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An LED-based photovoltaic measurement system with variable spectrum and flash speed

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ABSTRACT

Outdoor environmental variability generates the need for indoor systems for PV module characterisation. To combine the advantages of the most commonly used simulators (steady-state and pulsed) and eliminate their disadvantages, an LED-based solar simulator prototype has been developed. The system can produce light at variable flash speeds and pulse shapes or can operate as a continuous light source for long-term measurements. The system achieves 1-Sun intensity at a closely matched, continuous spectrum. Full control of all light sources allows variable intensity and spectral distribution during measurements. A technical description and the results of initial qualification tests are given.

1. Introduction

Due to natural variability of test conditions outdoors, indoor tests are desirable to carry out tests when required and not when the weather determines suitable measurement conditions. These solar simulators are more controllable than outdoor measurements and a much shorter time is needed for photovoltaic device characterisation. Advances in photovoltaic technologies, specifically multi-junction as well as high-efficiency, high-capacity devices, have increased the complexity of indoor measurements and have shown a need for improvement.

Both solar simulator types in use today, steady-state and flash, have advantages and disadvantages. For example, a steady-state simulator can deliver highly accurate measurements for solar devices with a long time constant, but introduces thermal control issues and has high operation and maintenance costs, mainly due to the short life-time of the light sources and the frequent downtime needed to replace them. Flash simulators, on the other hand, influence device temperature to a lesser extent and the operating costs are lower, but care must be taken to avoid measurement artefacts such as capacitive effects [1], which can distort *I–V* curves and lead to inaccurate power rating. Both types have in their simple single lamp realisation the disadvantage of significant distortion of the spectrum due to the illumination source.

To retain the advantages of both simulator types and eliminating the disadvantages, an LED-based solar simulator, such as the prototype reported here, can be used (see Fig. 1 for physical layout). LED-based solar simulators have been reported in the past (see e.g. h.a.l.m. electronics [2], Tokyo University [3,4]) but to the authors' knowledge this is the first system with quasi-continuous spectrum and also the only one which achieves 1-Sun intensity. It should be noted however, that in this prototype development, the near infra-red (NIR) is provided by halogen lamps. It is planned to replace these with additional LEDs in the final system.

LEDs as main light sources have a much longer lifetime than conventional high-intensity simulator bulbs (up to 100,000 h), which reduces maintenance costs to a minimum. This life-time is a factor 50 higher than most lamps and modern LED dies have a comparable luminance to that of halogen lamps. LEDs can be controlled very accurately and stable output is achieved within microseconds. After this, the junction temperature rises and a degradation of power output is observed. Running them in stable condition for a long time opens possibilities to measure both short- and long-term effects on solar cells in one simulator. The aim of this work is partially to investigate the need for tighter control and to assess whether or not a water-cooled LED array is stable enough for solar PV device characterisation.

The unit is capable of producing variable flash shapes in variable speeds as well as providing a continuous-wavelength light output and achieving more than 1-Sun intensity over an area of more than 200 mm × 200 mm. Furthermore, with conventional simulators PV devices are generally measured at one irradiance level, with other intensities achieved by either mechanically

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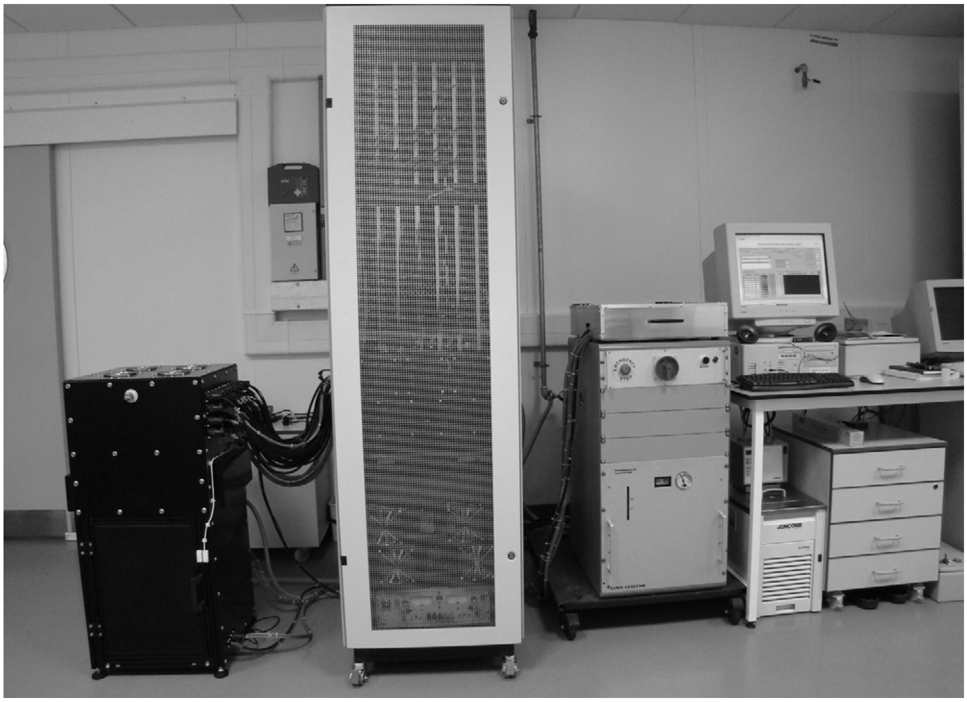

Fig. 1. LED based solar simulator.

adding a neutral density filter of some sort (most commonly used are wire meshes) or by regulating the current through the lamp. The latter has the disadvantage that the spectrum is changed. Using LEDs removes this problem, as they are spectrally stable over a wide range of output levels. Using different colours with separate controls allows a dynamic adjustment of the spectrum as presented here. This provides a good tool for measuring and characterising multi-junction solar cells, which is one of the main applications for this work. This spectral control is required to remove any effects of spectral mismatch on the fill factor of the device [5] and thus to decrease the uncertainty of such measurements.

2. Technical description

The principle construction of an LED-based solar simulator is not too dissimilar from that of conventional multi-lamp halogen solar simulators. As depicted in Fig. 2, the main difference is to have differently coloured LEDs on an array of light sources as the main illuminating source. Installing many different narrow wavelength LEDs can provide a quasi-continuous-wavelength light output on the solar cell test area.

The newly developed LED-based solar simulator array of light sources consists of several hundred LEDs in 8 different colours, to cover the light spectrum from the ultraviolet end at 375 nm to the red end of the spectrum at 680 nm. In this prototype, halogen lights are used to cover the infra-red part of the spectrum, while developments are ongoing to replace this with LEDs in the final product. The area of the light sources is 380×380 mm and the distance to the illuminated test area is 650 mm. The type and bin of the LEDs were chosen according to a simulation result based on their data-sheet values for matching the airmass (AM) 1.5 G spectrum used in standard test conditions [6].

The control system, shown in a simplified schematic overview in Fig. 3, allows independent control and adjustment of the intensities of all light sources. This makes it possible to match the AM1.5G spectrum, as well as to simulate the change from blue- to red-rich spectra, closely reproducing the variation seen in realistic outdoor conditions. The light source control allows LED flash frequencies up to 500 Hz in all imaginable flash shapes (see Fig. 4). Single or multiple flashes are easily implemented making this a useful tool for scientific investigations of different types of solar cells.

The *I–V* curve is traced by an analog 4-quadrant high-speed operational amplifier. The irradiance and current and voltage of the device under test are measured simultaneously as required by the IEC60904-9 edition 2 standard [7] and any variation in the light is corrected for increased accuracy using the irradiance correction given in IEC60891 [8]. Measurement speed is fully adjustable and can be as short as 10 μs per measurement point, including regulation delays of the *I–V* tracer and sampling period.

A PV device temperature control system is also embedded in the simulator, capable of regulating the test device temperature from 10 to 80 °C. The temperature control consists of a remotely operated Julabo heating and cooling unit circulating the thermal-transfer liquid through a custom-made cooling block and regulating the temperature of the block independently.

The simulator is controlled by a personal computer with in-house developed LabVIEW software. Routines for long- and short-time measurements can be easily configured and are carried out fully automated.

3. Qualification

The aim was to demonstrate the possibility of obtaining a purely LED illuminated system that is capable of class AAA as defined in IEC60904-9 edition 2 [7]. In the following, the prototype is assessed as class B, which is mainly due to shortcomings of the halogen illumination rather than the LED sources. However, there are also clear avenues for improving on this which will be implemented in the device developed in the next stage of this project.