20-Year field exposed polycrystalline silicon PV modules: detailed visual inspection and analysis

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Introduction

70 polycrystalline glass-glass modules from Helios technology were installed in 1991 in the outdoor test field at the European Solar Test Installation in Ispra. The modules consisted of 36 series connected pseudo square solar cells, divided into two strings, of 19 and 17 cells. The modules were divided into two groups, each connected to an inverter, keeping modules in operation around their maximum power point. The system was field exposed without interruption from 1991 to 2010 in moderate subtropical climate, and the analysis of electrical parameters degradation as well visual inspection according to IEC 61215 has been published [1]. We present the results of detailed visual inspection performed according to the protocol proposed by Packard et al. [2] and the spatially resolved analysis using LBIC and electroluminescence techniques.

Visual inspection:

Visual inspection according to IEC 61215 was performed on the majority of modules in 2010. More than 90% of defects were due to 4 types:

- Cells discoloration
- Degraded cable feed through
- Delamination and bubbles formation
- Chipped or cracked glass (module front or back)

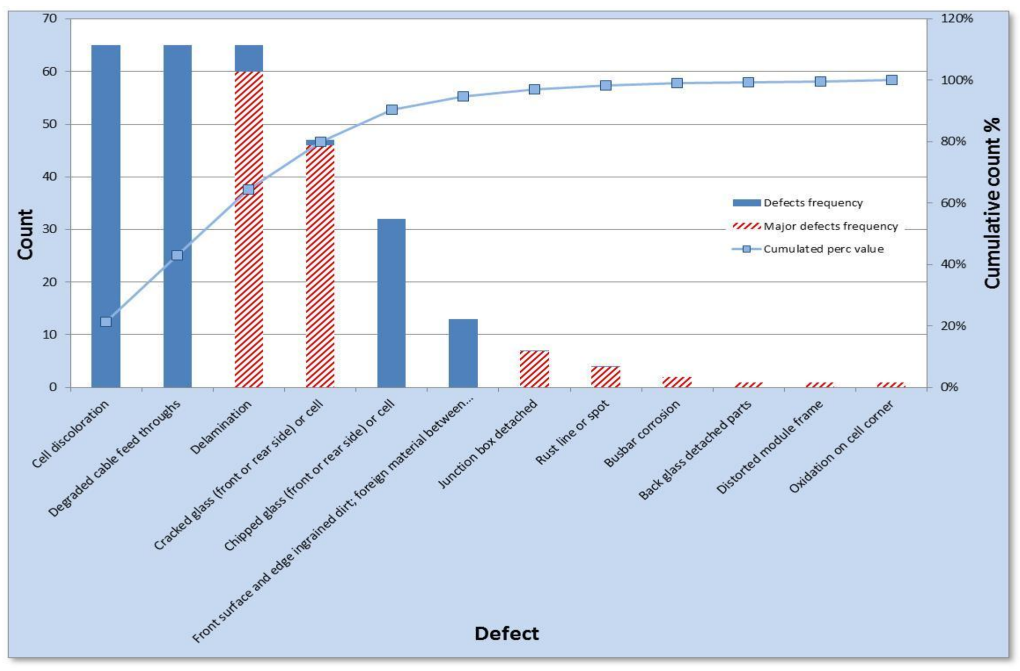

Fig.1: result of 2010 visual inspection

Visual inspection was repeated for all modules according to the protocol proposed by Packard et al. [2]. Part of the results together with the cumulative percentage of defects are reported in the graphs of fig.2

Characteristics of the graph:

- Height of columns: occurrence of each defect as a percentage of the total number of defects found with the visual inspection in all modules.
- Each defect type is divided into four severity levels corresponding to protocol indications eg.:
  - "cells dark discoloration": severity 4 = 75% - 100% discolored area
  - "cracked glass": severity 1 = 1 crack; severity 2 = 2 cracks; severity 3 = 3 cracks

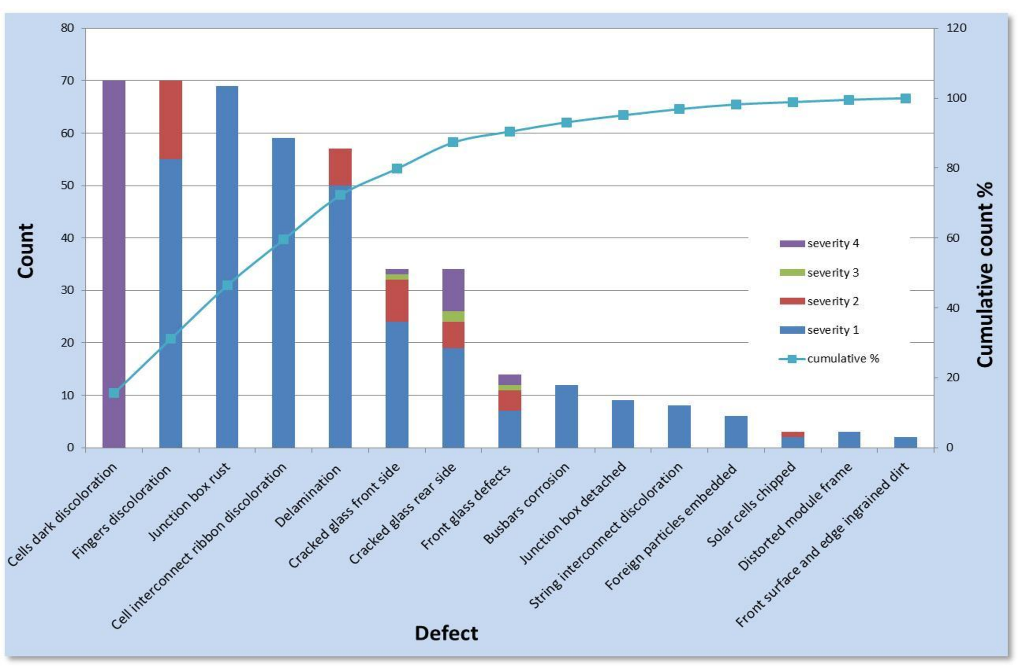

Fig.2: result of 2013 visual inspection

Figure 2 contains a selection of information useful to compare the results of the previous visual inspection.

Some defect types found in 2010 are not present in 2013 eg: "degraded cable feed throughs". This defect was not evident in 2013 as the cables were removed from modules in 2010 after visual inspection.

Comparison of the two methods:

- The new protocol contains more detailed description of defect types
- Each defect type is analyzed in more detail by "severity" classification

Electrical comparison:

Direct correlation between visual defects and electrical degradation was not found even taking into consideration defect severity as a parameter. This is due to the low average degradation rate (-0.24% P_{max} per year)

- Data analysis showed correlation between degradation of P_{max} (-0.24% /y) and I_{sc} (-0.15% /y) (fig.3).

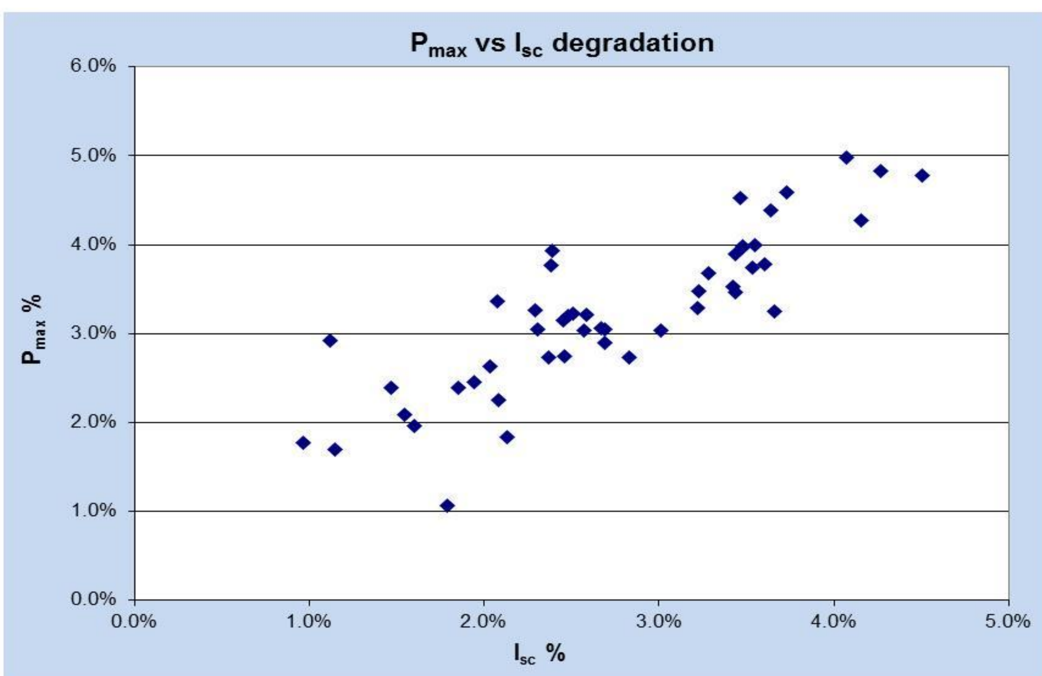

Fig.3: 1991–2010 P_{max} versus I_{sc} degradation

LBIC and electroluminescence analysis:

I_{sc} degradation was found to be related to extensive yellowing on all modules. Analysis was performed by means of visual, LBIC and electroluminescence inspections:

- LBIC: scan of the complete module with 633nm HeNe laser and lock-in amplifier
- EL: picture taken with injection of I_{sc}

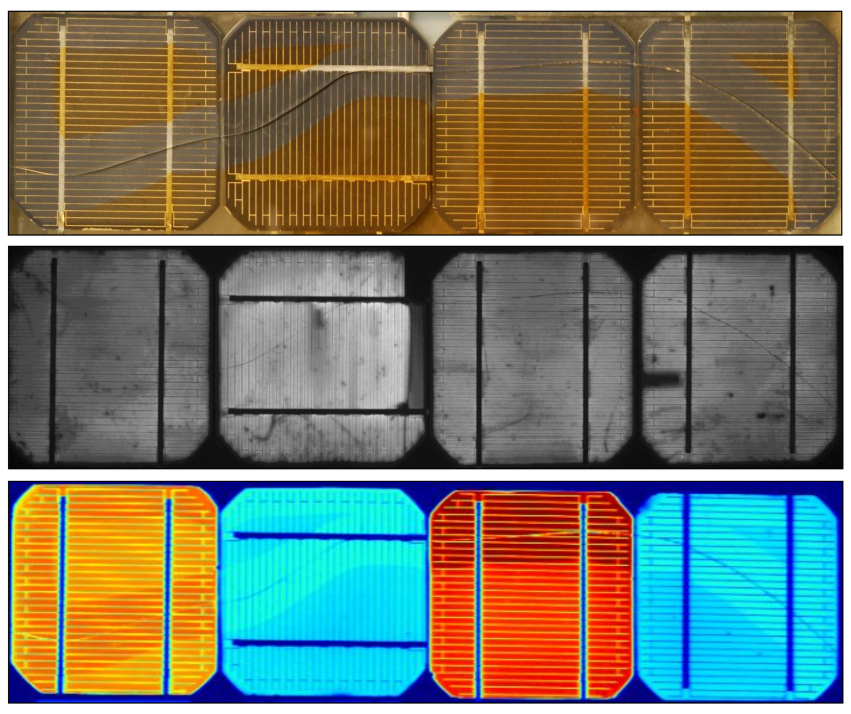

Fig.4: Visual, EL and LBIC images of the same module area

Visual: extensive EVA yellowing, extensive glass crack, no yellowing near cracked area (effect due to oxidative bleaching)

EL: several defects visible (cracked cell, finger interruptions, scratches). No difference between area with and without yellowing. Cells do not show damage by moisture ingress from glass crack.

LBIC: higher photogenerated current in the area without yellowing (optical coupling is limiting factor for current).With dark LBIC technique, only the difference of response inside a cell is to be considered. (Cell to cell comparison is not possible as the response is dependent on the complete string connection).

Conclusions:

Visual inspection:

- Quantitative information on defect types and occurrence available with new proposed protocol.
- Possibility to analyze more in depth the correlation of visual defects and electrical parameters degradation.

LBIC and electroluminescence analysis:

- Main degradation factor was found to be optical coupling degradation due to extensive yellowing, present in all modules, causing I_{sc} losses.
- Moisture ingress from glass crack did not cause cell degradation.

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[1] Polverini D. et al. "Polycrystalline silicon PV modules performance and degradation over 20 years", *Progr. Photovoltaic: Res. Appl.* 2013; 21: 1004-1015

[2] Corinne E. Packard et al. "Development of a Visual Inspection Data Collection Tool for Evaluation of Fielded PV Module Condition", *Technical Report* NREL/TP-5200-56154 August 2012