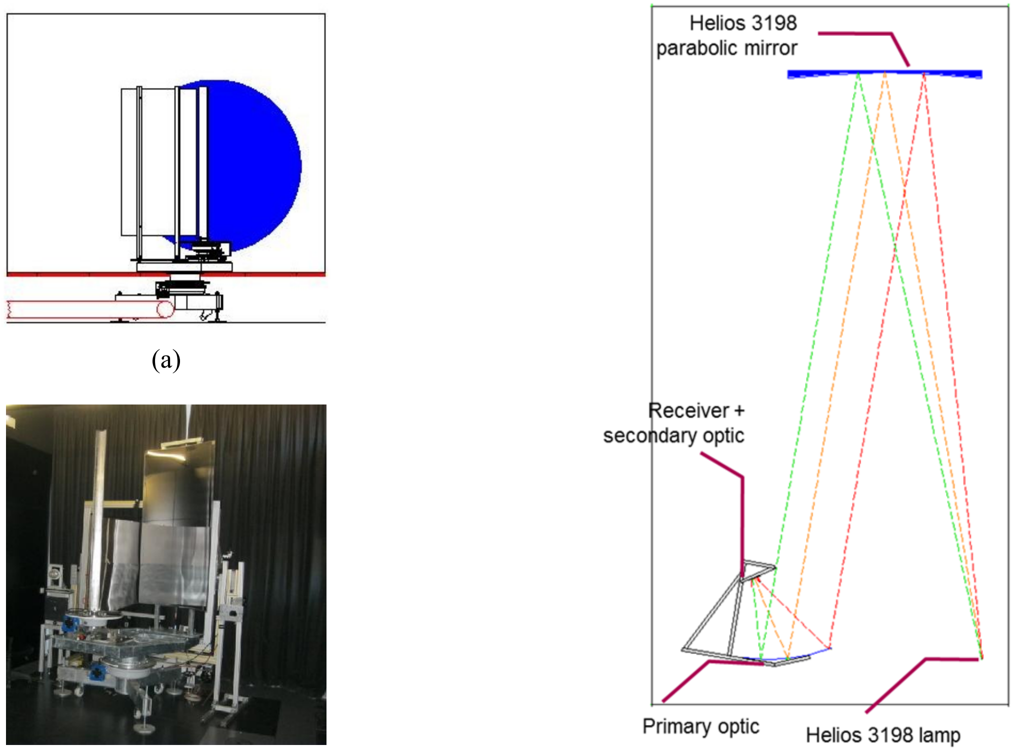


(a) (b) (c)

FIGURE 1. (a) Scheme of the structure of the LCPV prototype to install in the solar simulator lab. (b) LCPV prototype installed in the solar simulator room. (c) Layout of the solar simulator lab with the LCPV prototype and the off-axis configuration

The Helios 3198 solar simulator illumination system is based on a flash lamp placed at the focus of a parabolic mirror. The bulb radiates light in many directions, but only the fraction reflected by the mirror generates the collimated beam used to illuminate the CPV module. The rest of the light impinges on the ceiling, floor and walls and is then scattered and reflected. Part of this light may reach the aperture area of the module, but the narrow angular acceptance of HCPV modules filters out this light. However, LCPV modules are characterized by a larger angular acceptance, which may result in allowing part of this diffuse light to reach the prototype to measure or the reference sensor and thus generating a non-uniform light profile that distorts the measurement. The influence of the non-uniformity of the light in solar simulators is described in [6].

The next two sections describe the works carried out, first to identify the origin of the diffuse light and the solution adopted to filter it and secondly the study carried out to verify the uniformity of the light profile in the measuring area.

DIFFUSE LIGHT ANALYSIS

As it has been said before, the diffuse light that it is reflected by the walls, floor and ceiling of the lab can distort the measurement of the LCPV prototype, see fig. 2(a). The origin of the distortion in the result can be the effect of the diffuse light over the light sensor of the solar simulator or over the LCPV prototype.

Diffuse Light Effect over the Light Sensor

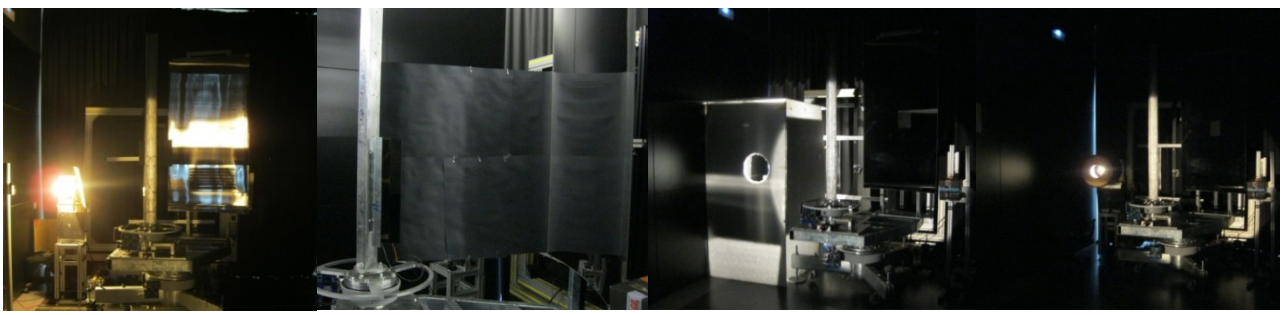
The Helios 3198 solar simulator uses a light sensor to determine the irradiance level during the measurement. In this case, if a bare cell, without optic, is used as light sensor, the amount of diffuse light reaching this cell will be larger than that collected by the concentrator. Thus, the electrical efficiency of the concentrator will be underestimated.

This effect of the diffuse light in the light sensor can be easily avoided by reducing its field of view. The solution adopted is a collimator tube added in front of the cell reducing the aperture angle to ±2.5º (like a pyrheliometer and in the same range as the LCPV acceptance angle). The current measured for the LCPV prototype has been increased in a 20% when the collimator tube is implemented and the undesired diffuse light is filtered from the light sensor.

Diffuse Light Effect over the LCPV Prototype

However, the solution of the collimator tube added in front of the prototype cannot be used for the large aperture area of a LCPV module because of the huge dimensions of the resulting collimator. Instead, the aim is to reduce the fraction of diffuse light being scattered at the tunnel. For this purpose, different solutions have been envisaged:

- Firstly, a black curtain was installed between the flash lamp and the LCPV prototype to avoid the direct illumination from the flash lamp to the mirror or the receiver, see Fig. 2(b).
- Some baffles or screens were introduced at the tunnel, close to the flash lamp, to avoid that the diffuse light scattered at the surroundings of the lamp (i.e. with a large intensity) reaches the receiver directly see Fig. 2(c).
- To reduce the fraction of diffuse light, the wide emission angle of the lamp has been limited by means of a special deflector chamber, which captures the undesired light rays inside it; see Fig. 2(d).



(a) (b) (c) (d)

FIGURE 2. (a) Diffuse light in the solar simulator room. (b) Black curtain between the flash lamp and the LCPV prototype. (c) Baffles or screens around the flash lamp. (d) Deflector chamber in the flash lamp

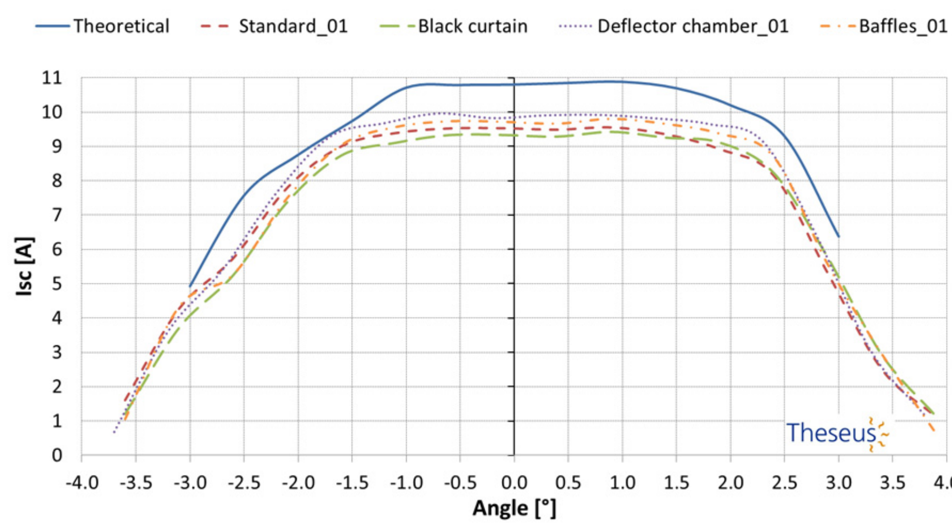


FIGURE 3. Angular transmission curve measured to the LCPV prototype with the different solutions to eliminate diffuse light.

Figure. 3 shows a comparison of the measurements carried out to the LCPV prototype with each one of the solutions. The variable and measurement used to verify the effect of each solution is the acceptance angle and the angular transmission curve. The effect of the elimination of the diffuse light is that the knee of the curve becomes sharper because the angular extent of the light source has been reduced and also the absolute value of the current measured rises up.

The graph of Fig. 3 shows the angular transmission curve of all the solutions. The representation of the theoretical curve is in continuous blue line, this is the curve to reach as it is a simulation of the best performance. The dashes red line is the measurement carried out with the standard method used for HCPV, without any filter to the diffuse light. The measurement made implementing the black curtain is represented in long dashes green line, this case is better that the previous one as the shape in the knee is a bit sharper. Next, the measurement carried out with the baffles installed in the tunnel is represented in dashes and dots orange line and it can be observed how the absolute value is a little bit higher and also the knees are sharper. Finally, the measurement carried out with the deflector chamber over the flash lamp is represented in dots purple line. This last curve is the best one, with the higher absolute value and also the sharpest knees of all the cases, so it is conclude that the use of the deflector chamber in the flash lamp is the best way of filtering the diffuse light.

Best Solution: Deflector Chamber Description

The deflector chamber is made up in three phases as it is shown in Fig. 4(a). This geometry permits the capture of the diffuse light inside the chamber; see Fig. 4(b). The undesirable light directions of the flash lamp are reflected multiple times inside the collimator until they are completely mitigated or they can escape but in a non-useful direction. Therefore the deflector chamber only permits the emission of light directly to the simulator mirror.

Figure. 4(c) shows the light profile generated when using the deflector chamber. The interior is a uniform light cone with a base diameter longer than the mirror diameter but around it appears a ring of non-uniform light because of reflections in the output edges of the deflection chamber. This non-uniform ring will not affect the measurements since the diameter is larger than the mirror so it is not going to be reflected back to the measuring area

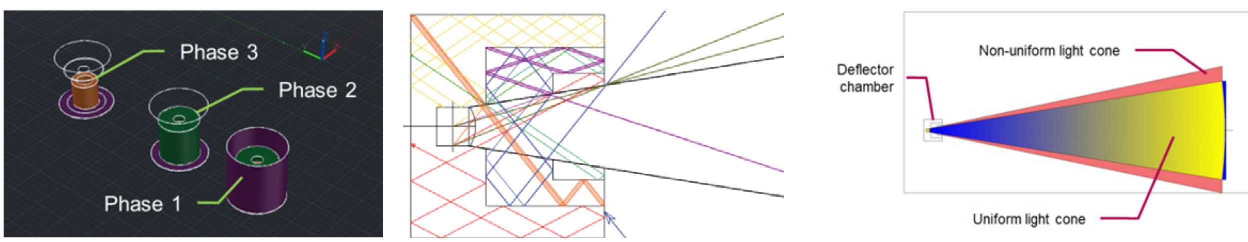


FIGURE 4. (a) 3 phases deflector chamber break up. (b) Scheme of the internal partitions and how the light is captured inside the deflection chamber. (c) Light profile generated using the deflector chamber

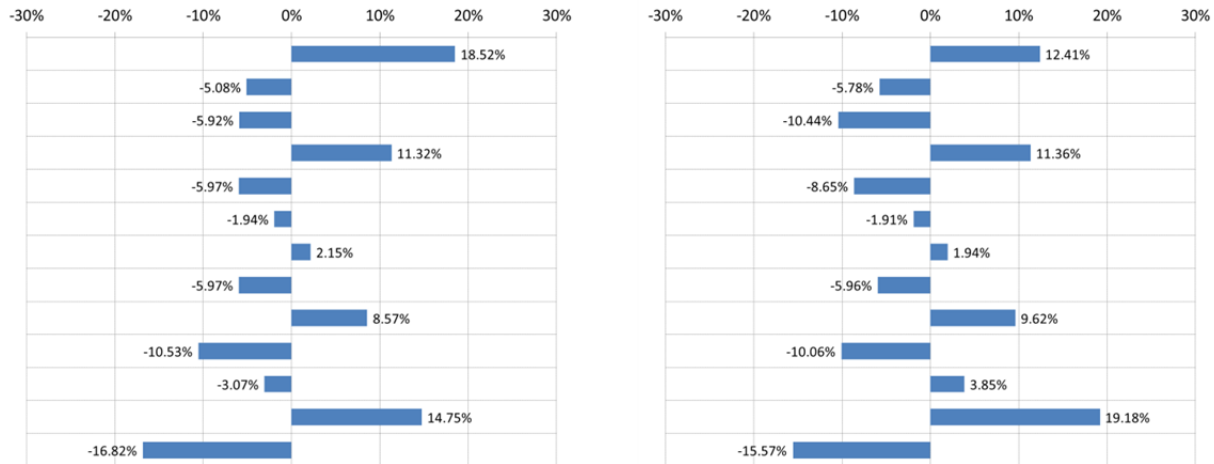
Finally, to ensure the viability of the solution, the uniformity of the light in the measuring area is evaluated when the deflector chamber is installed around the flash lamp.

LIGHT UNIFORMITY STUDY

The objective of this last study is to ensure that the deflector chamber is not introducing non-uniform areas in the measuring region of this LCPV prototype. As a first approximation, the uniformity of the light in the receiver area is evaluated and finally the uniformity of the light source with and without the deflector chamber is compared.

Evaluation of the Light Uniformity in the Receiver Area

In this first evaluation the uniformity of the light in the receiver area is checked by measuring the current generated by a single cell, of the same technology and with the same encapsulation, in all the cell positions of the receiver. The current generated in each position is normalized using the average of the current measured in all positions, calculating like this the deviation in the current for each position. Figure. 5 presents the comparison of both cases, current deviation for each position without deflector chamber (Fig. 5(a)) and with deflector chamber (Fig. 5(b)).



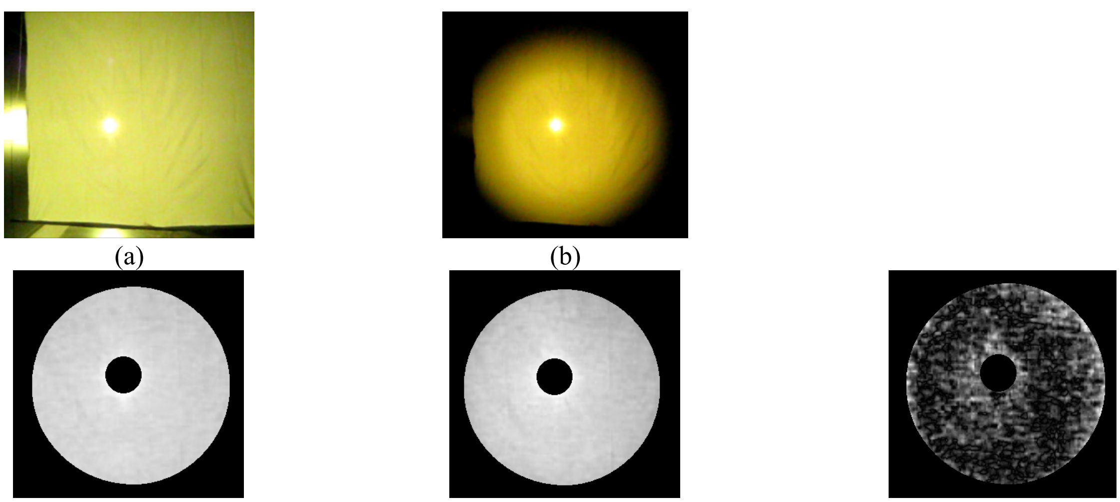
(a) (b)

FIGURE 5. (a) Current deviation without deflector chamber. (b) Current deviation with deflector chamber

The first conclusion obtained is that the result is similar in both cases, what means that the deflector chamber is not introducing additional non-uniformity areas in the measuring region. Moreover the deviation in the uniformity of the light is in the range of 35% for both cases. But, as it can be observed in the graph, the intermediate region is more uniform and the largest deviations are observed in the upper and lower positions, which correspond with the edges of the solar simulator mirror. If those upper and lower areas are avoided, the deviation in the uniformity of the light is reduced to the 20%.

Comparison of the Light Source Uniformity with and without the Deflector Chamber

Finally, the last verification carried out is the comparison of the uniformity of the light in the source with and without the deflector chamber.



(c) (d) (e)

FIGURE 6. (a) Flash lamp light projection over the screen without deflector chamber. (b) Flash lamp light projection over the screen with deflector chamber. (c) Processed image to analyze without deflector chamber. (d) Processed image to analyze with deflector chamber. (e) Image with the differences with/without deflector chamber

The experiment is: the light of the lamp is projected over a screen that has been mounted between the lamp and the mirror and the photographic camera is used to capture the light projection over the screen. Both images, with and without the deflector chamber, are compared looking for differences in the illumination. But first the images were prepared: only the area that corresponds to the mirror is going to be analyzed and the area of the lamp, in the center, is also eliminated, the image is converted to greyscale image and each one is normalized with its average brightness to separate the effect of the different brightness of each image.

Figure 6(a) and (c) show, respectively, the raw and processed images taken to the light source without the deflector chamber and Fig. 6(b) and (d) are the same representations but with the deflector chamber.

Finally, Fig. 6(e) shows the difference between both images. As it can be observed, both images are practically the same, the difference in the flood field uniformity is of only a 2.5%, and most of the differences (white areas) are located in the edges of the region, what correspond to the ring of non-uniformity generated by the output edges of the deflector chamber.

CONCLUSIONS

The capability to measure a LCPV prototype of the Helios 3198 solar simulator has been evaluated; both the hardware and the methodology. The main challenge is to deal with the diffuse light generated by the scattered and reflected light coming from ceiling, walls and floor of the lab that distorts the measurement because of the larger angular acceptance of LCPV vs. HCPV. For instance, the efficiency of the prototype was increased a 20% by adding a collimator tube in the light sensor to reduce its field of view.

Different solutions have been tested to eliminate or reduce the diffuse light in the measuring region, being the most effective a deflector chamber installed around the flash lamp. Consequently it has to be determined how this new element affects the uniformity of the light. In the receiver area there are no major changes because of the use of the deflector chamber. But, what has been detected is that the uniformity of the light decreases in both ends, corresponding to the area of the solar simulator mirror edges. The light uniformity increases a 15% if those areas are avoided. If the light source is analyzed, the difference because of installing or not the deflector chamber in the flood field uniformity is of only a 2.5%, being located as well in the edges. In this case because of the ring of non-uniformity generated by the output edges of the deflector chamber.

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