



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

## Publications

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Project coordinator name: Christian Reise  
Project coordinator organisation name: ISE Revision [1]

[Revision \[1\]](#)

## PERFORMANCE Publications

### First year

**C. Reise, G. Ebert, M. Köhl, “PERFORMANCE – A Science Base on PV Performance for increased Market Transparency and Customer Confidence”, Proc. of 21st European Photovoltaic Solar Energy Conference Exhibition, Dresden, Germany, 2006, pp. 2081–2087**

PERFORMANCE stands both for the name and the subject of an Integrated Project within the 6<sup>th</sup> Framework Programme of the European Commission. The PERFORMANCE project covers all pre-normative aspects from cell to system level and from instantaneous device characterisation and system measurement to their lifetime performance prediction and assessment. The limitations of current indoor and outdoor calibration measurement technology will be investigated and precision will be improved, both in the laboratory and in production facilities. Current technologies will be covered as well as new and advanced cell and module concepts. Methods will be developed to connect from measurements of module power to module energy production. In addition, methodologies for the assessment of the service life time and the long term performance of PV modules will be developed. Next to this significant scientific effort, intense involvement of a large number of European companies along the value chain will be organised systematically through feedback loops. Project results will also be fed directly into standardisation processes on CENELEC and IEC level.

At the time of writing, this project is in an early phase. The paper will describe the project concept and the work to be carried out. Because the project work plan needs to address the requirements of a wide range of players, it is vital to obtain feedback and support from the whole of the PV community. This paper, accompanied by additional presentations on subprojects, thus forms one part of that consultation process.

**N. M. Pearsall, H. Scholz, T. Zdanowicz and C. Reise, “PV System Assessment in PERFORMANCE – Towards Maximum System Output”, Proc. of 21st European Photovoltaic Solar Energy Conference Exhibition, Dresden, Germany, 2006, pp. 2574–2579**

As the PV market develops, it becomes increasingly important to ensure high quality, reliable PV systems are provided to a wide range of users. The achievement and maintenance of high performance requires an understanding and quantification of system losses across the operating period, so that the maximum output is achieved over the system lifetime. This in turn requires the measurement and analysis of system performance, according to the needs of the system and the system user. This paper discusses the updating of the European PV monitoring guidelines, within the EC project PERFORMANCE, to provide a framework for the monitoring of the full range of systems now available and to accommodate advances in technology in the last decade. The approach to the construction and delivery of the new guidelines is described.

### Second year

**A. Guérin de Montgareuil, J.-L. Martin, F. Mezzasalma, J. Merten, “Main Results of the First Intercomparison Campaign of European Irradiance Sensors at INES Cadarache (2007)”, Proc. of 22nd European Photovoltaic Solar Energy Conference Exhibition, Milan, Italy, 2007, pp. 2601-2607**

The European research program PV Performance is an integrated project of the FP6. Its main issue is to address the problem of performance of Photovoltaics. It is clear that the accuracy of the prediction of the energy output of photovoltaic modules and systems depends highly on the accuracy of measurement of incoming irradiation. In order to assess the influence of the irradiation measurements on the performance on Photovoltaics, an intercomparison work on 30 irradiance sensors of different technologies sent by 11 major European laboratories has been performed at the outdoor test facility of INES / CEA, located at Cadarache, in south of France. The intercomparison work showed that the initial calibration coefficients provided by the institutes brought to important discrepancies in the measurement of irradiance and irradiation. The use of in site measured coefficients showed a lot less important discrepancies ( $\pm 2\%$  instead of  $\pm 4.6\%$ ). Then, it is proposed: to use irradiance sensors

of the same technology as the cells of the monitored systems; to express the irradiance level in Suns and the irradiation in hours of Sun, rather than W/m<sup>2</sup> or Wh/m<sup>2</sup>; to compare carefully the sensors at one site before system monitoring campaigns.

**H. G. Beyer, R. Gottschalg, G. Friesen, “Modelling IV Characteristics of CdTe Modules“, Proc. of 22nd European Photovoltaic Solar Energy Conference Exhibition, Milan, Italy, 2007, pp. 2617-2620**  
For the modelling of the IV-Characteristics of CdTe solar cells the use of a conventional one or 2 diodes equivalent circuit model proved to be inappropriate. Whereas individual curves measured at unique values of irradiance and device temperatures may be represented accurately by a single diode model using a specific set of parameters, no such parameter set can be found to represent the IV-curves for different irradiances and temperatures with equal quality. This indicates that the equivalent circuit model commonly used for CdTe cells is not appropriate and needs modification. The approach presented here is the addition of a Schottky-type back diode in the equivalent circuit. This represents an additional non ohmic resistance which can describe the majority of the effects observed in realistic operating conditions.

**R. Gottschalg, T.R. Betts, J. Hohl-Ebinger, W. Herrmann, H. Müllejans, “Effect of Spectral Mismatch on Power Rating Measurements – A Comparison of Indoor and Outdoor Measurements for Single and Multi-Junction Devices“, Proc. of 22nd European Photovoltaic Solar Energy Conference Exhibition, Milan, Italy, 2007, pp. 2621-2624**

The paper investigates the effects of varying spectra on the current production of devices. The use of measured solar simulator spectra as well as simulated clear sky spectra allows us to establish the magnitude of effects that can be expected when e.g. carrying out a round robin intercomparison of different test installations.

There are significant variations within each technology group, which will also be affected by the solar simulator class. The findings demonstrate that it is not, however, a clear relationship because it is shown that even within the same solar simulator spectral classification both over- and an underestimation of the current produced by the test device are possible. A methodology based on the average photon energy characterisation of spectra is suggested to carry out spectral correction for outdoor measurements. In the case of solar simulator measurements, this is more difficult and the only way to reduce uncertainty is the use of an appropriate reference cell.

The behaviour of multi-junctions is highly dependent on the specific shape of the spectrum and there is as yet no solution of how to correct a solar simulator measurement using a single reference device.

**G. Friesen, R. Gottschalg, H.G.Beyer, S. Williams, A. Guerin de Montgareuil, N. van der Borg, W.G.J.H.M. van Sark, T. Huld, B. Müller, A.C. de Keizer, Y. Niu, “Intercomparison of Different Energy Prediction Methods within the European Project ‘PERFORMANCE’ – Results of the 1<sup>st</sup> Round Robin “, Proc. of 22nd European Photovoltaic Solar Energy Conference Exhibition, Milan, Italy, 2007, pp. 2659-2663**

Eight separate energy prediction methods, developed independently across European Universities and Research Centres, have been compared with respect to their estimated DC energy generation for five different photovoltaic (PV) module technologies and 7 different sites distributed over whole Europe. The analysis of this work is the basis for further improvements of each of the modelling approaches and thus enables a reduction of the prediction error in PV yield estimations.

The recently completed first of three planned round-robin inter-comparisons found that the agreement for all methods and all technologies is within  $\pm 5\%$  on an annual basis, provided that the environmental parameters incident irradiance and the module temperature are well described. This good accuracy was also found when translating the energy yield measured at one location in Europe to another for an identical module utilising shorter time periods (months). Significantly higher errors were found when using different PV modules of the same manufacturer and technology to predict the energy yield at other sites. Here the variation in module power rating dominated the results of the energy prediction methods and a correction for these differences had to be applied.

**S. Mau, S. Zamini, B. Bergmair, E. Ruppert, S. R. Williams, J. Roy, T. R. Betts, R. Gottschalg, H. Müllejans, “Quantifying Environmental Effects for different Device Technologies based on**

***proposed Energy Rating Standard***, Proc. of 22nd European Photovoltaic Solar Energy Conference Exhibition, Milan, Italy, 2007, pp. 2664-2668

The most common parameter for comparison of photovoltaic (PV) modules is the output power at Standard Test Conditions (STC), which is a static set of test conditions which is reproducible under laboratory conditions but not necessarily a good indicator of operating performance in the field. Profitability of PV-systems has become more important and consequently the energy production or energy rating of modules. Therefore an easy to use energy comparator is required for industry, installers and customers. A method for the determination of module energy was proposed in the draft standard IEC 61853, which currently is under discussion. This paper investigates the importance of the different measurements suggested in the original draft on the absolute energy yield for three module technologies, thus providing a sensitivity analysis of the expected modelling accuracy.

**W. Herrmann, S. Mau, F. Fabero, T. Betts, N. van der Borg, K. Kiefer, G. Friesen, W. Zaaiman, "Advanced Intercomparison Testing of PV Modules in European Test Laboratories", Proc. of 22nd European Photovoltaic Solar Energy Conference Exhibition, Milan, Italy, 2007, pp. 2506-2510**

The EC-funded Integrated Project PERFORMANCE, which commenced in January 2006, includes a subproject devoted to improving the comparability of PV module performance measurements among European test laboratories and to elaborating guidelines for harmonised measurement practices in the PV industry. Recently published results of international round-robin tests with PV modules revealed measurement differences between laboratories [1,2,3] that proved to be significant for thin-film and multi-junction devices. This shows a clear need for the development of new and adapted measurement procedures suitable also for use in the PV industry. In this context, comprehensive intercomparison tests with PV modules have been performed that reflect the state-of-the-art of present PV technologies. Specifically, several high efficiency c-Si technologies were studied for which problems are known to occur in measurements with pulsed solar simulators [4,5,6,7]. Of significance is that for the first time our investigations were not restricted to the comparison of STC performance data but also were aimed at understanding and analysing measurement effects. Consequently technology-specific measurement programmes were defined, such as variation of the measurement parameters of the solar simulator and preconditioning by light exposure. In addition, we have documented the variety of measurement equipment (i.e. solar simulator performance) and techniques in use. This paper presents the results of the first round robin performed with 5 PV module types covering the range of commercially available crystalline silicon cell technologies (size, wafer type, high efficiency). Our studies revealed a 2% spread in maximum power for the 6 participating test laboratories. The resulting database will assist laboratories in further developing their measurement hardware and techniques. Guidelines and adapted measurement procedures for the PV industry can also be elaborated.

**H. Scholz, N.M. Pearsall and T. Zdanowicz, "Development and Delivery Concept of the Modernised European PV System Monitoring Guidelines", Proc. of 22nd European Photovoltaic Solar Energy Conference Exhibition, Milan, Italy, 2007, pp. 2922-2929**

The paper reports on the delivery concept developed for web-based, modernised and extended European Guidelines in regard to monitoring Photovoltaic Power Systems. The history and development of monitoring PV-systems is briefly discussed. Today addressing a wide range of different sizes, types and applications, the delivery system will render a fit-for-purpose and thus cost-efficient selection of monitoring instructions from a library. The library is organised in technical blocks of instructions, ordered by rising analytical complexity, achievable precision, etc. A detailed categorisation of today's PV-system monitoring users is presented, the adaptation of the information given and the guidance level to the optimum solution, still with the possibility of deriving more detail from the web-based application if desired. Based on a literature study on PV-system failure probabilities, a discussion of the possibilities for cost-optimised application of monitoring is presented. The goal is to guarantee increase of revenue or service from a PV-system, in which losses of energy and functionality are avoided as far as possible, but at the same time the investment into system monitoring components and services is not exaggerated.

*With Acknowledgement to PV-CATAPULT (contract 502775) and reference to PV-PERFORMANCE (contract 019718)*

**J.C. Jol, H. de Moor and E. Despotou, "A Roadmap for BIPV Engaging the Construction Sector in PV", Proc. of 22nd European Photovoltaic Solar Energy Conference Exhibition, Milan, Italy, 2007, pp. 2966-2969**

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PV on buildings is the major market segment for PV in Europe. To fully exploit the potential, a shift to a customer oriented approach is needed. The construction sector has to be addressed in their language and PV must be beneficial for all the actors in the value chain. Three main market segments were identified: sloped roofs on dwellings, flat roofs and high-architectural (office) buildings, all with their own spearheads and approach. The challenge is to develop low-cost, highly standardized but flexible, PV building products that fit in the regular building process and culture and add (aesthetical) value to the building [1]

**M. Bregulla, M. Köhl, B. Lampe, G. Oreski, D. Philipp, G. Wallner, K.-A. Weiß, “Degradation Mechanisms of Ethylene-Vinyl-Acetate Copolymer – New Studies including Ultra Fast Cure Foils”, Proc. of 22nd European Photovoltaic Solar Energy Conference Exhibition, Milan, Italy, 2007, pp. 2704-2707**

The specific estimation of PV-modules lifetime has an important impact on dissemination of photovoltaic systems as it leads to lower risks for producers and investors. One base for this extensive testing and simulation work is the knowledge of the chemical degradation processes and their kinetics, as well as of the permeation of water and oxygen into the module, especially of the encapsulant. Market data show that the dominant material for encapsulation is ethylen-vinylacetate copolymer (EVA), especially for modules with crystalline silicon solar cells. Lots of work is done in the field of thermal, photo-thermal and oxidative degradation of EVA, but not for the new ultra fast cure EVA grade.

Accelerated durability tests were performed in relation to the established grades standard cure and fast cure. The paper reports on several measurement methods for analysis of the polymer that were used, namely thermogravimetric analysis (TGA), differential scanning calorimetry (DSC), attenuated total reflection (ATR), dynamic light scattering (DLS), fluorescence spectroscopy (FS) and mass spectrometry (MS). It is very important to identify degradation products and intermediates in order to identify the leading degradation processes and their kinetics as well as potential interactions between different processes.

Another important factor for the degradation of the PV-modules and the concerned polymers in particular, is the permeation of reactive substances, especially of water vapor, into and inside the modules. The paper shows results of exact permeation measurements of the new material, too.

This work should contribute to the calculation of the chemical degradation using numerical simulation tools in future.

**W. Herrmann, S. Mau, F. Fabero, T. Betts, N. vander Borg, K. Kiefer, W. Zaaiman, G. Friesen, “Results of European ‘Performance’ Project on PV Module Testing”, Proc. of 17th Workshop on Crystalline Silicon Solar Cells and Modules: Materials and Processes, Vail, Colorado USA, 5-8 August 2007**

The EC-funded Integrated Project PERFORMANCE commenced in January 2006 includes a subproject which is dedicated to the improvement of the comparability of PV module performance measurements between European test laboratories and to elaborate guidelines for harmonised measurement practices in PV-Industry. Recently published results of international round-robin tests with PV modules revealed measurement differences between laboratories [1,2,3], which proved to be significant for thin-film and multi-junction devices. This shows a clear need for development of new and adapted measurement procedures suitable also for use in PV industry. With this background, comprehensive intercomparison tests with PV modules were performed that reflected the state-of-the-art of present PV technologies. In particular, several high efficiency c-Si technologies have been involved, for which problems are known if measured with pulsed solar simulators [4,5,6,7]. It must be pointed out that for the first time our investigations did not only focus on the comparison of STC performance data but were also aiming to understand and analyse measuring effects. Therefore, technology specific measurement programmes were defined. For example, this includes variation of measuring parameters of the solar simulator and preconditioning by light exposure. In addition, the variety of measuring equipment (i.e. solar simulator performance) and measurement techniques in use have been documented. This paper presents the results of the first round-robin performed with 5 PV module types covering the range of commercially crystalline silicon cell technologies (size, wafer type, high efficiency). Our investigations revealed a 2% spread in maximum power for 6 participating test laboratories. The resulting data basis enables laboratories to further develop their measurement hardware and techniques. Furthermore, guidelines and adapted measurement procedures for PV industry can be elaborated.

**M. B. Strobel, R. Gottschalg, G. Friesen, H.G.Beyer, “Uncertainty in Photovoltaic Performance Parameters – Dependence on Location and Material”, Technical Digest of the International PVSEC-17, Fukuoka, Japan, 2007**

When considering the system yield, one needs to know the uncertainty in key parameters for the annual yield in order to determine the confidence limit. This requires a consideration not only of the instrumentation but also of the operating environment. The importance of this is demonstrated by carrying out an uncertainty analysis for different locations, technologies and instrumentations. The accuracy of the key parameters is determined with regards to whether the uncertainty margins allow meeting contractual obligations for guarantees of results. It is shown that different operating environments have different boundaries. The main uncertainty is in the irradiance which ranges from 0.6-1.5% and filters into the PR with up to 6% for northern Europe (Site 1).

**G. Friesen, H.G. Beyer, R. Gottschalg, S. Williams, A. Guerin de Montgareuil, N. van der Borg, A.C. de Keizer, W.G.J.H.M. van Sark, “Vergleich von Verfahren zur Abschätzung der Jahreserträge unterschiedlicher PV-Technologien im Rahmen des Projektes Performance – Ergebnisse eines ersten ‘Round Robin’ Tests”; Proc. of the 22<sup>nd</sup> Symposium Photovoltaische Solarenergie, Kloster Banz, Bad Staffelstein, 7. – 9. März 2007**

Im Rahmen des Teilprojekts 4 des EU-Projektes PERFORMANCE sollen unter anderem die zur Zeit diskutierten Modellansätze zur Abschätzung des standortabhängigen DC-Jahresertrags von PV-Modulen verglichen und bewertet werden. Dabei werden zum einen die verwendeten Modellierungsverfahren, zum anderen die jeweiligen Verfahren zur Ableitung der notwendigen Modellparameter aus vorliegenden Messdatensätzen betrachtet. Ziel ist es, die Modellgenauigkeit bis in den Bereich Genauigkeit hochwertiger Messungen zu führen.