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Light- and elevated temperature-induced degradation impact on bifacial modules using accelerated aging tests, electroluminescence, and photovoltaic plant modeling

Julien Dupuis[1] | Gilles Plessis[1] | Gilbert El Hajje[1] | Eric Lajoie-Mazenc[1] | Eric Sandré[2] | Khalid Radouane[2] | Patrick Dupeyrat[1]

[1]EDF R&D, EDF Lab Les Renardières, Moret Loing et Orvanne, 77250, France

[2]EDF Renouvelables, 100, esplanade du Général de Gaulle, Cœur Défense - Tour B, Paris La Défense Cedex, 92932, France

Correspondence
Julien Dupuis, EDF R&D, EDF Lab Les Renardières, Avenue des Renardières, 77250 Moret Loing et Orvanne, France.
Email: julien.dupuis@edf.fr

Abstract

The authors report on the light- and elevated temperature-induced degradation (LeTID) effect observed on bifacial photovoltaic modules and its potential impact on photovoltaic plants performance. Indoor LeTID quantification using indoor carrier-induced degradation (CID) is carried out using current injection. Power measurements yielded higher LeTID sensitivity for the rear side of bifacial modules compared to the front side, hence leading to a variation of the bifaciality factor by several percentage points. The difficulty in evaluating the maximal power degradation caused by LeTID is also highlighted as a reduced number of samples are used most of the time and as cells within a single module do not have always the same performance evolution trends. Using indoor CID results with the help of empirical fitting and Arrhenius relation, the yield impact of LeTID on a bifacial power plant is simulated under three different climates. Modeling results help to identify the main parameters related to LeTID modules sensitivity that impact photovoltaic (PV) plants yield: maximal power degradation, stabilized power value after regeneration, activation energy value, and LeTID kinetics. In some cases, the yield variation caused by LeTID sensitive modules could be mitigated by carefully selecting the modules as a function of climatic conditions.

KEYWORDS

bifacial, electroluminescence, LeTID, modeling, plant performance, photovoltaic module, yield

1 | INTRODUCTION

Initial module power degradation is a key parameter for new photovoltaic (PV) projects, especially when it comes to new technologies such as passivated emitter and rear cell modules (PERC modules), with performance losses ranging from 0% to more than 9% in laboratory tests.[1] Recent studies have highlighted the role of the light-and elevated temperature-induced degradation (LeTID) on PERC modules.[1–4] This phenomenon is still not fully understood yet, but numerous studies have pointed out hydrogen excess as a possible root cause.[5–8] Its limitation is handled nowadays by most manufacturers using specific thermal treatments during the solar cells manufacturing process.[9–11] These solutions enable in general to secure a limited module power degradation when tested with the light-induced degradation (LID) or carrier-induced degradation (CID) methods.

Even with some process adaptation, uncertainties remain as the kinetics and impact of LeTID on module power can differ greatly depending on material type (monocrystalline or multi-crystalline silicon), process (atomic layer deposition [ALD], contacts firing) and post-treatments (light-induced recovery [LIR]). Furthermore, a global LeTID testing method is not yet completely defined and can vary significantly in terms of protocol and results depending on testing institutes or companies.[1–4] A good understanding of the physics behind the LeTID phenomenon will be the key to quickly and accurately evaluate its effect. The final goal is to be able to quantify the dynamics of LeTID on any sort of module and to model its impact in any location in the world based on irradiation and temperature profiles.

In this paper, we address these issues with a special focus on bifacial modules. PV plants using this technology are sensitive to various parameters like the soil albedo or the PV plant design but also the efficiency of light conversion on the rear side of these modules.[12] The bifaciality factor, defined by the ratio between the power generated by the rear side and the power generated by the front side of bifacial modules at one sun exposure, is the main indicator. This study was performed by analyzing three batches of modules coming from three different manufacturers. CID testing, performance measurements, and electroluminescence (EL) were carried out in order to determine accurately the LeTID sensitivity of the front and the rear sides of these bifacial modules. Modeling is then used to simulate the impact of LeTID on real power plants performance using our experimental results in an Arrhenius-based model in three representative climates: moderate, tropical, and dry.

2 | EXPERIMENTAL DETAILS

2.1 | Modules types and CID parameters

Table 1 details the modules specifications used for these tests.

All module batches come from three different Tier 1 manufacturers. For PERC 1 and PERC 2 modules, four modules were tested unlike PERC 3 modules where only two modules were available.

CID testing was used to activate LeTID phenomenon. The protocol for LeTID evaluation in silicon modules is still under debate, and institutes have tested currents ranging from Isc-Impp (0.5 to 1 A usually) to Isc (8 to 10 A) and temperatures ranging from 75°C to 85°C. This yielded different LeTID impacts as the kinetic is modified. In particular, the detection of the maximal degradation caused by the phenomenon can vary by several percent or even be undetectable.[1–3] Recent results suggest that using current injection of Isc-Impp gives the best representability for LeTID degradation and regeneration as carrier density is quite similar to 1 sun illumination in maximal power point (MPP) mode and because indoor results are in agreement with some real power plants.[4] The drawback of using low current values is a longer testing time to render the LeTID behavior. Even if high temperatures can accelerate the phenomenon, the modules should not be operated at temperatures above 85°C as that is the maximum working temperature allowed for a classical solar module. Carrying out the experiment at high temperatures entails the risk of activating other unwanted failure modes.

As no information on the aspects of the rear side of bifacial modules was available in the literature, we chose to evaluate LeTID using CID and a large current injection range: 0.5 A (≈Isc-Impp), 5 A (≈Isc/2), and 10 A (≈Isc). One module was tested for each current. PERC 3 modules had been tested only at 0.5 and 5 A current injection because of limited number of modules available. The temperature was set to 75°C in order to avoid working at too high temperature with the risk of activating failure modes unrelated to LeTID. No light soaking at low temperature was performed prior to LeTID testing. Modules were stored in the dark before the test.

2.2 | Current voltage and EL characterization

Electrical characterization of the PV modules was carried out using a PASAN flash tester AAA SunSim 3b. The complete measurement system is located in an air-conditioned room with an ambient temperature of 25 ± 1°C and a module temperature control under standard testing conditions (STCs) of 25 ± 0.5°C. Calibration of the flash tester is performed using PERC gold modules calibrated at Fraunhofer ISE with ±2.5% power uncertainty. The module temperature is measured by Pt100 temperature sensors attached to the back of the module. The reproducibility was estimated at ±0.5% based on the reference modules used during the experiment.

EL measurements are done on a Greateye Lumi Solar Professional system. The imaging system resolution is 250 μm/pixel. The applied voltage range for this setup ranges from 0 to 150 V. The system is equipped with two charge-coupled device (CCD) matrix cameras characterized by a sensor format of 2,048 × 512 pixels, a pixel size of 13.5 × 13.5 μm and high sensitivity in the near-infrared region, which is suitable for our silicon PV modules EL images. The spatial resolution of the system is estimated at 0.5 mm, for a 50-mm focal length, a numerical aperture of 1.4, and 0.95 m of working distance. Applied voltage was adjusted to get EL images of PV modules in short circuit conditions.

TABLE 1 PERC modules specifications

Module specifications	PERC 1	PERC 2	PERC 3
Technology	60 p-PERC cells	72 p-PERC cells	144 half p-PERC cells
Silicon type	Mono	Cast mono	Cast mono
Average bifaciality factor (%)	65.5	68.5	69.5
Rear side material	Glass with white serigraphy	Glass	Glass with white serigraphy
Power (Wp)	300	330	355

2.3 | Yield modeling

Following the experimental quantification of LeTID impact of bifacial modules performance, the modeling approach is used in order to quantify the possible outcome on a bifacial PV power plant yield caused by this effect. The chosen strategy to transpose indoor CID results to simulated PV plants under real operating conditions is performed by an empirical fitting of the CID results in order to generate electrical module specifications at any defined time. Then, a time equivalence determination as a function of the location temperature profile is carried out using an Arrhenius model.

The empirical fitting of the experimental data was performed with an improved version of the methodology proposed by Pander et al.[13] with the following equation:

$$\Delta P(t) = -at^b e^{-\frac{t}{\tau}} + P_\infty\left(1-e^{-\frac{t}{\tau}}\right)$$

where

- $\Delta P(t)$ is the time-dependent module power change because of LeTID at STC.
- a, b, and τ are coefficients obtained by fitting the module power data during CID.
- P_∞ is the module power value after full LeTID regeneration taken from experimental results.

The same methodology was used for fitting Voc, Isc and FF as these parameters are following similar LeTID trend. This method allows to simulate sets of module electrical parameters at any chosen time.

The time transfer from indoor to outdoor results is performed by an Arrhenius law: $t_{eqv} = \sum_{i=1}^{n} \Delta t_i \exp\left(-\frac{E_a}{R}\left(\frac{1}{T_i} - \frac{1}{T_{ref}}\right)\right)$

where

- t_{eqv} is the equivalent test time at T_{ref}.
- T_{ref} is the reference temperature.
- Δt_i is the duration at a temperature T_i.
- T_i is the module temperature for each step time.
- E_A is the activation energy.
- R is the universal gas constant.

This model considers the temperature to be the main factor influencing LeTID evolution. At a high temperature, carrier injection is supposed to be constant, representative of module in MPP state exposed at 1 sun or Isc-Impp current injection[3,13] the model does not consider LeTID recovery during cold sunny days. This recovery can lead to seasonal effects and slow down the degradation and regeneration process.

An activation energy E_A of 0.9 eV is considered. This value is representative of a previous comparison carried out on LeTID sensitive modules set up in a power plant and tested in accelerated aging conditions.[14]

The reference temperature is taken at 75°C, equal to our LeTID indoor testing protocol.

The extraction of T_i requires to choose a specific climate and a power plant configuration. We selected three places representative for three types of climates according to the Köppen–Geiger climate classification[15] to simulate a 490-kWp bifacial PV power plant. Main places properties are summarized in Table 2.

The PV plant modeling was carried out using our ray-tracing-based 3D tool developed at EDF R&D, PVNOV.[16–18] This software is dedicated to accurate prediction of PV systems yield. Its main application is for building numerical models of PV plants. It allows to predict the theoretical yield of the future project before it is built depending on the equipment chosen. It can take into account the performance of different kind of modules and inverters and make it possible to study the irradiance, thermal, and electrical phenomena that affect the yield estimate. Its development was performed to assess the performance of innovative technologies, which were not accurately taken into account by commercial tools, such as bifacial technology, half-cell modules, or floating PV.

PVNOV accuracy was also validated using experimental measurements and comparison against several model outputs at 10-min time step. Results have shown a consistency with other PV simulation tools based on ray-tracing such as Fraunhofer ISEs.[19]

The module temperature extraction is performed by simulating the PV power plant using initial module performance with PVNOV for the three different climates. The software is using a thermal model based on available literature.[20–24]

The equivalence time between indoor testing and outdoor PV plant is then calculated for the three places studied. Modules estimated performances are calculated for each year thanks to the empirical data fitting equation. Lastly, PV plant yields are determined for each year with PVNOV.

3 | CID RESULTS

3.1 | Power trends

The power evolution of the three module types for front and rear sides are plotted in Figures 1–3. For all these modules, changing the

TABLE 2 Place specifications for PV plant modeling

Location	Country	Climate	GHI (kWh/m²/year)	Albedo (%)
Bordeaux	France	Moderate (Cfb)	1,317.5	35
Campeche	Mexico	Tropical (Aw)	2,022.7	35
Al Madinah	South Arabia	Dry (BWh)	2,248.9	35

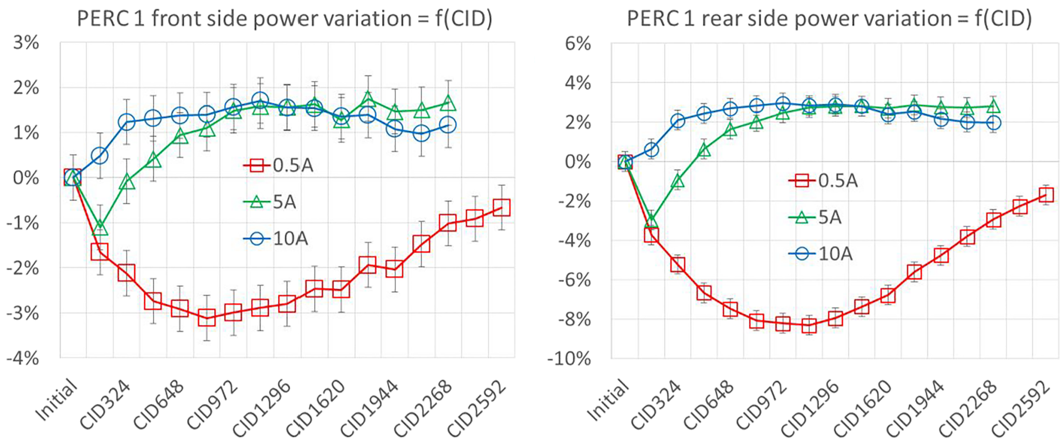

FIGURE 1 PERC 1 bifacial monocrystalline modules power evolution [Colour figure can be viewed at wileyonlinelibrary.com]

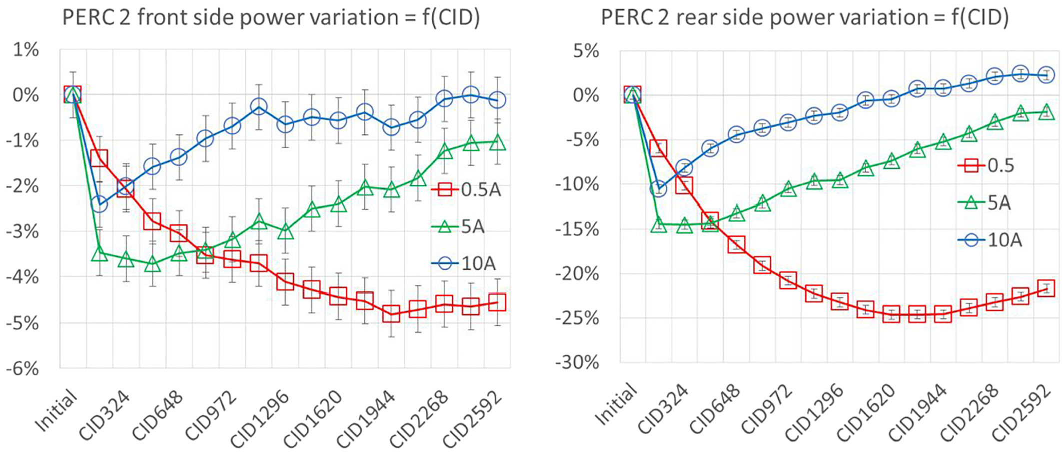

FIGURE 2 PERC 2 bifacial cast-mono modules power evolution

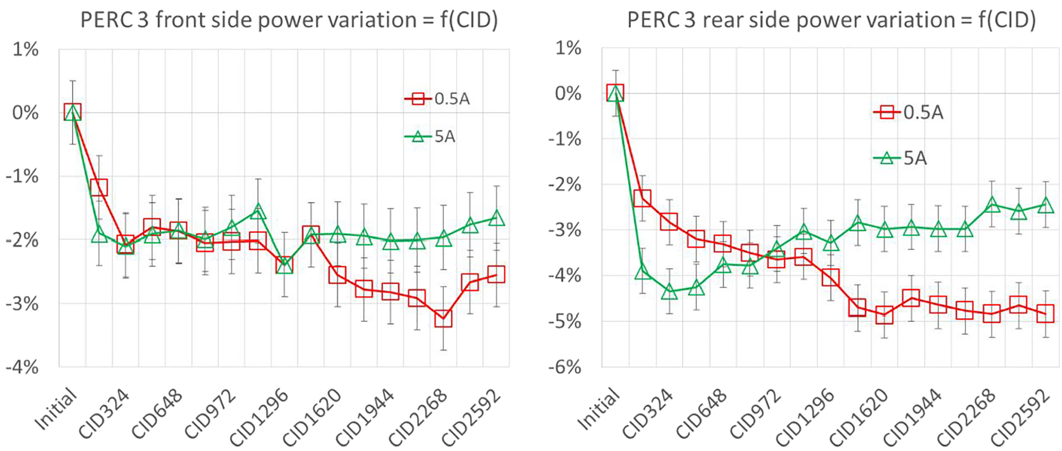

FIGURE 3 PERC 3 bifacial cast-mono modules power evolution

excess carrier density by current injection modifies the impact of LeTID effect: The typical degradation–regeneration trend is accelerated by increasing the current injection as already discussed in previous papers.[1–8]

The maximal degradation value can be missed at high current injection because of a LeTID degradation time inferior to the control time step as emphasized for PERC 1 and PERC 2 modules at 5 and 10 A current injection. In the case of monocrystalline silicon PERC modules (PERC 1), no degradation is even visible for a 10 A injection. Stabilized power is not yet achieved for 0.5 A current injection after 2,500 h of testing, but it is reached for 5 and 10 A current injection after less than 1,000 h of testing. Interestingly, the stabilized power after LeTID regeneration is the same for 5 or 10 A injection. This stabilized power is higher than the initial power of the module by 1.5%. The rear side is showing an even higher stabilized power with nearly 3% gain. The higher gain at the rear side has a direct impact on the bifaciality factor of the module going from 66.0% initially to 66.8%. Focusing on the Isc-Impp current injection, a clear power degradation followed by a regeneration is visible for the front and rear sides. It has to be noted that the rear power evolution is more impacted with a maximum degradation of 8% of its initial power contrary to 3% for the front leading to a decrease of the bifaciality factor from 66% initially to 61% at the minimum.

The cast-mono PERC modules tested (PERC 2 and PERC 3) have different power evolution trends.

In particular, the PERC 2 modules are more affected by LeTID than previous PERC 1 modules and the stabilization time seems to be at least three to five times longer before being almost visible (except for the lower current injection). Moreover, the LeTID intensity is higher compared to PERC 1 or PERC 3 modules especially at 0.5 A current injection with 5% degradation for the front side and 25% degradation for the rear side. As already observed for PERC 1 module, the bifaciality factor is highly impacted and changes from 69% to 55% before the regeneration step.

Lastly, the second cast-mono PERC modules (PERC 3) power evolution is significantly different. No evident LeTID is visible on the front side as the power looks stabilized after a first phase of power decrease. This could emphasize a process optimization during the cell manufacturing to limit the LeTID phenomenon. The rear side power state is slightly different: The module with a 5 A current injection seems to show a small regeneration phase after an initial decrease. Moreover, as observed on PERC 1 and PERC 2 modules, the rear side is more degraded than the front.

3.2 | EL measurements

On sensitive LeTID modules, EL measurements reveal the typical chessboard pattern caused by the different cell sensitivities to this effect.[3,13] Figures 4 and 5 exemplify this aspect on mono (PERC 1) and cast-mono modules (PERC 2) showing that solar cells within the same modules have not the same sensitivity to LeTID. More surprisingly, as shown in Figure 5, the solar cells can also have a different degradation–regeneration kinetic. The red circles focus on a cell evolution at different LeTID stages. Contrast change with neighboring cells seems to highlight a faster evolution of this cell compared to the cells just below.

Rear side EL was also carried out on some modules. As shown in Figures 6 and 7, EL signal contrast is similar for all cells on front and rear sides either on mono than on cast-mono modules.

3.3 | Discussion

Evidence that LeTID effects depend on various factors is highlighted by the results shown: Module testing is required to evaluate the LeTID sensitivity of modules, and similar module technologies can lead to very different power variations.

Moreover, despite having similar EL aspect, the rear side is found to be two to five times more sensitive to LeTID than the front side on the tested modules regarding the module electrical characteristics, even on the LeTID mitigated PERC 3 modules. This higher sensitivity could be linked to the origin of LeTID effect as current hypothesis is explaining the phenomenon to involve the rear side process and properties of the solar cells.[5,6] This difference between front and rear sides has to be taken into account for yield estimation in a future PV plant through the bifaciality factor variation.

In addition to LeTID front and rear side sensitivity variation, the difference in behavior and maximal degradation observed within the cells inside the same module makes the LeTID effect forecasting more

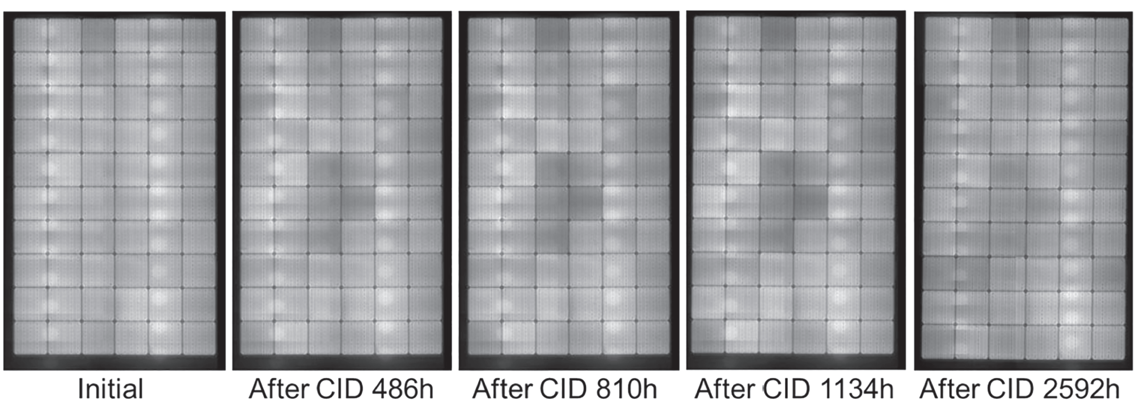

FIGURE 4 EL pictures of PERC 1 module with 0.5 A current injection

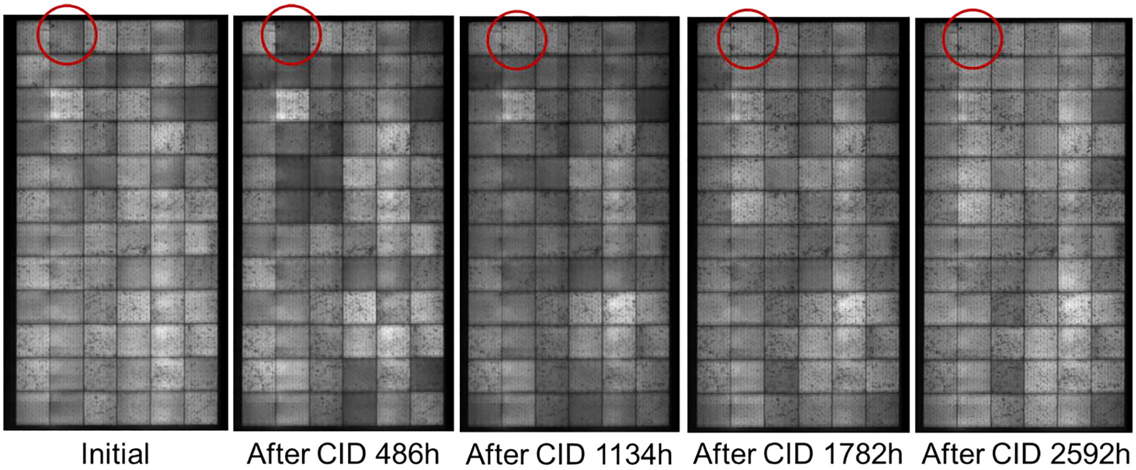

FIGURE 5 EL pictures of PERC 2 module with 5 A current injection. Red circles highlight evidence of different cell LeTID degradation–regeneration kinetics within this module

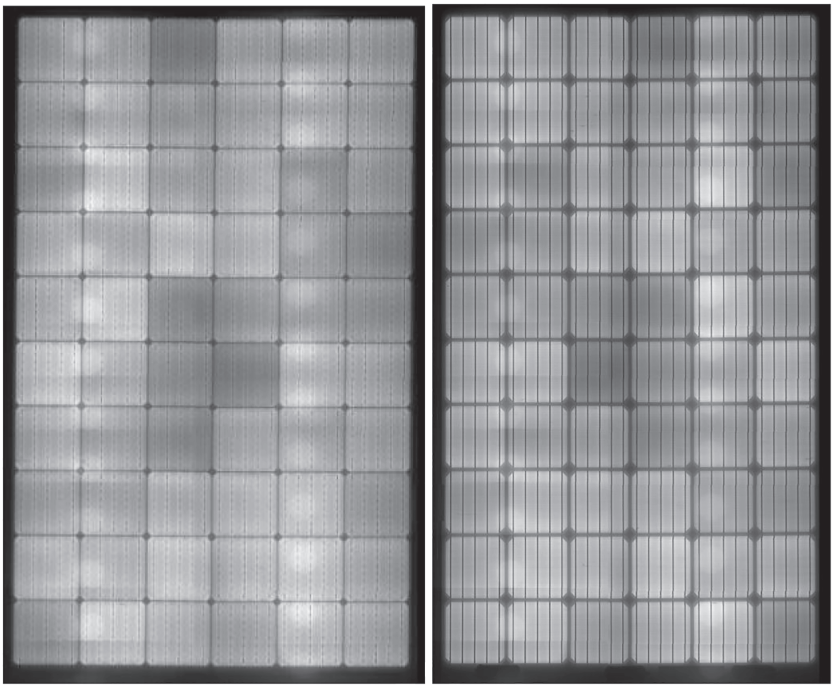

FIGURE 6 Front (left) and rear (right) electroluminescence pictures of PERC 1 module with a 0.5 A current injection after 1,134 h of CID

difficult. Cells are usually sorted by power at the end of cell line, and the same power class cells are used to make modules in order to limit the mismatch of series connected cells. As shown in Figures 4 and 5, having different LeTID sensitive cells in the same module in terms of maximal degradation value means that electrical mismatches will appear and maximal power degradation may vary from one module compared to the other as modules are containing randomized LeTID sensitive solar cells. This is for instance visible in the paper of Fokuhl et al.[1] where two modules from the same batches are tested with the same protocol and gave up to 1.5% maximal degradation difference.

Moreover, we also put in evidence a different LeTID degradation–regeneration kinetics within the cells of PERC 2 modules as emphasized in Figure 5. This effect seemed to be absent on the two other PERC 1 and PERC 3 modules. The physical explanations behind these differences is still an open question, but we already observed that different types of modules containing similar cells types could have different LeTID dynamics with a maximal degradation not obtained after the same CID time. It can be seen on the tested modules results in the Pander et al. paper[13] for instance.

These maximal degradation and kinetic variations confirm that testing only one or two modules could lead to difficult average maximal power degradation evaluation in a real power plant.

One way to overcome partly this problem can be the extraction of cells electrical characteristics using advanced methods like quantitative EL as the one proposed by El Hajje et al.[25] The impact of LeTID for each solar cell in the module gives the spread observed toward

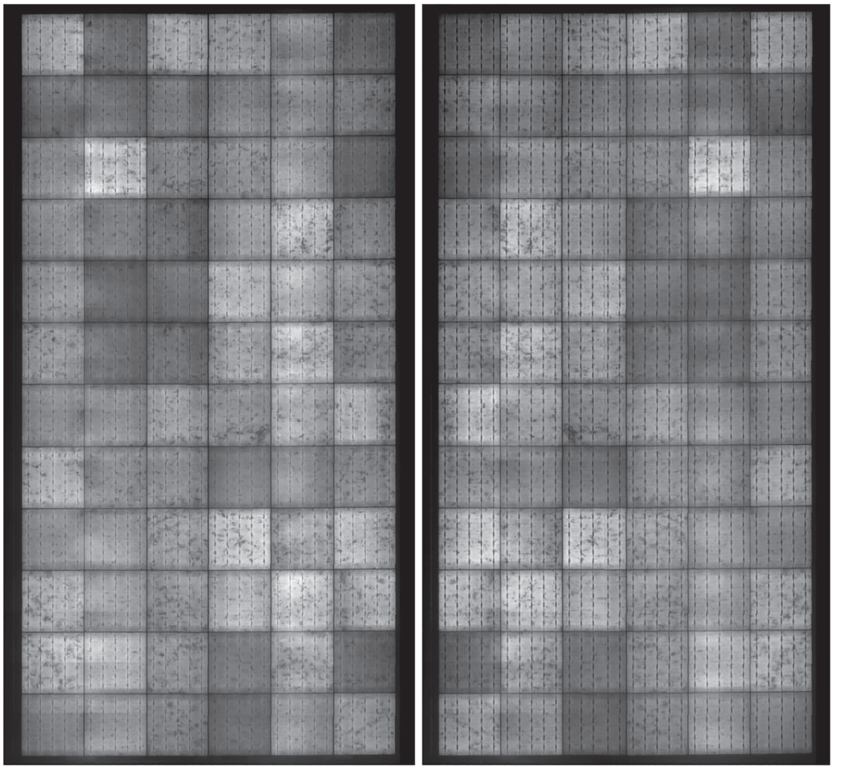

FIGURE 7 Front (left) and rear (right) electroluminescence pictures of PERC 2 module with a 5 A current injection after 486 h of CID

cells LeTID sensitivity and can be transposed to "virtual" PV modules. This solution may help to better evaluate the average maximal power degradation for all the modules and expected mismatch in a string of modules. Its limit is still the testing of only one or two modules that are not fully representative of all cells produced by the module manufacturer.

Results presented also highlight the similar stabilized values of power obtained after CID using different current injections. In particular, in the case of monocrystalline PERC 1 module, both modules power are ending at similar values. This is also confirmed on all other electrical parameters as presented in Figure 8. Module with 0.5 A current injection is still in test to validate this trend.

For cast-mono modules (PERC 2 and PERC 3), full LeTID regeneration is not yet achieved, it is not possible to confirm the same behavior yet. It seems that only few publications have detailed if all cells from a module achieve similar stabilized values. Kersten et al. have put in evidence that nearly all cells have similar aspect on EL images after stabilization on multi-crystalline PERC modules,[3] but some of them were keeping a lower signal intensity. In this paper, EL results after 2,592 h of CID presented in Figures 4 and 5 tend to prove that cells within PERC 1 and PERC 2 modules could end with low current mismatch after stabilization as the signal contrast is decreasing between all cells. Even if the mismatch is reduced after stabilization, it will not ensure similar performance between all modules tested at various current injections. More return of experience is needed to validate this hypothesis and its uncertainty.

The confirmation of enough robustness on results obtained by this method could help to reduce the needed time for LeTID evaluation. Low current injection could be used to determine the maximal power degradation. High current injection could be used to determine the stabilized power value after LeTID.

Lastly, it has to be noted that PERC 1 modules achieved a higher stabilized power than initial. This trend was previously observed by Fokuhl et al.[1] on mono-PERC modules as well. It is unclear if this gain could be caused by LeTID regeneration or by some B-O LID regeneration. More investigations are needed to validate this point.

4 | MODELING

Indoor CID results can be used to make an estimation of PV plants yields impacts caused by LeTID at any chosen place by using modeling. The empirical fitting of the experimental data will allow the generation of module parameters impacted by the LeTID at any specified time. The modeling needs some key data as electrical module parameters when maximum power degradation occurs and when full regeneration is achieved. We will focus on PERC 1 modules as all needed parameters are available. Only LeTID phenomenon is considered for the yield evaluation, no other degradation mechanism is taken into account.

4.1 | CID fitting

Based on PERC 1 CID results, stabilized module characteristics using 5 and 10 A data were extracted, and electrical parameters obtained for 0.5 A CID (≈Isc-Impp) were fitted with the previously defined function. The time equivalence between indoor testing and the three

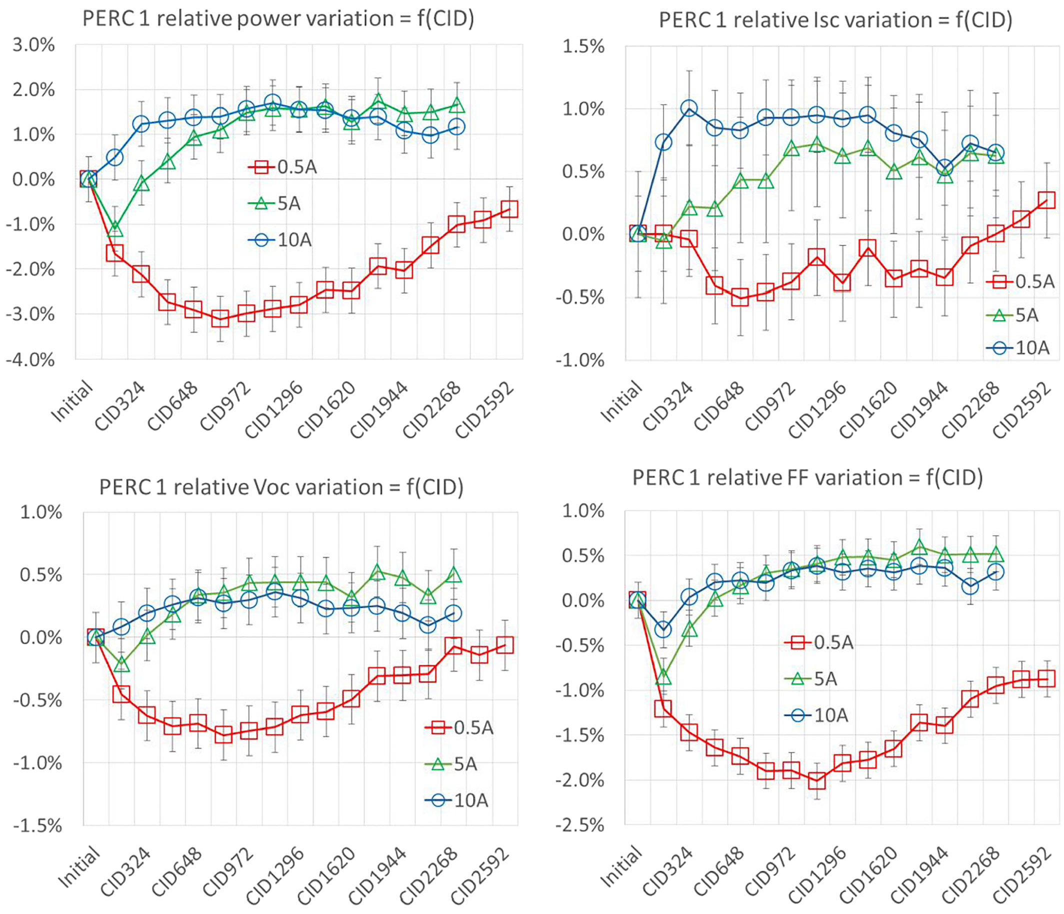

FIGURE 8 Power, Isc, Voc, and FF relative variation with CID for the front side of PERC 1 module. Reproducibilities are estimated to be ±0.5% for power, ±0.3% for Isc, and ±0.2% for Voc and FF

selected places is calculated using the Arrhenius law for Ea = 0.9 eV. For instance, module P_{MPP} variations at STC are displayed on Figure 9, and an example of time equivalence between indoor CID results and Bordeaux city (France) is shown in Figure 10.

The model fit was performed with nonlinear least squared algorithm. In this case, the model had three parameters (a, b, and τ) and the lab data contain 15 samples (measurement error mentioned earlier); thus, we have 12 degrees of freedom for the model fit.

Standard deviations and confidence intervals were checked in order to assess the goodness of the fit. The results are display in Table 3. b and τ are well captured by the fit, but the a parameter is rather uncertain. The limited number of sample data in the degradation phase and/or the model structure can explain this uncertainty level.

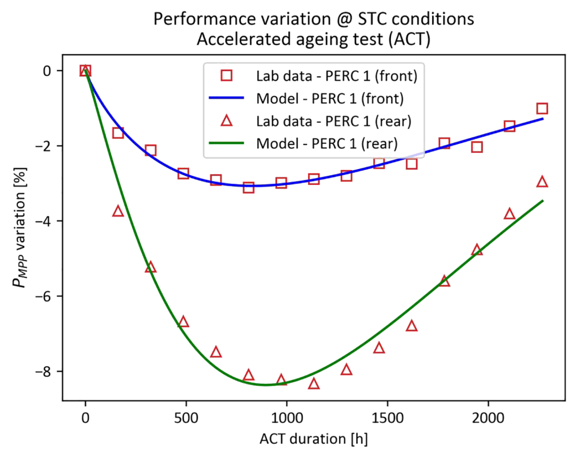

FIGURE 9 PERC 1 module P_{MPP} model

4.2 | Yield modeling

With the previously determined module parameters projection, module electrical specifications were generated year by year for each different climate. The results were used in PVNOV as inputs for a simulated 490-kWp PV plants using 1-axis trackers. The power plant contained 48 strings of 34 modules. The 105-kWp inverters were used resulting in a DC/AC ratio of 1.17. An overview of the PV plant is presented in Figure 11.

The resulting yearly yields over 30 years are displayed on Figure 12. The typical degradation–regeneration behavior caused by LeTID is visible for the three considered locations. The difference in kinetics is directly linked to the temperature: the hotter the place, the quicker the LeTID is occurring.

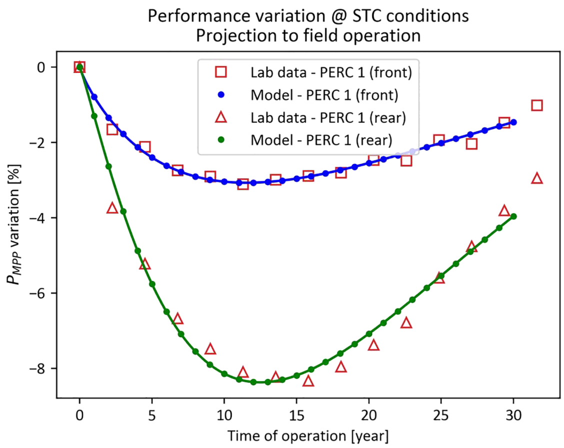

FIGURE 10 PERC 1 module P_{MPP} model projected to field operation for Bordeaux climate (Cfb)

Bordeaux climate is not hot enough for the power to fully regenerate contrary to Campeche and Al Madinah. As already emphasized, the stabilized module power after LeTID is higher than its initial power resulting in a better yearly yield than initial. The slightly higher yield gain in Campeche compared to Al Madinah is explained by a higher bifacial contribution (8.7% compared to 7.6%) caused by a lower global irradiance (the resulting rear contribution is then higher).

Lastly, Figure 13 highlights the rear side contribution to the yield as bifacial modules are used. The higher rear side sensitivity to LeTID can lead to 0.5% yield variation for the three considered climates.

4.3 | Discussion

Yield modeling is showing a direct impact of LeTID degradation mechanism on a large part of the PV plants lifetime. Temperate climate like Bordeaux is not hot enough to achieve a stabilized module power after 30 years but enough to begin the LeTID regeneration phase after 12 years. This is different of the projection from the Pander et al.

TABLE 3 Fit parameter values and 95% confidence intervals for front and rear side power of PERC 1 modules

Model parameters	Front	Rear
a	0.02 [0.01, 0.05]	0.01 [0.00, 0.04]
b	0.88 [0.72, 1.05]	1.13 [0.95, 1.32]
τ	1,099 [932, 1,329]	865 [744, 1,026]

paper[13] where temperate climates were not hot enough for the module to end the degradation phase before 20 years. The main difference is the time constant τ from the empirical modeling which determines the kinetic of LeTID based on indoor CID testing, especially when the maximal degradation occurs. In our case, this value is achieved after 900 h of testing for the PERC 1 module at Isc-Impp current injection instead of 1,700 h for the modules modeled by Pander et al. One has to avoid selecting a LeTID sensitive module for which the maximal power degradation is occurring at PV plant mid-life. In this case, the degradation caused by LeTID will be non-negligible as it has been seen in the presented Bordeaux modeling.

Moreover, in hotter places like Campeche or Al Madinah, the maximal degradation will occur in the first years after the PV plants completion using PERC 1 modules. Besides, as the stabilized power after LeTID is higher than the initial module power for PERC 1 module, some yield gain is visible even before the mid-life of the PV plant. This is illustrated in Figure 12 for Campeche and Al Madinah where the yield becomes higher than the first year after respectively 7 and 12 years of exploitation. Lastly, as pointed out on the Figure 13, the variation of the yield gain from the rear side is responsible for 15% to 20% of the global yield variation and shall be taken into account.

Even though it is unreliable to count on possible gain in yield has the exact phenomenon is unclear, this could help to mitigate the impact of power degradation after medium and long-term exploitation for hot countries as presented in Table 4.

These simulations point out the key parameters needed to estimate as accurately as possible the LeTID impact on PV plants: the maximal degradation, the stabilized power value, the kinetics of the

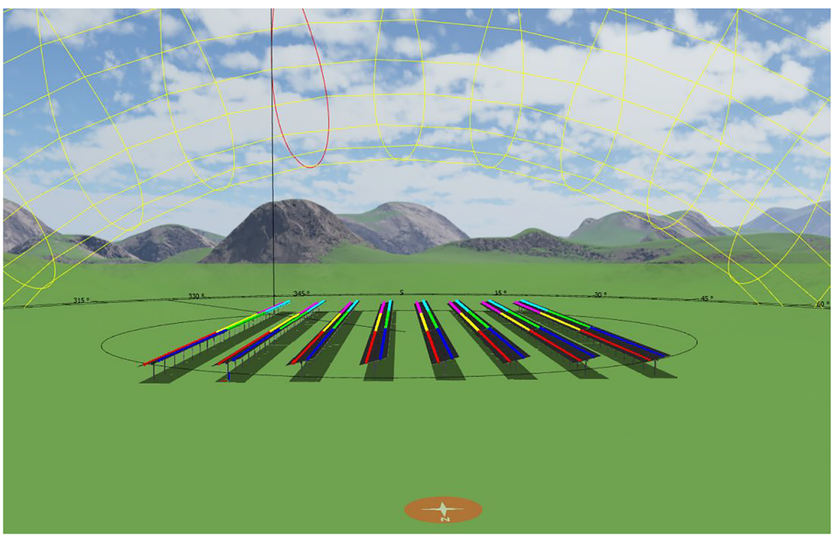

FIGURE 11 Simulated PV plant overview in PVNOV

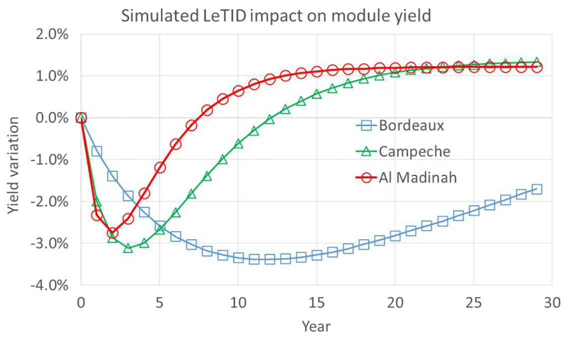

FIGURE 12 Simulated LeTID impact on module yield

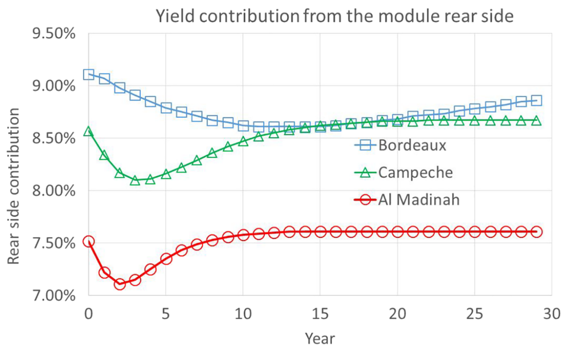

FIGURE 13 Yield contribution from the rear side of PERC 1 modules used in a PV plant on three different places

TABLE 4 LeTID yield impact on the three considered places using PERC 1 modules

LeTID impact on yield	Bordeaux (FRA) (%)	Campeche (MEX) (%)	Al Madinah (SAU) (%)
Average 10 years	−2.1	−2.0	−1.1
Average 20 years	−2.7	−0.8	+0.0
Average 30 years	−2.5	−0.1	+0.4

phenomenon (time constant) and the time equivalence between indoor testing and outdoor temperature (activation energy). More data are needed to evaluate the reliability of transposing indoor testing results to real power plants as well as exact physical reasons behind the LeTID effect.

5 | CONCLUSION

In this paper, we have contributed to better understand the impact of LeTID on bifacial modules using indoor reliability testing and PV plant simulation. Our results show a higher sensitivity to LeTID on the rear side of all modules impacting the yield gain of bifacial modules.

Determining key parameters like maximal power degradation, stabilized power value, and kinetic of the phenomenon on a batch of modules is not straightforward considering the different cell behavior under LeTID within the same module. To reduce LeTID quantification uncertainty, a large number of modules should be tested or at least, each cell power evolution has to be followed and quantified in a smaller number of modules.

Transposing these results to real place in order to evaluate LeTID impact on PV plants seems feasible but with still uncertainties like the right value of the activation energy or the use of a basic Arrhenius equation without taking into account the irradiance on the LeTID kinetic.

More data need to be collected in order to improve the modeling and provide a better understanding of LeTID, hence allowing to accurately forecast its impact on a PV power plant.

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ORCID

Julien Dupuis https://orcid.org/0000-0002-2051-3079
Khalid Radouane https://orcid.org/0000-0003-0803-4232

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