Numerical model for the prediction of the electric response of Solar Cells in presence of cracks

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Outline

A global/local finite element approach is proposed to provide an accurate prediction of crack opening displacements of cracks in solar cells. Based on these predictions, a generalized one-diode electric model proposed by the authors is then applied to predict the electric response of cracked solar cells for different global deformation level. The dependency between the localized electric resistance and the crack opening, introduced to model partial conductive cracks, is properly identified by matching experimental results with the theoretical predictions.

Global/local finite element approach

- **Global model** ➞ Compute displacement, stresses and strains inside the PV module, for each bending configuration.
- **Displacements** at the solar cell (from point A to B) passed as **boundary conditions** to the **local model** of the solar cell (3D finite elements used to discretized the continuum, interface elements with a cohesive zone model to simulate cracks).

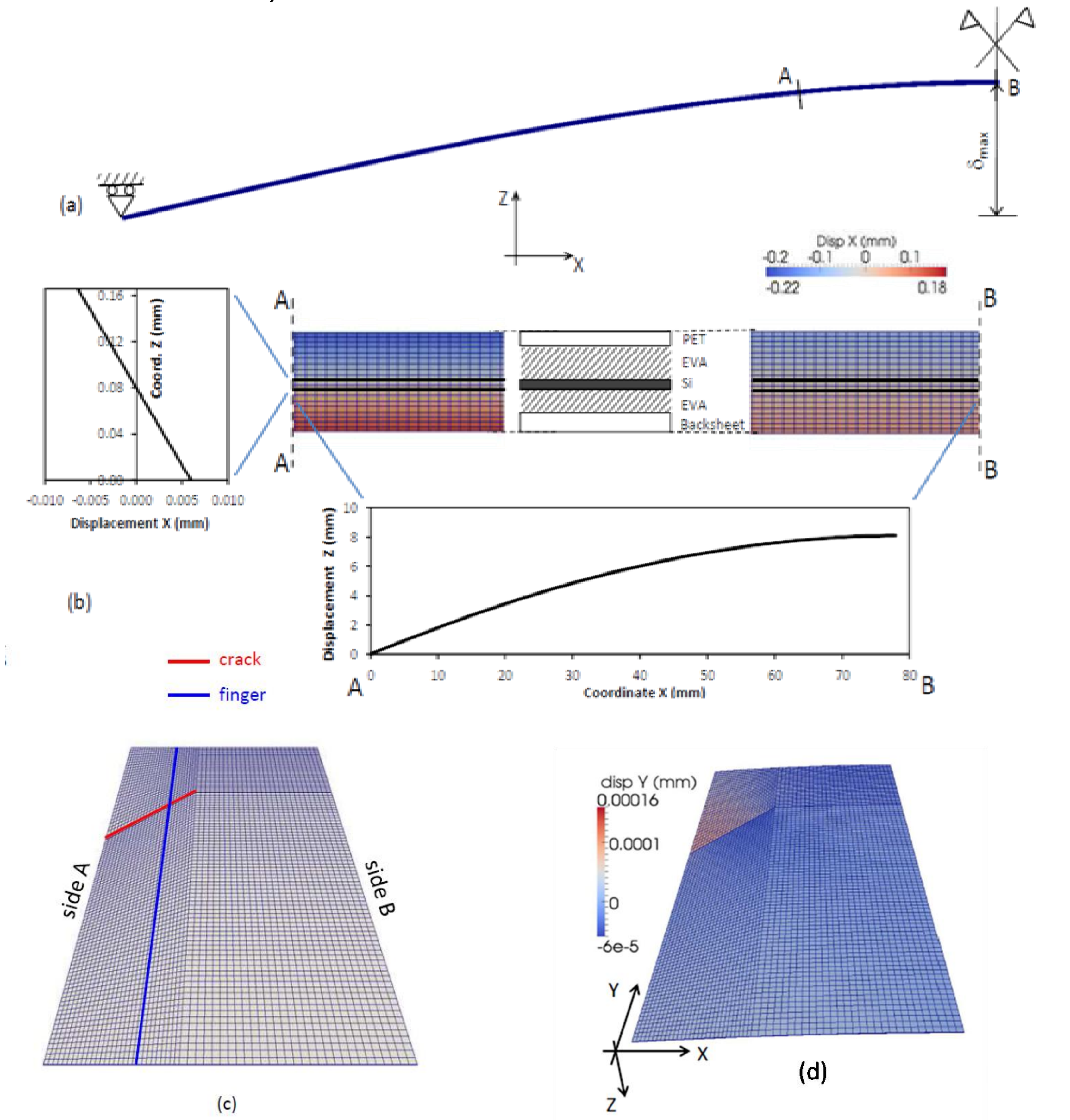


Fig. 1 (a) The global FE model of the PV module tested in bending; (b) displacements passed to the local model of the solar cell located between points A and B; (c) mesh of the local 3D FE model of the solar cell, (d) Contour plot of in plane displacements of the cracked cell for mid-span defection of the module of 6 cm.

Experimental tests

- Curvature imposed to a semi-flexible module with mc-Si cells (convex side after bending corresponds to the PET side) ➞ **Tensile** stress state inside solar cells .

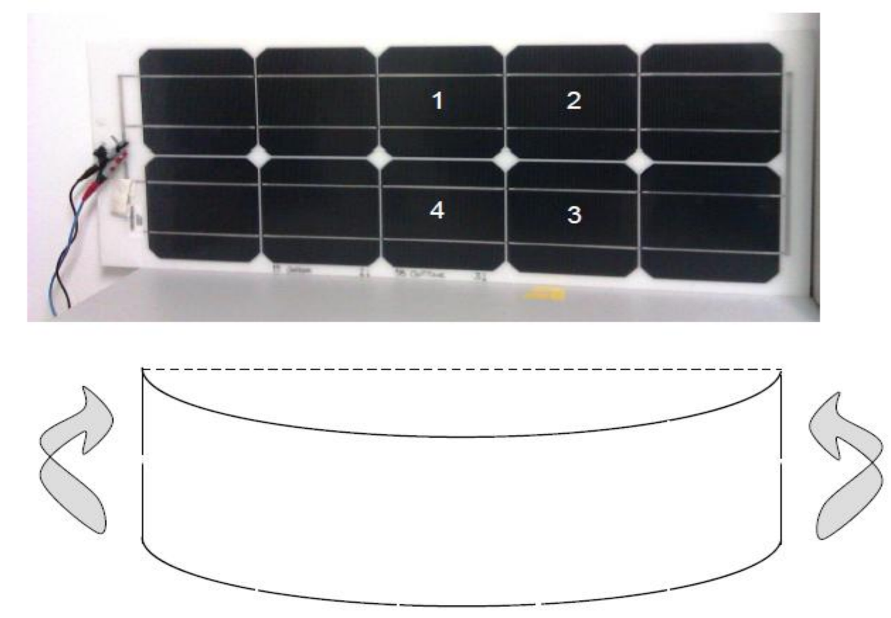


Fig. 3 Sketch of the mechanical test. The cells 1-4 were monitored by EL.

- Parameters used in the simulations: I_{SC} = 0, R_{loc} = 0.2 Ωcm^2, V_T = 25 mV, ρ_S = 0.13 Ωcm; I_{01} = 1.48 × 10^{-12} mA/cm^2. V_0 and R_{CR} are free parameters used to fit the experimental results obtained from EL images.

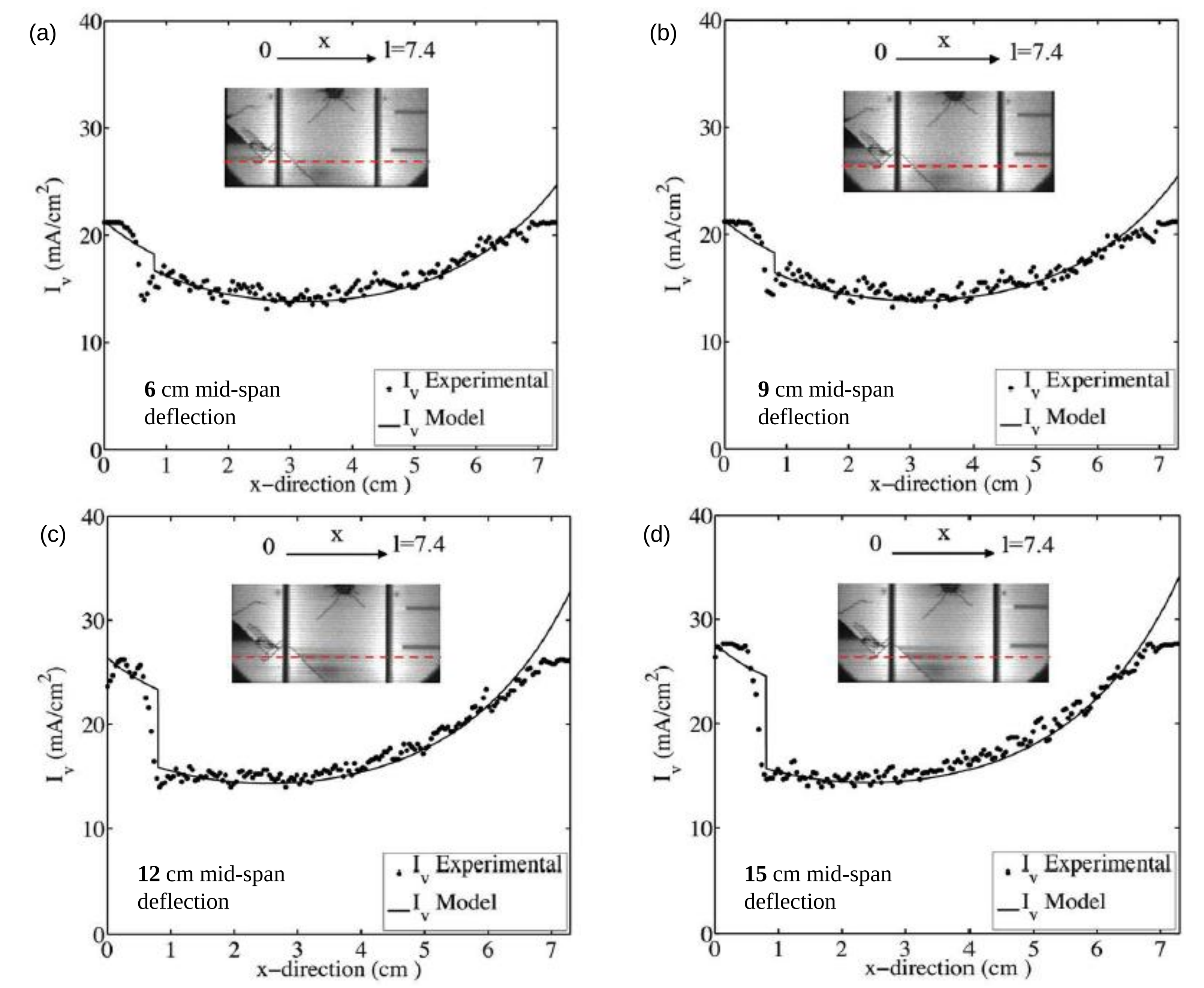


Fig.4 Vertical current in the cell 1 of Fig. 3 along a finger crossed by a crack for mid-span deflections of (a) 6cm, (b) 9 cm, (c) 12 cm, (d) 15 cm..

Electrical Model

- Ordinary differential equations (ODE) of the 1D electrical model for each finger [2]

$$\frac{\mathrm{d}V(x)}{\mathrm{d}x} = -\rho_S I_h(x)$$

$$\frac{\mathrm{d}I_h(x)}{\mathrm{d}x} = I_v(x)$$

$$\frac{\mathrm{d}^2V(x)}{\mathrm{d}x^2} = \rho_S I_v(x)$$

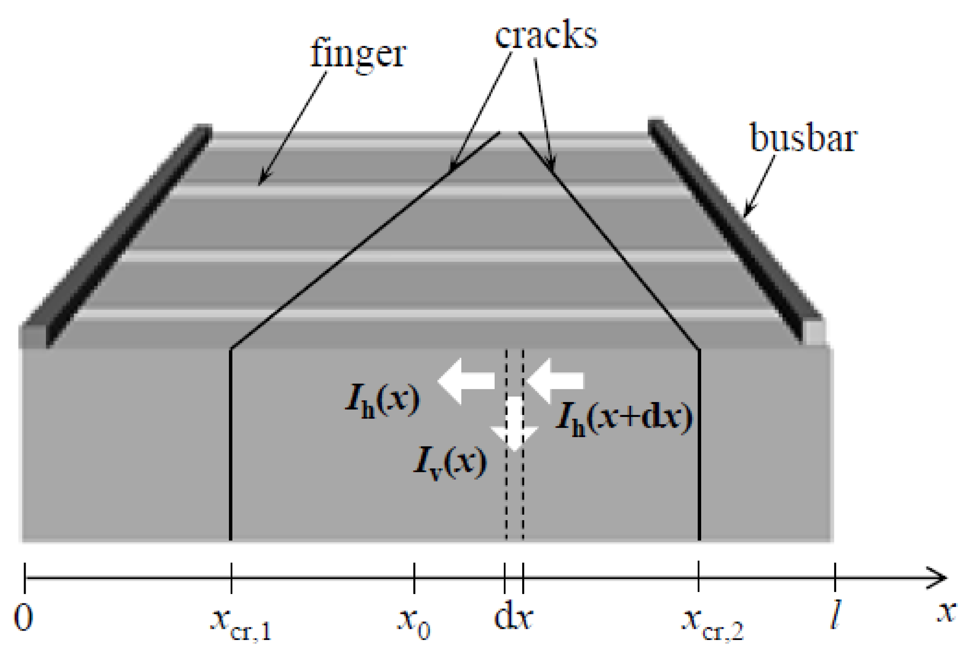
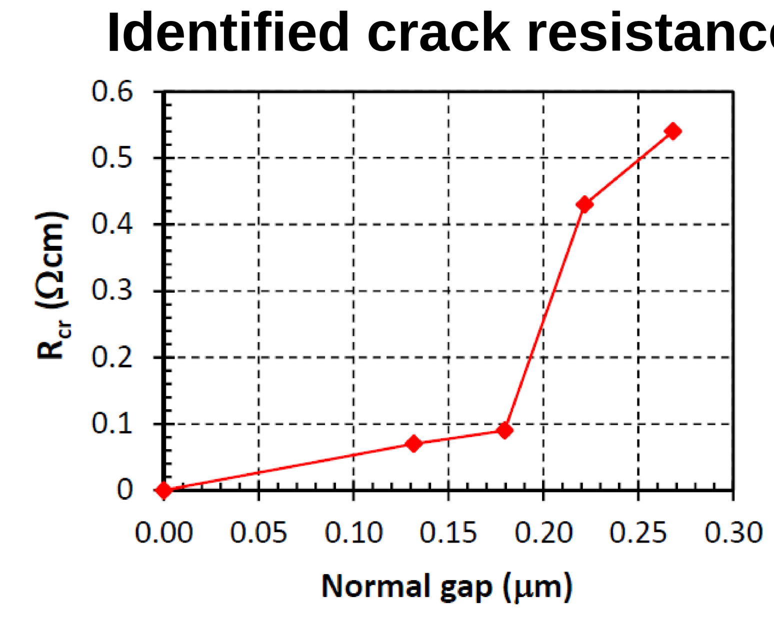


Fig.2 Schematic representation of a grid intersected by two cracks.

- Numerical integration ODE equations by discretizing the grid line with spacing dx
- Crack opening displacement sufficiently large ➞ discontinuity in the voltage [3].

$$V(x_{cr,1}^-) = V(x_{cr,1}^+) + R_{cr,1} I_h(x_{cr,1})$$

Identified crack resistance vs. crack opening relation



The localized crack resistance is an increasing function of crack opening (normal gap).

Fig.5 Localized crack resistance vs. crack opening for the for cases shown in Fig.4.

Conclusions

- Proposal of a **global/local** finite element approach for the simulation of **cracking** in solar cells embedded in PV modules to quantify the **crack opening** ;
- Electric resistance and the crack opening **relation** will be used as input of the electric model to simulate the electric response of cracked solar cells.

References:

[1] M. Paggi, I. Berardone, A. Infuso and M. Corrado. Fatigue degradation and electric recovery in Silicon solar cells embedded in photovoltaic modules. Scientific Reports. doi: 10.1038/srep04506,2014

[2] O. Breitenstein and S. Rißland. A two diode model regarding the distributed series resistance. Solar Energy Materials and Solar Cell, 110: 77-86, 2013

[3] I. Berardone, M. Corrado ,M. Paggi. A generalized electric model for mono and polycrystalline silicon in the presence of cracks and random defects. Energy Procedia; 55:22-29,2014

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