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PV module testing – how to ensure quality after PV module certification

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ABSTRACT

By definition, PV module certification is simply based on conformance to standards. The IEC norms for PV modules are considered to be adequate quality requirements for guaranteeing initial quality. However, it is commonly understood that two products A and B may meet the standard's requirements, but overall quality – considering long-term stability, performance and safety – can still be quite different. PV module testing should therefore be carried out more frequently and beyond IEC requirements. A factory inspection once a year – as suggested by most certification bodies to ensure continuous quality of certified crystalline modules – may not be sufficient. The need for additional control is demonstrated in this paper, with reference to our experience from PV module testing and quality assurance activities for wholesalers and project developers. We present the necessity of additional measurements under standard test conditions (STC) and advanced testing methods, which are becoming essential for reliability.

Introduction

Solar panels are expected to have a guaranteed service time of 20 to 30 years with typical degradation rates of 0.3–0.5%/a of STC power output for crystalline modules. Because of the introduction of Germany's PV feed-in tariffs (regulated by the Renewable Energy Sources Act), PV systems became attractive for long-term investments, based on a thorough calculation of return over their lifetime. The first plants have actually reached the designated service lifetime and have shown that a service time exceeding 20 years is possible without major losses of performance. However, recent failures in the open field have indicated that theoretical and actual service lifetime can differ significantly, with failures already occuring a few weeks after installation in some cases. In this paper we will report four years of experience within the accredited PI-Berlin laboratory, beginning with an overview of the results of the tests carried out, including major fail criteria for certification. The results of studies that focused on peel-off, gel content and potential induced degradation (PID) tests, as well as the results of quality assurance actions, are presented. In the studies only IEC-certified module types were investigated.

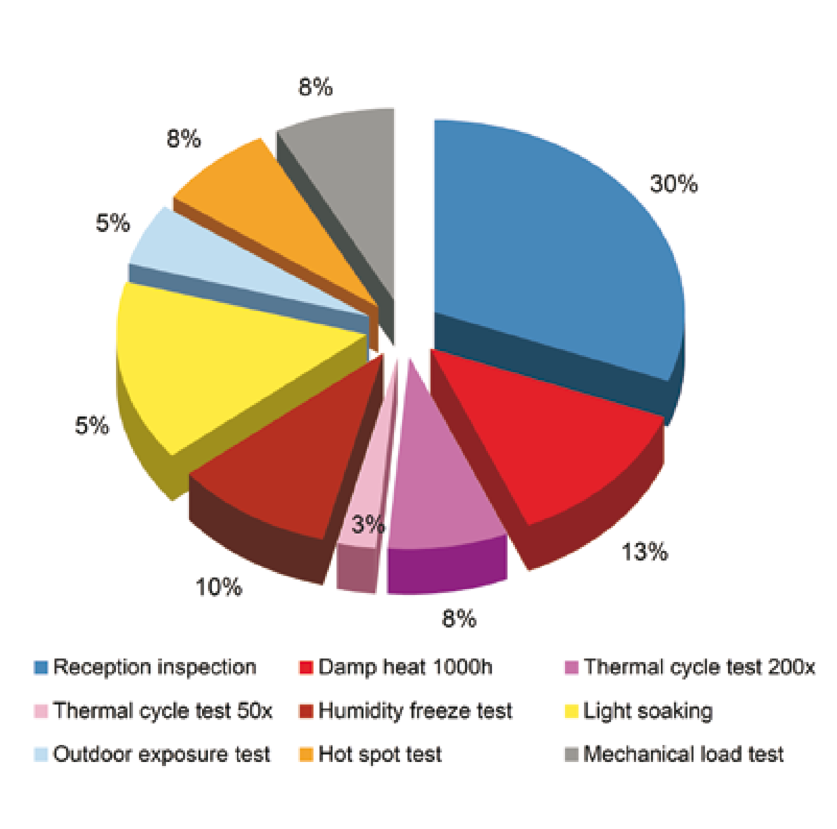

Figure 1. Distribution of fail criteria during the certification process for all tested modules.

IEC-certification, quality assurance and field-test analysis

We have tested PV modules at every stage of product life – certification for product launch, production process quality assurance, incoming quality, etc. – as well as acting as expert for legal actions after product installation. All these tasks were able to be carried out in house, since the PI-Berlin group consists of a comprehensive range of subsidiaries involved in all aspects of a module's lifetime: certification (PI-Berlin), quality assurance (PICON), planning of large-scale PV projects (PI-Experts).

Certification according to IEC

Since 2008 the PI-Berlin AG test laboratory, acting as CBTL (certification body test laboratory) in the CB scheme of the IECEE (IEC System for Conformity Testing and Certification of Electrotechnical Equipment and Components), has worked on 140 cases with TÜV-Süd as a certification body for PV modules.

A total of 32% of certifications have been aborted due to major problems, and

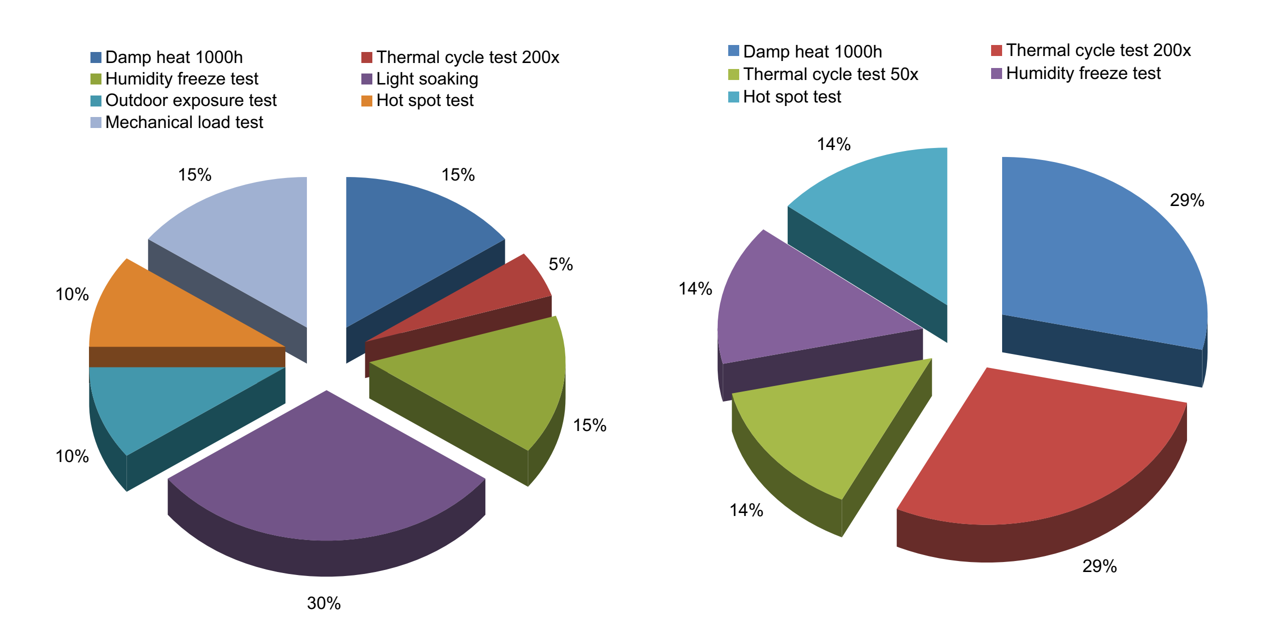

Figure 2. Comparison of failures during the certification processes for thin-film technology modules (left) and c-Si technology modules (right).

a breakdown of the tests involved in those failures is shown in Fig. 1. Often obvious problems such as insufficient initial STC power output, deficient insulation and visual defects have caused premature termination of the testing and certification process.

> “The hot-spot test is problematic for both thin-film and c-Si technologies.”

Fig. 2 shows a comparison of the reasons for the aborts, in terms of the cell technology applied (thin film vs. c-Si). The main reasons for aborts for thin-film technologies have been the mechanical load test, insufficient STC power output (in stabilized conditions) and environmental tests (outdoor exposure test, measurement of NOCT (nominal cell operation temperature)). For c-Si modules, 86% of failures are due to climate chamber tests (damp heat, humidity-freeze and thermal cycle tests). The hot-spot test is problematic for both thin-film and c-Si technologies. Initial aborts (visual inspection, initial insulation test) have been excluded from the statistics.

Quality assurance

For quality assurance tests, randomly chosen modules are taken either from the free market or from a delivery at the customer site, such as a specific PV power plant project. The number of tested modules depends on the scale of the power plant (e.g. 10 STC/MW_p). These modules are tested according to IEC standards and also beyond these standards by performing several repetitions of standard tests or special tests – laminate peel-off, EVA gel content, EL, etc.

Upon inspection of the STC power output of the modules shown in Fig. 3, it is evident that there is a tendency for STC power output to be deficient. Only a few cases lie outside the range –5% to +2%. Because of the primacy attached to profit,

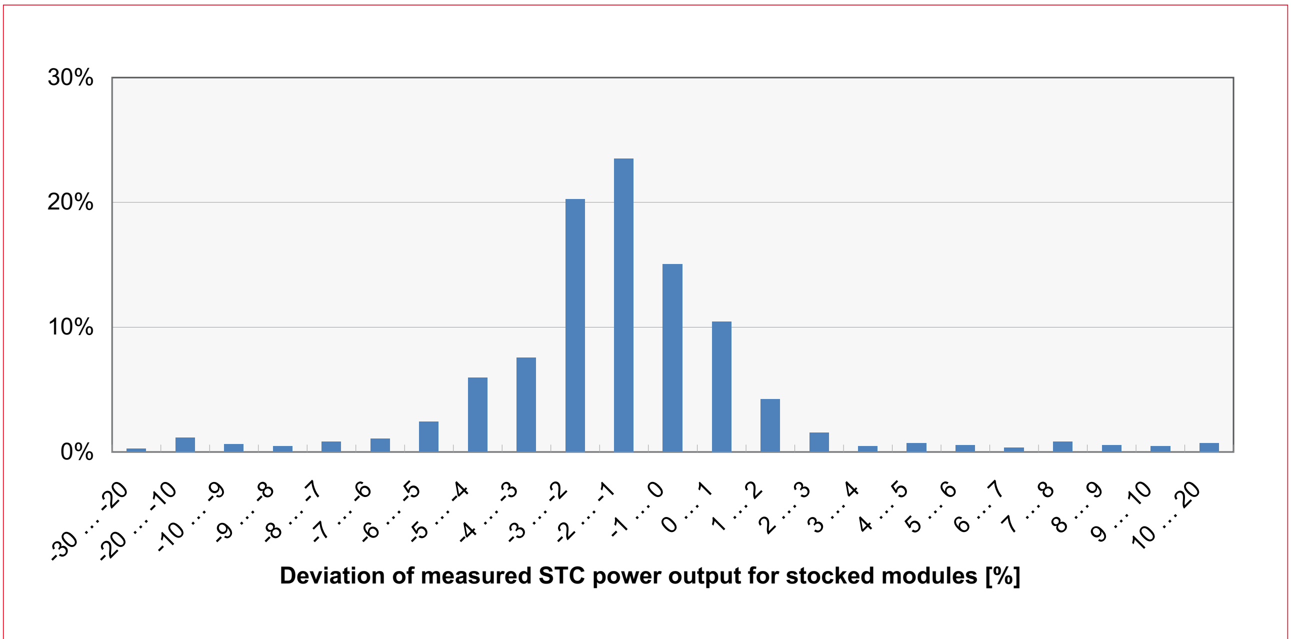

Figure 3. Frequency distribution of deviations of the independently measured STC power output from the labelled power for ex stock modules.

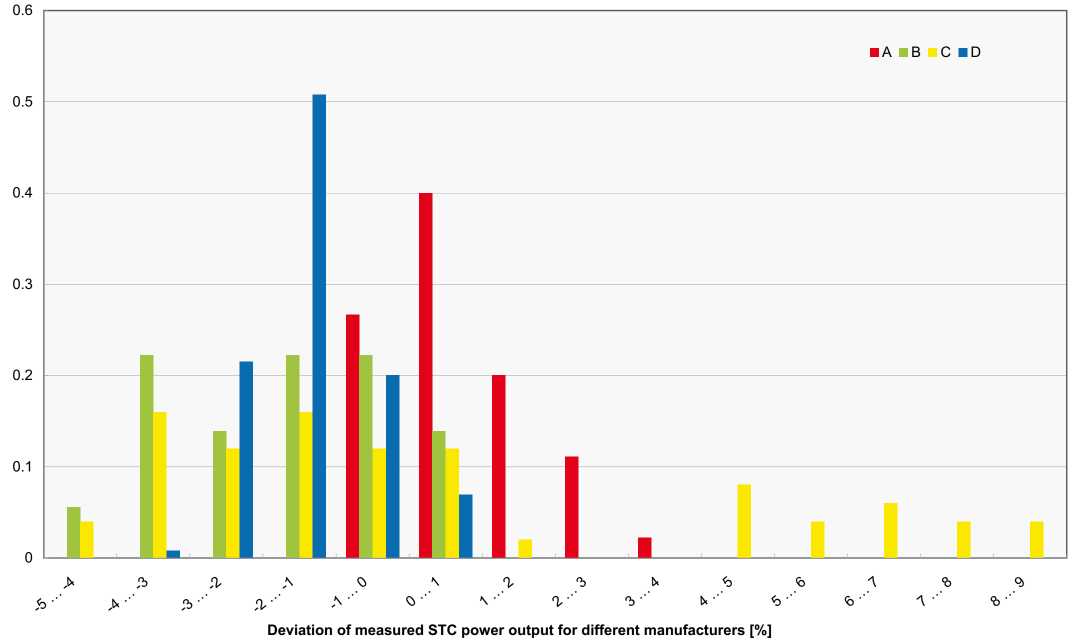

Figure 4. Frequency distribution of deviations of the independently measured STC power output from the labelled power for modules from four different manufacturers A, B, C and D.

positive deviations are in general caused by imprecise calibration of manufacturer's equipment. However, recently, 'plus tolerances only' are becoming a new marketing feature for some manufacturers.

As Fig. 4 shows, manufacturers have different attitudes towards quality control. Producer A has a tendency to overstate the power on the label, while D has a tendency to underestimate actual power output. Producer B has the same tendency as A, but with a broader distribution. Producer C apparently has two factories with different tendencies.

Lamination quality

EVA gel content test

Another quality attribute is the gel content of the encapsulation material. Generally an encapsulate material made of ethylene vinyl acetate (EVA) is used in PV modules. This encapsulate is produced as a film and delivered and stored in rolls, which are protected against humidity and light. The length and the width of the rolls may vary. Most EVA producers recommend storage at a temperature below 30°C (optimum 22°C) and a relative humidity below 50%, for a maximum period of 6 months after production. The rolls should not receive direct sunlight and should always be wrapped tightly in their original packaging. A cut piece of EVA should be stacked and used within 8 hours.

The film is composed of the co-polymer EVA. Initially, the polymer is a thermoplastic, but the manufacturer of the film adds a curing agent and other chemicals (e.g. UV stabilizer). The curing agent is peroxide, which decomposes with increases in temperature and starts a chemical reaction, namely the curing process in the laminator. When the curing process is over, the original thermoplastic has become an elastomer, which can no longer be melted. The material is then irreversibly cured.

The known problems of EVA are:

- **Evaporation of the curing agent before curing:** there may not be enough curing agent left for the curing process due to incorrect storage or mistakes made on the producer side.
- **Too short a curing time:** an insufficient curing time may have been selected in order to achieve process optimization and increase the production. This results in inhomogeneous curing across the modules, or homogeneous but only partial curing.
- **Incorrect curing parameters:** too high or too low a temperature for curing may have been chosen. As in the case of an inappropriate curing time, a partial curing could result, or the material may be irreversibly damaged.
- **Non-uniform curing:** since the development of ultra-fast, fast-curing or similar curing sheets, in combination with the increase in module sizes, the curing process might not be completed across the whole module. The curing level has been found to deviate up to 20% within the area of a single module. The problem is the time difference between the curing temperature

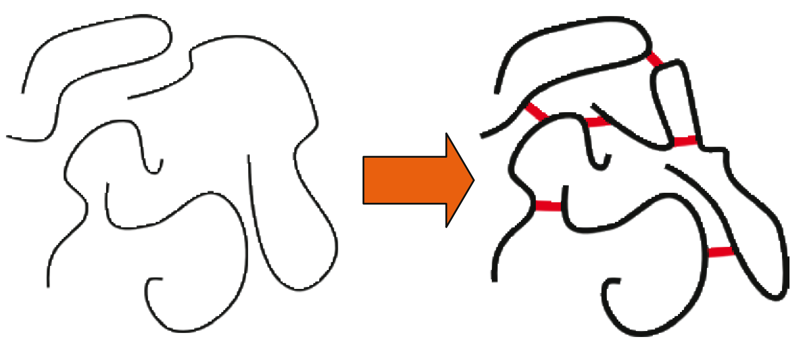

Figure 5. Schematic of the EVA curing process.

reaching the centre and the corner of a module. In addition, thermal stress might result in bending of the module, which lifts parts of the module away from the laminator surface and reduces heat transfer and temperature development.

- **Error made by supplier:** it could happen that the supplier does not put enough peroxide in the EVA, stores it for too long or just mixes different qualities of EVA to improve profit. Non-uniformly distributed curing agents and other chemicals in the foils may cause different properties within the module area. In highly optimized processes this may lead to partial curing.

The *gel content* is a ratio describing the actual proportion of cured EVA in a sample and is a satisfactory quality indicator for the lamination process parameters and the materials used. Results of EVA gel content tests by PI-Berlin are presented in Fig. 6. Typically, the EVA manufacturer recommends a gel content > 75%, but about 60% of tested modules do not in fact reach this value. As shown in Fig. 7, a wide distribution of gel contents is possible within the same manufacturer. Therefore, the quality of processing deviates not only among manufacturers but also within one producer.

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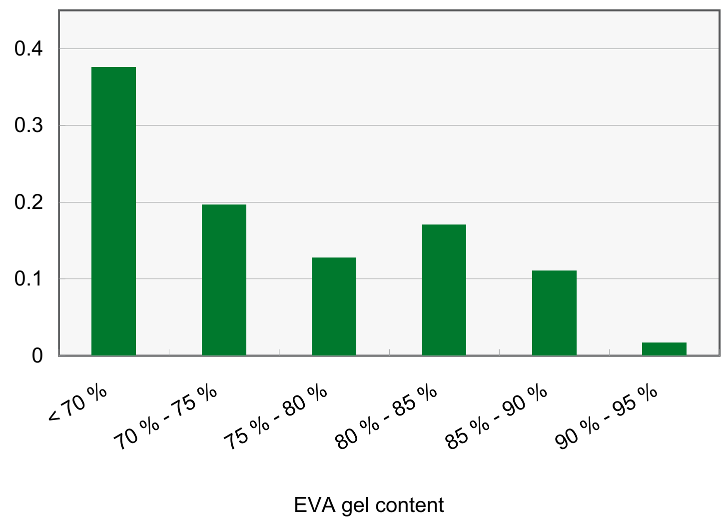

Figure 6. Frequency distribution of EVA gel content of 120 analyzed PV modules.

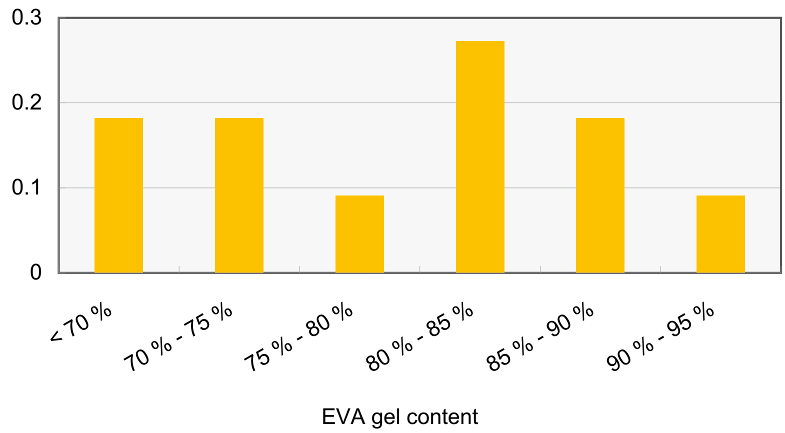

Figure 7. Frequency distribution of EVA gel content of analyzed solar modules from manufacturer A.

Peel-off test

A proper sealing of the modules is important for ensuring a long service time. The peel-off test checks adhesion and consists of measuring the force required to separate the module layers. Typically, it is possible to test the adhesion between:

- encapsulant material (EVA and back sheet) and the back side of the solar cells;
- encapsulant material (EVA and back sheet) and the bus bars;
- encapsulant material (EVA and back sheet) and the front glass;
- layers within back-sheet material (or back-sheet laminate).

Preparation of the module consists of preliminary cuttings of 1cm-wide strips

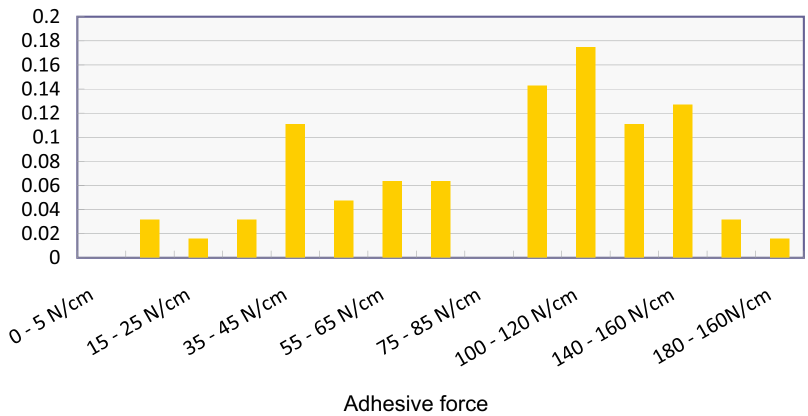

Figure 8. Frequency distribution of the measured adhesive force between EVA and glass.

Note: If cleanliness of the surface of the laminated components is not considered, the EVA gel content test (see above), carried out as the only laminator quality indicator, may be misleading. The gel content test may give acceptable results, but the adhesion of the laminate components (and the service time of the module) may be significantly less than the gel test alone would suggest.

at the centre of the back sheet of the module. The peeling test has to be initiated manually in order to have a 1cm-long free strip, which can be clamped in the wedge grip. An increasing force is applied to the wedge grip, and the specific force is recorded (in N/cm) at the point when the strip starts to separate from the module. As seen for gel content measurements of EVA, a broad distribution of the adhesive strength between EVA and glass can be observed. Fig. 8 shows the results of the peel-off test: in some cases EVA can be easily peeled off from the glass of the module, with little force involved. For other test samples, the back-sheet material breaks before separation occurs. Some clustering of test results can be observed for forces above 95N/cm, but there is no standard defined for this test yet.

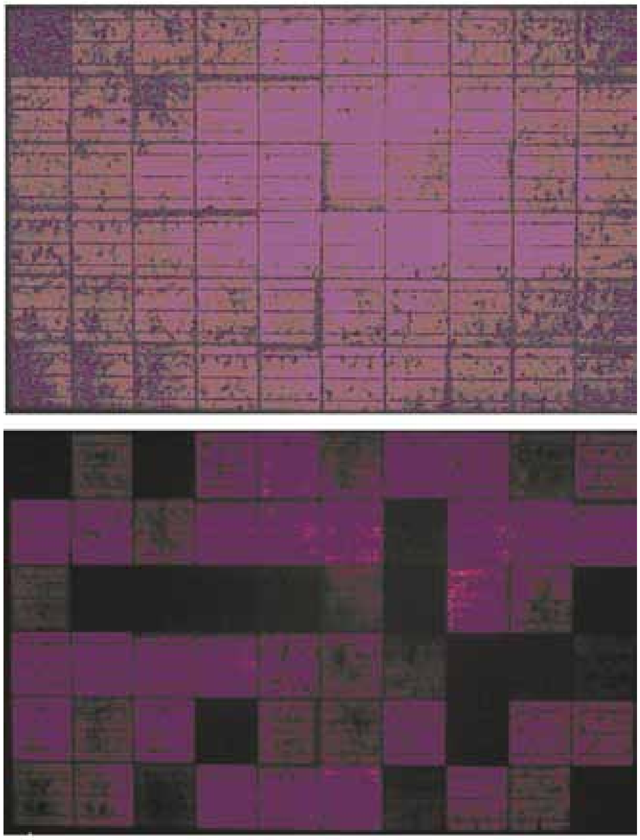

Figure 9. Results of an accelerated PID test (48h at –1000V) in a climate chamber (damp heat: 85°C, 85% r.h.). Top: module in initial state. Bottom: same module after treatment, with a loss of 40% of initial STC power output.

Potential-induced degradation (PID)

It has been known for several years that the STC power output of PV modules may degrade, due to electrical potential between the frame and the cells, and this effect is known as 'potential-induced degradation' (PID). The results of this power-reducing process can be detected via an electroluminescence analysis. In PV systems, PID can be detected by a reduced fill factor (FF), but in advanced stages of the process the I_{sc} (short-circuit current) decreases as well. The affected cells (or some areas on the cells at the beginning of

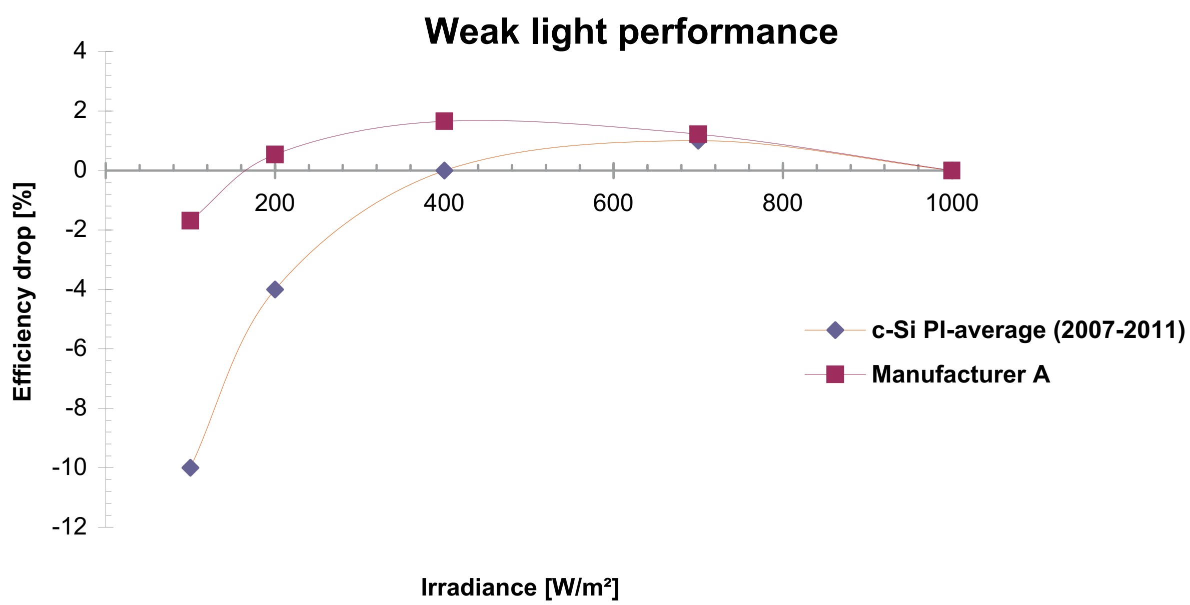

Figure 10. Weak light performance curve of a module with a 'positive' weak light behaviour. An efficiency drop of 30% is also possible.

the process) no longer contribute to power output and are recognized as 'black-cells' in electroluminescence images. For installed modules, PID first affects modules with the highest electrical potential and those located in humid environments (near to the ground, or frame parts with water inside). Precautions taken in the design of the power plant (reduction of potentials) may counteract this effect, or a preliminary filtering of modules with PID affinity is also possible. For the majority of c-Si modules, the PID effect is almost completely reversible.

> "For installed modules, PID first affects modules with the highest electrical potential and those located in humid environments (near to the ground, or frame parts with water inside)."

The sensitivity of a module or of cells to PID can be detected in accelerated damp-heat climate chamber tests, as shown in Fig. 9. The modules were treated for 48 hours in a damp-heat chamber (85°C and relative humidity of 85%), with a potential of –1000V at the terminals. The results for a large number of tests range from a total power loss (–100%) to no effect on STC power output (–0%).

Weak light behaviour

In addition to the temperature coefficient, the efficiency of modules at low irradiation levels is a crucial factor for the energy yield of a PV system. At PI-Berlin, weak light behaviour is measured in a Pasan IIISb flash light sun simulator. Using diverse absorption filters, it is possible to reduce irradiance without spectral changes to almost any value between 50 and 1200W/m^2. The change in electrical efficiency relative to STC efficiency is evaluated. The behaviour is often quite specific to a technology, but has been measured for multicrystalline Si (m-c-Si) technology modules, with a wide variation of the results. PI-Berlin's internal criterion for a 'positive' weak light behaviour at an irradiance level of 100W/m^2 is a maximum efficiency loss of 10%. Fig. 10 illustrates the measurements of one manufacturer's module compared to PI-Berlin's average data. In the average data, the worst performers have shown a decrease in relative efficiency of 30%.

Field data

An unexpected low energy yield of a PV system is often the reason for testing already installed modules. This may be true for single modules, as shown in Fig. 11, but equally for entire strings of modules in a PV power plant, as shown in Fig. 12. The beginning of the degradation process can be detected by adequate monitoring of a photovoltaic system. The reasons for less power output cannot be determined by simple power output measurements; further analysis requires removing the modules and transferring them to the laboratory environment (e.g. to check for PID). This process is quite time consuming and expensive, but can often be prevented by performing quality checks before mounting (e.g. using the tests mentioned earlier).

> "The beginning of the degradation process can be detected by adequate monitoring of a photovoltaic system."

Conclusions

Based on PI-Berlin's experiences in module damage, low energy yields and quality assurance actions, it has become clear that certification according to IEC and all follow-up actions are not sufficient for ensuring a service time of 20 or more years. It is remarkable that – even for IEC-certified modules – there is a significant variation in quality not only between manufacturers but also within the delivered charge from a specific manufacturer. For already installed modules, it is difficult to ascertain later whether impairments are degradations due to unsatisfactory design of the solar power system or inherent problems of the modules themselves.

In the setting up of large-scale PV projects, it is possible to prevent these problems and confirm the long-term stability of modules by quality check-in

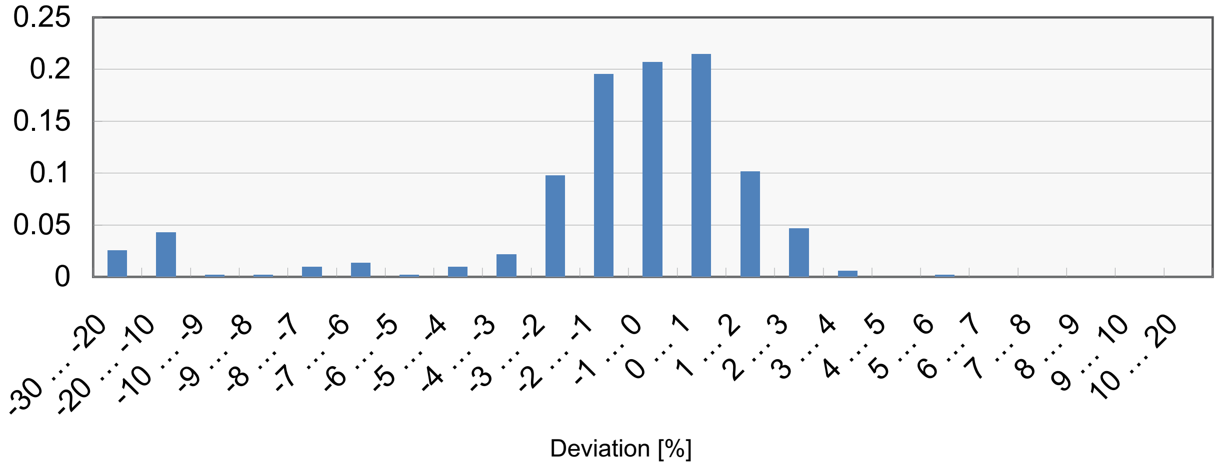

Figure 11. Deviation between measured and labelled STC power output of unmounted photovoltaic system modules.

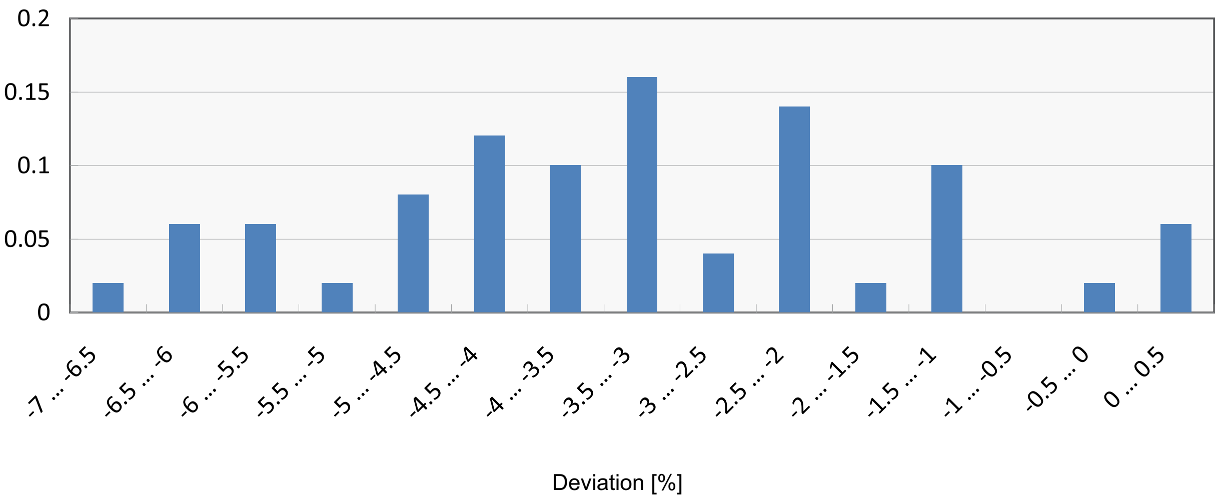

Figure 12. Deviation of measured and labelled STC power output of separate strings of modules in operating photovoltaic systems.

tests, which include factory inspections, climate chamber tests beyond IEC standards, advanced visual inspections, electroluminescence analysis, UV treatments, hot-spot tests, EVA gel content tests and peel-off tests. Moreover, the knowledge of the implemented quality assurance actions triggers an educative effect on the part of the manufacturer.

About the Authors

Alexander Preiss is responsible for the PV outdoor laboratory of PI-Berlin AG, which he set up in 2007. He also works as a project engineer for the accredited PI-Berlin laboratory. From 2000 to 2007 he studied physics at the Humboldt University in Berlin and received a master's degree in experimental solid-state physics. For his thesis he carried out a feasibility study for the optimization of CIS solar cells at the Hahn Meitner Institute. Alexander started his Ph.D in 2007 on yield simulation of PV generators in the Department of Electrical Drives at the University of Technology Berlin (TUB).

Stefan Krauter is a professor at the University of Paderborn and head of the Department of Sustainable Energy Concepts. He received his Ph.D. in electrical engineering for work on performance modelling of PV modules from the University of Technology Berlin (TUB) in 1993. He co-founded Solon in 1996, and in 1997 received a visiting professorship for PV systems at UFRJ-COPPE in Rio de Janeiro, and later at UECE in Fortaleza. During his stay in Brazil he set up a series of congresses and fairs (RIO 02/3/5/6/9/12 – World Climate & Energy Event, together with the Latin America Renewable Energy Fair), to promote the global use of renewable energy. Professor Krauter has been back in Germany since 2006 and co-founded PI-Berlin AG, participating on the board of directors and acting as a senior consultant.

Michael Schoppa is head of the accredited and internationally accepted PV-testing laboratory of PI-Berlin AG, which specializes in quality and material control of PV modules and components. In 2004 he worked on long-term stability for new solar concepts as a research associate at the Monash University in Melbourne, Australia, and later as a graduate at the Hahn Meitner Institute in Berlin. From 2006 to 2007 he was a project engineer in the area of international certification for TÜV Rheinland and in charge of customer support and supervision. Michael participated in the formation of PI-Berlin's PV-testing laboratory and quality management, and under his direction the laboratory gained national accreditation in 2008 and admission to the international CB Scheme (NCBTL) in 2009.

Ilka Luck has a Ph.D. in physics and an MBA. She worked on international R&D projects in the areas of CIGS and international industry cooperation as a scientist at the Hahn-Meitner-Institut Berlin (now the Helmholtz-Center Berlin) from 1998 to 2001. She is the co-founder of several companies in the renewable energy sector, notably Sulfurcell Solartechnik GmbH (now Soltecture) in 2001 (managing director 2001–2006) and PI-Berlin AG in 2006. From 2007 to 2008 she was the managing director of Global Solar Energy Deutschland GmbHand and in that position was responsible for setting up the 30MWp production facilities. Dr. Luck founded PICON Solar GmbH as an operating partner in 2008, to provide a wide range of consulting services focused on PV.

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