LEDs Based Characterisation of Photovoltaic Devices

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Abstract: This work discusses the advantages and disadvantages of using LEDs in a solar simulator. Details of a prototype simulator developed in CREST are given and ongoing developments of the system are discussed. Possible applications unique to simulators using LEDs are outlined, which show its potential to outperform conventional systems and reduce measurement uncertainties while at the same time offering an extensive variety of device performance investigation avenues.

I. INTRODUCTION

Photovoltaic (PV) devices increase in complexity and thus introduce new characterisation challenges. There is also a move from power to energy rating of PV devices as this parameter is more relevant to the end-user and investor. Energy rating standards impose further challenges as one needs to simulate realistic conditions, which are significantly different from existing standard test conditions. While the output spectrum of some solar simulators is adjustable to some degree, generally only light intensity and module temperature can be varied. This means that most solar simulators do not provide the variability of environmental conditions required for full characterisation and it remains particularly problematic to measure multi-junction solar cells.

Additionally, both solar simulator types in use today, steady state and flash, each have their own advantages and disadvantages. For example, a steady state simulator can cope very well with slow responding devices, but can cause thermal instability during measurements and its operation and maintenance costs are not negligible. With a flash simulator the device maintains its temperature and operating costs are much lower, but care must be taken to avoid measurement artefacts such as capacitive effects.

These limitations can be overcome by using light emitting diodes (LEDs) as simulator light sources instead of conventional sources. LEDs have unique characteristics which make them a strong candidate for solar simulator light sources, which was the motivation for the development of an LED-based solar simulator (see Fig. 1) in CREST.

This work discusses the pros and cons of using LEDs in a solar simulator. Details of the prototype LED-based solar simulator are given and ongoing developments of the system are explained. Last but not least, applications unique to LED based solar simulators are outlined.

Fig. 1: LED-based solar simulator prototype

II. PROS & CONS OF USING LEDS

Firstly, LEDs have a very fast response time which means they can be regulated to any intensity within microseconds. At the same time LEDs can also be kept at stable light output continuously. Thus, a flash solar simulator can be combined with a steady state simulator. Hence, capacitive effects can be prevented while minimizing thermal changes of the device during the measurement.

The second advantage is that LEDs have a narrow output spectrum (except for white LEDs) and are available in a wide variety of wavelengths from ultraviolet (UV) to infrared (IR). An individual LED cannot meet the spectral standard for solar simulation [1], but when combining a number of different colours a closely-matched AM1.5G spectrum [2] can be generated. By adjusting the intensity of each colour, one can also alter the spectrum, which means one can measure device characteristics for energy yield prediction under more realistic light conditions. Also, a variable spectrum enables accurate characterisation of multi-junction PV devices.

Thirdly, recent developments in new high power LEDs have improved the light intensity and efficiency of LEDs immensely. Bundled in arrays, they have the potential to reach intensities of more than $1000 W/m^2$. Furthermore, with up to 100.000h lifetime (dependent on type and production quality) LEDs surpass multiple replacements of flash or steady state sources. This not only compensates the initial higher cost per light intensity but also means lower maintenance, recalibration and reclassification costs and downtime.

One drawback is that LEDs heat up and require efficient cooling or long settling times to maintain temperature flash-to-flash. The light output and efficiency drops with rising operating temperature, which can lead to temporal light instability during I-V measurements when the LED is current regulated. This problem can be overcome with a direct irradiance regulation.

As with all light sources, LEDs also show some dependence of the relative spectral output on drive current. Furthermore, temperature affects the dominant output wavelength. Nevertheless, compared to spectral changes seen from other light sources as such as halogen or Xenon, the effect is small and LEDs are in general seen as being virtually unaffected from spectral change. Highest accuracy in characterisation of PV devices can be achieved by monitoring the output spectrum. Nevertheless, good cooling of LEDs is essential which at the same time reduces intensity drop and increases lifetime.

As with conventional light sources, an unavoidable disadvantage is the degradation of LED light output during their lifetime. Degradation-rate depends very largely on the operating temperature of the LED and the effect can be largely reduced by appropriate cooling and by operating the LED at lower currents than rated. Since the degradation effect cannot be eliminated, the solution is a system designed to initially supply higher irradiances, so conditions can still be applied when the LEDs have degraded to some degree.

Overall, LEDs are a good candidate for an advanced solar simulator that is capable of measuring characteristics of all PV device types and materials.

III. LED-BASED SOLAR SIMULATOR

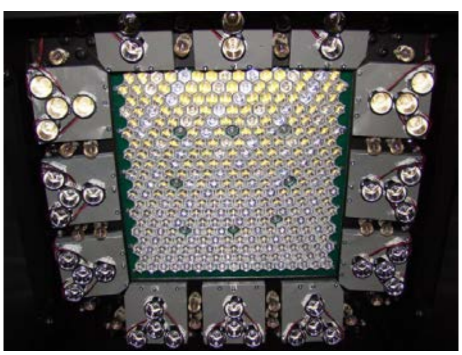

Fig. 2: LED array of simulator

The schematic of the solar simulator is not fundamentally different to conventional multi-source systems. The only main difference is that the light source is made up from a large array of LEDs rather than one or multiple high power lamps. The array of the LED-based solar simulator prototype (Fig. 2) consists of 376 LEDs in 8 different colours which to cover the light spectrum from UV to red. This prototype uses halogen lights to cover the IR part of the spectrum, albeit developments are ongoing to replace this with LEDs in the final product. The control system allows fully separate control and adjustment of the intensities of all light sources. As visible in Fig. 3 it is possible to match the AM 1.5G spectrum as well as to simulate the change from blue rich to red rich with increasing air mass (AM), as seen during PV device outdoor operation.

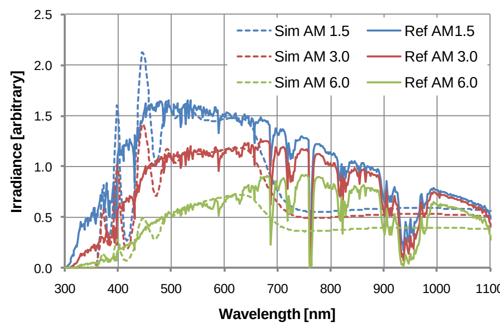

Fig. 3: simulator output compared to sunlight

For current-voltage (IV) tracing, an in-house developed 4-quadrant high-speed power supply is used. To avoid errors during IV tracing, current and voltage and irradiance are measured simultaneously. Measurement and IV tracing speed is adjustable and can be as short as 2.5µs per measurement point.

A PV device temperature control system embedded in the simulator is capable of regulating the test device temperature from 15°C to 85°C.

According to the standard for solar simulator classification [1] the system is classified as AAB. The light intensity uniformity is ±1.9% (Class A) over a target area of 4.5 x 4.5cm. The light intensity stability is variable dependent on the measurement time but can be virtually always maintained at class A (within ±2%). The spectral match is class B due to a lack of light emissions in the 700 to 800nm range (see Fig. 3). The combined measurement uncertainty for c-Si devices on power output is ±5% (95% confidence, k=2). Further details of the measurement system are given in [3, 4].

IV. ONGOING DEVELOPMENTS

Developments to improve upon the prototype system are ongoing. The main improvement is the output spectrum. This can be enhanced by using a broader set of 20-30 LED colours in the full spectral range of

350nm to 1100nm and thus replacing the remaining halogen light sources. The simulation, illustrated in Fig. 4, shows that it is possible to achieve a near perfect match to the standard spectrum.

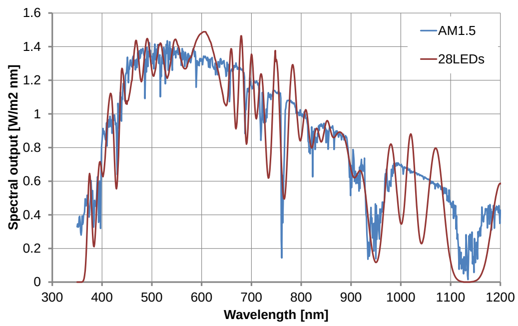

Fig. 4: Simulated spectrum using 28 LED colours

The class A light intensity uniformity is planned to be extended to a larger area to be able to measure full wafer solar cells and eventually PV modules. This can be done with the help of optics that first of all mix the incoming light from all LED colours and then collimate it onto a square target area. This should also largely eliminate spectral variations over the illumination area.

To improve measurement accuracy developments are in place to reduce the angle of incidence of the incoming light onto the PV device by increasing the distance to the LED array. Reducing the angle of incidence from 17° down to 5° would reduce the impact on device current uncertainty from 1.48% down to 0.13% (k=1).

Last but not least it is planned to switch form LED current regulation to an intensity regulation to overcome uncertainties due to temporal stability and spectral changes during IV measurements.

V. UNIQUE APPLICATIONS

Due to the unique characteristics of LEDs, a solar simulator using them can be used for a wider range of applications than just measurements of IV curves.

With the possibility of changing incident spectrum one can investigate the performance of devices at much more realistic outdoor conditions in a G-T-E (Irradiance – Temperature – Spectrum) matrix [5]. These measurements are useful for energy yield prediction of solar PV.

Due to the availability of a wide range of LEDs from UV to IR one can also investigate the spectral response of single and multi-junction solar cells [6]. It is also possible to automatically calibrate a device, by detecting its type, its number of junctions, measuring the spectral response and the IV curve in one procedure [7]. This has potential to save time in the calibration process and reduce uncertainties.

A number of other investigative avenues can be lunched such as preconditioning and degradation effects, light soaking and aging factors, validation and development of physical models of PV devices and energy prediction software, and irradiance and temperature influences on spectral response.

VI. CONCLUSIONS

Although LEDs are not without some drawback, the advantages clearly outperform its challenges. Its characteristics exploited in a solar simulator provide a much greater flexibility in measurements conditions than any other type of solar simulator. It is an ideal tool for power rating of multi-junction solar cells and it provides the base for more detailed performance measurements for energy rating and yield prediction of all PV device types.

LED-based solar simulators are at present a hot topic in the area of device characterisation and have become commercially available within the last years. With further improvements and enhancements of the technology, such simulators will outperform conventional systems and will redefine photovoltaic device characterisation.

VII. ACKNOWLEDGEMENT

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