SWISS MOBILE FLASHER BUS: PROGRESS AND NEW MEASUREMENT FEATURES

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ABSTRACT: The Swiss Mobile Flasher Bus (SMFB) was developed in July 2009 and is equipped with a standard high-quality Pasan flasher. In the past year several measurement orders were carried out and a very high throughput of up to 200 PV modules per day could be reached at customer site. The measurements of the SMFB are calibrated with a set of four 230W standard polycrystalline silicon modules, each tested at ISE, Freiburg by a precision performance measurement with an uncertainty level of 2% (95% confidence level). A calculation of the SMFB measurement uncertainty budget is presented based on the uncertainty of this four reference modules. Additional test measurements with the SMFB were performed, to estimate the sensitivity of parameters, responsible to further increase the overall uncertainty budget. For instance the non-uniformity was measured over the whole area of 2m by 2m, the module temperature was varied in the range of larger than 5°C around STC and module inclination was systematically changed to account for unknown variations due to not identically mounting situations of the module position and the reference cell. The resulted expanded combined uncertainty is ±3% at a 95% confidence level for standard crystalline Silicon modules. This uncertainty value is about 1% larger than values of the best stationary test labs but enables still very accurate measurements at ambient temperature conditions with the advantage to make more measurements directly on customer's site.
Particular regard was set on the measurement of module efficiency from STC down to low-irradiance of 70 W/m^2. Thin film technologies like CdTe modules come up with an efficiency characteristic with about 4% relative higher values in the range of 400 W/m^2 compared to standard crystalline Silicon modules.
Since summer 2010 the SMFB offers the measurement of the spectral response characteristic on module scale. This is realised by placing optical band pass filters of 50nm spectral width, in front of the flasher light source in steps of also 50nm from 400nm to 1100nm. The spectral response measurement will allow even more accurate measurements of the power performance because the spectral mismatch factor can be quantified und thus this spectral uncertainty contribution will be minimised. Successful spectral resonse measurements could be performed using single junction devices like standard cr-Si modules CdTe and CIS modules.

1 INTRODUCTION

In July 2009 the Swiss Mobile Flasher Bus (SMFB) was constructed, by the integration of a commercial Pasan flasher [1] (Pasan type SunSim 3c; illuminated area 2 m x 2 m, distance lamps to DUT 5.5 m) into a Mercedes Sprinter bus. Since then several measurement tasks were performed under the responsibility of EKZ. The goal of the SMFB is to take measurements at the customer's site and to test up to 200 modules a day. In spring 2010 the prototype of a PASAN spectral response measurement feature on module scale was implemented into the SMFB.

2 EXPERIENCES WITH THE MOBILE FLASHER TESTING

2.1 Standard Measurements

In the first year of operation different orders were carried out with the SMFB (see Figure 1). One of the most important measurement projects was the reference measurement at the EKZ Outdoor Test Reference Installation in Zurich (see Figure 2). EKZ is testing five different module technologies from crystalline silicon to thin film technologies (see Table 1) The aim of this EKZ project is to rank the investigated module technologies by their kWh/kWp performance, as well as the decrease of the nominal power. By the use of the SMFB all these 100 modules were measured periodically at least once a year [2]. Results of the first test series, performed with the SMFB just before the first outdoor exposure, was found to be within about +/-2% of the manufacturers flasher data [1]. The second flasher test series at EKZ Outdoor Test Field in summer 2010 was also successfully. By flasher testing each module for example a reduction of the STC performance data of several of the CdTe modules larger than 10% was analysed, after this one year outdoor exposure. The standard PASAN multi-flash mode was used to perform STC power measurements of high efficiency HIT-type silicon modules (see Table 1).

Table 1: Each of this five different PV module technologies are permanently traveling with the SMFB as test modules to periodically test the drift of the performance measurement setup (see also Fig. 2).

Cell technology	Pn [Wp]	Manufacturer	Type
Polycryst. silicon	230	Sunways	SM230
HIT-type silicon	215	Sanyo	HIP215
a-Si/uc-Si; tandem	120	Oerlikon	
CIS - $CuInSe_2$	110	Avancis	PM110
CT- CdTe	75	First Solar	FS275

Several other measurements performed at customer's site for example in Germany showed the effectiveness of the on-site measurement concept. The throughput of up to 200 modules, of standard crystalline silicon modules per day, could be reached, by applying only one single flash for each module. Measurement tasks conducted in December 2009 at an average outdoor temperature and thus module temperature of approximately down to 4°C. By the use of a customer owned crystalline Silicon reference module the temperature corrected SMFB results of STC power was tested. Even at 4°C the SMFB values lay within 1.5% of the STC value tested in a high quality independent test lab (2% at k=2) at 25°C. This is remarkable because the DUT Device Under Test is placed behind the rear door of the SMFB and therefore the module temperature is regularly close to ambient temperature. Thus it was demonstrated that the temperature measured by PT1000 sensor on the modules backside together with the temperature correction using the modules manufactures datasheet temperature coefficient resulted in deviations of below 2% at a temperature difference to STC of about 20°C. In chapter 3.1 the uncertainty of the temperature correction is discussed.

Figure 1: The Swiss Mobile Flasher Bus in operation. The Bus is equipped with a high accurate SunSim Flasher from Pasan and five different reference modules of different technologies on board. (Image source: Photon 2009)

Figure 2: The EKZ Outdoor Test Reference Installation in Zurich is equipped with about 100 PV modules out of five different technologies (see Table 1). The modules of each technology are grid connected by a typical 3 kW inverter and one PV module is independently IV curve tested each minute. All measurement results are recorded in a database structure and further on analysed [2]. All modules are periodically tested by the SMFB.

2.2 Measurements at low irradiance conditions

The nominal power at STC conditions is the most relevant performance parameter of a PV module. Other module characteristics are needed to estimate the annual energy yield of a PV-plant. In central Europe locations, like Vienna, about halve of the solar input energy of a solar collector, mounted with low tilt angel, is below about 400W/m^2. This is one pre-condition, why some of the independent institutes, like Fraunhofer ISE, results with up to 5% higher energy output prediction for some thin film modules technologies with excellent low irradiance performance compared to standard crystalline Silicon modules.

The SMFB is equipped with the PASAN standard low irradiance measurement feature in the range of 70 W/m^2 to 1200 W/m^2. In this mode one of the four different masks with different transmission values will be placed between flasher lamp and DUT. Thus irradiance values at the DUT of 700, 400, 200 and 100 W/m^2 will be reached, powering the lamp with the same current than at STC standard flashes without masks. No spectral changes of the light spectra of the lamp itself will occur. Other irradiance values are obtained by additionally control the power of the flasher lamp. This will have an effect on the spectral characteristics of the lamp leading to small systematic spectral mismatch error if DUT and reference cell will not have exactly the same spectral response behaviour. As illustrated in Figure 3 two other low irradiance measurements performed with 10% higher and 10% lower lamp power for each mask.

In illustrations of the low-irradiance performance normally the changes of the module efficiency versus imposed irradiance is plotted. To reduce spectral mismatch measurement uncertainties in the ratio of the current measurement between the reference cell of the flasher and the DUT, the product of the open circuit voltage Voc and the fill factor FF normalized to STC values is plotted in Figure 3. Assuming that the short circuit current is directly proportional to the irradiance this value corresponds exactly to the efficiency at low irradiance.

$$\eta = \frac{P_{MPP}}{P_{IN}} = \frac{V_{OC} \cdot FF \cdot I_{SC}}{k \cdot I_{SC}} = \frac{V_{OC} \cdot FF}{k} \qquad \text{Eq 1}$$

Another relevant reason for using that reduced figure of merit of the low irradiance characteristics is the comparison with outdoor measurements. Using the product of Voc and FF to plot the daily low irradiance characteristics versus short circuit current of the DUT, changing spectral mismatch factors between irradiance sensor and DUT during the day, is neglect able according to Eq. 1. The accurate temperature correction of the used module parameters have to be taken into account.(see Fig. 14)

The results of the measurement at low-irradiance conditions show a slight increase of the efficiency between 1000 W/m^2 and 400 W/m^2 up to 2% for polycrystalline Silicon as expected. The Cadmium-Telluride module showed an even higher increase in efficiency of up to 6% at 400 W/m^2 relative to STC.

2.3 Comparing outdoor low irradiance measurements

The power performance of each technology at the EKZ Outdoor Test Reference Installation is measured every minute as a current voltage measurement of a single module and the DC/AC parameters of the small grid connected sub plants (see Figure 2). In addition also the irradiance measured with pyranometers and several filtered crystalline silicon reference cells and the module temperatures are acquired and stored in the database. Out of the periodically collected current voltage data of a single module the low-irradiance characteristics was determined. Therefore it is very important to accurately correct the outdoor data according to the measured module temperature. The PT1000 temperature sensors are directly glued on the backside of the modules with a heat conducting adhesive tape. In Figure 4 the blue curve displays raw data of the power measurement of a crystalline silicon module. In the morning the modules are cold and the efficiency is higher (top blue curve) than during afternoon when the modules are already hot (bottom blue curve). Applying the temperature correction to 25°C STC values both curves come together (purple curve). Compared to the flasher measurement (green) the outdoor measurement showed an approximately 2% higher efficiency.

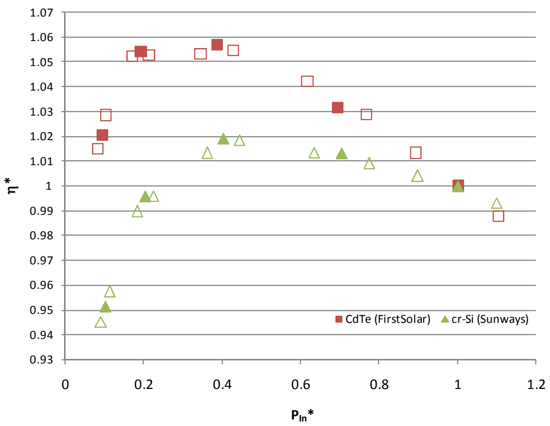

Figure 3: Measured efficiency at low irradiance of a polycrystalline Silicon and CdTe Module (see Table 1). The efficiency η* is shown as the product of Voc and FF normalized to STC and the irradiance P_{In}* is Isc normalized to STC (see Eq. 1). The four data points with the filled marker are measured with powering the flasher at STC condition and using masks with different transmission values. The unfilled data points resulted adjusting the power of the flasher lamp 10% above or beneath STC lamp power.

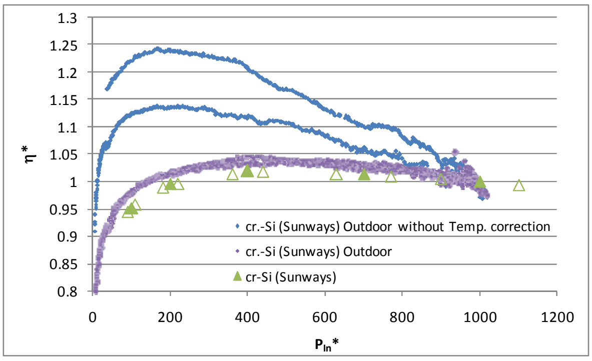

Figure 4: The characteristics of low-irradiance efficiency, measured outdoor (see Fig. 3), is shown together with to the measurement results of the sun simulator (triangle data point symbol) according to Eq. 1. The data of the outdoor measurement was acquired on 31.07.2010 under clear sky conditions. The outdoor irradiance was measured by the use of a pyranometer. The temperature coefficient applied to the outdoor measurement data is -0.3%/°C and the module temperature itself was measured with a PT1000 sensor.

This value lies in the range of the SMBF measurement uncertainty as given in Table 2, reduced by the uncertainty of the reference calibration, because only relative changes of irradiance will apply her. The outdoor efficiency measurement has an absolute uncertainty of approximately 4% and again the relative one is lower.

As mentioned above the used calculation of the low irradiance characteristics according to Eq. 1 reduces the uncertainty of the spectral mismatch between DUT and irradiance sensor. Otherwise a change of the conventional efficiency Pmp(DUT)/Pin(SENSOR) of up to 10% may occur in outdoor measurements in the morning and late afternoon due to the spectral mismatch of pyranometer and DUT especially at low irradiance conditions.

Due to Eq 1 the general measurement uncertainty of the irradiance sensor together with the associated, electrically data acquisition plays a negligible rule on low irradiance characteristics if the assumption of linear characteristic of Isc to irradiance power holds out.

Finally Eq1 can be an powerful link in a energy prediction model starting with the spectral mismatch correction of the Isc and than calculating the power under low irradiance and finally apply the temperature correction.

At outdoor irradiance measurements below 200 W/m^2 the direct sunlight differs largely from orthogonal irradiance condition on the fixed mounted module plane, causing lower light absorption relative to the pyranometer reading. Hence, higher uncertainty values have to be taken into account at very low irradiance conditions.

3 CALCULATION OF THE UNCERTAINTY

Every measurement needs a declaration of the uncertainty in order to demonstrate its validity. Therefore the contributors of the uncertainty budget were analysed in detail. All measurements are referred to a set of four polycrystalline silicon modules which were measured at the ISE Fraunhofer Institute in Freiburg (nominal power around 230W with an uncertainty level of 2% at k=2. For the calibration of the SMFB the sensitivity of the monitor cell is controlled each month in order to get the same measurement result as measured at ISE. In the following paragraphs the uncertainty budget will be discussed.

3.1 Temperature uncertainty

The DUT modules in the SMFB are not controlled at the STC temperature of 25.0°C. They are placed on the rear door of the SMFB during the measurement procedure with module temperatures of usually close to ambient temperature. On the backside of the PV module the temperature is measured by a PT1000 sensor and thus the temperature correction to STC 25°C is done using typical the module manufactures temperature coefficients and the procedure according to equations of IEC 60891. To verify the uncertainty of this temperature correction procedure, different modules were heated up to approximately 45°C module temperature by outdoor exposure to regular sunlight. Then the STC power was measured several times with the SMFB, applying the above temperature correction, during the module was cooling down (see Figure 5). In a range of 25°C to 35°C the STC power of the polycrystalline Silicon modules was within a range of approximately ±0.3%. With that result it can be inferred that the temperature coefficients were determined here with a maximum guaranteed uncertainty of less than 0.03%/°C for crystalline silicon modules. As a conservative result we used a maximum limit of +/-0.5%/°C in STC power in further uncertainty calculations due to imperfect temperature correction including the uncertainty of module temperature measurement itself (see Table 2).

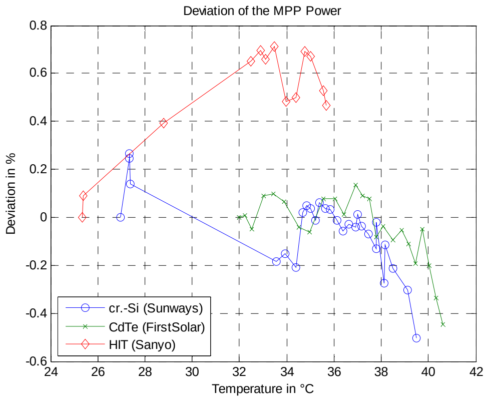

Figure 5: Deviation of temperature corrected STC power of three module technology measured by the use of the SMFB at different module temperatures.

3.2 Optical spatial non-uniformity

The spatial non-uniformity of the Pasan SunSim 3c was measured with a mono-crystalline solar cell which covered an area of 100 cm^2. Overall 400 measurement-points would be needed to cover the whole illuminated area of 2 m x 2 m. This procedure would be very time consuming. Therefore the measurements were performed with a high resolution in the area where a standard crystalline silicon module with a size of 1.1 to 1.6m usually will be placed as shown in Figure 6.

The measurement was repeated at different irradiances values as: 1000 W/m^2, 400 W/m^2 and 100 W/m^2.

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
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A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T

Figure 6: The yellow squares indicate the location of test cell where the measurement was taken. The red square shows the position of the monitor cell.

The measurement results were linear fitted over the whole area for all measurement sets at different irradiances. In Figure 7 the results at 1000 W/m^2 are illustrated. It is obvious that in the area of the top lines number 2 to 5 (see Fig. 5) the irradiance level is higher (red) than at the bottom lines number 20 (blue). This probably results of the slightly no parallelism between the lamp and the test plate. It can be conceived a smaller irradiance on the middle of the test plate according to the mean value. Nevertheless the measurements yield to a very good uniformity according to the IEC non-uniformity formula (Eq 2) [3]. This measurement was done also one year before on module size (1.7 m^2) in the test lab of Pasan in Neuchatel. There the non-uniformity factor resulted in 0.68% [1].

$$U = 100 \cdot \frac{I_{SC_{max}} - I_{SC_{min}}}{I_{SC_{max}} + I_{SC_{min}}} = 0.89\% \qquad \text{Eq 2}$$

This very good result confirms class A for non-uniformity, which requires less than 2%. The measurement setup of the SMFB consists of a module mounting platform which is pulled out from the rear door of the bus and supported by two pillows (see Fig. 1). If the actual module mounting condition leads to misaligned to the optical lamp axis, higher values of the optical spatial non-uniformity factor will be produced. The non-uniformity measurement at irradiance of 400 W/m^2 shows similar results as before, but the non-uniformity increased to 1.96% (see Figure 8).

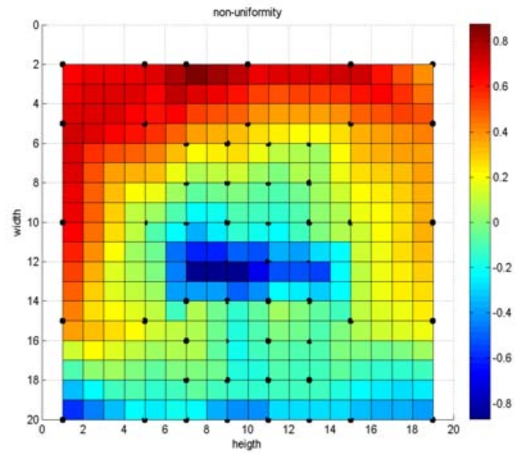

Figure 7: Illustration of the non-uniformity measurement results in % of the 1000W/m^2 irradiance. The black dots indicate the position of the location of the 10cm * 10cm test cell during measurements.

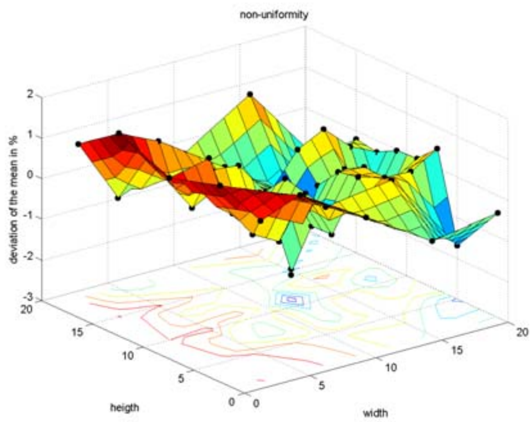

Figure 8: Illustration of the non-uniformity measurement results in % of the 400W/m^2 irradiance. The black dots indicate the position of the location of the 10cm * 10cm test cell during measurements.

The non-uniformity measurements at irradiance of 100 W/m^2 still lead to good results. The non-uniformity yields to 2.54% (see Figure 9). Performing measurements at low irradiance this higher non-uniformity factor must particularly be considered.

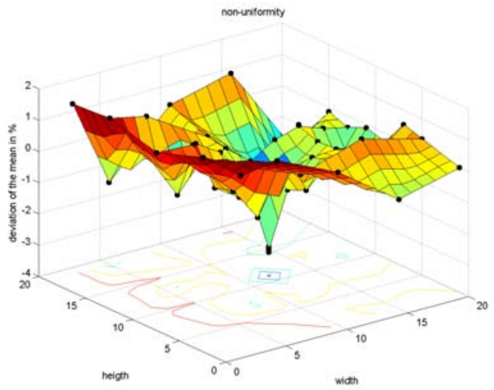

Figure 9: Illustration of the non-uniformity measurement results in % of the 100W/m^2 irradiance. The black dots indicate the position of the location of the 10cm * 10cm test cell during measurements.

3.3 Misalignment DUT

The device under test is mounted on the module holder which is part of the extendable rear platform of the SMFB vehicle (see Fig. 1). Each module type has to be fastened according to the frame thickness of the module.

To estimate the uncertainty of the module misalignment a test run of measurements was executed by varying the angles between DUT and the optical lamp axis. For this test a CdTe-module and a standard crystalline Silicon module were used (see Table 1).

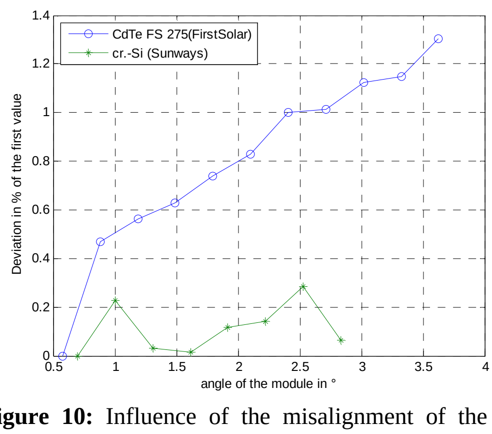

Figure 10: Influence of the misalignment of the axis perpendicular to the device under test plain relative to the optical lamp axis.

As it is obvious in Figure 10 the STC power increases with greater misalignment angles. This is due to the fact, that at higher values of the misalignment angle the bottom of the CdTe module is closer to the lamps and thus irradiance increases. Even then it is recognizable that the declination has only a slight influence on the measured power. An angle between 0.5° and 1.5° has only an influence of approximately 0.6%. And it is easy to place the module more precise than 0.5° with the present mechanical setup.

3.4 Position of the monitor cell

The monitor cell is the key sensor of the whole measurement setup. By the use of the monitor cell the irradiance is controlled to 1000 W/m^2 for STC measurements. If the DUT and the reference cell have a different distance to the flasher lamps the DUT is not illuminated with the correct light intensity. Therefore the monitor cell must be positioned exactly at the same distance to the flash light than the DUT. In order to estimate the uncertainty the monitor cell was moved relative to the DUT plane toward the flash lamps. The monitor cell was placed close to the DUT in the middle of longer module side. The measured nearly linear dependency is given in Figure 10.

Without any problem it is possible to adjust the reference cell with an accuracy of ±0.5 cm relative to the DUT. This results in a maximum positioning error of approximately ±0.2%.

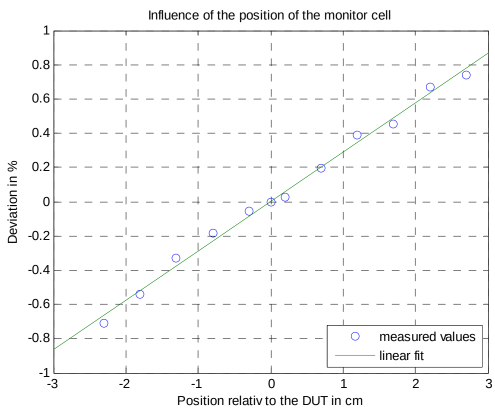

Figure 11: Deviation of the SMBF measured STC power of polycrystalline silicon module (see Table 1) versus difference of the distance of DUT plane to the plane of the monitor cell.

3.5 Electrical reproducibility

The electronic loads together with the used data acquisition system are sources of measurement uncertainty. In the present software version the maximum power point of the current voltage characteristics is not calculate by fitting several data points but the single maximum is used. Thus scattering is also present if the absolute maximum power among the typical 250 measurement points of current voltage characteristics is determined by simply using the largest single value.

All this contributions are merged in ‘electrical reproducibility’ and a measurement test series was taken. A polycrystalline module was measured 20 times with no changes in the mechanical adjustments. The results are shown in Figure 12. The standard deviation of these measurements is 0.18%.

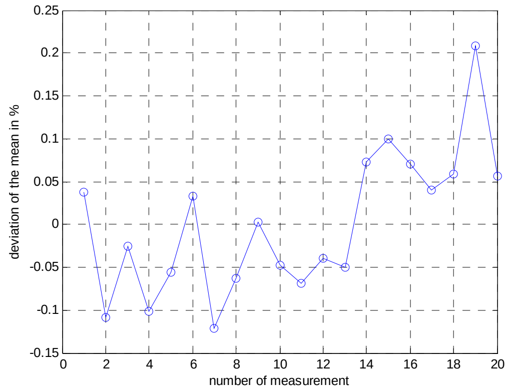

Figure 12: Deviation of the performance of 20 measurements with the same polycrystalline Silicon module (Table 1) and no changes in the mechanical adjustments.

3.6 Expanded combined uncertainty budget

In Table 2 all the previous discussed contributors of the uncertainty are given. According to the international GUM Guideline of Expression the Uncertainty in Measurement all contributors are included by adding the individual amounts of their variance values. The following contributors are assumed to have a rectangular frequency distribution and are accordingly divided by the root of 3 in order to get the standard deviation: 'Temperature uncertainty', 'Optical uniformity', 'Misalignment DUT', 'Position monitor cell' and 'Miscellaneous' additional unknown uncertainties. The expanded combined uncertainty for power measurements with the SMFB is 3.0% for crystalline Silicon standard modules at confidence level of 95%.

Table 2: SMFB uncertainty budget with final confidence level of 95% (k=2) of crystalline silicon modules in the module temperature range between 15°C and 35°C. In the colon dist. it is stated if a rectangular (R) or Gaussian (G) distribution is assumed (uncertainty calculation according to GUM, ISO Geneva 1995)

	limit	dist.	variance
Reference module	1,00	G	1,00
Temperature uncertainty	0,50	R	0,08
Optical uniformity	0,89	R	0,26
Misalignment DUT	0,60	R	0,12
Position monitor cell	0,12	R	0,01
Electrical reproducibility	0,18	G	0,03
Spectral mismatch	0,50	G	0,25
Miscellaneous	1,20	R	0,48
		Σ	2,24
		$2*\sqrt{\Sigma}$	3,0%

As stated in the introduction of this chapter the uncertainty calculation is referenced on the reference module which was initially measured at Fraunhofer ISE (2% at k=2). The second important known uncertainty contribution is the optical spatial non uniformity of the light source. The measured value of the IEC non uniformity factor 0.89%, as calculated in Eq 2, is taken as the limit of a rectangular distribution and thus divided by √3 to find the combined overall uncertainty [4].

4 DEVELOPMENT OF THE MOBILE SPECTRAL RESPONSE MEASUREMENT

Module technologies differ in their spectral response characteristics. In order to make a very accurate power performance measurement the spectral response characteristic of a module must be known to correct the spectral mismatch between the monitor cell and the DUT [5]. This correction will reduce the uncertainty of the measurement by approximately 1% depending on the used spectra. Thin film modules technology can even have higher spectral mismatch correction but will less important if the flasher light itself is closer to the standard AM1.5 spectra.

The Swiss Mobile Flasher Bus has been equipped with 15 band pass filters in the range of 400 nm to 1100 nm [6]. Each filter covers a range of 50 nm. The spectral shift of the characteristics by a deviation of the perpendicular irradiance on the PV module of smaller 10 is negligible [6]. The measurement set-up was calibrated with a mono crystalline Si-cell embedded in a standard module (180 Wp), which was initially measured at Fraunhofer ISE in June 2008 [7]. Now it is possible to measure the spectral response on module level. The result of the first measurement is displayed in Figure 13.

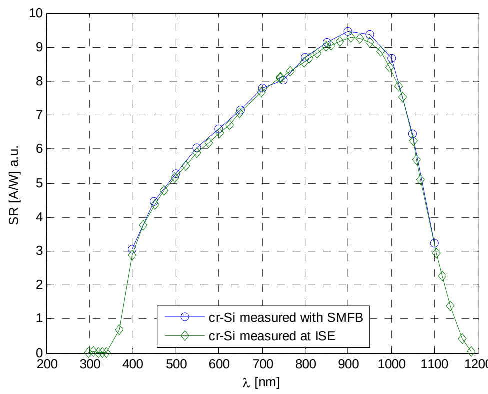

Figure 13: Relative spectral response measurement results performed with SMFB on a 180W crystalline Silicon module compared to ISE measurements on a single crystalline cell embedded in the same module.

The spectral response measurement at ISE acquires 42 data points. There the back sheet cover of the standard module has to be opened to contact a single cell of that module. Then the spectral response measurement at ISE was measured by the use of a grating monochromator and the lock-in measurement technique. To compare these values with the 15 data-points of the measurement with the SMFB operating with 15 single band pass filters, the ISE-values were taken as the reference by interpolating to the data-points of the SMFB.

In Table 3 the standard deviation of these single short current measurements of the SMFB are shown, with a mean value of 0.7% of all standard deviations at single wavelength. The results of spectral response measurements of mono cr. silicon and CdTe are shown in Figure 14.

Table 3: Standard deviation of spectral response measurement results with the SMFB compared with quantum efficiency measured of ISE.

wavelength [nm]	ISE cell QE	SMFB module QE	std. deviation
400	0.67	0.68	1.3%
450	0.87	0.89	1.4%
500	0.94	0.95	0.3%
550	0.98	0.99	0.6%
600	0.98	0.99	0.6%
650	0.99	0.99	0.3%
700	1.00	1.00	0.0%
750	0.98	0.96	1.6%
800	0.98	0.98	0.1%
850	0.97	0.97	0.0%
900	0.94	0.94	0.5%
950	0.88	0.89	0.8%
1000	0.76	0.78	1.4%
1050	0.54	0.55	0.7%
1100	0.27	0.26	0.3%
		mean	0.7%

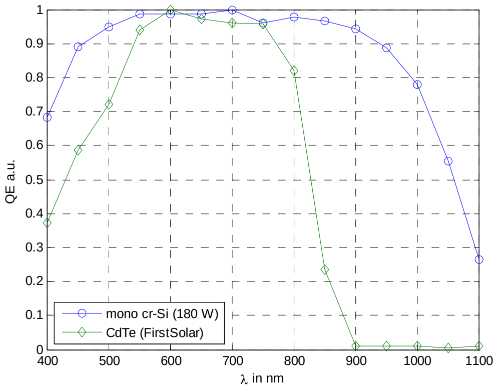

Figure 14: Relative Quantum efficiency of CdTe and crystalline silicon modules measured by the use of SMFB. The band gap for CdTe is at approximately 900 nm and for crystalline silicon at 1100 nm.

5 CONCLUSION AND OUTLOOK

The capability of the SMFB to measure modules on site could be demonstrated with a high throughput of modules a day. With the implementation of the spectral response measurement on module level another milestone could be reached, establishing the first mobile spectral response measurement tool on large module scale.

The calculation of the measurement uncertainty resulted in +/-3% k=2 for crystalline Silicon standard modules. The uncertainty calculation is the base for the quality certification process of a qualified PV test laboratory. The temperature uncertainty of measurements with the SMFB was determined at 0.03%/°C. In the uncertainty budget a contribution of 0.05%/°C was included in order to get a conservative result.

This certification process is going to be fulfilled within the next year. The spectral response measurement will be focused on tandem modules with a-Si/uc-Si.

REFERENCES

[1]. *F. P. Baumgartner et al.; Proceedings 24th European Photovoltaic Solar Energy Conference, (2009), 4AV.3.94.*

[2]. *Oerlikon Solar, Headquater Switzerland is the other project partner within the EKZ outdoor PV test facility operated in Dietikon, Zurich.*

[3]. *IEC 60904-9 2007 Photovoltaic devices: Part 9: Solar simulator performance requirements.*

[4]. *H. Muellejans, W. Zaaiman, A. Virtuami; Meas. Sci. Technol. 20 (2009) 075101 (12pp).*

[5]. *IEC 60904-7 2008 Photovoltaic devices: Part 7: Computation of the spectral mismatch correction for measurements of photovoltaic devices 3rd edn.*

[6]. see also the presentaion 4AV.3.74 in this conference P.R. Beljean et. al, 'Module spectral response measurement using large flashers '
and
IEC 60904-8 1998 Photovoltaic devices: Part 8. Guidance for the measurement of spectral response of a photovoltaic (PV) device 2nd edn.

[7]. *Test report of ISE Freiburg.*