Electroluminescence inspection: Revisiting the hidden side of a PV module

Inspection | The advancement of solar cell and module technology has meant ever larger, higher power modules are being manufactured, shipped and installed at increasing speeds, placing renewed importance on product testing and inspection. Here, Enertis explores the role of electroluminescence inspection throughout the lifespan of a PV project.

Credit: Enertis

Electroluminescence testing underway.

The large solar PV deployment experienced in recent years is a consequence of dynamic advances and optimisations of several techno-economic and social features, so that the present state of the solar PV market is now healthier than ever. Today's PV plants are based on hundreds of thousands of large size crystalline silicon panels made of *e.g.* 150 pieces of state-of-the-art solar cells, linked through innovative connection approaches, with bifacial modules becoming a mainstream technology. These modules are, in turn, produced inline by gigawatt-based companies and shipped to sites in record times worldwide.

Regarding module manufacturing, the continuous – sometimes not properly validated –innovations and production line upgrades required to mass-produce brand new modules and serve the rising market demands have historically led to novel solutions, but also, to a misjudgement of not easily detectable quality defects coming from solar cell assembly into modules. Likewise, construction costs, mounting and grid connection lead times for utility-scale PV plants have been drastically reduced over the years.

Overall, this suggests that the implementation of increased levels of inspection by means of cost-effective and fast techniques is more than ever justified. Thus, considering that a PV module could be constantly subject to damages at different stages of a PV project, there is no doubt that the oft-used Electroluminescence (EL) inspection technique is one of the most widespread tools able to survey PV modules in a massive and affordable way. Indeed, today, everyone involved in PV project development is aware of the EL inspection as a non-invasive and hands-on methodology for the detection of electrical-based defects in solar PV modules [1].

Briefly, performing an EL measurement over a PV module implies injecting current in forward bias through a DC supply source, typically in dark conditions, in order to reach proper signal-to-noise ratios and then get good-quality EL outcomes. As a result, the PV device's active parts spontaneously emit luminescence radiation in a certain wavelength, which is then collected by a suitable detector. The EL emission is processed into a contrast image or map, unveiling regions with different luminescent activity, ultimately interpreted as defects, which cannot be detected by the human eye.

In practice, an EL analysis will reveal healthy or defective regions within the sample being inspected, presenting different series and shunt electrical resistances, in a qualitative, fast and straightforward way. Modulating the level of current injection will account for different electrical resistance regimes, therefore helping understand what is going on in the cell or module under test. Therefore, any low EL image contrast feature will generally infer the existence of hidden defects in its structure or architecture causing it to happen.

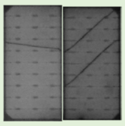
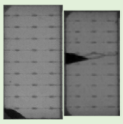
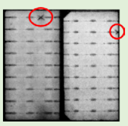
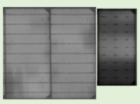
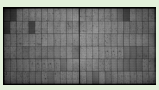
Since early times, from the works by Fuyuki *et al.* [2], the EL inspection keeps being implemented, together with the Infrared Thermal inspection (IR), as a reliable, cost-effective and massive quality screening technique for PV module suppliers, laboratories and even EPC players. Over the years, the patent and extended implementation of the EL testing has motivated great improvements in operational inspection modes, such as mobile labs [3], drones [4] and also advanced image processing [5], to the point that, nowadays, the original and rather utopic ability to also perform EL imaging in standard daylight conditions has been realised [6].

A wide range of EL signal collection detectors are at present used for various applications; in short: silicon-CCD systems, cost-effective CMOS reflex cameras (duly adapted to the 1150 nm emission of crystalline silicon devices), or those based on InGaAs, expensive but especially efficient for certain cases. Choosing one of them is, in the end, a trade-off amongst resolution, sensitivity, spectral range and, ultimately, price, depending on the EL inspection context and eventual goal.

However, as a common evolution for every new technology that is rapidly and successfully applied in end-user market applications, the affordable, non-destructive and intuitive nature of EL has in turn led to certain overuses and misinterpretations, sometimes leading to major consequences influencing a PV project's economics. This comes from the use of the unquestionably valuable, but somewhat limited qualitative-based information that is accessible from an EL picture.

The interpretation of an EL image has always suffered from biases or a certain subjectivity, stemming from the lack of consensus in the industry about what an EL defect is. Also, the often rather unknown physical and chemical mechanisms and ensuing short-to-long term impacts behind the issues revealed in a damaged solar cell makes the consequences of EL analysis more complicated. In this regard, the TC 82 work group of the International Electrotechnical Commission (IEC), devoted to solar systems and devices, recently released the IEC TS 60904-13:2018 document [7], aimed at establishing a series of recommended practices for capturing, processing and interpreting an EL image, as a preliminary guideline of an eventual standard applicable in the PV industry.

In any case, even if the mainstream market ends up adopting these standard guidelines, it is likely that there will always be room for EL interpretation to eventually become a universal, conflict-free and unbiased methodology for defects detection and categorisation. This is especially relevant in cases where EL inspection is used to correlate images with PV module performances, despite the interesting attempts made to date [8]. In some situa-

EL defect	Supplier						
	A	B	C	D	E	F	G
Microcrack 	Severity: MAJOR q≤2; Q<1/20	Severity: MAJOR q≤3; Q≤6%	Severity: MAJOR 1) l<10mm ignored 2) q≤2; Q≤8 3) Total l; q=0	Severity: MINOR q≤1; Q≤8;	Severity: MAJOR 1) l≤1/5L; q≤1; Q≤4)	Severity: N/A A≤5%; Q≤8%	Severity: MAJOR q≤1; Q≤3
Breakage/Inactive area 	Severity: MAJOR A≤5%; Q<1/20	Severity: MAJOR q≤1; A≤5%; Q≤5%	Severity: MAJOR q≤1; A≤2%; Q≤2	Severity: MINOR A≤5%; Q≤2	Severity: MAJOR q≤1; A≤2%; Q≤3	Severity: N/A A≤8%; Q≤6%	Severity: MAJOR q≤1; A≤5%; Q≤3
Cross-shaped crack 	Severity: MAJOR l≤1/15L; q≤2; Q≤4	Severity: MAJOR l≤1/15L; q≤2; Q≤3	No specific criterium. Applying above microcrack criteria	Severity: MAJOR l≤8mm; q≤2; Q≤10	Severity: MAJOR l≤1/15L; q ≤1; Q ≤4	Severity: N/A q≤2; Q≤8	Severity: MAJOR l≤1/12L; q ≤1; Q ≤2
Soldering defect 	Severity: MAJOR 1) A≤5%; Q≤1/12 2) A≤10%; Q≤1/24	Severity: MAJOR A≤10%; Q≤5%	Severity: MAJOR q≤1; 2<Q<5	Severity: MAJOR 1) Total l, q=0 2) A<10%; Q≤10	Severity: MAJOR 1) Total l; q=0 2) W ≤1/6; Q≤10%	Severity: N/A 1) A≤6.7%; Q≤8% C 2) 6.7%<A≤10%; Q≤5%	Severity: MAJOR 1) l≤1/8L 2) Total l; q=0
Mixed-cell activity 	Severity: MAJOR Non-objective criteria Numbers of cells: no limited	Severity: MAJOR 1. Gray difference <25%, allowed. 2. 25%≤gray difference≤30%; Q≤5% 3. Gray difference>30%. Not allowed	Severity: MINOR Q≤4	Severity: MINOR Non-objective criteria; Q≤6	Severity: MAJOR Non objective criteria; Q≤5	Severity: MAJOR Non objective criteria; Q≤5	Severity: MAJOR Non objective criteria; Q≤5

** q: quantity of defects in an individual cell; Q: quantity of cells affected; l: defect length; L: cell length; A: cell area; W: defect/cell width*

Table 1. Variations among current EL defect acceptance criteria of several top-sales Tier-1 manufacturers applicable for different module datasheet products.

tions, extrapolating EL-based outcomes to financial or legal consequences does lead EL inspection to be complemented by other well-known module characterisation approaches such as I-V curve measurement or IR thermography, enabling a complete understanding of the mechanisms behind the defects and then draw more accurate and fair conclusions, especially in cases where penalties or warranty claims are involved.

Notwithstanding this, and thanks to the surveying role of expert third-party inspection and testing entities such as Enertis; EL will remain an essential means to check the quality condition of a PV module in different situations during the PV project lifetime: i) yet from the definition of defect criteria in a Module Supply Agreement (MSA) or EPC contract; ii) through the physical collection and assessment of EL images during modules' production; iii) prior to shipment; iv) upon delivery; v) and even after installation in fixed structures and trackers.

EL inspection is, therefore, of great interest and support for the implementation of reliable solar PV power as the main source of clean energy worldwide. Thus, sooner or later during the development of a solar PV project, the discussion about setting module's EL defect criteria, sampling rules for testing and derived liabilities in case of non-conformities shall ultimately come up.

At this point, around fifteen years after EL burst onto the solar industry, within the era of the innovative and high-powered PV cells/modules being at present launched by vertically integrated gigawatt-based manufacturers, produced and then installed in amazingly short times, we herein review the circumstances for which an EL analysis, designed and performed by expert independent advisors, can be an important decision-making tool for EPC companies and PV owners.

For this purpose, real cases devoted to EL inspection activities performed by Enertis in different project development and market contexts are reviewed and commented, namely:

- Manufacturing and pre-shipment testing.
- Delivery inspection.
- Post-installation inspection.

Manufacturing and Pre-Shipment Testing

By default, the PV industry assumes that a commercial PV module device, due to its complex composition and large surface,

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can present visual and hidden defects. However, the *PASS* or *FAIL* condition of a PV module, from an EL inspection perspective, remains unresolved, being entirely subject to every specific project case and associated MSA context. In addition, the acceptable limits are characteristically set per type of defect, without considering their respective accumulation.

Considering those imperceptible at naked eye, only revealed by means of EL inspection, a great disparity vis-à-vis the definition and judgment of defects among the so-called Tier-1 module manufacturers is systematically found. This trend is currently pronounced, as a result of the rapid development and release of new PV cell and module designs. Altogether, the release of these new products takes us several steps forward with needing to update the respective EL quality criteria.

Such inconsistency is patent both in terms of categorisation of defect severity – *minor, major, critical* – and its individual description, to the point that most suppliers keep using pretty much the same EL criteria for years, regardless of the introduction of new cell sizes (210mm), device architectures (PERC, both mono- and bifacial) and busbar interconnectors (from the not long ago common three to multi-busbar tiling/shingled connections). Non-negligible discrepancies can be even encountered within the same manufacturer, for an identical module datasheet and PV project location, with no apparent effect on module price.

To illustrate this, Table 1 collects examples of archetypal defects today reported throughout inline inspections, including the specific criterion and consideration made by several top-sales Tier-1 manufacturers. For clarity purposes, and also confidentiality reasons, the defect definition has been homogenised, with some criteria slightly construed, without any distortion of the original proposals from the manufacturers. Moreover, the EL

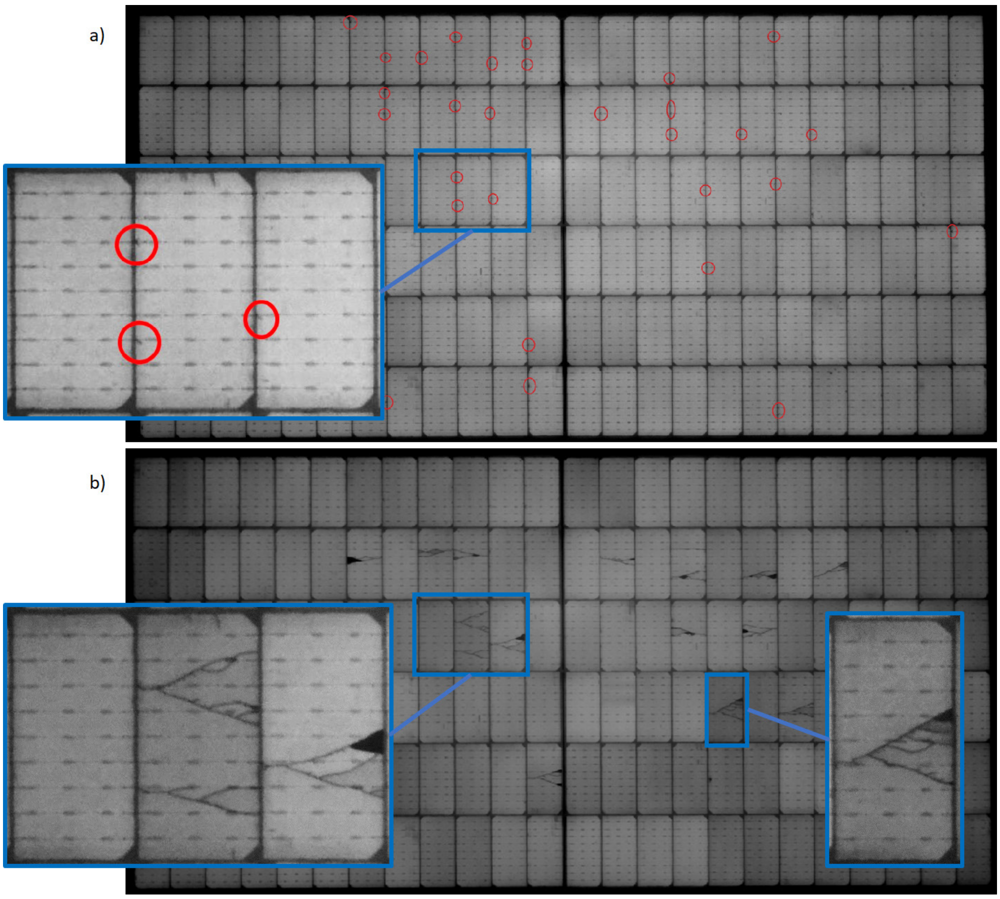

Figure 1. a) EL image of a PV module presenting cross-crack defects at cells' edges recorded by Enertis during batch acceptance testing; b) EL image after DML test (1000 cycles, 1000 Pa).

image insets were selected from production inspections performed by Enertis, as representative examples of each EL issue. As can be observed, the variability among suppliers is evident, both in terms of defect definition approach (areas, lengths, widths) and acceptance criteria (defect severity and/or limits). This market reality evidences the said lack of objective consensus when performing and interpreting an EL picture. Especially difficult is the case of the frequently observed *mixed-cell activity* defect in a PV module (Table 1), ascribable to the development of potential hotspot phenomena in the field, and also possibly reducing the long-term reliability of the panel due to the different electrical properties of wafers/cells taking part of the module's series connected substrings.

Therefore, the historical and somewhat reductionist tendency to consider a PV module as a commodity is, at present, looser than ever, even just from the determination and classification of a PV module through the type and quantity of relevant EL defects that are present, among the many other ways to inspect and validate a PV module, not to mention the abovementioned innovative new cell and module designs available in the market, from different vendors.

Furthermore, as per Enertis' experience, the level of restriction and discipline implemented by a vendor regarding EL testing and related actions is, by and large, a practical indicator of the capacity and willingness to provide the best products they can, extrapolating such modus operandi to other operational (e.g. traceability) and technical (Bill of Materials control, operators training, etc.) strategies and actions influencing the manufacturing process.

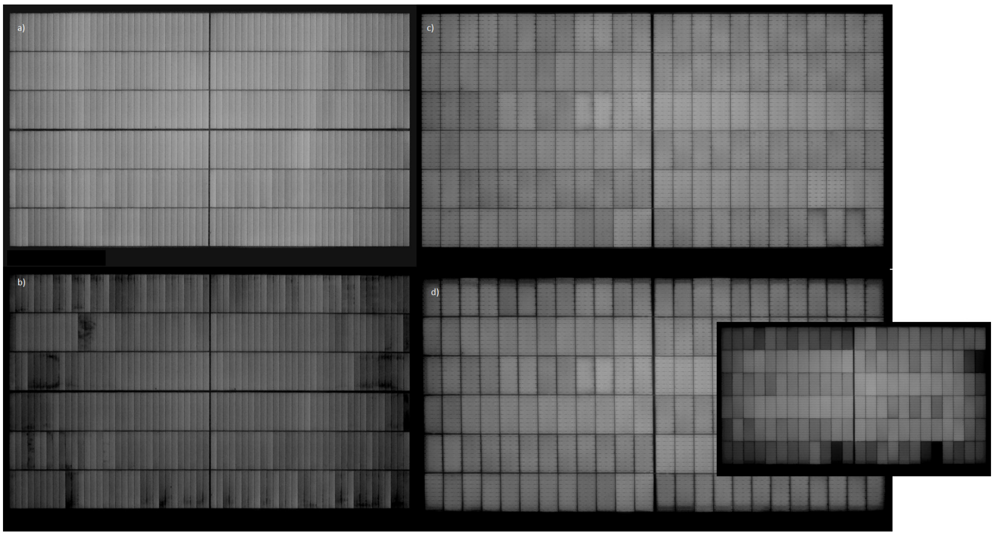

Figure 3. EL images of modules evidencing PID effects recorded at Isc; a) shingled PV module before PID; after PID test sequence, with many cells presenting low EL activity due to shunting phenomena; c) multi-busbar half-cut cell module before PID; d) after PID, for which several cells (especially those of module's borders) display poorer EL contrast, particularly at the perimeter, which might suggest the origination of shunt defects from cell cut process into halves. The inset EL image corresponds to module c) recorded at 10%Isc, in order to highlight the shunted cells in the module (PID test sequence: 96h, 85% relative humidity, 85°C, -1,500V). In both cases, from 4 to 6% degradations in maximum power were registered.

Today, it is well-known that reaching 600W+ output in a PV module implies enlarging module size and weight, basically due to the use of large silicon wafers going up to 210mm. Size increasing is to some extent palliated by all module suppliers via innovative cell interconnection approaches enabling non-active space reduction up to a few millimetres.

These novel welding methodologies, as well as the use of half-cut or even third-cut multi-busbar connected cells, can lead to rather insignificant, but harmful cross-shaped cracks in the vicinity of cell edges, particularly those affected by the laser cut into half or third sections, seldom reported by suppliers. This suggests that the mechanical stress occurring during cell soldering, plus the potential presence of chips at the wafers cut edges would facilitate the formation of such defects. Figure 1 depicts this effect in a visual and representative way. Despite the tiny affected surface and length of the micro-fissures, after a standard dynamic mechanical load (DML) test, as per IEC TS 62782:2016, nearly all cross-shaped cracks in cells from inner substrings in the module propagated into multi-cracks, also leading to cell disconnection issues in some wafer areas.

Another issue to tackle during manufacturing and pre-shipment inspections comes from the often-found variability among suppliers when capturing and processing the EL images inline. As mentioned before, diverse EL test conditions can account for varied defect mechanisms affecting the EL activity within the module, then resulting in differently nuanced EL outcomes. In Figure 2, a systematic weak soldering defect, not allowed by the supplier in the agreed EL quality criteria, could not be revealed in the inline controls performed by the supplier. In contrast, for the same module, the registered image by Enertis third-party laboratory during pre-shipment batch testing activities clearly unveiled the cell welding issue. In the present case, the EL technique triggered the rejection of a MWp-size batch on account of such defect. Furthermore, as corrective actions, the supplier adjusted the soldering process and EL test equipment accordingly.

In this regard, among suppliers, a noticeable disparity in terms of EL test setup can

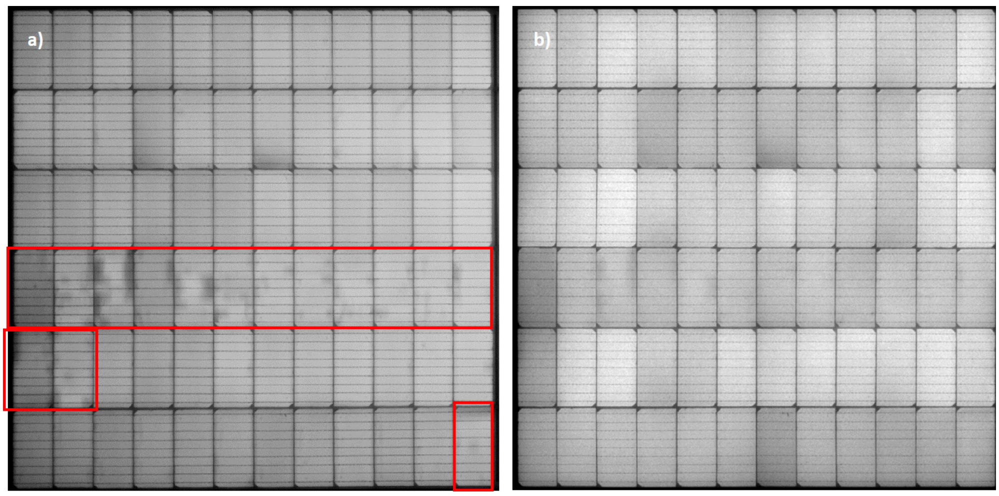

Figure 2. EL pictures of the same half-cut cell PV module (left side section) revealing marked defects associated to weak busbar soldering processes; a) registered by Enertis laboratory (10.6A polarisation DC current, CCD sensor); b) El picture recorded by the manufacturer (6.1A polarisation DC current, CMOS sensor) for inline quality control.

be evidenced during inline supervisions, even between workshops of the same manufacturer. In all the cases, polarisation current ranges from 5 to 8A, far below a module's short circuit current (Isc).

For many years, most PV module manufacturers have been declaring to sell products free from PID effects, including such condition in the respective panel datasheet through different labels such as *PID-free* or *anti-PID*. The usefulness of the EL technique as quick PID-detection means is well-known. Its use for performance-like issues such as PID (as well as LID and LeTID) remains effective to understand the propensity of modules to develop them. In fact, despite the efforts and undoubted advances made by most cell and module manufacturers so far, PID is yet to be fully overcome. Figure 3 illustrates this for two contemporary PV module designs, using the EL technique.

In summary, it seems clear that dealing with the assessment of EL defects during the shortlisting and future inspection process of a PV module supplier might not be as simple and standard as expected, especially if one pays attention to the current inconsistencies regarding EL-defect definitions, acceptance limits and potential consequences, considering the average thirty year-project's lifespan in front of the asset's owner.

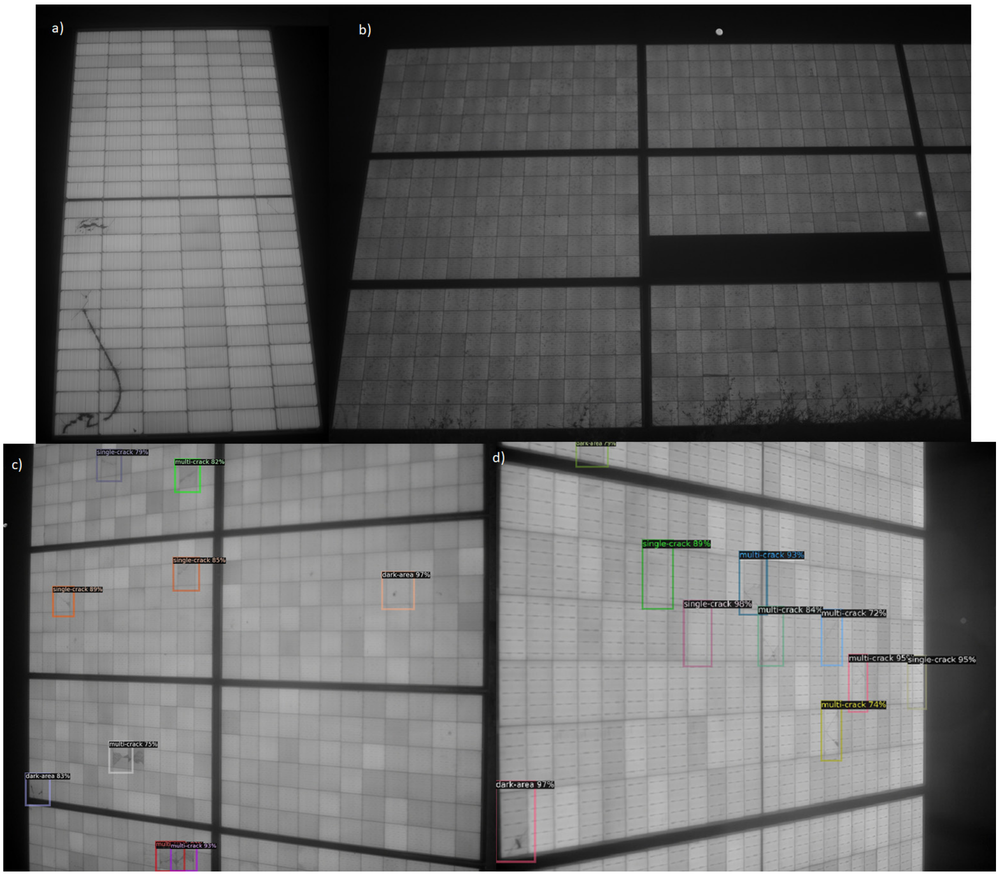

Figure 5. Examples of EL defects found on different PV modules installed in different locations worldwide; a) critical extended linear defect derived from rear side's cell damaging (typically from backsheet scratching issues); b) manifest junction box issue (either faulty diode or connection) leading to cell substring inactivity; c) and d) cell cracking defects and other minor issues accurately detected and categorised by Enertis EL software.

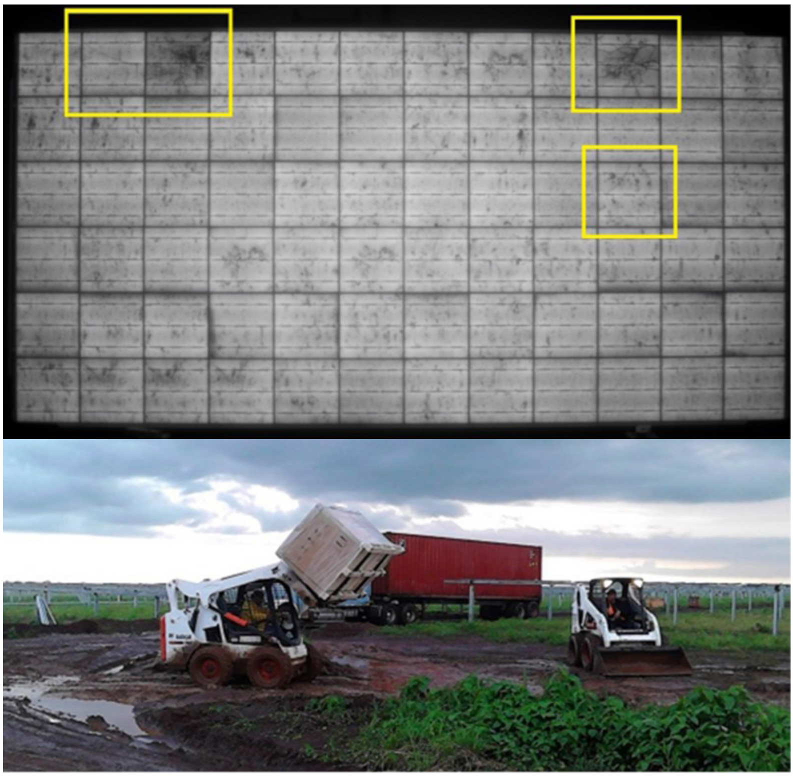

Figure 4. Example of mishandling onsite. The cracked cells in the EL image were produced by the toes of the forklift during transport of boxes across the site, which packaging were, in turn, upgraded for future shipments.

Moreover, safeguarding module traceability in a supply via EL inspection (all EL pictures from the factory should be shared by the vendor) becomes a powerful way to track down any sort of damage in a panel occurring upon delivery to the site, and then after mounting. This way, the evolution of the modules during the entire warranty period can be overseen.

Last but not least, the applicable sample selection strategy always depends upon the specific inspection context and purpose. In fact, very non-technical variables such as lead times, inspection deadlines and, why not say budgets, are often principal drivers. So, for any EL inspection action or campaign, a global understanding of the case and eventual objective, from the suitable investigation process turns out to be mandatory, in order to assure that accurate and valid conclusions from the convenient but sometimes limited EL technique can be drawn.

Delivery and Pre-installation Inspection

A suitable way to review the status of megawatt-based batches of acquired PV modules once they have been received

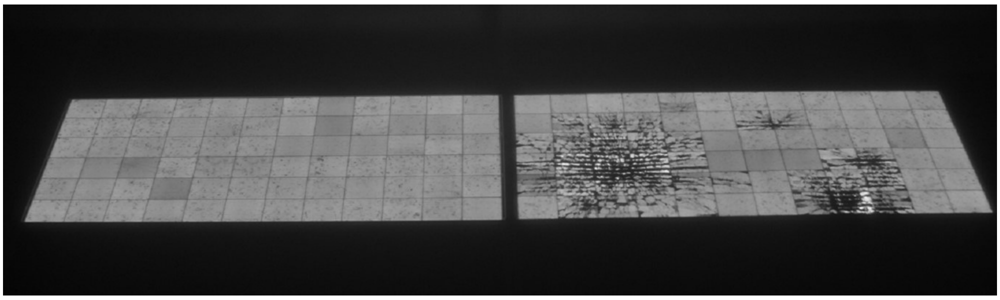

Figure 6. EL image of a mounted PV module showing critical damages (extended cell multi-cracks) due to an intense hailstorm.

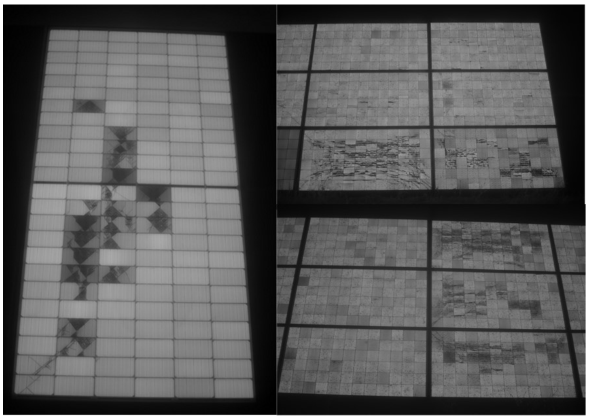

Figure 7. EL images of PV plants (both half and full-cell modules are represented) affected by harsh wind effects, showing remarkable cell multi-cracking issues.

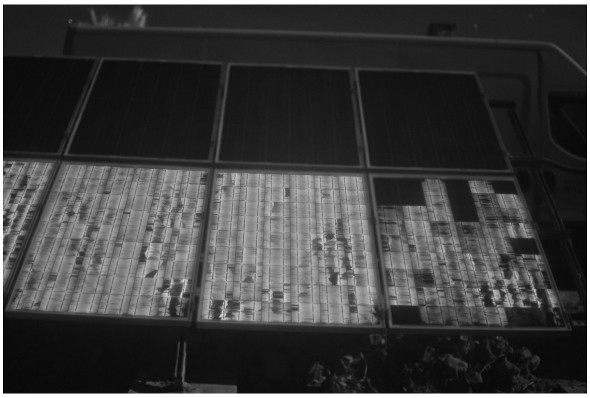

Figure 8. Multiple defects found trough EL in a PV plant affected by a massive flood issue. The EL inspection made possible an integrated diagnosis of the asset condition. Power and electrical insulation tests were also conducted, correlating data with EL outcomes. Serious degradations affecting power (disconnected cells, severe cracking defects) and safety issues (contacts corrosion) were eventually reported, defining subsequent actions to be triggered.

at the port of destination *(CIF incoterm)* or at a project's site *(DDP incoterm)* is a post-shipment analysis of a representative sample per batch, carrying out EL and Visual Inspection. This way, possible damages suffered during transport from the manufacturing site can be detected, as well as other manufacturing-related defects, especially in cases in which no previous pre-shipment inspections have been conducted. Whether it has been properly arranged in the MSA, the results of the tests can lead to rejection of containers or lots with an excess of defects as per the agreed acceptance criteria.

Likewise, EL testing is ideal for situations of accidental overturning or hitting of pallets during module handling and mounting, despite there being no visual evidence of damage (Figure 4) to the naked eye. Also, for locations where road transportation to access the site from the port is not facilitated, EL inspection can be of great help to determine any potential damage in the modules upon arrival.

Still, despite the demonstrated usefulness of post-shipment inspections, as an increasingly usual practice in the PV sector in multiple geographies, not all players involved in a PV project are prone to carry them out. This happens even with supplies based on DDP acquisitions, with module suppliers reluctant to accept such inspections in the agreements with module buyers. Therefore, adding properly designed inspections at the point of delivery in the corresponding MSA and EPC contracts is a practical and affordable strategy to increase the level of confidence and modules quality traceability for a PV asset owner.

EL to installed modules: post-installation, technical due diligence inspections, O&M.

After installation and plant energisation, EL testing is a must-do activity in a varied range of contexts, namely:

- Post-installation tests: EL can be performed on a sample of panels already installed in the structures or trackers, with the main objective of evaluating possible damages during the installation process (of course, damages originated in previous stages such as manufacturing or transport can be also captured). As mentioned in previous sections, EL inspection is not a standard technique, based on standard rules and conclusions. Therefore, through expert technical advisors, ad hoc acceptance and rejection criteria, wisely adapted to every context, are typically used.
  Thanks to EL inspections, it is possible to identify which panels should be replaced or monitored after having suffered damages during installation that could affect performance or even electrical safety. Likewise, if it has been properly stipulated at the contractual level, the suitable liabilities in case of proven issues can be set.
- Weather events: EL inspection over mounted modules is an outstanding tool to assess the mechanical integrity of PV modules after being affected by extreme meteorological events such as tropical storms, wind or hailstorms, as represented in Figures 5 to 8. On account of the already mentioned merits, EL inspection has become a widely accepted technique by international insurance companies in expert reports, being of maximum relevance to determine the compensations to be granted to the coverage claimant, whatsoever the incidence that caused the damage.

Table 2 collects some interesting examples of EL inspections recently carried out by Enertis in PV plants

PV Plant Size	Modules tested	Tested/Total modules (%)	Defect type/Modules tested (%)			
			No defect found	Minor[1]	Major[2]	Critical[3]
55 MWp	5,560	3.4%	4.80% of non-compliant modules as per agreed criteria			
50 MWp	7,976	5.3%	51.96% of non-compliant modules as per agreed criteria			
24 MWp	26,320	38.5%	88.69%	5.51%	1.79%	4.01%
385 MWp	61,380	5.5%	67.93%	19.50%	7.07%	5.51%
110 MWp	103,454	31.50%	68.78%	19.23%	11.98%	

Table 2. Examples of EL inspections recently carried out by Enertis in plants affected by extreme wind events.

[1] ***Minor*** *defects are not considered to be a threat to the performance or the useful life of the panel currently or in the short-term.*
[2] ***Major*** *defects are not critical at the time of the inspection as they do not imply a significant power loss, but should be monitored as they might develop into critical in the future, isolating electrical areas within the cells, due to the effect of daily thermal cycles and environmental conditions such as wind, hail, snow or others.*
[3] *Defects deemed as* ***Critical*** *cause great impact on performance already at the time of the inspection and shall be replaced.*

affected by extreme wind events and their results:

- PV project lifespan: During commissioning, as part of Substantial Completion/PAC or FAC activities and O&M duties, for warranty claims, or in contexts related to asset acquisitions and financing due diligence processes, EL provides a non-invasive and cost-effective way to diagnose PV modules' status, also acting as an efficient preventive and corrective maintenance tool. Besides providing valuable information regarding a modules condition at a given moment, it helps understand the issues that may cause safety problems or lead to significant power degradations in the modules, even in the short term. Table 3 includes recent examples of EL test activities carried out by Enertis as part of technical due diligence activities of projects, prior to acquisitions:

PV Plant Size	Modules tested	Tested modules/ Total modules (%)	Defect type/Total modules (%)			
			No defect found	Minor	Major	Critical
9 MWp	36,476	100%	70.04%	16.47%	9.88%	3.61%
1 MWp	338	8.7%	31.07%	1.48%	57.69%	9.76%
2 MWp	329	3.8%	69.30 %	8.81%	15.20%	6.69%
1 MWp	80	2.0%	61.25%	1.25 %	32.50 %	5.00%
2 MWp	80	0.9%	81.25 %	1.25%	15.00%	2.50 %

Table 3. Examples of EL inspection conducted in the context of asset acquisition processes.

Taking the large EL test campaign for the 9MWp plant collected in the table, the translation of the significantly reported EL findings into economic impact led to a significant reduction of price of the asset, obviously far above the cost of the EL testing itself. Therefore, the EL inspection, in such contexts, provided the potential purchaser with optimal knowledge of the condition of the modules, becoming a powerful tool towards the negotiation of the transaction.

Final remarks

Nowadays, in the era of new PV cell and module designs, with the trend to build increasingly larger and faster PV projects worldwide, the EL technique has it all to live a second youth as a key tool to determine the quality condition of a PV module (and thus a PV asset) in a massive, intuitive, cost-effective and non-invasive way.

Paradoxically, despite the unquestionable currency of the EL inspection methodology, its proven virtues can in turn lead to misuses and practical limitations.

Also, in the absence of robust standards capable to regulate, in full, the EL technique, elucidating whether a specific microcrack, a busbar soldering issue or a cell mismatch may be acceptable or not will be subject to every inspection background. Therefore, the quintessential qualitative nature of the information enabled by an EL analysis should be properly refereed and tackled by expert third-party entities, so that any valid penalty, warranty or liability claim may be fairly addressed.

In the context of MSA negotiations between buyer and supplier (also in EPC contracts covering issues out of module supplier's responsibility), it is highly recommendable to define in advance, among other testing activities, what a hidden EL defect is and how it should be detected. By and large, this consensus should be systematically implemented for any project stage in which the EL inspection is involved: i) throughout manufacturing; ii) before/after shipment; iii) before/after mounting (O&M phase, acquisition's due diligence processes, etc.).

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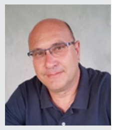
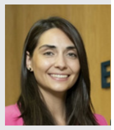
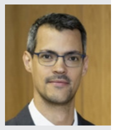
Ignacio J. Fernández, MSc Telecommunications Engineering
Ignacio is the Head of Testing and Optimization at Enertis Solar. With more than eight years of experience in the photovoltaic industry, Ignacio has managed project due diligence processes, EPC and O&M contract negotiations, expert works during arbitrations and QAQC campaigns related to more than 150 photovoltaic plants around the world. Currently, he leads Enertis Solar´s QAQC activities during post-shipment, post-installation, commissioning and operation phases.



Ruperto J. Gómez, PhD Physics
Ruperto is a Process, Manufacturing and Technology Senior Engineer with a 17-years' experience in the PV and semiconductor industries. Ruperto has led several projects with international partnerships related to turn-key projects of new PV module manufacturing lines in China, India, Mexico and Poland. Since 2017, he is the Quality Operations Manager in Enertis Solar.



Sofía Rodríguez, PhD Physics
Sofía is the R&D Manager at Enertis Solar. She has worked on the development of innovative defect detection systems in PV solar modules based on EL and PL, coupled with categorization and classification techniques. She is currently devoted to the coordination of different lines of research focused on the understanding and technical assessment of bifacial technology as well as on the application of machine learning technologies in different areas and works on the transfer of knowledge to Enertis services.



Lucas Viani, PhD Computational Chemistry
Lucas is a Senior Engineer devoted to Data Science activities for Enertis' Business Development area. He has more than 10 years' experience in the development of mathematical models applied to machine learning in different academic and industrial sectors, now focusing his work and know-how on the modelling of PV plant performances and EL/thermography image processing.

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