ComSolar Note Series

Issue 3: Quality assurance of PV modules in large scale power plants

Best practice experiences in Germany

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History of PV panel testing for large-scale power plants

The installation of large free-field photovoltaic (PV) plants started in Germany in 2004. In 2008 the market took off rapidly. The rate of installation has been above 7 GWp per year in Germany during the last three years. The largest bank financing PV power plants alone has financed more than 1,000 such plants above 500 kWp. Based on the experience of nearly ten years of history of commercial PV power plants, lenders and owners have developed a set of quality assurance (QA) strategies to safeguard their investments. As the modules still account for more than 50% of the total investment, they are in the focus of QA.

For about the past five years, laboratory tests have been a requirement for almost all MW-scale projects seeking bank financing. These tests provide information about the performance of the modules and, to a lesser extent, about their long-term stability. Three strategies, laboratory testing, electroluminescence on site and mobile laboratories, which have been developed over time and are somewhat complementary, are introduced here. Based on laboratory tests on different samples, the set of instruments was recently further improved with the introduction of on-site inspections of incoming goods. In a first step, electroluminescence (EL) imaging was moved from the laboratory to the building site. For large projects, the next step involves setting up a portable test laboratory directly at the building site, and the conducting of EL imaging along with the Standard Test Conditions (STC) tests of power output.

Requirements for successful quality assurance of PV modules

We regularly find that PV modules have poor readings in the test laboratory or during inspections of incoming goods, but that the purchaser is unable to claim compensation due to the lack of any corresponding terms within the sales agreement. As will be shown below using examples from real projects, it is a common mistake to purchase modules on the basis of a data sheet or confidence in a power guarantee from the manufacturer. The only guarantee of receiving modules of an acceptable level of quality is to have detailed technical specifications including all the testing processes and corresponding pass/fail criteria.

It is important, however, to not only consider new modules when conducting inspections of incoming goods. A considerably larger problem arises when trying to successfully claim for product defects that only become apparent after a period of usage.

LABORATORY TESTING

Common tests:

Power at STC (Standard Test Conditions)

For ordered products, it is natural to verify the quantity delivered. This also holds for measurement of the power output of PV modules. A distinctive feature in this case, however, is the large degree of measurement uncertainty, which is generally around 3% of the measured value. An explanation of the technical reasons for this high level of uncertainty would go beyond the scope of this publication, but at www.pv-lab.de a 40-page publication on power testing is available for download.

The measurement uncertainty level is important, because it generally becomes the burden of the party undertaking the measurement. If a customer asks for testing of a PV module rated at 100 Wp (tolerance -0%, +5%), all results falling between 97 and 103 are within the range of measurement uncertainty. A measured value of 98 Wp therefore does not determine beyond doubt whether the module actually has not met its specifications. But this is different for the measurement of large quantities of PV modules. Certain components of measurement uncertainty are systematic and always tend in the same direction, while others are subject to statistical spreads. The prevailing view therefore is that when testing a large number of new PV modules, the average of the values without a subtraction for uncertainty should at least meet the rated power. Although this is a widespread practice, we recommend expressly stating it within contracts.

The contract should also specifically describe how the modules are to be tested. Solar simulators are classified in accordance with IEC 60904-9. It is only possible to get measurements with a low level of uncertainty using Class AAA simulators. Each of the three letters corresponds to a technical parameter (spectral match, irradiation non-uniformity, temporal instability). There are providers of ‘Class AA’ simulators, but these do not mirror finance ratings in being almost as good as AAA; instead, the simulator fails to meet even the minimum requirements of the lowest Class C for one of the parameters, so the provider has dropped the third letter. The parameter in question is usually the spectral match. The graph clearly shows that some of the single LED simulators only cover around one-third of the spectrum, which means they are entirely blind in terms of measuring effects across broad ranges of the spectrum.

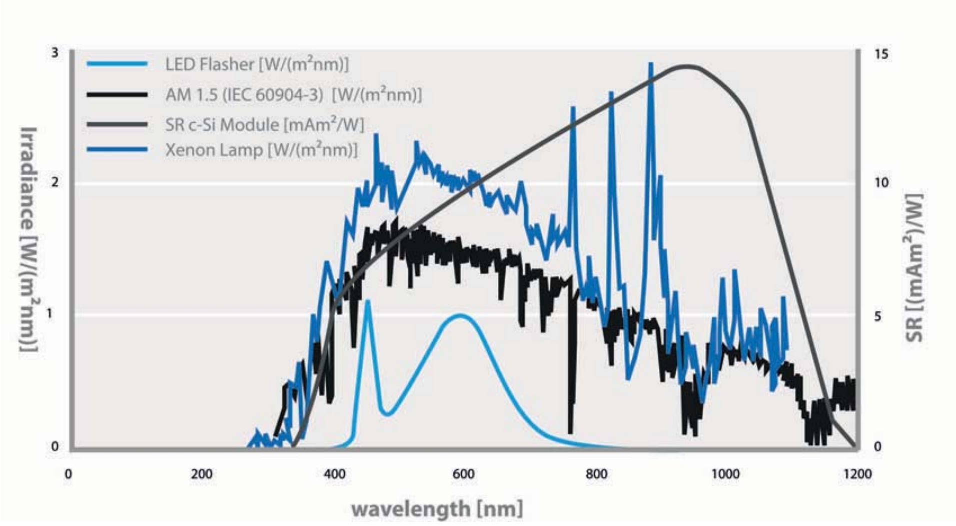

Figure 1:

Spectrum of a xenon lamp, Class AAA solar simulator (black) and single LED flasher. The grey line indicates the sensitivity of a silicon cell.

Particular care should be taken when selecting the reference cell or module against which the solar simulator will be calibrated. Reference cells and reference modules are conventionally used, and a short-circuit current ISC is applied for calibration purposes. Typical measurement uncertainty levels for ISC references fall within 0.5% for good reference cells and 2.3% for a typical reference module. In the graphic, which provides the example of distribution of a short-circuit current of reference cells and reference modules, it is clear that reference modules are considerably more prone to systematic non-conformity than reference cells. PV power testing should be specified precisely, particularly in the case of large-scale projects.

Power testing is already quite complex for new modules. It becomes even more difficult when the aim is to assess conformity with the manufacturer's guaranteed power ratings in cases where an entire array is not performing to specifications. Furthermore, specific problems arise for thin film modules with their distinctive features.

Since performance warranties are voluntarily provided by manufacturers, they are also free to set the conditions of the warranty as they please. Generally, the performance warranty is limited to the specific module. These warranties usually do not provide compensation for the full power loss, but rather just for the proportion needed to reach the guaranteed minimum output.

In combination, these two factors have far-reaching consequences.

Sample calculation:

PV Module 140 Wp, tolerance +/- 5%
Measurement uncertainty: 3%

Performance warranty: 10 years 90% of minimum power output

Minimum power output: 140 Wp – 7 Wp = 133 Wp

Guaranteed output within the first 10 years:

133 Wp * 90% = 119.7 Wp

Minus 3% measurement uncertainty:

119.7 Wp * 0.97 = 116.1 Wp
In our example, which is based on a real-world situation, the warranty only applies when performance of 17% below the rated level is measured.

In the sample calculation, a level 17% below the rated power must be determined in order to fulfil the warranty requirements. If a module's power output is found to be 20% below the minimum, then compensation corresponding to 3% of output can be claimed. In many cases, this would be insufficient to even cover the costs of removing the module.

An even more critical circumstance is that the evidence needs to be collected at the individual module level. Imagine for a moment that you own a park that is about five years old containing the modules described above; measurements show that half of the modules are generating at -15% of rated power while the others are at -20%. The cost of carrying out an STC measurement is about the same as the original cost of a module. When considering long-term security of investment, it is clearly a worthwhile use of time to carefully check the details of the performance warranty.

- Verification on an individual module level, or statistical verification.
- The form in which compensation is made, and its extent.
- Who bears the costs, and under which conditions, for removal, re-installation and shipping of the modules.
- Who bears the costs, and under which conditions, for the power measurement.

Finally, attention must be drawn to a specific characteristic of thin film modules, many of which are meta-stable, which means that their output changes depending on external influences. The Staebler-Wronski Effect has an impact on amorphous and micromorph silicon thin film modules. During use, the cell's power level drops, and the new level depends on the operating temperature. This loss of power can be counteracted by exposing the module to high temperatures. There are some manufacturers who make use of this mechanism and peg the performance warranties to power measurements following annealing or lightsoaking.

Using this procedure, the power level measured within a laboratory can be more than 15% higher than the actual power in regular usage.

Power at low irradiance / weak light behaviour

Power at low irradiance is understood to be the output at an insolation of 200 W/m². Weak light behaviour is not clearly defined, but is generally understood to be the characteristic curve showing the relative efficiency depending on irradiance.

The PV module manufacturers supply these curves to the providers of simulation software. The yield reports generated based on these simulations form the basis for decisions by banks to provide financing for a system. They are also commonly consulted when comparing modules in order to make investment decisions. There are leading manufacturers of crystalline modules that report on their spec sheets a 95% efficiency level based on STC, at an irradiance level of 200 W/m². This figure can serve as a reference point for a high-quality module.

Many purchasing agreements neglect to specify the values on which the simulations are based.

Electroluminescence (EL)

Electroluminescence is a diagnostic process that was introduced in 2005 by T. Fuyuky for solar cells, and which, in a manner of speaking, ‘reverses’ the photovoltaic effect. Current is applied to the PV module and the resulting radiance levels are recorded using a camera capable of detecting near-infrared light. The result is an image that resembles an X-ray. One of the strengths of this procedure is that it can recognise a wide range of module defects extending across all the steps in the manufacturing process, from casting the ingots to damage caused during transport. In a practical sense, electroluminescence is used for quality assurance during the manufacturing of the modules to find micro-cracks. These are tiny cracks in the cells that cannot be distinguished with the naked eye, but which can lead to electrical insulation across entire segments of the panel. If cracks form in particularly unfavourable locations within a single cell, they can lead to a 33% reduction in power at low irradiance across the module.

One disadvantage is that there is no uniform or standardised procedure for interpreting the electroluminescence images. Furthermore, there is no scientifically-based procedure for assessing the probability of subsequent damage that could be caused by the micro-cracks. Useful research findings on micro-cracks were presented by Marc Koentges, who provides a good summary:

Köntges et al., Quantifying the risk of power loss in PV modules due to micro cracks, 25th European Photovoltaic Solar Energy Conference, Valencia, Spain, 6-10 September 2010

A group of experts and laboratories issued a joint recommendation in the June 2013 issue of PV Magazine regarding practical evaluation within the context of quality assurance:

Jaeckel, B., Arp, J., Krömke, F., Looking into the future, PV Magazine, Oct. 2013, P. 46 ff.

Electroluminescence makes particular sense when conducting incoming goods inspections at the building site. Damages in the form of micro-cracks arising from transportation and rough installation processes are among the greatest risks facing PV modules. For investors and general contractors, it is almost impossible to assign responsibility for damage without conducting an electroluminescence test when receiving goods.

Light Induced Degradation (LID)

Crystalline solar cells exhibit a minor power loss within the initial hours of operation. For multi-crystalline cells, this should not exceed 0.4%, and in the case of mono-crystalline cells, 1.5%. During an LID test, an inspection is conducted of whether the power meets the agreed specifications following the initial degradation. We recommend carrying out an LID test based on IEC 61215. Prior to the power measurement, a preconditioning of 5 kWh/m^2 is provided for, which roughly corresponds to a sunny day. Depending on the type of contract, a pre-agreed limit on power loss must not be exceeded before or after the preconditioning, or the minimum power level must be reached following the preconditioning.

Potential Induced Degradation (PID)

Potential induced degradation, or the voltage-dependent ageing of photovoltaic modules, is a type of power degradation that generally appears on the negative side of the module string and can affect almost any type of photovoltaic module. The susceptibility of modules to PID depends largely on the anti-reflex layer of the cells, but can also be due to other encapsulation parameters. Experiences over the past years have shown that PID certification can only apply to modules that are absolutely identical to the tested modules. In practice, this is often not the case, and we therefore recommend picking test specimens from a number of different batches.

Currently, there is no standardised procedure for testing PID susceptibility, but one is expected in the near future. At this point, two different procedures are being used. We will introduce the simpler of these two procedures, which takes somewhat longer to carry out, but does not require expensive climate chambers. For this procedure, a piece of aluminium foil is placed on the module and grounded. The inner circuit is brought to a -1000 V potential and left in this state for 168 hours at 25°C. A power loss of 5% should not be exceeded in measurements before and after this period.

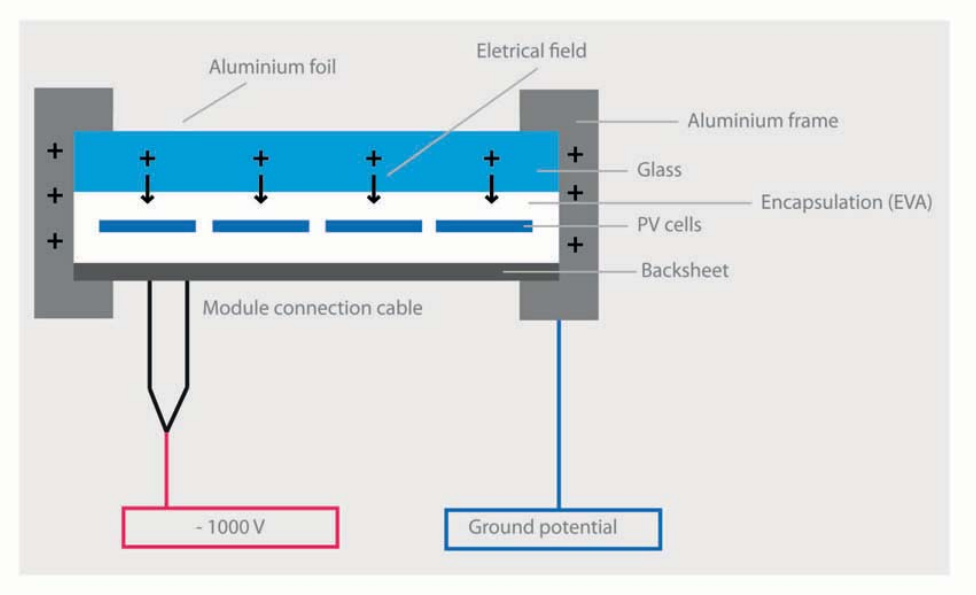

Figure 2:
Procedure for testing PID susceptibility

The following graph portrays results from typical PID tests collected in a laboratory setting. In these cases, two separate test cycles of 168 hours each were run one after the other, and power was measured at the end of each cycle. Two modules from each manufacturer were measured.

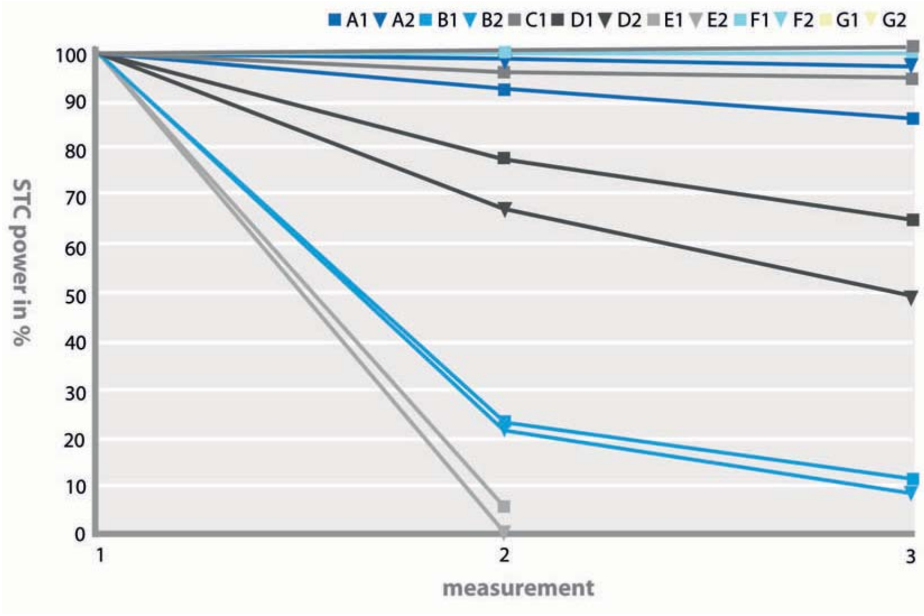

Figure 3:
Results from typical PID test in Laboratory

Electroluminescence images show how the performance of cells is impaired by the PID effect.

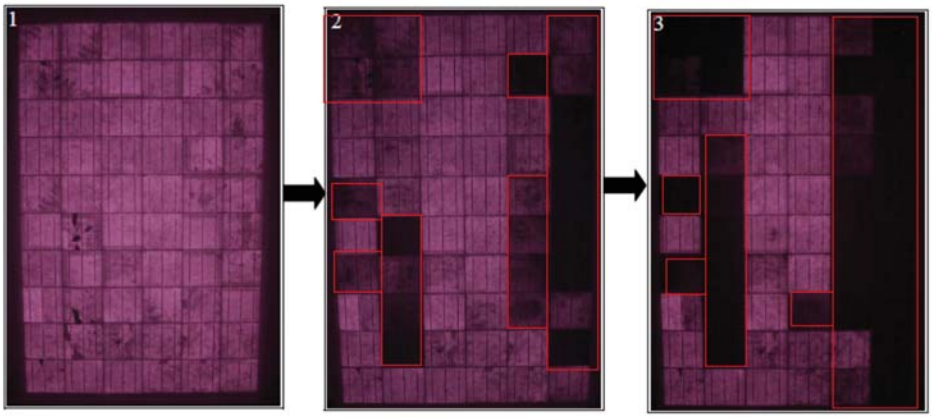

Figure 4:

Modules in PID Test after 0 h, 168 h and 336 h

EVA cross-linking

The EVA cross-linking test determines what percentage of the transparent bedding material can be released using a solvent. The remaining portion is then termed the cross-linking level. If the level of cross-linking is too low, it can be an indicator of an increased risk of delamination, which ultimately can lead to the module's failure. Cross-linking of 80-85% is judged to be optimal. Various factors during the manufacturing process can lead to lower cross-linking levels, for example, by doing the lamination process too quickly, or using too low temperatures. There is no standard for the minimum level of cross-linking, and different EVA manufacturers state a variety of minimum cross-linking values. To our knowledge, the lowest allowable value is 65%, but there are other EVA manufacturers who recommend higher values. Suppliers must be asked to state the required minimum value set by the EVA manufacturer. Most laboratories set a pass criterion of 65%.

There are different procedures for determining EVA cross-linking, which will also provide slightly different results. The values mentioned above were collected using Soxhlet extraction with xylene. The wet chemical analytical method for determining EVA cross-linking is highly susceptible to specific conditions and can result in significant measurement errors in individual cases. Therefore, individual values should not be used for decision-making, but rather analytical results from multiple modules whenever possible. In addition to meeting minimum values for individual modules, the achievement of uniform results across all specimens tested is a further quality criterion.

Peel-off test

This test aims to measure the adhesion of the bedding material (generally EVA) to glass. No standardised procedure exists for this type of testing, and the manufacturers proceed in a variety of ways, based to some extent on different standards and procedures (ASTM D903, DIN EN 1939, IPC-TM 650, 2.4.9.). Variation across the test parameters is primarily found in the following: peel-off speed, width of the test strip, removal angle.

For photovoltaics, a 180° removal angle is widely used. The pass/fail level depends on the laboratory and manufacturer, but is generally between 40 and 60 N/cm. Some EVA manufacturers even specify a peel-off force of at least 80 N/m. The peel-off test should be considered as fail, if the peel-off force that is too low could indicate that the production process was carried out with the wrong parameters, or expired materials were used.

Wet-leakage test

The wet-leakage test is defined by IEC standards, and measures resistance between the inner circuit and a water bath. The result is multiplied by the surface area of the module and may not exceed 40 MOhm*m². This test is relevant from a safety viewpoint.

Criteria for sample size

Samples are generally drawn on the basis of standards such as IEC 60410 or ISO 2859. Alternatively, many banks in Germany have introduced simplified rules of thumb that are pragmatic in an economic sense, but carry the disadvantage of having a reduced confidence level for systems within the low single-digit MWp range.

Bank rules:

10 specimens per MWp for:
- Visual inspection
- Power at STC
- Electroluminescence

5 specimens per MWp for:
- Low irradiance
- Wet leakage

3 specimens per MWp for:
- PID test
- LID test
- EVA cross-linking test
- Peel-off test

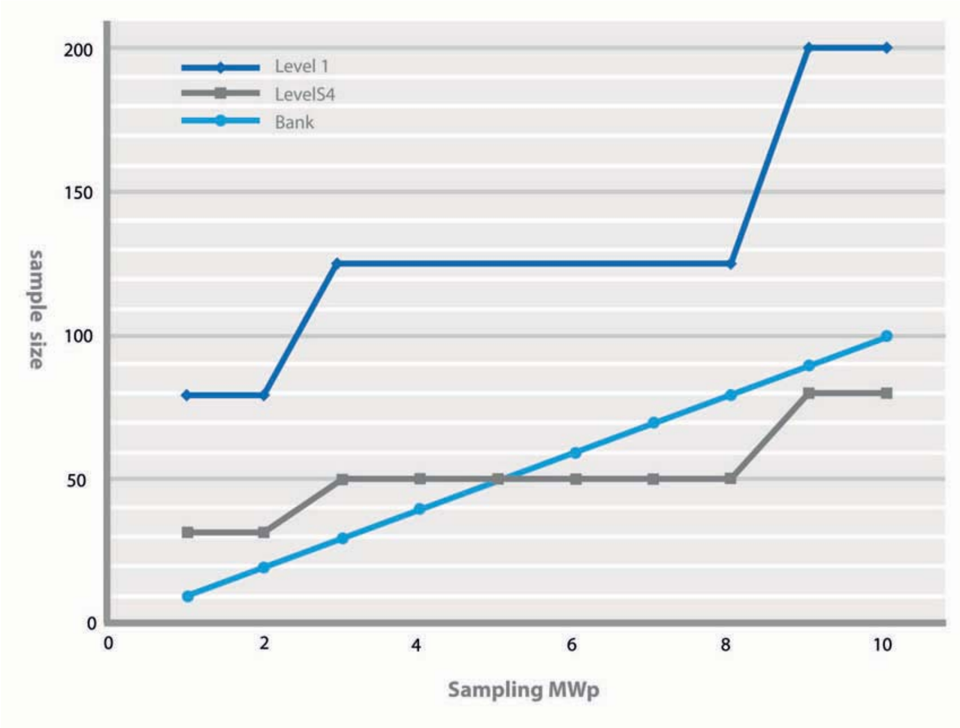

Figure 5:
Variation of sample size with sampling MWp

For the first three tests, which are conducted in large quantities, the quantities for Inspection Level I can be selected as an alternative. The different approaches are shown in the graph.

A useful overview is provided in the article '*Lose ziehen*' by Jaeckel, Erdmann, Krömke in PV Magazin 01/2013, p. 113 ff.. The article should also appear soon in the English-language edition of the journal, PV Magazine.

Cost of laboratory testing

The costs of quality assurance are recouped directly. Two scenarios are compared in the graph. Scenario 1 shows comprehensive testing in which there is an assessment of the performance of the modules as well as their manufacturing quality, which is important for their service life.

Scenario 2 only includes the rests that are required for assessing the module's power output.

Both test scenarios incur for larger parks costs of between 2,000 and 5,000 US$/ MWp (0.2-0.5 ct/Wp).

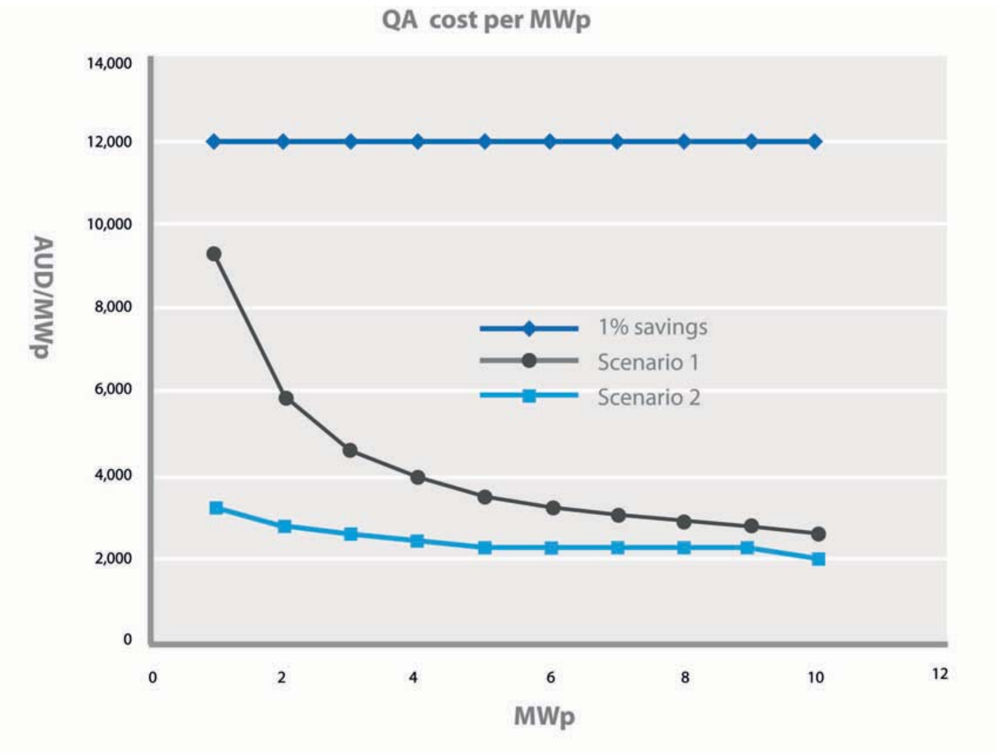

Figure 6:
Cost and benefit of QA testing per MWp

The green line represents the damage that arises from a 1% power loss. Studies by various institutes and test laboratories in Germany show that projects with an agreement on performance testing on receipt of goods are supplied with modules that have higher levels of power output.

Electroluminescence test at the building site

Laboratory testing produces robust findings, but is subject to two problems. Due to cost issues, sample size is heavily limited, and in the specific case of electroluminescence testing, it is often not clear in the case of negative findings whether the defects could have been caused by the transportation to the laboratory.

Therefore, in 2012 a procedure was established together with a large-scale installer of PV systems, which introduces electroluminescence testing directly at the building site as a criterion of receipt of goods. A simple EL chamber was installed on the building site. A palette was removed from each container and tested prior to offloading, which was only allowed to proceed after the test had been passed. For one of the large building projects, such severe transport damages were found in 13 of the roughly 400 containers that the modules in these containers were subjected to further testing by the manufacturer.

Photo: Mobile EL chamber

The cost of this quality assurance measure was on the scale of several a few thousand dollars, leading to a very good cost-benefit ratio.

Mobile laboratories on location

A logical further development of the on-site EL testing would be the deployment of mobile laboratory units directly at the building sites. This process is currently in its introductory phase and there are a variety of approaches.

One variation is the choice of light sources for power measurement. A number of suppliers use high-quality Class AAA simulators in the mobile units. Others try to lower costs by using simpler light sources. Since the consequences of increased measurement uncertainty in the simpler measurement systems already greatly exceed the costs of a mobile laboratory when scaled up to the size of a medium-sized park, it must be critically questioned whether this is the correct approach.

The second difference is whether the temperature control in the modules takes place inside or outside the mobile laboratories. Both approaches have pros and cons, but if one is striving for lower levels of measurement uncertainty, then temperature control should never be foregone.

In 2014, the construction of a mobile test laboratory should be cost-effective for parks on the scale of 50 MWp upwards.

For further helpful info please see www.solarguidelines.in – the pathway to project finance and implementation.

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