Implementing risk mitigation strategies through module factory and production inspections

Quality | Developers and investors must be proactive to ensure the quality of modules they purchase is as high as possible. Vicente Parra and Ruperto Gomez detail some of the practices they can follow to mitigate module quality risks during the manufacturing process

Today, every player involved in the development of a large-scale solar PV project is aware of novel PV module concepts like half-cut cell, double-glass, mono/multi-PERC, black silicon or bifacial technologies, among many others. All of them are innovations or upgrades to the common crystalline silicon technology that has been used for many years, the well-known glass/back-sheet Al-BSF design. Each year, module manufacturers announce their brand-new, high-efficiency and cost-optimised PV modules in vast exhibition events worldwide. This systematic tendency has probably been the main driving force for the present, 'here-to-stay' deployment of the PV industry and market, globally. While this is good news for the PV technology evolution, all innovation is usually inferred by investors as a potential risk, in the sense that the long-term behaviour of these new devices is not properly known and tested yet. Indeed, the abovementioned classical Al-BSF module still suffers from outdoor failures and underperformance issues, notwithstanding its well-studied device structure and performance.

Therefore, the main concerns for PV investors and developers continue to be the quality and reliability of the modules, very complex concepts that must be duly scrutinised and warranted, usually in close cooperation with independent PV consultants, such as Enertis Solar.

Credit: Hanwha Q CELLS

Quality control

In the last 10 years, the expenditures related to PV plant construction and operation have been reduced considerably. CAPEX reduction accounts for approximately 85% and OPEX has dropped by more than 50%. Cost reduction has also been a key cause for the global market growth that is currently being experienced. For instance, the public renewable energy auctions for large-scale power projects that are being implemented worldwide today are leading to unprecedented low solar energy prices, such as those of Mexico, Chile or Saudi Arabia, as important examples. Nowadays, no one is especially surprised to find press releases covering new PV project developments with 150MW, 200MW or even larger capacities, as standard figures. As a comparative reference, in 2008, the largest PV plants in Spain (leading market at that time) hardly exceeded 15-20MW of installed power, using nearly 50% less powerful PV modules than today.

This 'big-size/lower-cost' scenario is definitely changing the development of a PV project. This is especially significant with regard to the acquisition of large PV module orders from Asian manufacturers, which need a very carefully planned process by the buyers.

Thorough inspections of modules prior to shipping is a key part of the quality control process

A 150MWp supply comprises around 450,000 individual PV modules. These are made of approximately 20 different materials of varying structures, purpose and composition (e.g. PV cells devices, glass, polymer encapsulants and back-sheet, metal ribbon connectors, adhesives and potting material, junction box, cable, by-pass diodes, etc.). These materials, in turn, can come from many different suppliers, which are able to produce diverse models based on individual features and performances. Altogether, the final list of materials comprising the PV module is the so-called 'bill of materials' (BOM), a major concept related to quality that will be revisited later in this article. Likewise, the manufacturing of large supplies of PV modules will usually encompass the use of more than one factory location (a factory usually contains one or more workshops; a workshop is based on one or more production lines) during several uninterrupted months.

Consequently, there are many variables (different materials and factories, extended time, etc.) to be carefully set up by a manufacturer before undertaking the production of a MWp-based supply of PV modules. Therefore, the implementation of consistent, traceable and stable manufacturing processes all over the production period becomes mandatory to safeguard and ensure the quality of the PV modules, which are the energy generator, and thus the core of the power plant.

In this regard, mitigation practices for quality risks during manufacturing are being increasingly demanded by any sophisticated PV developer and investor, by implementing third-party inspection activities throughout the production period (including on a 24/7 basis). They are understood as customised ways to mitigate risks at early stages of the PV project development. As evidenced by Enertis experience, many PV module failures and underperformance issues arising at a PV plant during its lifetime can be directly associated with the implementation of low-quality production processes or the use of non-certified BOM lists and materials.

Frequently, when a PV developer or EPC contractor ask for quotations for a, e.g. 150MWp PV project to five different Asian PV module suppliers (let's consider the so-called Tier-1 manufacturers), the respective commercial proposals are based on different module technologies among suppliers, with diverse power distributions. Occasionally, the manufacturer suggests several manufacturing workshops, some of them OEM-based (modules produced by a third-party manufacturer), to be potentially involved in the production of the supply (commonly in China or Southeast Asia countries). If, just a few weeks later, a new buyer replicates this request, for an equivalent project site, it will most likely receive (very) different technical proposals from these same five suppliers. Therefore, the PV module market depends upon the existing availability at the time of request, the estimated production capacities in the short/mid-term and the specific market goals and strategies that each supplier seeks to develop. However, the level of adequacy of the PV device (including constructive materials to be used) for the specific environments and conditions of the PV plant (high irradiances, desert locations, shore environments, windy sites, etc.), are scarcely considered as major variables when the supplier submits the quotation.

In any case, by default, the maximum product quality is assumed and confirmed by the manufacturers via IEC and ISO standard certificates, including BOM and factories/workshops to be eventually used in production. Unfortunately, according to Enertis Solar's experience, the assurance of the quality and reliability of the eventual supply needs further verifications, at various levels. In theory, Tier-1 suppliers are a trustworthy choice for any stakeholder involved in the development of a PV project, even though the commercial-based metric for the company, which is somewhat clichéd these days, should not be automatically associated with "Quality-1". Also, as per Enertis Solar experience over recent years, with more than a 40GW track record as a PV consultant and independent engineer, a PV module is still far from being considered a commodity, precisely because of the dozens of variables that influence its performance, quality and reliability, not to mention the new device concepts steadily coming to the market.

It is known that many Chinese Tier-1 suppliers suffered from financial problems in the recent past. Their operations are typically based on debt, in an industry that does not favour positive cash flows. Furthermore, most of these manufacturers are systematically undertaking huge capacity expansion plans, in order to satisfy the increasing PV market demands in China and the rest of the world, in a continuous context of price fluctuations and tight delivery schedules.

In summary, notwithstanding the accredited and well-proven technological/R&D know-how and supply capacity of the PV manufacturing industry over the years, this market scenario creates a risky cocktail for PV developers, investors and lenders.

A quality risk mitigation strategy

Therefore, it is highly recommended for PV module buyers (either PV plant owners or EPC contractors) to design a Quality Assurance and Quality Control (QAQC) strategy before tackling the purchase of thousands or millions of PV modules for their utility-scale PV projects.

This strategy should be based on the three main aspects below:

i) The determination of a detailed module technical specification sheet, to be included in the corresponding request for proposal process, indicating any specific need to be fulfilled by the supplier, addressing the special environmental conditions of the PV site, if any. These needs are usually covered by, but not limited to, the IEC standard certificates.
ii) A shortlisting process via technical due diligence or supplier assessment.
iii) The establishment of a suitable 'module supply agreement' (MSA) with the manufacturer that accurately stipulates every aspect related to module quality requirements and batch acceptance before shipment from the factory and after delivery at the site.

This MSA should collect all certification quality requirements for both modules and factory capabilities, the protocols for production inspection, a clear definition and requisites for the BOM, and the sampling and module testing procedures to be implemented to regulate the pass or fail condition of a batch prior to shipment.

As mentioned before, solar PV technology has experienced a tremendous evolution in the last few years. In contrast with this optimistic evidence, there is a consensus among PV developers and independent consultants regarding the certain obsolescence of the module warranties still offered by the suppliers (the so-called Product and Performance Warranties). Therefore, as part of the risk mitigation strategy, in Enertis Solar's opinion, these standard warranties should also be subject to revision and updates in the MSA, redefining the concept of defect, together with the valid protocols to control and confirm any module failure event in a practical and undeniable way.

A highly recommended practice, to be also stated in the MSA, is what Enertis calls a Pre-Production Factory Audit. This audit process seeks to detect any potential quality risk associated to the Standard Operational Procedures (SOP) and Quality Management System (QMS) of the manufacturer. This is especially important when the supplier proposes several workshops from different locations, even countries, sometimes even based on OEM factories, as the respective SOP, QMS and BOM management can diverge more than expected. Additionally, other key aspects under evaluation are the in-house PV laboratory capacities, the traceability system and the training level of the operators (these factories often experience high rotations of personnel over short periods of time). The audit outcome, per production workshop, is its 'pass' or 'fail' condition to guarantee a minimum level of quality in the modules. Even if the result is a pass, a corrective or improvement action plan is usually triggered, which should be addressed and completed by the manufacturer prior to the official commencement of the production plan. This task is carried out by the auditors in close collaboration with the manufacturers, which, indirectly, helps them improve their processes and protocols.

During the audit, it is also recommended to select some module samples with an equivalent BOM (at least the PV cell device) to the one included in the supply, and then produce calibrated modules in an external and independent PV test laboratory. These modules will be used as standard references for the maximum power measurements, via I-V flash testers, during the inline production period and laboratory retesting for individual batch acceptance purposes. These reference modules will help guarantee the measurement of accurate maximum peak power values of the modules under production. Moreover, these added-value modules should be carefully handled and stored in the workshops, then shipped to the PV site, as their role can be very useful in subsequent testing activities upon delivery at the PV site and any time during the lifespan of the PV modules (warranty claims, for example).

For the batch acceptance testing, it is worth defining the size of the individual *manufacturing batch*, which should correlate, preferably, with the *delivery batch*, so that the sampling and quality criteria stipulated in the MSA can be directly ascribed to a well-defined module population.

Ideally, a batch should be based on only one BOM, defined as a closed list of construction materials, limited by one model per each material. Usually, most module manufacturers propose BOM lists that imply hundreds of potential material combinations, with the use of, for example, 10 PV cell providers, six glass models, four polymer encapsulants and back-sheets and three different junction box/connector suppliers. The final BOM list/s should be duly certified according to the individual IEC certificates requested for every project, going beyond the basic IEC 61215 and 61730 standards. By 'duly certified', we mean updated certificates associated with the selected workshops, coupled with the corresponding test reports per IEC certificate, including the BOM used to pass the respective test or test sequence. The well-known Constructional Data Forms (CDF) are typically considered as proof of BOM compliance versus IEC requirements, although these documents do not actually constitute irrefutable evidences of such technical agreement.

Additional inspection procedures related to the quality control of modules can also be proposed, in a different context than that of an MSA, extending the responsibility in the event of module underperformance to other project stakeholders beyond the PV module supplier. This topic is out of the scope of the present communication and is worthy of an entire article in itself.

Overseeing module production

As mentioned before, the manufacturing of a large supply of PV modules needs to be consistent and reliable over the entire production period, and in every workshop eventually implemented by the supplier and previously accepted by the independent auditor.

"The implementation of consistent, traceable and stable manufacturing processes becomes mandatory to safeguard and ensure the quality of the PV modules"

For this purpose, current market practices are the use of third-party inspector companies that verify that the MSA requirements are strictly followed during production and oversee the previously audited SOP and QMS procedures of the manufacturer. This basically covers control points such as: warehouse conditions, production orders (BOM verification), incoming material quality controls and every production step involved in the process (tabbing/stringing, lay-up, lamination, framing, junction box adhesion, curing, flash test process, etc.).

As it happens in any inline manufacturing process, not only in the PV industry, a series of defects (either of random or systematic nature) and non-conformities may arise during production, affecting the materials condition, the adequacy of the equipment maintenance and adjustment, the process traceability, etc. In consequence, a detailed third-party inspection is really useful for monitoring and correcting any potential deviation encountered during production, and especially in critical production steps like soldering, lamination, flash testing and packaging.

This inspection should be thoroughly coordinated with the manufacturer, in order to assist the operators and production engineers with the identification and fulfilment of the specific quality criteria and features of the supply under production, which might evidently differ from others simultaneously running, based on different MSA conditions.

An essential part of this oversight process is the so-called Pre-Shipment Inspection (PSI) testing, which aims at the determination of the pass or fail condition of the previously defined batch of modules. This has to be performed before shipment to the PV site, either at the manufacturer's facilities or in an ISO/IEC 17025 accredited laboratory managed by the inspector (both laboratories can even be involved). This testing task needs to be swiftly completed, almost in real time during production. For this purpose, the PSI must be based on a well-established module sampling, selecting a limited quantity of modules that represent the respective batch (the BOM is usually a variable included in the sampling equation).

The idea behind this key exercise is to get rapid and reliable knowledge about the main quality condition of the batches under production. The type and quantity of tests is not standardised by any international body and so it will always depend on the specific MSA conditions and PV project features. Therefore, the PSI testing is usually accomplished via straightforward measurements like visual and electroluminescence inspections, hotspot checking, electrical insulation-based tests or maximum power retest, as simple and fast methods to diagnose any major defect in a PV module. Moreover, if a sampling and testing plan is properly coordinated with the respective shipment dates, per batch, extended tests that address the propensity of the modules to certain degradation phenomena can be also conducted, even within a PSI batch context.

Especially valuable are tests for light-induced degradation (LID), applying short light soaking periods, and potential-induced degradation (PID), following, but not restricted to, the somewhat limited IEC TS 62804 guidelines. These tests, in spite of their inherent time-consuming nature, have been systematically implemented by Enertis Solar in many PSI procedures, leading to batch acceptance/

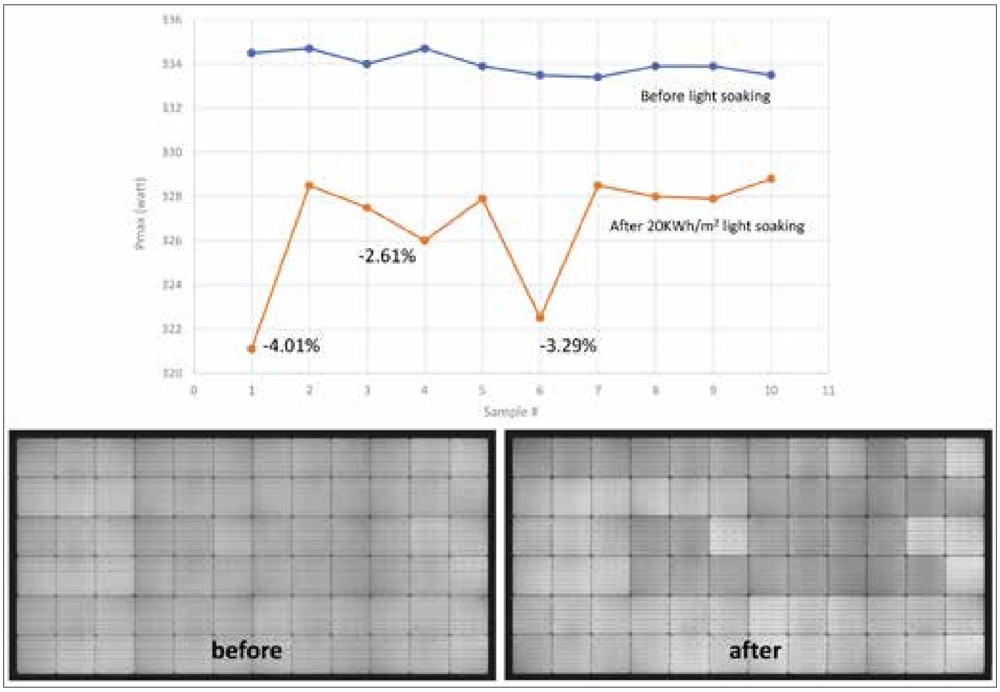

Figure 1. a) Maximum power flash test results before and after 20KWh/m², for a small sample of 72-cell multi-crystalline silicon PV modules from the same production batch. Up to 4% degradation can be evidenced, despite the short light soak period applied; b) electroluminescence images of a mono-PERC based module after an equivalent outdoor exposure period, resulting in 3.3% maximum power degradation. The images show a lower cell activity behaviour in some of the cells because of transient LID effects

rejection outcomes and/or change of BOM materials. LID behaviour, even after short outdoor exposures (20KWh/m2) in open circuit conditions, is quite variable, as it depends upon the individual characteristics of the solar wafers and cells forming the module, and so it is worth checking (Figure 1).

Regarding PID, as per Enertis Solar's experience, it is nowadays much better controlled by PV module and solar material suppliers. Still, many PV investors and developers consider PID as one of the most harmful degradation effects that a PV power plant can be affected by, and so they continue to request maximum warranties against it. In fact, the tacit 'PID-free' condition usually claimed in module datasheets is not well proven yet. Figure 2 collects a box-plot analysis with a series of PID stress tests involving new and randomly selected crystalline silicon PV modules, from several suppliers (BOM variable was not controlled, purposefully), all of them claimed to be PID-free. From the plot, it seems evident that, notwithstanding the promising low degradation values shown by most of the manufacturers (medians well below 5% degradation), the technical risk does remain latent, with severe outlier module degradations found in some cases (from 10 to 35+% degradations).

Many other testing approaches may be proposed and agreed with a manufacturer, with no necessary correlation to individual batch acceptance/rejection purposes, per se. Common examples are the temperature coefficients crosschecks, maximum power behaviour at various temperature-irradiance conditions or extended UV-resistance tests.

In conclusion, despite the unquestionably elevated know-how of most PV manufacturers worldwide, the current PV module market status is opening the way to the implementation of QAQC risk mitigation strategies at earlier phases of project development, so that maximum returns on investment can be ensured, especially when large-scale PV power plants are involved. ■

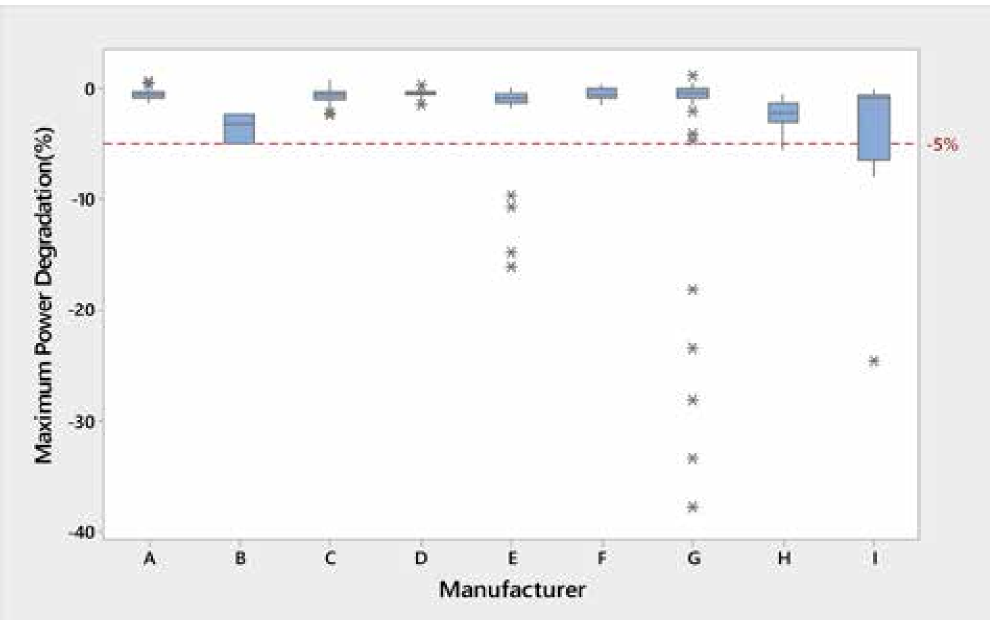

Figure 2. Box-plot analysis showing PID degradation results from some randomly selected PID-free modules manufactured by several Tier-1 suppliers. The basic IEC TS 62804 guidelines were applied, as a simple method to check the general propensity of a module to be affected by PID phenomenon

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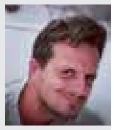

Dr Vicente Parra is the head of quality, innovation and technology at Enertis Solar. He has a 10-year track record in the PV industry, as technology manager in solar companies devoted to silicon ingots, wafers, cells and modules manufacturing. Vicente has managed testing projects dealing with 15,000+ PV modules, from nearly 50 suppliers and 200+ PV plants worldwide. Also, he has led many factory/production inspection and supply agreement advisory activities, totalling more than 3GWp so far.

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