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Spectral Response Measurements of Photovoltaic Devices using a Pulsed Source Solar Simulator

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Abstract
This paper presents a method for spectral response determination of photovoltaic devices using a commercially available pulsed source solar simulator and broadband filters. A fitting algorithm which is an iterative process is developed to model the spectral response curve. The method is tested on two different technologies of photovoltaic modules and the result shows that a fair agreement between the modelled and calibrated spectral response could be achieved with the improvement in the quality of measurement.

Introduction
The conversion of solar energy in photovoltaic (PV) modules is subject to electrical and optical losses. Exact knowledge of performance data, which is used to determine the electrical output of modules in the field, requires more precise measurements of the basic IV-curve parameters at standard conditions as well as those characteristics which include spectral and angular effects, required for energy prediction [1]. Due to this, there is a need for a highly reliable basis for the improved measurement precision of PV-technologies of all types and sizes, since most commercial PV devices that are currently available on the market have physical dimensions up to 2m.

In this paper, a method that is applicable to pulsed light sources for spectral effect measurements of PV devices is discussed. The aim of the work is to propose an alternative method to improve on conventional (monochromatic) spectral response (SR) measurement techniques, which will lead to a higher accuracy and reliability while reducing the more complex demands of the equipment. The idea is to maximise the throughput of irradiance coming from a pulsed light source for SR measurement, hence improving the signal-to-noise ratio that contributes to uncertainties in narrowband monochromatic methods. For this, instead of narrowband filters, polychromatic broadband filters are placed in front of the light source.

Owing to the high irradiance throughputs at the measurement plane, signal-to-noise ratio, particularly in the ultraviolet and near infrared ranges is significantly improved. This method is feasible as an alternative to that of conventional methods, especially for SR determination of full scale PV modules using pulsed source solar simulators considering the simplicity of the experimental set up.

Experimental Setup

A commercially available PASAN 3b solar simulator is used as the light source. It consists of a capacitor bank as a power supply, electronic load for data acquisition, and software for measurement control. It has four xenon lamps which are arranged in a proper orthogonal arrangement to
ensure an excellent uniformity across the measurement plane (Fig.1). A spectral match to AM1.5 is obtained by using customized interference filters, and the spectral distribution is measured by EKO MS-700 spectroradiometer which has been calibrated at CREST, fixed on the measurement plane. The EKO MS-700 is chosen due to its rigid optical components geometry, as it is important to ensure the spectroradiometer in use is able to give an accurate measurement read repeatedly.

The PASAN 3b solar simulator can measure an I-V curve in a single stabilized pulse of 10ms duration. A monitor cell is placed in the measurement plane to measure the irradiance coming from xenon lamps. The position of the EKO input and the surface of the monitor cell are aligned to make sure both are illuminated by the same level of irradiance within the same period of time.

14 broadband filters with various light transmittance at selective wavelengths are used to create a variation of spectral distribution that illuminates the DUT. For the test setup, the broadband filters are fixed on the measurement plane, just in front of the DUT and spectroradiometer, as illustrated in Fig.4. The short circuit current produced by DUT \( (I_{\text{meas}}) \) and spectral irradiance of the incident light \( (E_{\text{meas}}) \) are measured simultaneously when the PASAN is flashed. The measurement is done under controlled temperature, according to standard test condition (STC), i.e. 25°C. This process is repeated for all 14 broadband filters.

At the end of measurements, a set of \( I_{\text{meas}} \) and corresponding \( E_{\text{meas}} \) for each broadband filter is obtained. These data are then utilised for the determination of spectral responsivity of DUT by means of fitting process.

### Modelling Spectral Response

The proposed work is tested on mono-crystalline (c-Si) and amorphous (a-Si) modules, which have been spectrally
calibrated previously by the European Solar Test Installation (ESTI) using a standard, monochromatic method.

Using the information gained from earlier measurement \((I_{\text{meas}}, E_{\text{meas}})\), fitting is performed to a model of the SR of each module. For this, the current value \((I_{\text{model}})\) is calculated using the measured \(E_{\text{meas}}\) as in equation (1),

\[
I_{\text{model}} = A \int_{\lambda_{\text{min}}}^{\lambda_{\text{max}}} SR_{\text{model}} E_{\text{meas}} d\lambda
\]

where \(A\) is the cell area of DUT in m\(^2\), and \(\lambda_{\text{max}}, \lambda_{\text{min}}\) are the range of wavelength in nm, measurable by EKO MS-700. A fifth order Gaussian distribution function is chosen as \(SR_{\text{model}}\) which is expressed as in equation (2),

\[
SR_{\text{model}} = \sum_{i=1}^5 a \exp\left[-\left(\frac{\lambda-b}{c}\right)^2\right]
\]

where \(a, b, c\) are the parameters. The value of these parameters was tuned iteratively until the product of equation (1), \(I_{\text{model}}\), gives the most approximate value to \(I_{\text{meas}}\). Finally, the obtained \(SR_{\text{model}}\) is compared to the calibrated SR of each module for the goodness-of-fit evaluation. The whole fitting algorithm is illustrated in Fig. 6.

### Integration of Model with Measurements

\(I_{\text{meas}}, I_{\text{model}}, \text{ and } I_{\text{calc}}\) (calculated short circuit current using equation (1), except the calibrated SR \((SR_{\text{meas}})\) is used) post fitting for each filter is plotted in Fig. 7. From this figure, it can be seen that \(I_{\text{meas}}\) and \(I_{\text{model}}\) have a good agreement while \(I_{\text{calc}}\) is slightly higher for most of the filters. For the c-Si module, \(I_{\text{meas}}, I_{\text{model}}\) and \(I_{\text{calc}}\) of filter GEL 118, GEL 119, and RG9 shows that they all have a similar value to each other, which indicates that the error in measurement for these filters is smaller compared to that of the other filters (filters GEL 119, GEL 132, RG9 for a-Si module). Another fitting was performed by using the measurement result of these filters and the final result of \(SR_{\text{model}}\) for both cases are compared in Fig. 8.

![Flowchart of SRmodel determination of a PV device by fitting process](image)

Through the fitting process, it can be observed that the modelled SR curve for both c-Si and a-Si modules managed to replicate the shape of the calibration SR curve. The shape is enhanced however...
when only the measurement results from selected filters are used.

**Fig. 8.** Comparison of calibrated SR, and two cases of modelled SR for c-Si (top) and a-Si (bottom).

Differences between calibration and modelled SR are significant, especially within the long wavelength region for c-Si module (Fig. 9). This is believed to be caused by the lack of variation of the spectral signal throughput of the filters in use. The difference is reduced across the wavelength range when the SR is modelled using only selected filters for both c-Si and a-Si modules. This shows that the efficiency of the proposed method depends highly on the quality of measurements.

**Fig. 9.** Differences between two modelled SR curves to the calibrated SR curve.

**Conclusions**

We have demonstrated a method of SR determination technique of PV modules which is simpler compared to that of the conventional, monochromatic method where only a pulsed source solar simulator and broadband filters are used. The method is tested on two different PV technologies and the result shows that the agreement between the modelled and calibration SR curves is reasonable and could be further enhanced by optimisation of the filter selection.

**References**

