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Evaluation of Cells Cracks Impact on PV Module's Performance

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Abstract. This work aims to perform an assessment of cell cracks impact on PV module's performances. Cracks can occur during transportation, severe weather conditions such as hailstorms [1], poor installation practices and manufacturing [2]. Even with multiwire interconnection technologies, the impact of such defects can affect PV module's performances as well as the energy yield and lifetime of a photovoltaic installation [3]. Moreover, cracks will leave the silicon edge unpassivated with a risk of being more sensitive to external stresses, especially on highly efficient technologies like TOPCon. The main objective of this work is studying the cracks impact on new module's technology performance to quantify its impact on the production yield and forecast power plant performance. A laboratory testing sequence was performed on two different Glass/backsheet PV technologies: PERC and TOPCon. First, a cracking procedure was conducted to generate several cracks patterns on two batches of PV modules similar to the patterns observed on powerplants sites. An electrical characterization was then performed to carry out a first evaluation of power losses after the cracks. Moreover, several accelerated aging sequences were conducted on the cracked and reference modules to quantify the average losses after each accelerated aging test.

Keywords: Photovoltaic Technologies, Cracks Impact, Degradation Rates

1. CRACKS GENERATION AND EXPERIMENTAL PROCEDURE

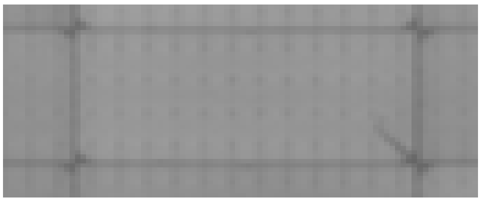
1.1 Generation of the cracks

Several testing sequences for cracking methodologies were first performed in order to choose the most suitable one for the cracks patterns we wanted to generate. One of the main challenges of the experimental work was to limit the cracking generation at the module's cells level without cracking the glass or the backsheet. Different equipment was used for that purpose including:

- Static mechanical loads applied on the backsheet side of the modules.
- Repetitive shocks using stainless balls with specific weights.
- Shocks with rubber mullets oriented on the cells corners to generate the required cracking patterns.

1.2 Modules selection and experimental procedure

The PV modules tested were a batch with Passivated Emitter and Rear Cells (PERC) (405 Wp) and a batch with Tunnel Oxide Passivated Contacts (TOPCon) cells (425 Wp) using a Glass/backsheet configuration from tier one manufacturers. Two major aspects were considered at this first experimental level: the cracking patterns and the number of cracked cells within the PV module. The cracking patterns generated were of two types representing the defects observed in module electroluminescence images from several PV powerplants sites. These are small crack patterns, as shown in Figure 1, and medium crack patterns, as shown in Figure 2.



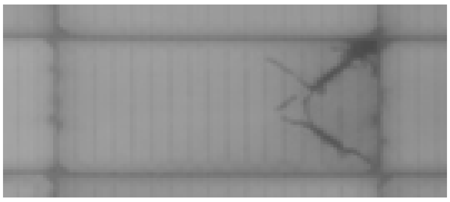


Figure 1. *Small crack pattern* ***Figure 2***. *Medium crack pattern*

The percentage of cracked cells within the module was generated according to Table 1:

Table 1. *Percentage of cracked cells*

Number of modules	Cracks patterns	Percentage of cracked cells
3 modules	Small	10%
1 module	Small	20%
2 modules	Medium	10%
3 Modules	Reference without defects	-

A batch of 9 modules for each technology was selected to perform the experimental tests. Reference modules from each batch, without any defects, were used in order to perform the degradation assessment for each crack pattern and percentage of cracked cells. An example EL image of each module type, with small and medium crack patterns, are shown in Figures 3 a) and b) respectively.

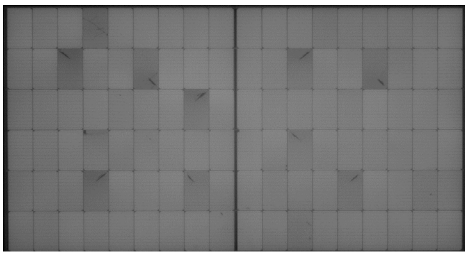
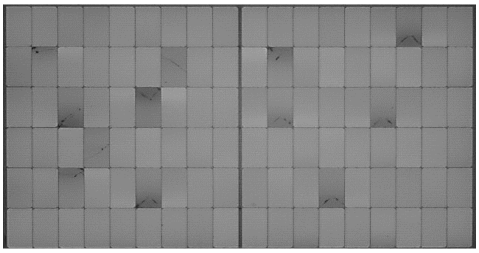
a)  b) 

Figure 3. *a) a PERC module with 10% coverage with the small crack pattern and b) a TOPCon module with 10% coverage with the medium crack pattern*

1.3 Characterization procedure

The characterization procedure of the selected PV modules was carried out using two main pieces of equipment:

- Electrical parameter measurements were made at different irradiances using a PASAN flash tester.

- Electroluminescence measurements were made using a high-resolution XT IQ4 Phase One camera (150 MPixels) without infrared filtering. The EL images were taken at Isc and Isc/10 current injections.

These measurements were performed at different steps of the experimental procedure:

- Before and after each cracking
- After each accelerated aging test sequence
- After the final stabilization of the PV modules

1.4 Results

A power degradation assessment was carried out by comparing the electrical parameters before and after the cracks using the flash tester at different irradiance levels. Table 2 summarizes some power degradation losses of the tested PERC and TOPCon modules at 1000W/m² and 200 W/m² irradiance and 25°C.

Table 2. *Power losses, PERC vs TOPCon modules at different irradiances*

Technology	***PERC***		***TOPCon***	
Pmpp Losses (%)	***at 1000W/m²***	***at 200W/m²***	***at 1000W/m²***	***at 200W/m²***
Module 1- Small crack 10% cracked cells	0.41	1.39	0.86	1.83
Module 2- Small crack 20% cracked cells	0.71	1.83	1.58	2.59
Module 3- Medium crack 10% cracked cells	0.67	1.82	1.97	4.41

As shown in Table II, the power losses are higher at low irradiances (200W/m²) for both technologies due to shunt defects at the cracked cells level. The electrical characterization after the cracks revealed a drop of the short circuit current and fill factor parameters. The main power losses observed for modules 1 and 2 were also observed on Isc losses parameters. Module 3 with medium cracks power losses were observed on Isc and FF parameters as well. These defects are also visible on EL images where we can notice the cells darkening under low irradiance (Isc/10) (Figure 4).

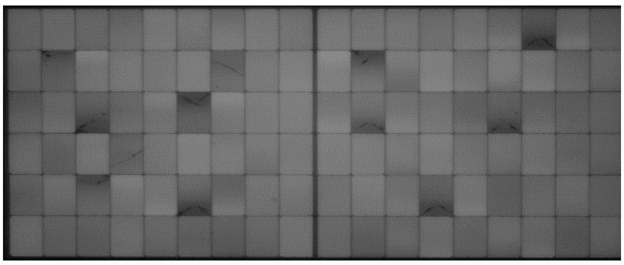


Figure 4. *EL image of Topcon module*

The power losses are higher for medium patterns and bigger cracked cells coverage. Moreover, the first results showed higher losses for TOPcon technology compared to PERC mainly observed at the fill factor and short circuit current parameters. This is probably caused by a higher sensitivity toward the apparition of unpassivated area at the TOPCon surface where remaining passivation defects are initially lower compared to PERC. This phenomenon can be compared to other publications showing the interest in passivating edges of half-cut of shinged solar cells to keep a high efficiency [4].

2. ACCELERATED AGING SEQUENCES

Further experimental testing was conducted applying several accelerated aging sequences on the cracked modules as well as on the reference modules. The main purpose of these experimental tests is to understand the cracked modules behavior over time. This behavior can be determined by observing the cracks patterns evolution and power degradation evolution after each testing sequence. The testing sequences conducted consisted of:

- Thermal cycling: TC 200
- Damp heat: 1000h

Several intermediate characterizations were performed within these tests before the final stabilization (48 hours Isc current injection) and characterization of the modules.

2.1. PERC and TOPCon modules results

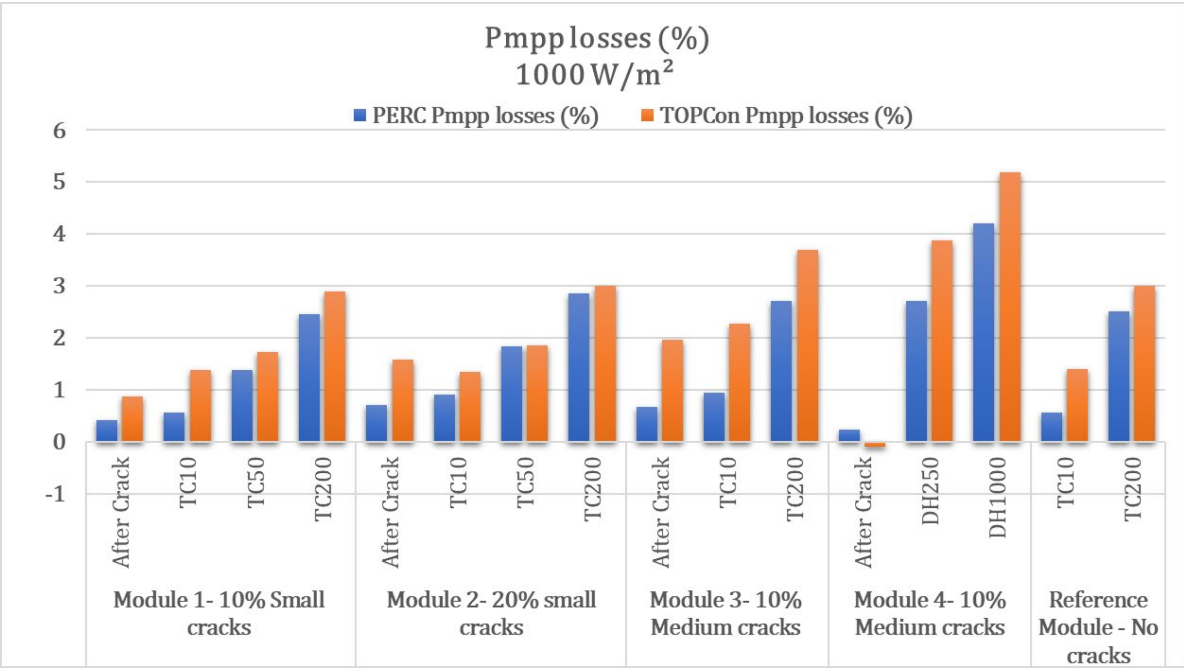


Figure 5. *Power losses for PERC and TOPCon technologies at 1000W/m² after accelerated aging sequences*

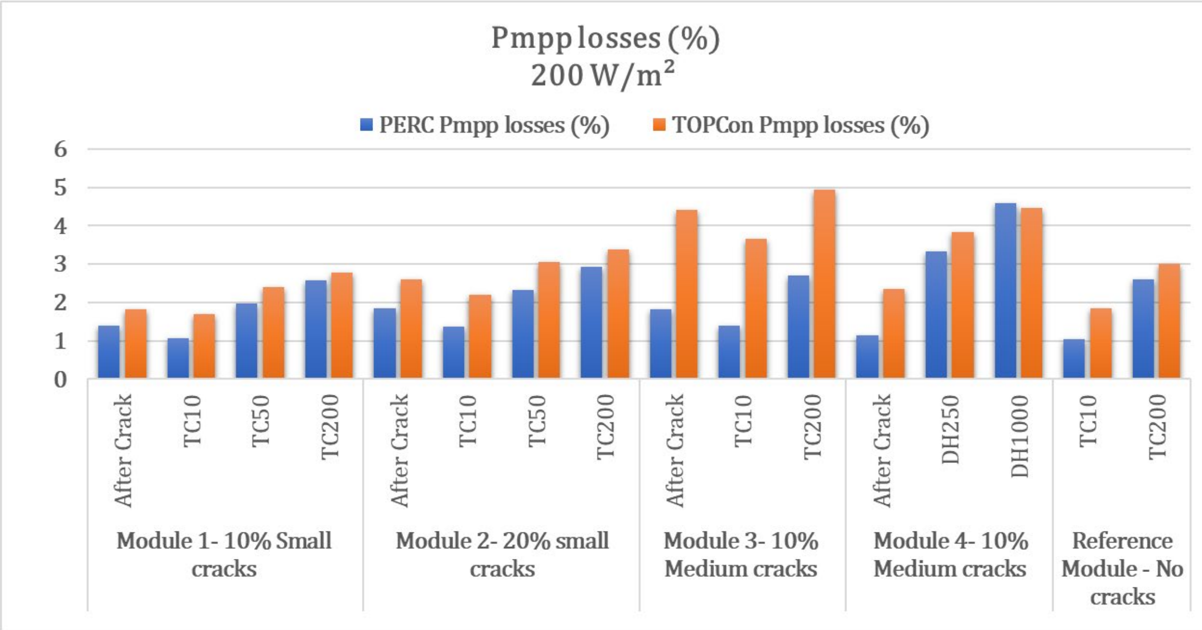


***Figure 6**. Power losses for PERC and TOPCon technologies at 200W/m² after accelerated aging sequences*

Figures 5 and 6 show the power losses for PERC and TOPCon modules after the cracks and after each accelerated aging sequence compared to the initial state of the module. The results are illustrated for high (1000 W/m², Figure 5) and low (200 W/m², Figure 6) irradiances levels. In order to perform an assessment of the cracks impact on the accelerated aging, the reference module aging results of each technology are presented as well.

For PERC modules, as observed in Figures 5 and 6, the TC power losses are slightly higher for module 2 with 20% of cracked cells reaching 2.9% compared to the module 1 with 10% of cracked cells. Module 3 with medium cracks didn't show significant difference in power losses compared to module 1 with small cracks patterns. The highest losses are observed after DH 1000h sequence for module 4 reaching 4.2% at 1000W/m² and 4.6% at 200W/m². For the reference module with no cracks patterns, the losses obtained after TC 200 were in the range of Module 1 losses (with 10% small cracks) showing no significant impact of such cracks after TC 200 on electrical performances.

For TOPCon modules, the TC power losses are higher for the module 2 with 20% of cracked cells reaching 3.3% at low irradiance (Figure 6) compared to the module 1 with 10% of cracked cells. Module 3 with medium cracks showed higher power losses as well compared to module 1 with small cracks patterns reaching 3.7% at 1000W/m² and 5% at 200W/m². The highest losses are observed after DH 1000h sequence at 1000W/m² for module 4 reaching 5.2%. For the reference module with no cracks patterns, the losses obtained after TC 200 were also in the range of Module 1 losses (10% small cracks) showing no significant impact of such cracks after TC 200 on electrical performances. Nevertheless, an evolution of the cracks was observed on EL images after TC 200 as will be shown in the next paragraph.

2.2. Results discussion

The performance characterization after the accelerated aging sequences showed higher losses for TOPcon technology compared to PERC for damp heat and thermal cycling sequences (due mainly to fill factor and short circuit current losses). However, compared to the reference modules (Table 1) that didn't present any cracks or other initial defects, the main results obtained showed that the cracks don't have much impact for the TC tests. Nevertheless, the DH testing sequences highlighted an important impact on the cracked modules with efficiency losses reaching 4.6% for PERC and 5.2% for TOPCon after a 1000h testing sequence compared to the reference module mainly caused by humidity ingression through the backsheet. However, an evolution of the cracks after the TC 200 cycles sequence was noticed on EL images (Figure 7) and may have higher impacts on degradation rates compared to reference modules if we increase the thermal cycling sequences.

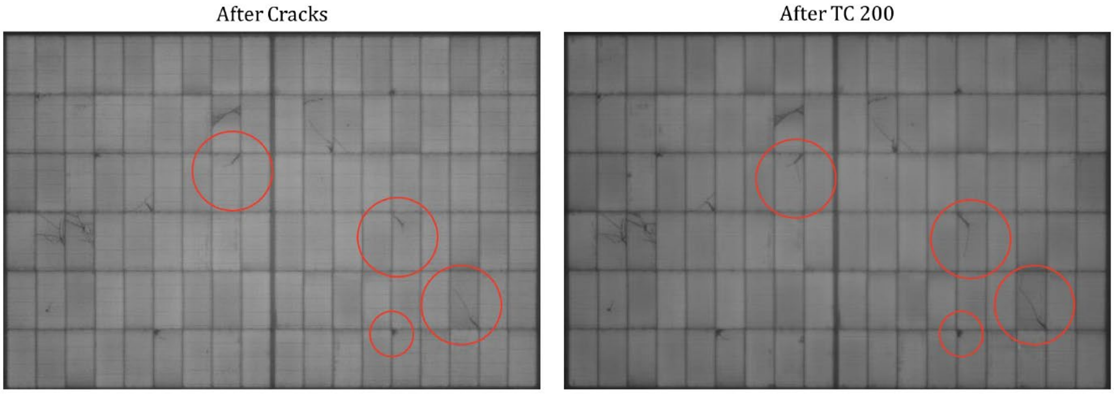


Figure 7*. Cracks evolution after TC 200 cycles on a TOPCon module*

3. Conclusion

In this work, an evaluation of the cracks impact on PV module's performances was conducted. An experimental work on several modules of two different technologies was performed: First different cracking patterns and coverage were generated. Second, several indoor accelerated aging sequences were conducted using climatic chambers. The first experimental work showed power degradation up to 1.82% for PERC and 4.41% for TOPCon modules after the cracks generation. These results show that TOPCon technology is more impacted by cracks with higher efficiency losses as observed in the electrical characterization. The accelerated aging sequences were conducted to come up with conclusions regarding the lifetime and performance of powerplants with such defects. Damp heat testing presented the highest degradation factors for cracked modules of both technologies while TC sequences showed quite similar degradation rates compared to reference modules without defects. Further accelerated aging sequences may reveal higher sensitivity for the modules presenting cracks or microcracks that will potentially progress with the module's operation time.

Underlying and related material

All relevant raw data were submitted with the article and can be asked directly to the authors.

Author contributions

Christine Abdel Nour: Experimental work, data analysis and writing

Julien Dupuis: Formal analysis and writing

Paul Lefillastre: Formal analysis and writing

Axel Becker: Supervision and Funding acquisition

Competing interests

The authors declare no competing interests.

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