Publishable Summary for 16ENG02 PV-Enerate
Advanced PV Energy Rating

Overview

The aim of the project is to provide the metrological infrastructure, techniques and guidance to accelerate time-to-market for emerging photovoltaics (PV) technologies, which have the potential to significantly reduce the cost of photovoltaic energy.

The project has two main objectives: Firstly, to improve the PV energy rating standards and secondly, to improve the measurement equipment and methodologies to enable precise measurements of the parameters required for the energy rating.

Need

According to the United Nations Framework Convention on Climate Change COP 21 in Paris, anthropogenic greenhouse gas emissions must be reduced drastically. As direct combustion of fossil fuels is reduced, renewable energy sources will cover the energy needs to the greatest extent – directly in individual sectors such as heating or in the form of renewable electricity, particularly from wind and solar energy. It is estimated that by 2050, electricity will cover roughly 50 % of all our energy needs – compared with around 25 % today. Renewable electricity will increasingly be used as an energy source and will primarily use technologies that replace a large amount of fuel with a small amount of renewable electricity. To minimise costs of energy storage, around one third of the renewable energy will be produced by photovoltaics.

Currently PV modules are optimised, selected and sold on the basis of power produced under standard test conditions (STC), however this does not allow for differentiation according to the most relevant parameter in the marketplace which is energy production under specific climatic conditions. However, this metric does not always reflect real-world conditions as location-dependent variations in ambient temperature, irradiance, angle-of-incidence, spectrum and wind-speed cause deviations in annually-averaged module efficiencies of up to 20 %. This impedes the uptake of emerging and innovative technologies, such as modules optimised for specific climates.

A new set of standards, IEC 61853 provides a framework for energy rating of PV, including measurement, modelling and reference meteorological data. This is an important first step towards universal energy rating of PV modules, however, stakeholders have identified a number of remaining challenges arising from emerging technologies and market trends:

- Bifacial modules claim to increase energy yields by 10 % - 20 % by harvesting light from the rear of the panel, yet investors are nervous about the lack of standard tests and rating methods,
- PV modules on buildings experience different operating conditions compared to ground-mounted PV and this is not reflected in the current documentary standards,
- Module characterisation requires the use of new technology (such as LED simulators) for fast and accurate characterisation at the module scale and to harmonise handling of test data in order to improve the uptake of energy rating,

Thus, precise metrology and realistic, representative standards for PV are required to support one of the most important future energy sources.

Objectives

The aim of this project is to extend the metric for an energy-based photovoltaic classification to roof-mounted photovoltaics as well as to the fast-growing fields of bifacial and building-integrated photovoltaics.

The EMPIR initiative is co-funded by the European Union's Horizon 2020 research and innovation programme and the EMPIR Participating States

The specific objectives of the project are:

1. To define and realise standard testing conditions for the measurement of the power or the short-circuit current of bifacial solar devices Different approaches for laboratory measurements and for production line measurements will be developed, realised, compared, selected and standardised. This will form the basis for the extended energy rating and the standardisation of measurement of bifacial solar devices.
2. To improve the method of uncertainty evaluation of the spectral mismatch correction in the calibration of solar devices when combining the spectral irradiance and spectral responsivity, taking the correlation of the spectral data into account.
3. To develop traceable measurement methods for extending energy rating to bifacial solar modules and to modules (bifacial or monofacial) applied to or integrated into buildings. This will include the definition of a harmonised data format for solar device properties, required for PV Energy rating measurement standards.
4. To enable instantaneous measurement of the spectral radiance of the complete sky for improved determination of real outdoor measurement conditions and the irradiance spectral-angular distribution by hyperspectral imaging.
5. To develop more accurate measurement methods for traditional and emerging solar modules, including the spectral responsivity of the complete module, fast linearity measurements for modules, angular dependency of modules, with an uncertainty of <1 % for the angular dependency impact, <3 °C for the nominal operating module temperature (NOMT), <1 % for the impact of spectral responsivity and <1 % for the impact of non-linearity.
6. To facilitate the uptake of the technology and measurement infrastructure developed in the project by the measurement supply chain (NMIs, calibration laboratories), standards developing organisations and end users (photovoltaics industry).

Progress beyond the state of the art

This project improves upon the most recently developed methods for the determination of the energy rating characteristics, yield prediction, and the energy rating of solar modules, which are currently not applicable to some emerging technologies. The existing methods and calculations do not take into account the irradiance that impinges on the rear side of the solar cell and thus are not applicable to bifacial solar devices.

Power rating measurements of bifacial solar devices have had deviations in excess of 10 % reported between ISO/IEC 17025 accredited laboratories. This compares to less than 2 % for conventional technologies. This project will close this uncertainty gap by establishing appropriate measurement standards and verifying them by comparisons between the laboratories. (Objective1)

The spectral mismatch correction is one of the largest uncertainty components associated with the calibration of solar devices using solar simulators. At present only approximations for the uncertainty calculation of the spectral mismatch factor exist. The calculation method for the spectral mismatch will be extended to bifacial solar devices (cells and modules), taking into account both the front and rear spectral responsivities, and the correlation between spectral responsivity and spectral irradiance. (Objective 2)

Building integrated photovoltaics (BIPV) are becoming a more common installation mode, but complex urban environments and interaction with the building envelope require better consideration of the albedo component and thermal operating conditions. PV-Enerate will adapt the methods included in the IEC 61853 standards to deliver all data required for the yield prediction in a BIPV or BAPV mode. (Objective 3)

Standardisation technical committees have identified that the nominal operating module temperatures (NOMTs) of solar modules are difficult to determine and that results from the outdoor method are highly site-dependent. For this reason, a comprehensive analysis of the effects will be performed. The project will use and include data from the world's most advanced facility for simultaneous measurement of sky spectra from over 100 different directions, using a hyperspectral imaging approach. (Objective 4)

Advanced metrology for the characterisation of solar modules will be developed as part of this project. One example for such development is a non-destructive method for the fast measurement of current-voltage (IV) characteristics of each solar cell within a module using digital light projection and other modulation techniques. Another is the application of one of the first LED-based solar simulators worldwide for modules (incorporating about 19000 LEDs in total, of more than 20 different types), which will be used for the realisation of the different radiation conditions experienced by a PV module across a typical year of operation and the comprehensive characterisation of modules as required for the energy rating. (Objective 5). An LED based module solar simulator has been built at PTB and is currently being characterized. It will significantly extend the measurement possibilities that can be obtained by use of state of the art sun simulators that are use flashing Xe bulbs.

Results

To define and realise standard testing conditions for the measurement of the power or the short-circuit current of bifacial solar devices Different approaches for laboratory measurements and for production line measurements will be developed, realised, compared, selected and standardised. This will form the basis for the extended energy rating and the standardisation of measurement of bifacial solar devices.

Several recommendations have been submitted, mainly within discussions during the IEC TC82-WG2 meetings. The main issues being recommended by members of the PV-Enerate consortium are use of different background colours (gray and as black as possible) to enable an extrapolation to completely black background without interreflections. The second issue put forward by the consortium is the addition of a two light-source method (illumination of front side and back side) that can be used in addition to the previously favoured one light source method with increased light power. The two light-source method realizes more realistic test conditions and does not need over powering of the light source for the front side. A written recommendation that summarizes the oral discussion will be written when the experiments substantiate the two methods.

To improve the method of uncertainty evaluation of the spectral mismatch correction in the calibration of solar devices when combining the spectral irradiance and spectral responsivity, taking the correlation of the spectral data into account.
All involved partners are working on different new methods for the uncertainty calculation of the spectral mismatch. PTB provided a set of spectral responsivity curves with low uncertainty as base data for testing the algorithms. An internal workshop took place to compare the results of the partners which was held two days before the project meeting in December 2018.

To develop traceable measurement methods for extending energy rating to bifacial solar modules and to modules (bifacial or monofacial) applied to or integrated into buildings. This will include the definition of a harmonised data format for solar device properties, required for PV Energy rating measurement standards.

SUPSI provided first ideas for the inclusion of BIPV to the energy rating during the project meeting in February 2018 at JRC.

FhG published the report “From bifacial PV cells to bifacial PV power plants – the chain of characterization and performance prediction”. Three typical measurement conditions that shall be used for the guidelines or a technical report are described and will be presented at next the IEC meeting in April 2019 at PTB.

To enable instantaneous measurement of the spectral radiance of the complete sky for improved determination of real outdoor measurement conditions and the irradiance spectral-angular distribution by hyperspectral imaging.

The facilities are built for providing comparable data in 2019. The organisation of the intercomparison in Summer 2019 has begun.

To develop more accurate measurement methods for traditional and emerging solar modules, including the spectral responsivity of the complete module, fast linearity measurements for modules, angular dependency of modules, with an uncertainty of <1 % for the angular dependency impact, <3 °C for the nominal operating module temperature (NOMT), <1 % for the impact of spectral responsivity and <1 % for the impact of non-linearity.

The facilities for this deliverable are being developed by the involved partners.

Impact

A number of articles including 3 peer-reviewed journal publications have been written in order to disseminate the outputs of the project.

Partners had 15 presentations and 3 posters at international conferences where the project and its preliminary results were presented. In this period, the topic of advanced energy rating was presented at a parallel event to the EUPVSEC conference in September 2018. A minimum of 50 attendees were present from PV research and test laboratories, manufacturers of advanced PV and BIPV products, consultancies and software producers. The event was advertised via the EURAMET website.

The E-Learning has been setup by NPL with the introduction and a first chapter. A link from the PTB hosted project site to the E-learning system of NPL is given. It is intermediate level. The project homepage has a blog about PV metrology for energy rating with 4 articles now.

SUPSI carried out a session at the Monitoring and simulation of the performance and reliability of photovoltaics in the built environment training school from 23-26 October 2018. The school focused on the special requirements and challenges of integrating PV into the built environment and grids, with a focus on the determination and prediction of performance and reliability. School trainees (students, researchers, educators and practitioners) participated in expert lectures, interactive seminars and practical courses.

Impact on industrial and other user communities

Designers, manufacturers and end users of PV technology will benefit from the capabilities and outputs developed by the project. The extension of the IEC61853 energy rating standards developed by the project, and the capacity to measure PV devices according to the new standards will benefit industry by enabling a fair and impartial intercomparison between different technologies.

Faster and more accurate characterisation of PV cells and modules will enable manufacturers to better optimise their products for real applications and locations. The provision of accurate measurement data on BIPV and bifacial modules, as well as comprehensive indoor/ outdoor measurement comparisons will benefit the software used for the design and monitoring of PV installations, hence improving the accuracy of energy yield estimates from PV technology. The common data format for module energy rating developed by the project will be implemented into commercial modelling software within the duration of this project thus reducing barriers to collecting, sharing and implementing advanced module characterisation data. Uptake of new measurement standards will reduce the uncertainty in energy yield estimates at the planning stage of a PV project, provide technological solutions to reduce the costs of acquiring such data and encourage rapid uptake of energy rating measurements. Finally, customers will benefit from accurate validated energy rating standards and validated software to inform decisions on choice of technology and optimise system design, delivering more clean energy and better return on investment.

Impact on the metrology and scientific communities

New and improved measurement capabilities will be available within the NMIs/DIs to support the adoption of the new standard test conditions for bifacial PV devices according to the new IEC 61853 standards. Documented calibration methods for more accurate determination of PV module power output will be available. Two organisations will have new capability to measure the operating temperature of modules as a function of wind-speed, which is currently a significant source of uncertainty in module energy rating and this will lead to more accurate determination of the relevant coefficients. Adoption of the common data format for reporting and sharing module energy rating measurements will reduce the complexity and costs for customers of energy rating measurements and lead to more efficient implementation into end users' models. New measurement facilities, such as LED-based spectral responsivity, LED solar simulator and instrumentation for structure light sources will contribute to improved understanding of the properties and loss mechanisms of new solar technologies.

Impact on relevant standards

Recommendations will be submitted to project IEC 60904-1-2 on two different methods to extend the standard test conditions (STC) for bifacial solar devices together with a draft annex providing guidelines for the measurements of bifacial modules required for the energy rating standard IEC 61853. Guidelines on extending the energy rating model and reference conditions to include bifacial PV and PV on buildings will be submitted to IEC TC 82 WG 2 and a decision made on whether to propose new standardisation documents extending

IEC 61853-3 & -4. It is suspected that the reproducibility of the nominal operation module temperature (NOMT) measurement method described in IEC 61853-2 and required by IEC 61215 is a significant source of uncertainty in predicting the energy yield of PV modules, so should the task succeed in in reducing the uncertainty through improved methods, the findings will be reported to IEC TC 82 and/or an amendment proposed to IEC 61853-2.

Longer-term economic, social and environmental impacts

To achieve the target increase in photovoltaics as a source of electricity requires a large Europe-wide increase of PV installations by several 100 GW, with an associated investment cost of several 100 billion Euro. Thus, every percent measurement uncertainty in energy yield estimation leads to a financial uncertainty of several billion Euros. The techniques and standards developed in the project will enable a more precise classification of the expected energy output from different emerging PV technologies such as building-applied and building-integrated PV, based on realistic operational conditions. This will enable, for example, a seamless integration into smart grids through the accurate calculation of the power contribution dependent on the time of day and weather conditions, providing better security of supply. It will also enable more reliable requirements for power control, reducing balance-of-system costs and, most importantly, enable a much improved forecasting of solar yield. Without the latter, significant percentages of generated electricity may be lost as the distribution infrastructure is not in a state to accept injection from this energy source and it is instead dumped to ensure stability of the power network.

List of publications

[1] G. Koutsourakisa, M. Blissb, T. R Bettsb and R. Gottschalg, 2018, Utilising Digital Light Processing and Compressed Sensing for Photocurrent Mapping of Encapsulated Photovoltaic Modules, Proceedings of EUPVSEC, 1065-1071, DOI 10.4229/35thEUPVSEC20182018-5BO.11.6, https://dspace.lboro.ac.uk/dspace-jspui/bitstream/2134/35598/1/5BO.11.6%20final.pdf c

[2] J. Lopez-Garcia, A. Casado, D. Pavanello and T. Sample, 2017, Comparison of Electrical Performance of Bifacial Silicon PV Modules, Proceedings of EUPVSEC 2017, 1432-1437, DOI 10.4229/EUPVSEC20172017-5CO.7.3, https://www.eupvsec-proceedings.com/proceedings?paper=43071

[3] D. Shaw, J. Lopez-Garcia, R.P. Kenny, L. Pinero-Prieto and E. Ozkalay, 2018, Design Study of a Double-Side Illumination Solar Simulator for Bifacial Silicon PV Modules Characterisation Based on Low-Cost LED Bias Light, Proceedings of EUPVSEC 2018, 1001-1005, DOI 10.4229/35thEUPVSEC20182018-5BO.9.2, https://www.eupvsec-proceedings.com/proceedings?fulltext=A+SOLAR+SIMULATOR+OF+LOW+AND+HIGH+AM0+LIGHT+INTENSITY+FOR+ELECTRIC+PERFORMANCE+MeasurementS+of+TRIPLE+JUNCTIONS+space+solar+cells+at+Spasolab&paper=46494

[4] R. P. Kenny*,* E. Garcia Menendez*,* J. Lopez-Garcia *and* B. Haile, 2018, Characterizing the operating conditions of bifacial modules, AIP Conference Proceedings 1999, DOI org/10.1063/1.5049253, https://aip.scitation.org/doi/pdf/10.1063/1.5049253?class=pdf

[5] J. Lopez-Garcia, A. Casado and T. Sample, 2019, Electrical performance of bifacial silicon PV modules under different indoor mounting configurations affecting the rear reflected irradiance, Solar Energy (177), 471-482, DOI 10.1016/j.solener.2018.11.051, https://www.sciencedirect.com/science/article/pii/S0038092X18311514

[6] Dittmann, S., Friesen, G., Hohl-Ebinger, J. (Fraunhofer ISE, Freiburg, Germany), Gandy, T., Bothe, K., Hinken, D., Kröger, I., Winter, S., Pavanello, D., Salis, E., Dubard, J. and Müllejans, H.,2019, Results of four European round-robins on short-circuit current temperature coefficient measurements of photovoltaic devices of different size, https://doi.org/10.1016/j.solener.2018.10.051

<table>
<tr><td colspan="2">Project start date and duration:</td><td>01 May 2017, 36 months</td></tr>
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<tr><td>Internal Funded Partners:
1 PTB, Germany
2 Aalto, Finland
3 INTA, Spain
4 LNE, France
5 NPL, United Kingdom
6 TUBITAK, Turkey</td><td>External Funded Partners:
7 FhG, Germany
8 ISFH, Germany
9 JRC, Belgium
10 LU, United Kingdom
11 LUH, Germany
12 TÜV Rheinland, Germany</td><td>Unfunded Partners:
13 SUPSI, Switzerland</td></tr>
<tr><td colspan="3">RMG1: TUBITAK, Turkey (Employing organisation); PTB, Germany (Guestworking organisation)</td></tr>
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