DAYLIGHT ELECTROLUMINESCENCE INSPECTION OF PV PANELS ON-SITE VS. TRADITIONAL EL INSPECTION WITH SILICON CAMERAS

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ABSTRACT: This paper presents a comparative study of electroluminescence (EL) imaging of silicon photovoltaic (PV) panels in three currently operating PV plants. EL images were acquired using two methods: in a darkroom with a silicon sensor reflex camera after dismantling the panels; and during daylight without dismantling the panels using an InGaAs sensor camera (dEL). The results demonstrate that dEL can detect the same important defects in the PV panels while being not only less costly in terms of time and money but also able to prevent the production of new defects resulting from disassembly, transportation and reassembly of the modules. This way, dEL provides a more efficient and reliable procedure for quality control and maintenance.
Keywords: Electroluminescence, silicon panels, InGaAs camera, non-destructive inspection, daylight inspection

1 INTRODUCTION

Regular inspections of the solar photovoltaic (PV) plants are crucial to ensure optimal energy production and to prevent potential future failures and module degradation. Among the available inspection techniques, electroluminescence (EL) stands out as a powerful tool for detecting hidden defects and anomalies in panels [1, 2].

EL inspection involves applying a current to the panel and capturing the emitted light using specific cameras. Normally, this process is carried out with specialized silicon cameras, either at night (on-site), or by dismounting the panels and taking them to a darkroom or mobile laboratory. However, both alternatives present significant drawbacks:

Night-time inspection:
- Requires specific weather conditions (no nearby light or moonlight).
- Involves safety risks for personnel.
- Higher staff costs for night working.

Dismounting panels:
- Increases the risk of panel damage.
- Disrupts power generation.
- Time consuming and costly.

In the last years, on-site inspection techniques have gained much more acceptance [3]. Among them, daylight Electroluminescence (dEL) by using InGaAs cameras have been developed by several groups [4-7], including our own [8]. This innovative solution allows daylight inspection without disassembling the panels, overcoming the limitations of traditional methods. It also allows inspections to be performed regardless of the weather conditions (except for rain or high wind gusts), increasing operational efficiency, and minimizing downtime. By eliminating the need to remove panels, dEL also reduces the risk of potential damages of the modules, minimizes production losses, reduces labor costs, and ensures the integrity of the solar installation. With our compact and lightweight design, the camera-tripod is easily portable and convenient to transport, facilitating quick setup at various locations, see Fig. 1.

Figure 1: Compact dEL system developed by our group [8].

This communication presents a comparative study of EL images of monocrystalline and polycrystalline PV panels obtained using both conventional EL with silicon cameras in a darkroom (under standar test conditions, STC), after panel disassembly, referred here as high-resolution night EL (HR-nEL), and dEL, without panel disassembly. The dEL measurements were performed by our research group, while the HR-nEL measurements were performed by two different companies specialized in the inspection of photovoltaic systems. The aim of the study was to compare the advantages and disadvantages of each method in terms of image quality, ease of use, inspection time, cost and similarity of the defects detected by both techniques.

2 MATERIALS AND METHODS

More than 1,000 mono and polycrystalline modules from three different PV power plants currently in real operation in Spain were analyzed.

In order to compare both imaging methods, a first dEL inspection was performed on-site prior to dismounting the panels for a HR-nEL inspection in a dark room. After the latter, the modules were reassembled at their original location, and a second dEL inspection was finally conducted again on-site. This way, the potential damage induced by the disassembling/handling/reassembling processes could also be studied.

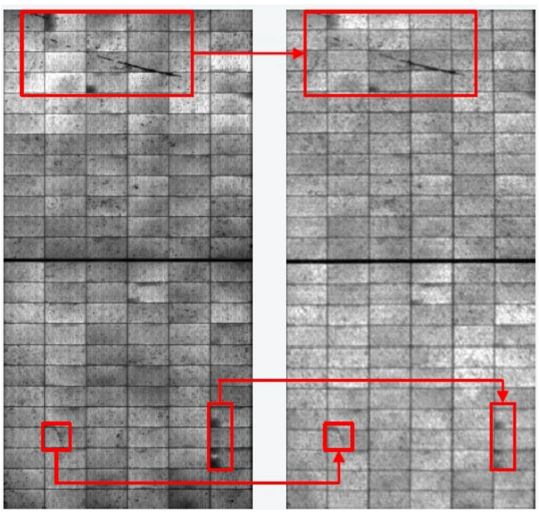
The InGaAs sensor used for the dEL imaging is a Hamamatsu C12741-03 (- 640 × 512 pixel – 0.33 MPixel) camera, which works at 14-bit resolution. The pixel noise and dark current of this camera are 250 e^- rms and 360 000 e^-/(px·s), respectively. The exposure time can range from 1 µs to 1 s; allowing the acquisition to be adapted to the different lighting conditions during the daytime.

Conventional EL was performed using two different silicon cameras (at least 24.2 MPixel – 6000 x 4000 pixels) in a dark room at STC conditions after dismounting the modules.

3 RESULTS

3.1 HR-nEL vs dEL

Fig. 2 shows EL images of a polycrystalline silicon panel.

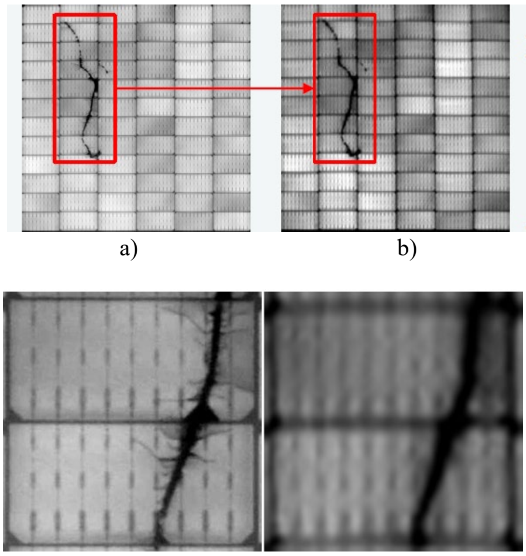


a) b)

Figure 2: Defects in a polycrystalline silicon panel. a) High Resolution night Electroluminescence (disassembling) obtained with a Si camera; b) dEL image (without disassembling) obtained on-site with an InGaAs camera.

They were obtained by the two procedures mentioned above: using a high-resolution reflex camera after disassembling the panels (HR-nEL) (a), and using an InGaAs camera (on-site), before disassembly (dEL) (b). The results showed that despite the lower resolution of the InGaAs camera, the most significant defects [2], which can lead to a reduction in panel performance or an increase in degradation, are still detected.

Fig. 3 shows the EL images of a monocrystalline silicon panel obtained by the two methods. The small fractures surrounding the large defect are not properly detect by dEL, although their contribution to the efficiency loss is considered lower.

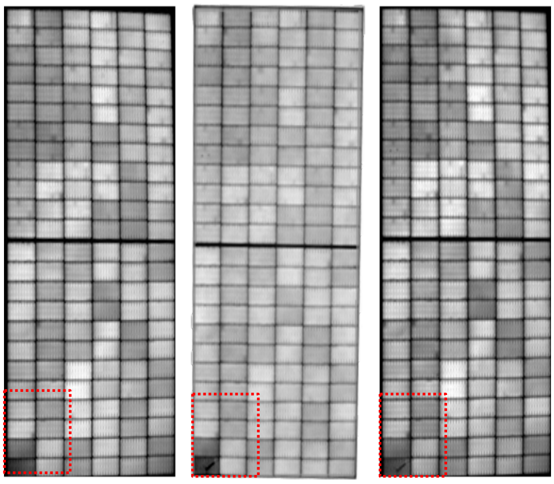


a) b) c) d)

Figure 3: a) HR-nEL image of an extensive defect in a monocrystalline panel; b) dEL image of the same monocrystalline panel; c) magnification of part of the defect in the same area observed by HR-nEL; d) same magnification in the dEL image

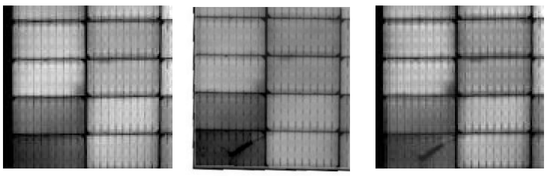
3.2 Induced damaged

In addition to the comparative analysis of EL imaging methods, the study also investigates the potential damage caused by panel disassembly, handling and reassembly. The results show that certain defects appeared in some panels at some point during these processes. Fig. 4 presents such a case. Three EL images are shown in the figure: Fig. 4a), taken with the InGaAs camera before disassembly; Fig. 4b), taken with a Si camera after disassembly; and Fig. 4c), a new image taken again with the InGaAs camera after reassembly. Fig. 4b) shows a defect not visible in Fig. 4a). Fig. 4c) confirms the presence of the defect, which was not initially found. Fig. 5 shows the area of this defect magnified for each image. The defect should be thus ascribed to the disassembled/handling process for the HR-nEL inspection. This finding highlights the importance of using non-destructive inspection methods, such as dEL imaging on-site, to prevent damage to PV panels during EL inspection procedures.



a) b) c)

Figure 4: a) dEL image taken with the InGaAs camera before disassembly; b) HR-nEL taken with the Si camera after disassembled the panel for a darkroom inspection; c) dEL image after reassembly. A defect has appeared in the lower left corner



a) b) c)

Figure 5: Magnification of the interest zone in Fig. 4 (red dotted); a) dEL image taken with the InGaAs camera before disassembly; b) HR-nEL taken with the Si camera after disassembled the panel for a darkroom inspection; c) dEL image after reassembly

4 CONCLUSIONS

In summary, dEL represents a significant advancement in EL inspection procedures, enabling daytime inspection of solar panels without dismounting them. This solution offers numerous advantages over traditional methods, including increased efficiency, safety (not only for the workers but also for the installation), cost reduction and convenience. The lower resolution of the InGaAs camera may not be sufficient to detect very small defects. However, the camera's ability to inspect panels during the day and without dismounting them makes it a valuable tool for identifying larger and more critical defects that can significantly impact panel performance. The study also highlights the inherent risks of the assembly and disassembly processes involved in performing EL inspections with Si cameras. The successful application of dEL technology in real-world settings demonstrates its potential to revolutionize the maintenance and inspection of PV systems, ensuring their optimal performance and longevity.

5 ACKNOWLEDGMENTS

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