Contract No. 019718 (SES)

PERFORMANCE

A science base on photovoltaics performance for increased market transparency and customer confidence

Integrated Project

Priority 6.1.ii – Sustainable Energy Systems

D1.2.4 Report on quality assurance measures for indoor measurement equipment in view of guaranteeing ±3% measuring uncertainty for crystalline silicon PV modules

Due date of deliverable: month 46

Actual submission date: 2010-05-25 (YYYY-MM-DD)

Start date of project: 2006-01-01 Duration: 48 months

Organisation name of lead contractor for this deliverable: TUV

Revision: FINAL

Project co-funded by the European Commission within the Sixth Framework Programme (2002-2006)		
Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (incl. the Commission Services)	
CO	Confidential, only for members of the consortium (incl. the Commission Services)	

1 Introduction

Power measurements of PV modules in test laboratories and industry are usually performed with solar simulators as so-called indoor measurement. The advantages of indoor measurements are obvious:

- The measurement is not dependent on weather conditions
- A high reproducibility is achieved because test conditions can be adjusted for certain ranges of module temperature and irradiance

The nominal power of PV modules is related to the maximum output power under standard test conditions (STC). According to **IEC 60904-3** *Photovoltaic devices – Measurement principles for terrestrial photovoltaic (PV) solar devices with reference spectral irradiance data*, these conditions are: irradiation = 1000 W/m², module temperature = 25°C, spectral irradiance = AM 1.5. Measuring techniques for solar simulators are, therefore, aiming to measure as close as possible to these conditions.

However, solar simulators are no perfect light sources, and the quality of emitted light can strongly influence the result of a power measurement. In particular, the following quality parameters must be considered:

a) <u>Effective irradiance</u>

The lamp power of the solar simulators must be adjustable to 1 000 W/m² effective irradiance in order to keep measurement uncertainties from irradiance correction low. Solar simulators have, however, been designed mainly for power measurement of crystalline silicon PV modules. To achieve the same level of effective irradiance for other technologies a considerably different lamp power might be required.

b) <u>Pulse length for flash type solar simulators</u>

The short pulse length of solar simulators determines the I-V data acquisition time for power measurements. It is typically in the range of 2 ms to 10 ms. A longer pulse length might be required for some PV technologies to avoid possible transient effects resulting from high-speed measurement. This applies for example for c-Si modules with high-efficiency cells. Multi-flash measurement techniques are available to address the problem.

c) <u>Spectral irradiance distribution of lamp</u>

The spectral response of solar cells is strongly dependent on the wavelength. For solar simulators in PV industry Xenon light sources are normally used. Spectral irradiance of this lamp type differs considerably from AM1.5 spectral irradiance. In this way, measurement errors will occur, if the PV reference device is not spectrally matched to the module to be measured. Moreover, spectral differences will cause so-called current mismatch between junctions in multi-junction PV modules. Therefore, filtering methods must be applied in order to reduce measurement errors.

d) <u>Uniformity of irradiance in the test area</u>

If a PV module is not uniformly illuminated, cells will deliver different photocurrents. If a serial connection of cells is considered high module currents in the range of I_{sc} will cause that all cell with lower photocurrent will be operated in the negative voltage range on its reverse characteristic. This means a negative contribution to module voltage and, thus, a deformation of the I-V curve in comparison with the ideal uniform case.

e) <u>Temporal instability of irradiance</u>

During I-V data acquisition time, irradiance is normally not stable but subjected to fluctuations. As the photocurrent generation of cells follows these fluctuations concurrently, irradiance correction of each I-V data point to the target irradiance is required. Measurement errors related to irradiance correction are directly linked to the module parameters. Therefore, exact knowledge of module I-V correction parameters – such as internal series resistance – is important to keep the correction uncertainties low.

The standard **IEC 60904-9** *Photovoltaic devices – Solar simulators performance requirements* defines a method for classifying solar simulators in three classes. As shown in Table 1, this classification includes three quality indicators. Suppliers of solar simulators for PV power measurement must specify the respective class for each indicator (e.g. AAA).

Quality indicator	Method	Classification		
		A	B	C
Non-uniformity of irradiance	Monitoring of irradiance distribution in the test area. Calculation from minimum and maximum of irradiance.	<2%	<5%	<10%
Spectral match to AM 1.5 reference spectral Irradiance (IEC 60904-3)	Ratio of contributions to intensity in 6 wavelength ranges (400-500-600-700-800-900-1100: Solar simulator/AM 1.5 reference	0.75 to 1.25	0.6 to 1.4	0.4 to 2.0
Temporal stability of emitted light (LTI = Long Term Instability)	Monitoring of irradiance at a fixed point in the test area. Calculation from minimum and maximum during I-V data acquisition time	<2%	<2%	<10%

Table 1: Classification of solar simulators for power measurement

However, **IEC 60904-9** contains no information on the related measurement uncertainty for power measurement of PV modules. Given this background, this deliverable defines requirements to guarantee ±3% measurement uncertainty for power measurement of c-Si PV modules in test laboratories. These requirements are based on the findings of research work under SP1.

2 Technical requirements for indoor power measurement

2.1 Solar simulator

- Minimum requirements for power measurement shall be fulfilment of class BBB requirements in acc. to IEC 60904-9.
- Generally, higher precision for power measurement is achieved if class AAA solar simulators are used and if test conditions are adjustable to STC, which means 1000 W/m² effective irradiance and 25°C device temperature.
- Highest requirements for power measurement in accordance with IEC 60904-2 (section 13) shall be fulfilled if the module under test shall be further used as reference solar device. In particular, 1% non-uniformity of irradiance will be required.
- Though no requirements related to the view angle of a PV module from the lams/s are defined in IEC standards it shall less than ±15°. Depending on the construction of reference device and test module regarding angular reflectivity and transmission of light, optical mismatch may occur for high view angle.

NOTE 1: The light source of solar simulators is subjected to ageing and needs to be replaced after a certain time of operation. Therefore, operational characteristics such as spectral irradiance may change and should be clarified.

NOTE 2: The uniformity of irradiance of a solar simulator is influenced by the test environment, such as dimensions of the test chamber or reflective conditions inside. Deviations from the standard test environment, as defined by the systems supplier, can lead to variations in the spatial uniformity of irradiance.

NOTE 3: Data tables for non-uniformity of irradiance and spectral irradiance shall be available in order facilitate optimal positioning of modules and spectral mismatch calculation.

2.2 Measurement system and I-V load

- ±0.2% accuracy of current and voltage measurement related to module Isc and Voc (IEC 60904-1)
- ±1°C accuracy of temperature measurement (IEC 60904-1)
- ±1°C module temperature stability (IEC 60904-1)
- Methods for avoiding capacitance effects available (multiflash option)
- Appropriate 4-wire connection technique of the module
- Voltage drop at Isc <3% of Voc

2.3 Data analysis

These requirements become importance if power measurements shall be related to STC but test conditions are different. Then, the accuracy of final results are dependant on duly performed data analysis.

- Correction from measured irradiance and module temperature to STC (1000W/m2, 25°C) according to IEC 60891, if required
- Calculation of spectral mismatch between PV module (test device) and reference device according to IEC 60904-7. Correction of measured I-V curve with spectral mismatch factor.

2.4 Reference cell

- Shall meet requirements of IEC 60904-2
- Use of primary or secondary calibrated reference cell (WPVS or similar design, annual recalibration or internal verification procedure)
- <2° coplanarity between the active surfaces of test module and reference device (IEC 60904-1)

2.5 PV module level

- Guarantee electrical stability (cell, glass cover). If necessary the module shall be sufficiently light soaked.
- Appropriate packaging to guarantee a safe transport (risk of microcracks of cells)
- Methods for documentation of module failures available (e.g. electroluminescence or infrared analysis)

2.6 Quality management

- Inclusion of all equipment in the quality management system
- Regular verification of measurement quality with internal reference modules (repeatability < ±0,5% for Pmax, Isc and Voc)
- Uncertainty analysis available for Pmax, Isc, Voc, FF
- Participation in round-robin tests with other test laboratories

3 Conclusions

Project work under SP1 provided a comprehensive data base for PV module output power measurement, that could be used to define quality assurance measures in view of guaranteeing ±3% measuring uncertainty. However, this applies only for crystalline silicon PV modules. For thin-film PV modules experiences have shown that measurement uncertainty must be individually evaluated for different thin-film technologies and that further research is needed to improve measurement techniques.