Intercomparison of Pulsed Solar Simulator Measurements between the Mobile Flasher Bus and Stationary Calibration Laboratories

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ABSTRACT: The Swiss Mobile Flasher Bus (SMFB) is equipped with a standard high-quality flasher and a very high throughput of up to 200 PV modules per day could be reached direct at customer site. Recently an analysis of the SMFB's measurement uncertainty budget was presented, resulted in an expanded combined uncertainty of ±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. In this paper this uncertainty values were tested by intercomparison of measurement results of the SMFB and the stationary JRC ESTI laboratory on the same PV modules performed within the same hour to reduce uncertainty contributions by instability of the device under test DUT. The largest difference of nominal power measurements was found to be smaller 0.5% for polycrystalline standard modules including the precision measurement at Fraunhofer ISE on the same DUT performed 20 months before. Measurements on standard thin film CIS PV modules resulted in deviations up to 3.7% which are within the calculated SMFB overall uncertainty value of 4%. No light pre-conditioning was performed to the CIS modules and different flasher pulse length was used, 10ms for the SMFB and 1.2ms for the stationary laboratory flasher.
In a second intercomparison run the spectral response measurement on module level of SMFB and the JRC ESTI was performed by the use of band pass filters of about 50nm width. The good correlation of the results show that the SMFB spectral response measurement is valuable to calculate the spectral mismatch factor to account for different spectral characteristics of measured PV module, the used monitor cell and the flashers spectra to optimise the overall measurement uncertainty of the SMFB.

1 INTRODUCTION

In July 2009 the Swiss Mobile Flasher Bus was constructed, by the integration of a commercial Pasan flasher [1], [2] into a Mercedes Sprinter bus (Fig. 1). Since then several measurement tasks were performed under the responsibility of EKZ with typically 50 to 200 modules tested a day right at the customer's site. (Fig. 1) The mobile test laboratory SMFB is able to perform flasher based nominal power measurements, spectral response measurements and low irradiance measurements all on module level.

In [2] the parameters dominating the measurement uncertainty budget was quantified like, reference module, optical uniformity, misalignments of module and monitor cell and temperature of the solar cells.

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 about 10°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 overall expanded uncertainty was found to be +/-3% at a confidence level of 95% for crystalline Silicon modules. [2]

During PV power measurement the module temperature under test, which depends on the outdoor conditions, is measured by a PT1000 temperature sensor on the backside of the module. On that base the measured nominal power is transformed to the 25°C STC values via using the modules temperature coefficient of power.

In the present paper the effectiveness of that procedure is tested again by measuring the same device under test DUT within a few minutes by the use of the stationary calibration lab of the JRC ESTI in Ispra, Italy and the SMFB at another temperature level. In this intercomparison of results of the same DUT the reference measurements performed month before at the stationary laboratory of ISE Freiburg are also discussed.

Figure 1: The Swiss Mobile Flasher Bus in operation at a customer site in Southern Germany in Dec 2009. The Bus is equipped with a high accurate Flasher from Pasan.

2 MOBILE FLASHER MEASURMENT SETUP

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).

The quality of the SMFB [3] is also based on a very stable light source and electrical measurement equipment, demonstrated by an electrical reproducibility [2] of about 0.09% standard deviation (see Fig. 2).

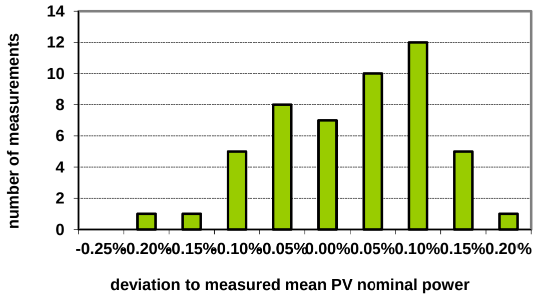

Figure 2: Histogram of 50 consecutive performed power measurements at the SMFB on a poly. cryst. Silicon module SM210. Standard deviation 0.09% of the data measured on the 12th of Nov 2010 at ZHAW.

Module technologies differ in their spectral response characteristics. In Fig. 3 it is demonstrated that the spectra of the light source is nearly not changing during the 10ms flasher pulse. Spectra of the mobile flasher at 1000W/m^2 and low light irradiance of 200 and 100W/m^2 using masks to reduce the intensity are given in Fig. 4.

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 corrections. The Swiss Mobile Flasher Bus has been equipped with 15 band pass filters in the range of 400 nm to 1100 nm and the optical transmission of each filter was measured (see Fig. 5). The SMFB set-up to perform spectral response measurements on module level was calibrated with a mono crystalline Si-cell embedded in a standard module, which was initially measured at Fraunhofer ISE [2].

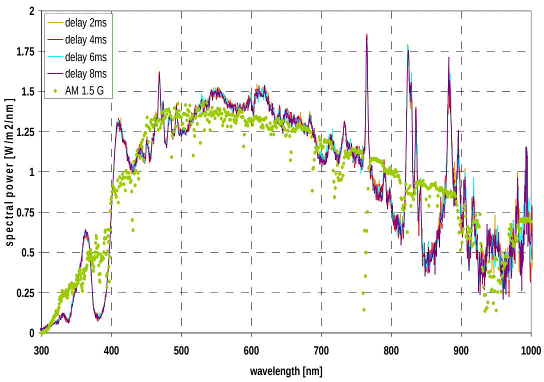

Figure 3: Stability of the SMFB spectra during the flash after 2, 4, 6 and 8ms after the pulse start, measured on the 24th Nov 2010 at ZHAW by the use of an AvaSpec-2048 USB2-UA-50 spectrometer.

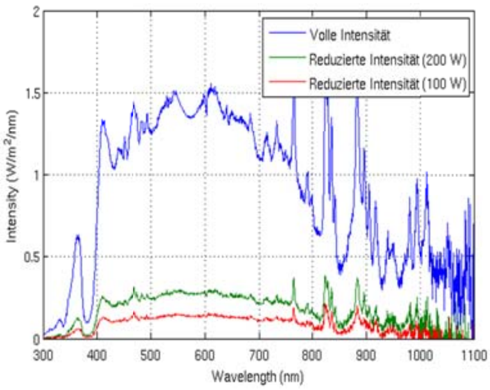

Figure 4: Spectra at low irradiance of 200 and 100W/m^2 of the SMFB flasher measured on the 24th Nov 2010 at ZHAW by the use of an AvaSpec-2048 USB2-UA-50 spectrometer.

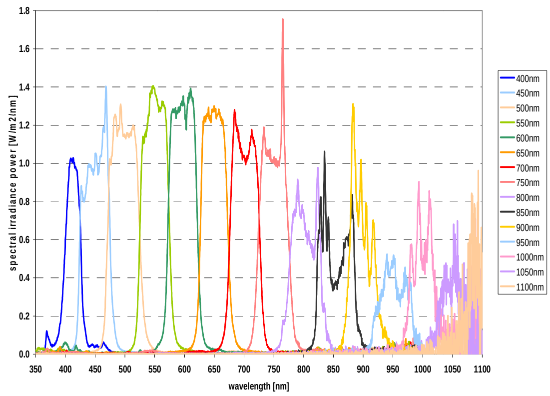

Figure 5: Spectra of the 15 band pass filters of the SMFB used during spectral response measurements in front of the Pasan 3c flasher, performed by the use of an AvaSpec-2048 USB2-UA-50 spectrometer with a 2ms measurement period on the 24th Nov 2010 at ZHAW.

3 INTERCOMPARISON RESULTS

On the site of the EU JRC in Ispra the mobile flasher SMFB was set up within a large laboratory building close to the entrance but outside the temperature controlled dark room of the ESTI laboratory where the ESTI flashers are located. The SMFB equipped with a Pasan 3c flasher applied a 10ms irradiance pulse [1], while the ESTI flasher, Spectrolab LAPSS [4] uses a 1.2ms flasher pulse. Both measurement units apply spectral response measurements to calculate the spectral mismatch correction [5] to minimize the measurement uncertainty of the nominal STC power. Two commercial standard modules were tested, polycrystalline silicon (SM210 Sunways) and CuInSe$_2$ (Power Max 110, Avancis). The measurement process of each of the modules used, started with power measurement at ESTI (at 25°C) than mount the modules again on the SMFB (module temperature 17 to 21°C), again measured at ESTI for the second time and finally performing the second power measurement on the SMFB. According to the uncertainty analysis of the SMFB given in [2] a maximum deviation of +/- 0.5% of nominal power is assumed, if the module temperature is within the limit of +/-10°C around 25°C due to imperfect temperature correction of the crystalline silicon module.

The results of the intercomparison of the crystalline modules nominal power measurement given in Table I and Fig. 6 shows a maximum difference of +/-0.25% of the power values, well within both labs k=2 uncertainty limits. The precision power measurement results of the same DUT performed in 2009-05-19 at the Fraunhofer ISE stationary test lab (ISE Order-No. 001EKZ0209), are also within the same limits (Fig. 6, Tab I).

Table I: Results of the pulsed solar simulator measurements performed either on the SMFB which was located a few meter beside the entrance of the stationary EU JRC ESTI calibration laboratory in Ispra and the measurement results taken at the stationary laboratory at ESTI Spectrolab LAPSS (indicated by ESTI). The DUT was a standard 230W commercial poly crystalline Silicon module. The ambient temperature at the location of the SMFB was about 17°C during the measurement period on 26th Jan 2011 while the module temperature within the climate controlled JRC ESTI Lab was always within 25°C +/- 0.4°C. (JRC ESTI mismatch factor of 0.992 was applied)

Flasher type	Date 25.01.2011	P_{mp} [W]	$u(P_{mp})$ (k=2)	T_{module} [°C]
ESTI	10:52	225.4	2.1%	24.7
SMFB	11:19	226.2	3.0%	18.3
ESTI	12:19	225.8	2.1%	24.6
SMFB	12:35	225.8	3.0%	20.5
SMFB	14:45	226.5	3.0%	17.4
ISE	2009-05-19	226.0	2.0%	24.4

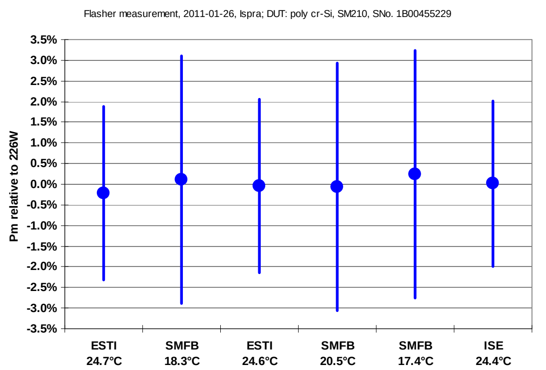

Figure 6: Differences of the power measurement results of Tab. I listed together with the relevant module temperatures below.

The same method was used for the intercomparison of thin film CIS technology either using the SMFB and the ESTI lab. The results of the power measurement given in Tab. II shows deviation of up to 3.7% within a combined measurement uncertainty of the SMFB for thin film modules of about 4% [2]. It was already discussed in [1] that due to the capacity effects of this CIS modules the nominal power result is about 2% higher for scan direction applying the IV characteristics from V_{oc} to I_{sc} compared to the opposite direction. This can also be found in Tab. II. Additionally, it has to be taken into account that pulse period of the flashers are 1.2ms for ESTI and 10ms for the SMBF which also might affect the results. The absence of any pre-conditioning treatment of the CIS module prior to the flash should not play a dominant rule because each measurement were performed in a short time frame (see Tab. II)

Table II: Results of the intercomparison of pulsed solar simulator measurements on the SMFB and the stationary EU JRC ESTI LAPSS setup performed on CIS - $CuInSe_2$ Modules (Avancis PM110; serial number AVANCIS 01011230906210080) without applying any pre-conditioning treatment.

Flasher type	Date 25th Jan 2011	P_{mp} [W]	$u(P_{mp})$ (k=2)	T_{module} [°C]	deviation to ESTI mean
conventional IV curve measurement from I_{sc} to V_{oc}					
ESTI	10:58	95.50	2.1%	24.8	0.6%
SMFB	15:25	98.29	4.0%	20.5	3.5%
ESTI	16:11	94.40	2.1%	24.9	-0.6%
SMFB	16:40	98.47	4.0%	22.4	3.7%
reverse IV curve measurement from V_{oc} to I_{sc}					
ESTI	10:58	95.50	2.1%	24.8	0.6%
SMFB	15:22	100.42	4.0%	21.1	5.8%
ESTI	16:11	94.40	2.1%	24.9	-0.6%
SMFB	16:30	100.63	4.0%	22.3	6.0%

Finally an intercomparison of the spectral response measurement performed on the same poly crystalline Silicon module (see Tab. I, Fig. 6) was done on the SMFB and the ESTI JRC lab both on module and not cell scale. Band pass filters were used at SMFB and ESTI JRC setup by applying a non-destructive measurement method, in contrast to other tests labs practice where the module back sheet is opened for a single cell spectral response measurement [2].

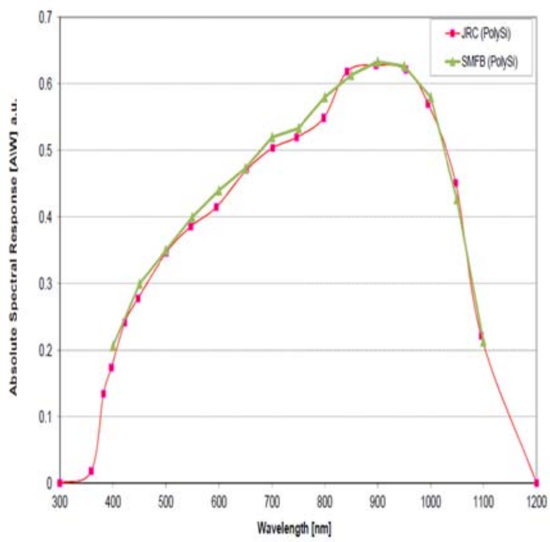

Figure 7: Intercomparison of the relative spectral response measurement results [A/W] performed with SMFB (15 band pass filters used) and JRC ESTI setup (18 band pass filters used) on the same 230W crystalline Silicon module on module scale.

4 CONCLUSION AND OUTLOOK

Excellent accordance of power measurements between the two analysed laboratories performed on crystalline standard modules was found well below the given uncertainty level of the SMFB.

Thus a round robin test, including a higher number of test labs, is possible by transferring the PV modules together with a reference instrument, the mobile flasher bus. One of the benefits of such an approach is to minimize the effects on the measurement uncertainties due to not stable thin film module technologies highly depended on several pre-conditioning effects of light/dark and temperature cycles.

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