Solar life-cycle management:

Is the spectre of lost returns holding solar energy back?

Data | The collection of inaccurate data at any point in the life cycle of a solar plant will undermine almost every aspect of the investment accounting. Mark Skidmore, Samantha Doshi, Matthias Heinze and Christos Monokroussos from TÜV Rheinland discuss the importance of precision data gathering in mitigating risk for builders, operators and financiers

The global PV power plant fleet now exceeds 100GW and is projected to reach terawatt levels within the next 10 years. Where the demand for installed power increases, the need for cost reductions follows closely behind, which calls for better methods of product quality surveillance. As aging PV fleets enter cycles of sale and re-acquisition, and subsidies decrease and tax incentives fall, secondary buyers must evaluate their asset's ability to fulfil their return on investment (ROI). This raises the value of assessing the precise financial performance of a PV system. With new energy trading mechanisms, the reliance on precise data and its complexity will only increase. In this paper the general principles of precision data gathering are described, and EL imaging in particular is highlighted.

"With new energy trading mechanisms, the reliance on precise data and its complexity will only increase"

Background

Reductions in capital costs and improvements to system efficiencies for solar power plants have spurred a dramatic growth in solar energy. In Q1 2017 the USA added 2GWdc of PV power, following an unprecedented year of more than 15GWdc installed in 2016 [1]. The industry is poised to continue this growth at a rate of 7.2% per year until 2050 [2].

Tax incentives have been a key motivating factor for investing in solar, so much so that often first owners are eager to step away from a project once the tax benefits have been fully utilised. This means that a change of ownership is likely to occur within a time frame in which the system is still new enough for potential failures to be hidden from secondary buyers.

It has become common practice, supported by mediocre independent engineer (IE) reporting, to optimise systems for an initial favourable performance ratio, which often means that DC watts are installed beyond actual need. The performance ratio is in this context is often understood to be simplified (i.e. not corrected for VAR and inverse availability, as defined by the IEC standard) as:

$$ACPR = \frac{\left(\sum_{1\,\mathrm{Year}} P_{\mathrm{predicted}}\right)/\mathrm{kWh}}{\left(\sum_{1\,\mathrm{Year}} P_{\mathrm{actual}}\right)/\mathrm{kWh}} \qquad (1)$$

This performance ratio has all the elements of uncertainty (i.e. not just P90) associated with it that affect a power plant, which investors may not be aware of.

DC leveraging has the 'benefit' of spreading fixed system costs over a broader wattage base at the expense of overinvesting, along with perhaps an initial AC performance ratio (ACPR) greater than 1. The unintended consequence of this DC leveraging is that it masks performance defects by exceeding production targets, or through, for example, inverter clipping as shown in Fig. 1.

For the first short-term owner, the excess capacity creates a 'clipping bank account', which yields extra capacity that widens the shoulders on the production curve (blue clipping curve in Fig. 1). This helps ensure that the plateau (in case of clipping or contractually limited feed-in) is as flat as possible for as long as possible. However, as the system degrades with time, the clipping bank account gradually draws down. The extent of the degradation is further hidden through AC performance, as most plants do not employ string monitoring, and the only view of the DC performance is through AC performance.

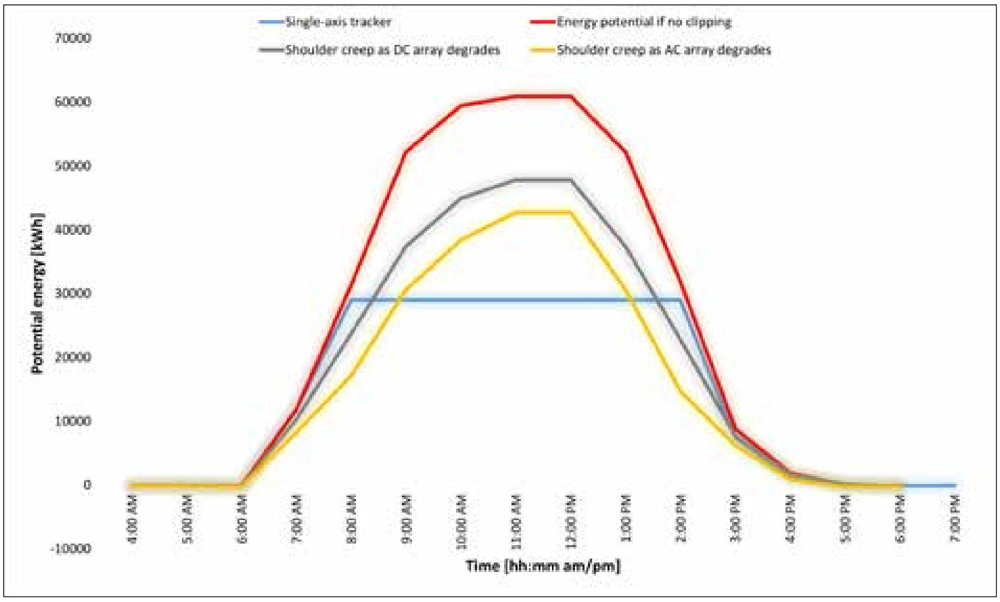


Figure 1. Defect masking through increased DC/AC ratio

Oftentimes the DC performance is being compared with weather data, but most on-site weather stations, if available, are uncalibrated and inaccurate over time. Note that calibration uncertainty is one of the factors affecting *u*PMAX, the overall measurement uncertainty:

$$u_{\text{PMAX}} = k \cdot \sqrt{u_1^{\,2} + \ldots + u_N^{\,2}} \qquad (2)$$

where, u_i = standard uncertainty for uncertainty source *i*, and *k* = coverage factor (*k* = 2 for 95% confidence interval).

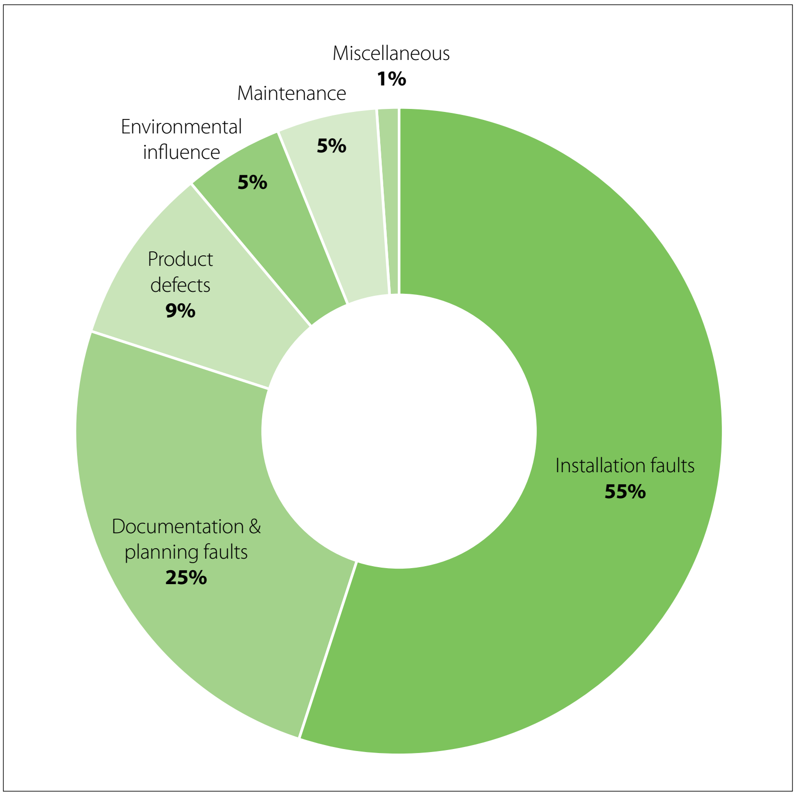


Figure 3. Percentage of serious defects noted by category

> "Bad data has the potential to invalidate warranty claims on underachieving components"

For secondary buyers, it becomes imperative to accurately determine the physical and electrical health of their assets in order to ensure that their investment can meet return expectations, reduce financing cost and minimise capital deployment. The potential owners must be able to vet power plants through sound IE due diligence assessments, so that they can leverage price reductions and premiums on the basis of quantified underperformance.

Calibration as an asset

The challenges involved in collecting data begin from the moment the site is selected, and continue through design and component selection to installation, commissioning and O&M. Thus, from mischaracterisation of component performance, defective discovery tests and inappropriate pre-installation, to inaccurate measurements of the system's effectiveness during periodic assessment, bad data has the potential to invalidate warranty claims on underachieving components, as well as overvaluing (or undervaluing!) a system upon secondary sale.

By way of example, TÜV Rheinland was recently called in by a project owner who was preparing to file a warranty claim against a manufacturer in the hope of curing financial shortfalls from a system performance deficit. The owner had already conducted tests with a third-party subcontractor in order to characterise, on a percentage basis, how much the solar array was underperforming in respect of the warranty; TÜV was tasked to validate these results by carrying out coincident, same day, same time measurements. Upon retesting with calibrated and spectrally matched instruments (as opposed to the uncalibrated, spectrally unmatchable instruments that had been used by the subcontractor), TÜV measured 10% lower irradiance levels than those indicated in the initial tests (Fig. 2). If the sensor believes that the irradiance is higher than what the module actually absorbs, the module performance will appear lower than it actually is.

From lab to field – more data, accurate data, appropriate data

Defects in power plants are not only caused by defective components but also built into power plants, despite the

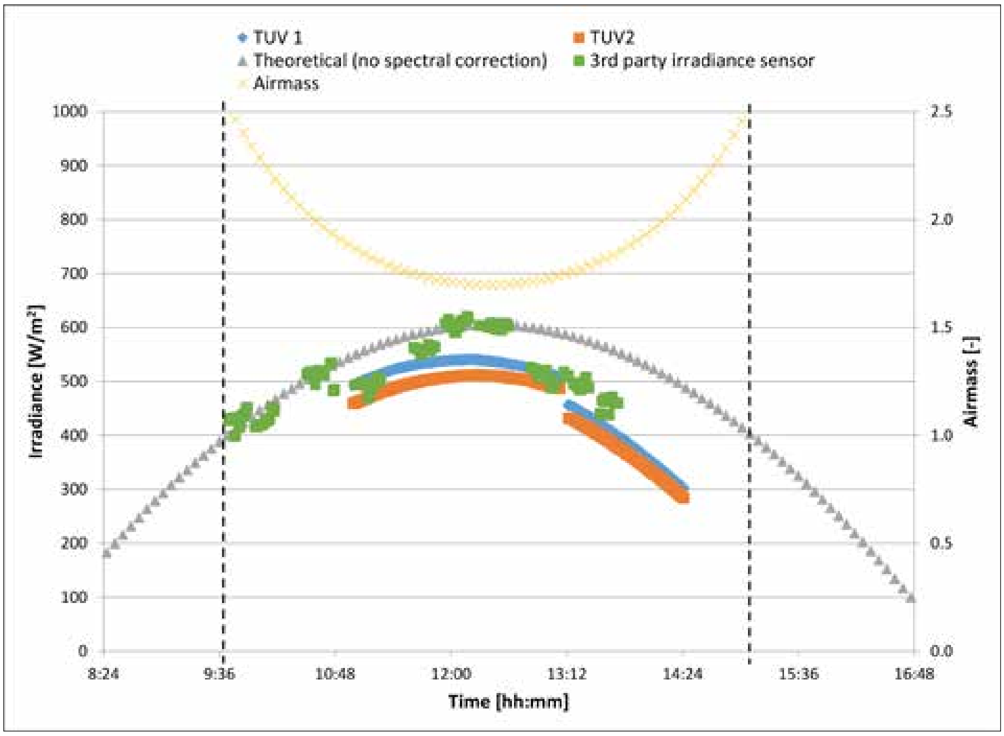


Figure 2. Measured plane-of-array (POA) irradiance comparison

best efforts of all parties involved. Many of the defects are simply not visible to the naked eye or cannot be derived via simple measurements. The results of a TÜV internal study from 2014 to Q1 2015 determined that 30% of power plants showed serious defects, while more than 50% of these defects were attributable to installation errors (Fig. 3).

Product quality is affected by the fiercely competitive markets, low financial recourse, personnel fluctuations, tight commissioning deadlines, indifferent IEs and supplier issues. These might result in abbreviated planning and installation using inexperienced sub-contractors, which in turn causes defects being built directly into solar installations, masked by the aforementioned clipping bank account.

Even those who think they are choosing the best products are bound to be disappointed with systematic defects originating directly from the manufacturers or as a result of improper handling on site. As the secondary market matures, current and future system owners must understand the status and value of systems looking forward. Installation contractors must employ accurate data to defend themselves against disputes from claims of nonvisible damages to defective components.

Especially for modules, it is vital to characterise the complexities of degradation. This way, poor-performing modules can be removed before they impact on the ongoing output, or, at minimum, their state documented to prevent future litigation. Since early-life degradation is often a very subtle phenomenon, solar industry stakeholders tend to believe it cannot be detected through typical outdoor monitoring. This perception is being disproved in the market, as field-testing services are now available to detect early-life degradation issues at appropriate time intervals and sensitivity levels, and with meaningful measurement accuracies. The testing of modules in the field means that results can be acquired without moving modules from their in situ locations.

One predictive method – electroluminescence (EL) imaging – takes advantage of the radiative interband recombination that occurs among excited charge carriers in solar cells. To obtain the image, the testing contractor operates a solar module as a light-emitting diode, so that it can detect the emitted radiation with a sensitive Si-CCD camera. For EL images, the solar cells are supplied, via their metal contacts, with a defined external excitation current while the camera takes an image of the emitted photons.

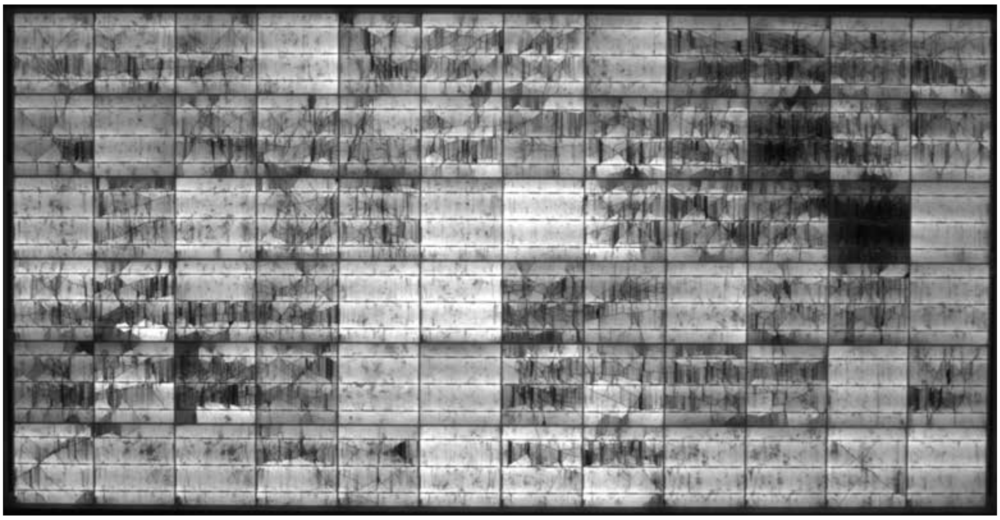


Figure 4. Field EL imaging, with modules installed in situ

As a general rule, damaged areas of a solar module will appear darker than fully functional areas (Fig. 4). EL techniques provide a much higher resolution than that produced by infrared (IR) images, and reveal many details, such as:

- Microcracks
- Bad finger contacts
- Electrical shunts
- Interconnection and solder faults
- Resistance faults
- Fragments in broken cells
- Electrically separated cell areas
- Grain boundaries
- Crystallisation faults in cell material

Overall, when deployed properly, baseline and periodic EL images allow system owners to finely chart and characterise dips in module performance. They can accurately determine if production shortfalls are the result of manufacturing defects or originate from damage that was inflicted after delivery to the installation site, or if the shortfalls are merely expected fall-off. With the use of EL imaging in combination with lot inspections at the manufacturing site, transportation issues become equally visible.

"The production of a traceable product-quality lineage provides protection and accountability"

In a recent case, TÜV Rheinland used EL imaging to conduct pre-installation module testing for an EPC client. The tests revealed that more than 40% of the client's modules had arrived on site with a defect which was otherwise imperceptible via alternative test methods. Moreover, these defects were of such a nature that they would worsen over time and prematurely accelerate the system's expected performance decline, which may conceivably be non-linear. The EPC was able to cease installation activities and initiate a replacement of the damaged product by the manufacturer.

Whether you are a component manufacturer, system owner, or system operator, the production of a traceable product-quality lineage provides protection and accountability, fundamentally establishing a strong level of trust among all parties. If a financier knows that such a lineage can weed out underperforming components early, and recoup losses in instances where underperformance can be traced to specific manufacturing defects, they are going to be more inclined to continue investing. If manufacturers know that they are not going be held responsible for on-site damage or design failure they too can breathe easier. Financial interests are protected for all stakeholders by involving a third-party process at critical milestones that uses scientific methods to produce standardised data across the value chain.

Managing for long-term returns – a function of measurement scope

Once solar modules have been fully deployed and are operational in the field, the focus for owners and investors shifts primarily to billing-meter data.

These owners most likely contract an asset management company to collect data about ongoing performance of the project. The data gathered relates to daily operations, but may also be generated from periodic inspections and maintenance. The questions are: how is this data used, how is it collected and who collects it? For example, system commissioning is often performed by the installation contractor, who is typically not motived by the accuracy of the data, but rather by the fact that the measurements trigger the next milestone payment. Along with this, installation contractors are not trained in accurate repeatable measurements and the applicable standard IEC 62446, nor are they familiar with calibration and factors affecting accuracy. The outcome is not just inaccurate data, but worse – non-comparable data (e.g. data with unknown accuracy). Generally, measuring the AC meter and cursory DC measurements does not provide insight into the performance or plant status. Yield or complex performance ratio – taking into account all environmental factors (e.g. soiling), equipment factors (e.g. degradation), business factors (e.g. demanded performance reduction IEC 63019) and technical complexity – is a necessary metric for measuring and optimising performance as well as maintaining the value of the asset.

The purpose of baseline information – continuous, compatible data – is that it can be used in a comparative manner to assess and predict degradation and future performance. In the case of solar modules this is done specifically to monitor warranted performance. For this to happen the module performance ratio, corrected for environmental (e.g. temperature and irradiance) and device factors (e.g. specified degradation), has to be taken into consideration. Other components (e.g. inverters) must be equally vetted for lifetime performance and should be subjected to continuous and periodic measurement. Remote monitoring on its own is therefore not sufficient: verifiable data, along with all performance factors and accuracy data, must be collected using standardised methods (e.g. IEC 61724) and recorded at milestone intervals.

No system owner will be able to test every module across its project (or projects), because of the high cost and long lead time: thus statistical sampling is essential for the propagation of good data [3]. As an example, advances in EL imaging technology enable owners to be more precise with defect detection, as well as allowing them to investigate larger sections of their arrays more efficiently. The use of EL imaging provides for a much greater sample size and ultimately yields a more accurate, and more statistically significant, representation of site performance than was possible just a few years ago.

With a larger scope of data at their disposal, market stakeholders have the ability to establish a whole new set of business goals and outcomes, and make more informed decisions.

Improve plant output, in real time

Better data will lead to improved operations. The first area affected will undoubtedly be the improvement in O&M efficiency, as well as the likely reduction in O&M costs on the basis of the accurate and timely data employed using methods such as cost priority number (CPN) to trigger cost-optimised O&M. This enhanced data and increased operational efficacy will surely be selling points in the secondary market by reducing the risk to new buyers and adding a measure of control that was not previously available.

Improve plant longevity

With a greater volume of functional data in hand, owners are better positioned to identify system weak points as well as system strengths. With independently conducted periodic milestone measurements of key system elements (inverters, modules, etc.) and continuous monitoring, CPN-based maintenance becomes an important tool for cost reduction and performance optimisation. As data patterns emerge, pending failures become manageable.

> "Documentation and irrefutable, precise data reduce doubt and uncertainty"

O&Ms prove their worth

Finally, in recent years owners and investors have thrown down the challenge to O&M providers to provide better communication about the value they are adding to projects [4]. O&M companies are not certified or trained to any central overarching standard. They are typically not subjected to process or data validation, as in the case of their construction counterparts. This all needs to change. Owners will be frugal with O&M dollars if this data is available to them, independently obtained, compatible and timely, using IEC (or IECRE) standards. O&M performance will not be measured relative to predicted performance, but will be flexible and based on precise and sufficient data. O&M contracts have often been signed with the contractor who built the system, a fundamental conflict of interest if used by the O&M as a way to recoup income that may have been lost in the construction negotiation process.

The key to communication lies in data about whether, and how, the operator has made a noticeable difference to plant performance and energy yield. It is not just about taking actions to improve yield, however: operators have to prove what they really did. The quality of documentation – the status, not just plant performance – has become an important metric in the value chain, and it is data that feeds this burden of proof.

A qualified IE will provide the trust to deliver the data needed for all stakeholders to interact in the project, continually and at critical life-cycle milestones, using standardised processes and measurement methods and precise, compatible data.

Risk mitigation in context

In order for investors, owners and other solar stakeholders to achieve long-term value, the focus will always be on narrowing down causal factors for performance loss, removing all sense of uncertainty, and mitigating risk.

Risk takes different forms for different stakeholders. For instance, EPCs and installation companies need to manage short-term risk; not only do they need to safeguard against initial performance shortfalls, but they also need to prove that their handling of the product did not alter the state of the product in any way. Documentation and irrefutable, precise data reduce doubt and uncertainty.

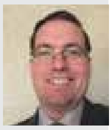
System owners and investors, on the other hand, need the system's output to not only cover and exceed a defined term of debt payments, but also produce maximal returns once the investment is free and clear.

The unifying factor for mitigating both of these risk profiles is to move away from the 'check the box' mentality that has become the norm for system testing. Solar products must already be certified *safe* by nationally recognised testing laboratories (NRTLs) [5], and the question deserves to be asked: what does the industry stand to gain if it holds itself to the same principle when testing for system quality and performance as well?

If manufacturers, owners, operators and investors all operate from the standpoint that the component life-cycle testing process must be calibrated, traceable and standardised, then trust among industry actors and lifetime value can each be unleashed to its true potential. The impact of bad data on operations, cash flow and ROI is just too great a risk to accept.

The industry has laid the groundwork with the SGIP 'Orange Button$^{\text{TM}}$' [6] and IECRE [7] standards, and so it is perhaps time for the industry to employ all the tools at its disposal. ■

Authors



Mark Skidmore has over 14 years' experience in the solar industry, and over 18 years' experience in the construction contracting industry. A registered professional electrical engineer (PE), certified energy manager (CEM) and NABCEP solar professional, he holds a university degree in mechanical engineering and is the solar plant services manager at TÜV Rheinland, Tempe (USA).

Samantha Doshi has over five years' experience in the areas of PV module certification, laboratory module and component testing, and field performance and failure analysis. She has a university degree in mechanical engineering and serves as the solar performance manager at TÜV Rheinland, Tempe (USA).

Matthias Heinze is the director of business development at TÜV Rheinland, and has several decades' experience in the areas of PV plant qualification and monitoring, laboratory module and component testing, performance measurement and failure analysis. He has a university degree in engineering and is an active member of the IECRE.

Christos Monokroussos received his doctorate in photovoltaics from Loughborough University, UK, and has 10 years' experience in PV research. His activities centre on solar cell characterisation, PV modules, PV measurement systems and PV module reliability. An active member of the IECRE, he is currently the director of R&D in the TÜV Rheinland solar and fuel cells business field.

References

[1] Wood Mackenzie, Limited/SEIA 2017, "U.S. solar market insight executive summary Q2 2017" [http://www.seia.org/research-resources/solar-market-insight-report-2017-q2].

[2] U.S. Energy Information Administration 2017, "Annual energy outlook 2017", p. 32, Table A16 [https://www.eia.gov/outlooks/aeo/pdf/appa.pdf].

[3] GTM Media 2013, "A more realistic take on solar module testing" [https://www.greentechmedia.com/articles/read/A-More-Realistic-Take-on-Solar-Module-Testing].

[4] PV Tech 2017, "O&M providers need to 'step into shoes of investors' – Intersolar Europe" [https://www.pv-tech.org/news/om-providers-need-to-step-into-shoes-of-investors-intersolar-europe].

[5] GTM Media 2012, "What do solar module test procedures prove?" [https://www.greentechmedia.com/articles/read/what-do-solar-module-test-procedures-prove].

[6] SGIP 2017, "Orange Button$^{\text{SM}}$" [http://www.sgip.org/orange-button/].

[7] IECRE 2017, "Solar PV energy" [http://www.iecre.org/sectors/solarpvenergy/].
