Project SOPHIA

PhotoVoltaic European Research Infrastructure

GA N° 262533

Data Beneficiary

Name Beneficiary	CREST – Loughborough University
Contact person	Jake Bowers/ Tom Betts
Postal address	CREST, School of Electronic, Electrical and Systems Engineering, Loughborough University, Loughborough, Leicestershire, UK, LE11 3TU
E-mail	j.w.bowers@lboro.ac.uk
Project Website	www.sophia-ri.eu

JRA 2: Greater accuracy of PV modules rated power and energy output prediction of PV modules and systems

D10.5 – Establishment of indoor measurement protocols and organisation of the Round Robin tests

Document Information

Document Name	**SOPHIA_D10.5_IndoorMeasurement.docx**
Revision	Final
Due date Annex I	M12
Author	Jake Bowers
Dissemination Level	Public

Document approval

Name	Position in the project	Beneficiary	Date	Visa
Philippe Malbranche	Coordinator	CEA	20/07/2012	PM

Document history

Revision	Date	Modification	Author
V1.0	11/01/12	Creation	Jake Bowers
V1.1	01/04/12	Participant list altered	Jake Bowers

Table of contents

1 Executive summary

1.1 Description of the deliverable content and purpose

The correct power rating of PV technologies is vital if accurate models and predictions are to be made for energy and life-time studies. The measurement of most crystalline silicon technologies is well known whilst the measurement of thin film and multi-junction devices remains a challenge due to ageing effects and metastability behaviour which are not well understood, and spectral mismatches between the sun, and the spectrum of the light source used for measurement. The implementation of regular round robin tests is important to ensure a common understanding between different test labs of measurement procedures, uncertainty and analysis.

1.2 Deviation from objectives, corrective action

Not applicable

1.3 Technical progress

Not applicable

1.4 Impact of the results

Not applicable

1.5 Dissemination activities carried out, planned

Not applicable

2 Technical sections

The comparison of measurements of PV technologies has been split into two separate Round robin tests between 10 test labs across Europe, which forms the basis of JRA 2.3. Round robin 1 will consist of measurements of crystalline silicon modules, whilst round robin 2 will consist of measurements of multi-junction and thin film solar modules. The purpose of round robin 1 is to validate test procedures and practices between the different test labs, using methods previously outlined in the FP6 Performance project which focused on the measurement of standard crystalline silicon modules and unconventional crystalline silicon modules, such as high efficiency back contacted and heterojunction devices which display capacitive behaviour. The purpose of Round robin 2 is to successfully establish a measurement protocol for thin film modules (specifically CdTe and CIGS modules) which exhibit preconditioning effects which vary according to the absorbing material, the manufacturer of the module and in some cases between different batches of the same module type. The preconditioning effects appear to be highly recipe dependent, and in some cases more than 1 mechanism appears to be contributing to the overall measured effect. Also, the measurement of multi-junction thin film modules (a-Si based) will be made during this round robin. Although the preconditioning effects of a-Si is well understood, the accurate measurement of these modules is difficult due to spectral mismatches between solar simulators and the solar spectrum. Under or over-estimations can be made if knowledge of the spectral response of the module is not known. Also knowledge of the lamp spectrum is vital during measurement and this can be difficult if flash simulators are used, especially with multi-junction devices.

2.1 Round Robin 1

As detailed previously, the first round robin will focus on the measurement of crystalline silicon modules and aim to validate testing practices of crystalline silicon modules between different labs. This is aimed to create an equal understanding of module measurement protocols and uncertainties across the different measurement laboratories, in preparation for round robin 2, which will focus on measurements of thin film modules. For this round robin, 3 module types have been selected to be tested and are detailed in table 1.

Module number	Technology	Quantity	Manufacturer	Model number	Comments
RR1-1a and RR-1-1b	Mono-crystalline silicon	2	Suntech	STP 180	Standard technology
RR1-2a and RR1-2b	Back contact Mono-crystalline silicon	2	Sunpower	SPR-90-WHT-I	High performance back contact module.

RR1-3a and RR1-3b	Mono-crystalline silicon/a-Si Heterojunction	2	Sanyo	HIT 214NKHE5	High performance hetero-junction.

Table 1: Crystalline silicon module types for round robin 1. Contains 1 'standard' technology and 2 high performance technologies with different architectures.

The crystalline silicon modules have been specifically chosen to give a range in the manufacturing techniques on offer in industry. The Suntech STP 180 module has been chosen since it is a standard technology which represents a large fraction of modules which are available commercially from different suppliers. The Sunpower SPR-90-WHT-I and Sanyo HIT 214NKHE5 module represent modules which can display capacitive effects if not measured correctly. This is particularly the case in high performance modules.

The round robin consists of 10 laboratories around Europe.

1. CREST (UK) - Indoor and outdoor.
2. ECN (Netherlands) - Indoor and outdoor.
3. Jülich (Germany) - Indoor measurements only.
4. AIT (Austria) - Indoor and outdoor.
5. SUPSI (Switzerland) - Indoor and outdoor.
6. JRC (Italy) - Indoor and outdoor measurement capability
7. ENEL (Italy) - Indoor and outdoor.
8. RSE (Italy) - Outdoor measurements only.
9. ENEA (Italy) - Indoor measurements only
10. INES (France) - Indoor and outdoor.

During each stage of the round robin, the laboratory should perform the following measurements according to each lab's capability of performing that particular measurement. The schedule for the round robin will be finalised at a later date, however provisionally will be performed from April 2012 to late 2012/early2013. The following measurements are listed in increasing order of difficulty. Each lab should carry out as many measurements as they can according to their capability.

Measurement number	Measurement name	Comments
1	STC I-V measurement	IV measurements at standard test conditions of 1000W/m^2, 25°C, AM1.5G. IV measurements taken according to IEC 60904-1. Spectral mismatch correction should be performed (dependent on data from measurement 4) according to IEC 60904-7. The AM1.5G reference spectrum is outlined in 60904-3

2	Low light performance	Measurements performed at 200W/m^2 at 25°C (Low irradiance conditions) only. Measurements should be performed according to IEC 61853-1, Clause7.
3	Temperature coefficient	Temperature coefficient, extracted from I-V measurements performed at varying temperatures, but set irradiance (ideally 1000W/m^2). This measurement should be performed according to IEC 60891.
4	Spectral response of modules	Spectral response measurements performed on large area modules. There is no scope for providing a small area equivalent sample for spectral response as an equivalent. Follow IEC 61853-2, Clause 7 and IEC 60904-8.

Table 2: Measurements to be performed during round robin 1.

The measurements outlined above will form the basis of the round robin. Each laboratory should conduct as many measurements as possible according to their individual capabilities. Those institutions that can perform indoor and outdoor measurements will be asked to primarily perfom the measurement indoor (if possible). Once the initial indoor measurements have been made, then time permitting, outdoor measurements can also be made. The labs which indicate that they can only perform their measurements either indoors **or** outdoors only, should perform their measurements according to their ability.

Each measurement in Table 2 is outlined specifically in the associated IEC standard indicated in the comments section of the table. Each measurement should be performed in line with the associated standard. For measurement 1 (STC I-V measurements), IEC 60904-1 defines the need of the spectral response of the device under test (according to IEC 61853-1) in order to adjust each measurement accordingly to account for spectrum differences. In this case, each lab should perform the measurement to their best capability, for each module type. At the end of the round robin, the spectral response of each module will be provided and a correction on the IV curve can be made. This accounts for the fact that the majority of the labs in the round robin will not have this facility. If individual labs do have the facility to perform module area spectral response measurements, then they should do so, and use their own spectral response for spectral mismatch corrections.

NB. A full GT matrix should be performed by labs which are capable of the measurement. The GT matrix should be carried out according to IEC61853-1, Clause 8. Whilst this measurement set has not been included in the main set of measurements, the inclusion of this set of measurements provides useful data, and cross comparison of this data is particularly important. This measurement has not been included in the main set of measurements due to the time consuming nature of this measurement, and so is considered only as an optional measurement. For the GT matrix, module RR1-1a only shall be measured.

Objectives for round robin 1

The main aim of the first round robin is to establish whether or not each participating laboratory's measurements of the same samples agree to within their stated uncertainties, testing both the measurement process compatibility and the applicability of uncertainty calculations to a variety of test samples. This is broken down into the following objectives:

- baseline comparison of basic measurement intercomparibility of standard crystalline silicon technology (key parameters from I-V curves measured at STC)
- assessment of measurement intercomparibility of high-efficiency crystalline silicon technologies (key parameters from I-V curves measured at STC)
- validation of uncertainty analysis from each partner institute in application to all crystalline silicon technologies tested, of all measurement types (e.g. I-V curves, temperature coefficients, spectral response, …) and at all measurement conditions (e.g. I-V curves at STC, at NOCT, at low irradiance, …)
- identify rectification actions in the event of discrepancies

This task will help all laboratories in reviewing their own procedures and in editing best recommended practices with regards to current PV module technologies.

2.1 Round Robin 2

Round robin 2 will focus on the measurement of thin film modules. Specifically CdTe, CIGS and a-Si multi-junction devices shall be measured and so pre-conditioning (CdTe and CIGS) and spectral match issues (multi-junction a-Si) will be the focus of the round robin. A full description of the round robin will be circulated later to partners once final tests have been made to determine the conditions for the initial light-soaking phase for CdTe and CIGS modules. Briefly though, the second round robin will also focus on measurement of STC, Low light and temperature coefficients of thin film modules, which should be challenging.

CIGS based PV devices exhibit considerable transient effects which are dependent on the exposure history of the module. The performance of the module varies depending on the type of light exposure and also on the time between light exposure and IV measurement. IEC 61646 defines a thin film module is stabilised once the power from two successive measurements (separated by 43kWh/m2¬¬¬¬ of light soaking) has resulted in a less than 2% difference. The standard also defines that a large variance in the light source which can be used, from natural light to a class CCC solar simulator. As such, significantly different light sources can be used from lab to lab to precondition these modules, which particularly in

CIGS based modules can affect what and where in the cell is preconditioned. For example, the common buffer layer in CIGS modules in CdS, which has a band gap of approximately 2.4eV. As such wavelengths below 520nm is absorbed by the CdS and light longer than this is passed through to the absorber layer. Light sources with a low output in the blue will have little effect on the CdS layer, whilst natural sunlight, which has a higher output in the blue, interacts heavily with the CdS layer. CdS is also photo-conducting, and so the use of a light source with a weak or strong blue output may be significant due to changes in the conductivity of the buffer layer. Finally, shorter wavelength light will be absorbed nearer the junction in the device than longer wavelength light, and so charge generation near or far from the junction may have an impact on preconditioning.

CIGS is a quaternary chalcopyrite material, and as such slight changes in composition can be seen between different manufacturers' recipes, particularly indium and gallium contents. Due to the nature of the deposition process, there may even be significant differences in the composition of the absorber from batch to batch by the same manufacturer. Also, under operation there may be significant movement of constituent metal ions in the absorber, which may rearrange themselves preferentially during light soaking. All these effects may/or may not contribute to the changes during light soaking, and since more than one mechanism may be involved, it is hard to determine what is taken into account during measurement. Different effects appear to have differing time scales, and so caution should be taken when performing measurements.

Similar issues arise for CdTe devices, due to the ionic nature of the back contact (elemental copper is typically used to decrease the back contact barrier height) which can diffuse through to the front of the device under an applied bias (either under dark bias, or illumination). Also CdS once again is used in this material as the buffer layer, but usually is thicker than that used in CIGS devices, and so is prone to a larger degree of blue light absorption.

If correct preconditioning protocols are to be implemented, the underlying mechanisms for the displayed meta-stabilities need to be resolved, possibly with alternative measurement techniques such as C-V measurements to understand the junction properties further. Extra characterisation of the module before I-V measurement may give insight into the subsequent preconditioning steps needed. Possibly if preconditioning with light sources is implemented, a higher specification to the spectrum of light used needs to be outlined to ensure repeatability across different labs as well as using a more realistic light soak, otherwise dark bias soaking may need to be implemented as an alternative.

Finally, multi-junction amorphous silicon devices exhibit both preconditioning effects, as well as spectral effects due to the tandem architecture of the device. Whilst the preconditioning effects of a-Si devices are relatively well known and understood, the spectral matching between AM1.5G and the test light needs to be investigated thoroughly. Procedures need to be implemented to ensure accurate current matching between the top and bottom junctions, which means the spectrum of the simulated light needs to be measured accurately. This includes both outdoor and indoor measurements, where the latter is particularly difficult due to the nature of the measurement technique used for module characterisation.

3 Conclusions

Round robin 1 marks the upcoming work associated with this subtask. The round robin will run from mid April to late 2012/early 2013. The schedule still needs to be finalised based on the inclusion and availability of some of the participating labs. This will be updated as soon as possible and communicated to the project partners at a later date. It should be noted that for each participating laboratory, details of their uncertainty analysis for each measurement will be required.

Round robin 2 will commence after round robin 1 has been completed. Before the start of round robin 2, work shall be done to finalise the preconditioning requirements of thin film modules, since the building of preconditioning equipment may be necessary for each participating lab. Finally, before the round robin starts, thin film modules will need to be sourced since there is no budget to purchase new modules.

4 References

Not applicable