EFFECTS OF PARTIAL SOILING ON THERMAL INFRARED IMAGING OF CRYSTALLINE SILICON PV MODULES

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Introduction

- Thermal infrared (TIR) images of operational photovoltaic (PV) modules are generally misinterpreted because of the dynamic nature of some types of soiling.
- TIR imaging is ideally conducted under steady climatic conditions, however under dynamic operational conditions different TIR images are observed.
- Wind blown dust is dynamic in nature and can settle on the bottom rows of PV modules.
- Cell anomalies, partial soiling and defective cells, can cause current mismatch in crystalline silicon PV modules and create hot spots which can be detected on TIR images.
- Mismatched cells impact on performance and longevity of PV modules.

Experimental set up

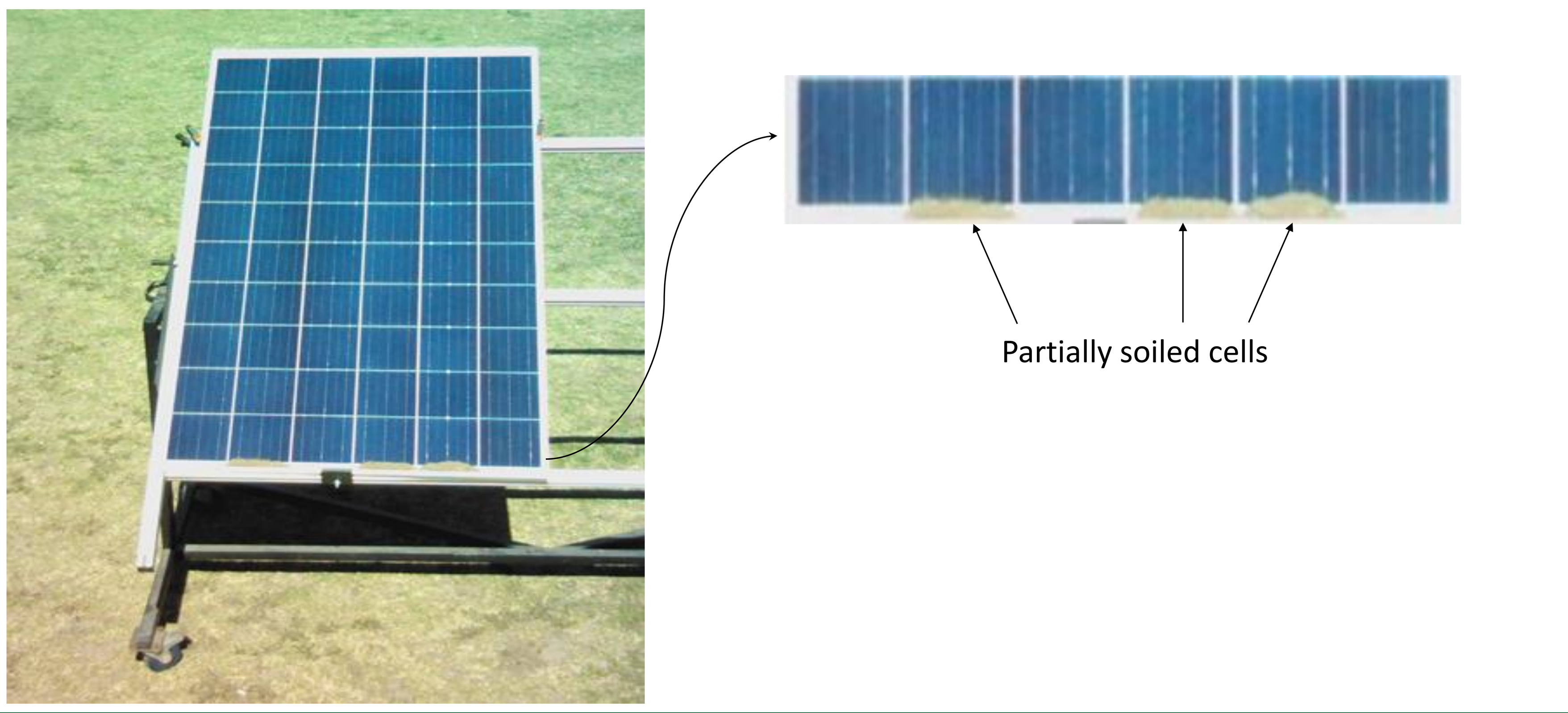

Fig 1: Soiled crystalline silicon PV module inclined for TIR imaging and I-V measurements.

- Crystalline silicon PV module set up to receive irradiance of more than 1000 W.m^{-2}.
- TIR images were recorded when the module was unsoiled and when three cells in different substrings were partially (<10%) soiled sequentially, while under short circuit conditions.
- Current-Voltage (I-V) measurements were taken for the soiled and unsoiled scenarios.
- Electroluminescence (EL) imaging was conducted to check cell anomalies which were not visually identified.
- The testing techniques were also conducted on an array of monocrystalline PV modules.

Results

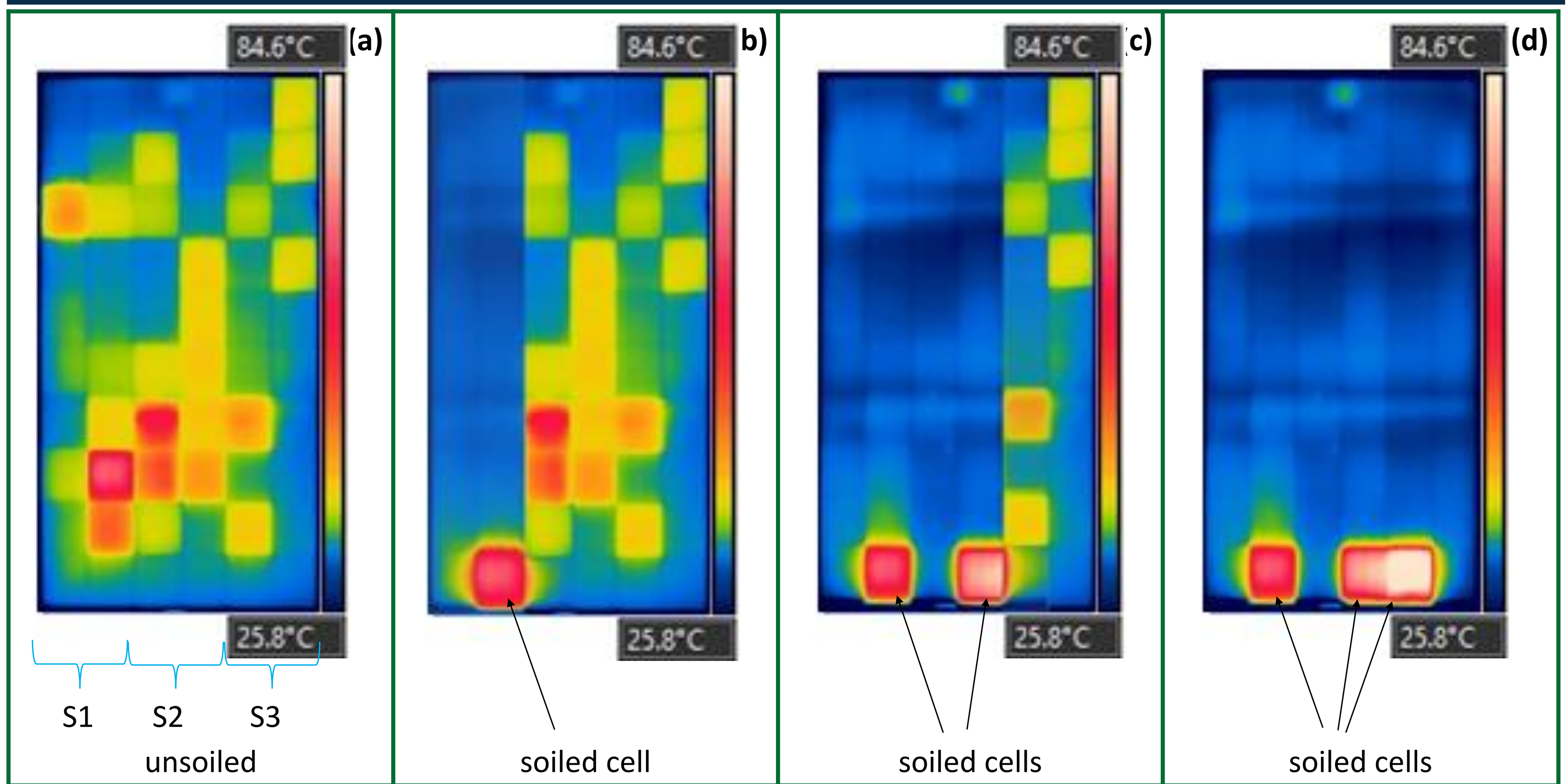

Fig 2: TIR images of the crystalline silicon PV module captured under short circuit and different soiling conditions.

- Non-uniform temperature distribution is observed on TIR image of the unsoiled module, Fig. 2(a), with the hot cells displaying a patchwork pattern in substrings S1, S2 and S3.
- When a good cell in S1 is shaded by partial soiling (<10%), it operates at an abnormal temperature, while the rest of the substring cells operate at uniform temperature, Fig. 2(b).
- The dynamics of thermal signatures is also observed when two and three cells in S2 and S3 were similarly partially soiled sequentially, as shown in Figs. 2(c) and 2(d).
- Partial soiling minimises current mismatch in the substrings resulting in the bad cells appearing as good cells on TIR image, Fig. 2(d).

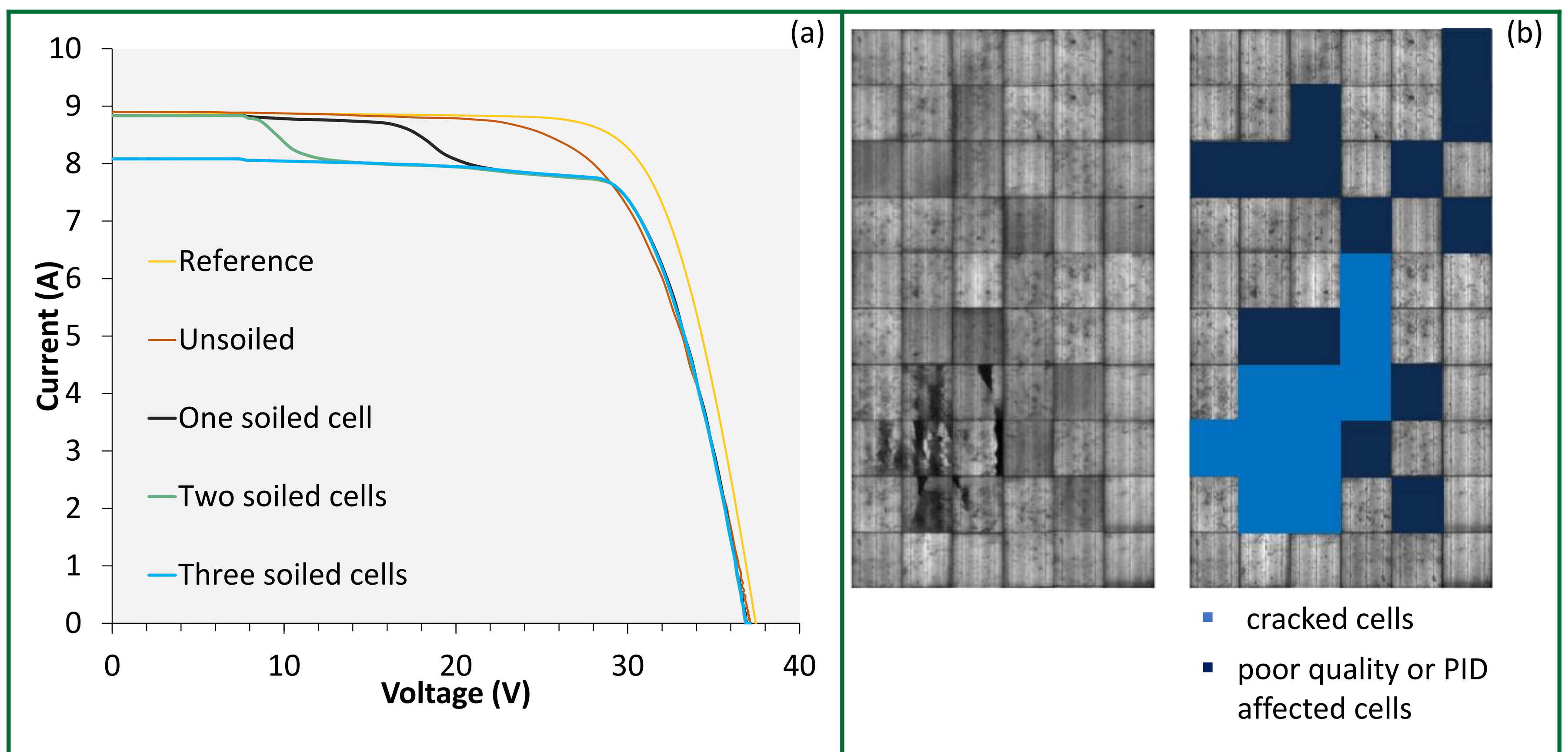

Fig 3: (a) I-V characteristics and (b) EL images of the crystalline PV module.

- The I-V curve of the unsoiled module deviated from the reference I-V curve, generated in PVSim, for voltages higher than 20 V due to cell anomalies which also caused a reduction in V_{OC} of ~ 0.5 V.
- Partial soiling created bumps on I-V curves reflecting active bypass diodes.
- When three cells in different substrings were partially soiled uniformly, no bypass diode was active hence no bump is seen in the I-V curve, but a drop in module's in I_{SC}.

- The EL image, Fig. 3(b), reveals that some hot cells in Fig. 2(a) that were identified when the module was unsoiled correspond to damaged cells and other hot cells were due to Potential Induced Degradation (PID) affected or poor quality cells.
- The damaged cells operated normally and appeared as good cells, on TIR imaging, when the substrings S1, S2 and S3 were partially soiled.
- In-depth knowledge on the state of the cells can be obtained by incorporating EL imaging.

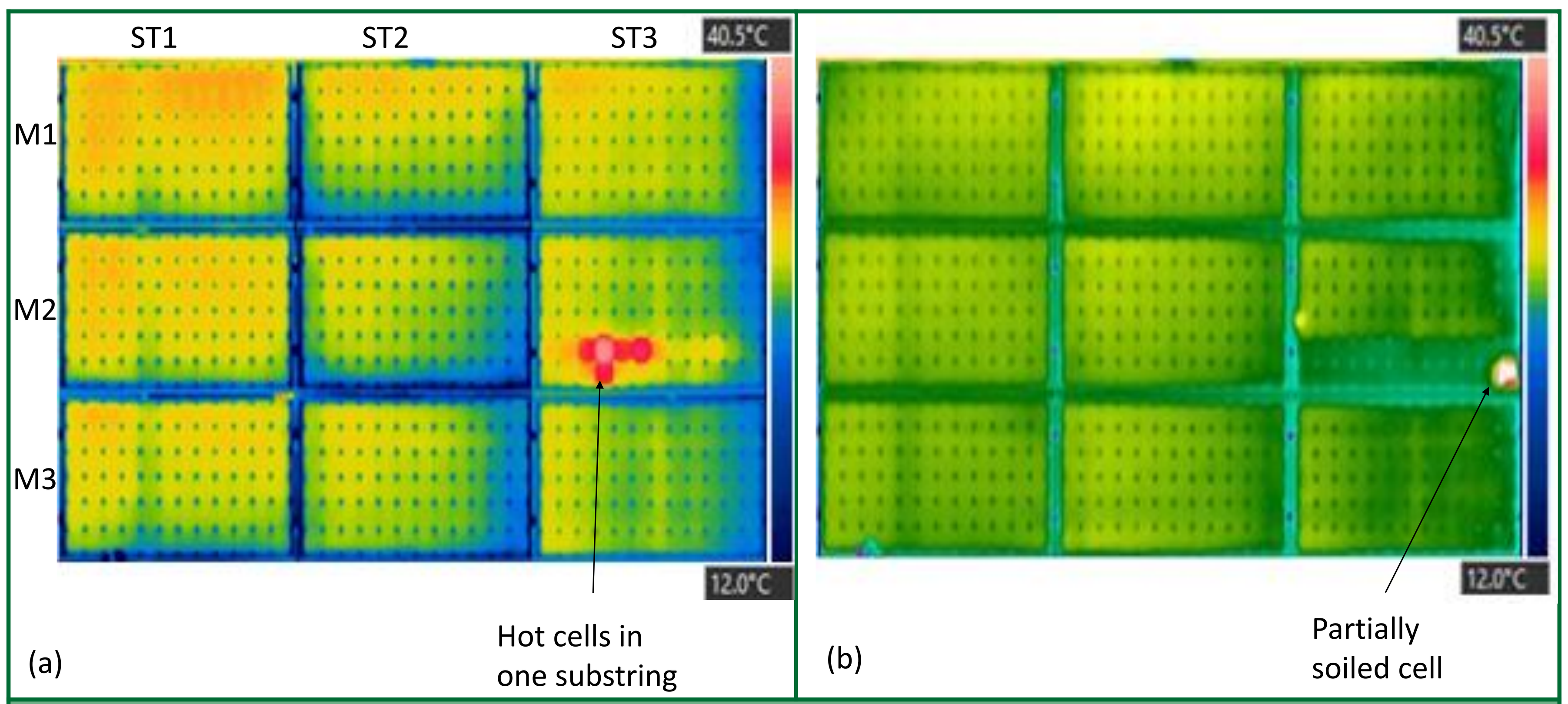

Fig 4: Thermal images of the monocrystalline array when (a) unsoiled and (b) partially soiled.

- Fig 4(a) shows non-uniform temperature distribution in the plane of array that was caused by several abnormally hot cells in one substring.
- The problematic cells were underperforming and were mismatched with good cells, forcing the bad cells to operate at elevated temperature.
- When one cell in the array was partially soiled (≤10%), Fig. 4(b), the whole cell heated up mainly due to current mismatch when the cell was operating in reverse bias.
- The bad cells in the soiled substring could not show their abnormal thermal signature due to partial soiling.
- Partial soiling influence current mismatch in operational crystalline modules and affect results on TIR images.
- Partial soiling can mislead, during PV inspections, to only cleaning the dirty modules yet other anomalies are hidden.

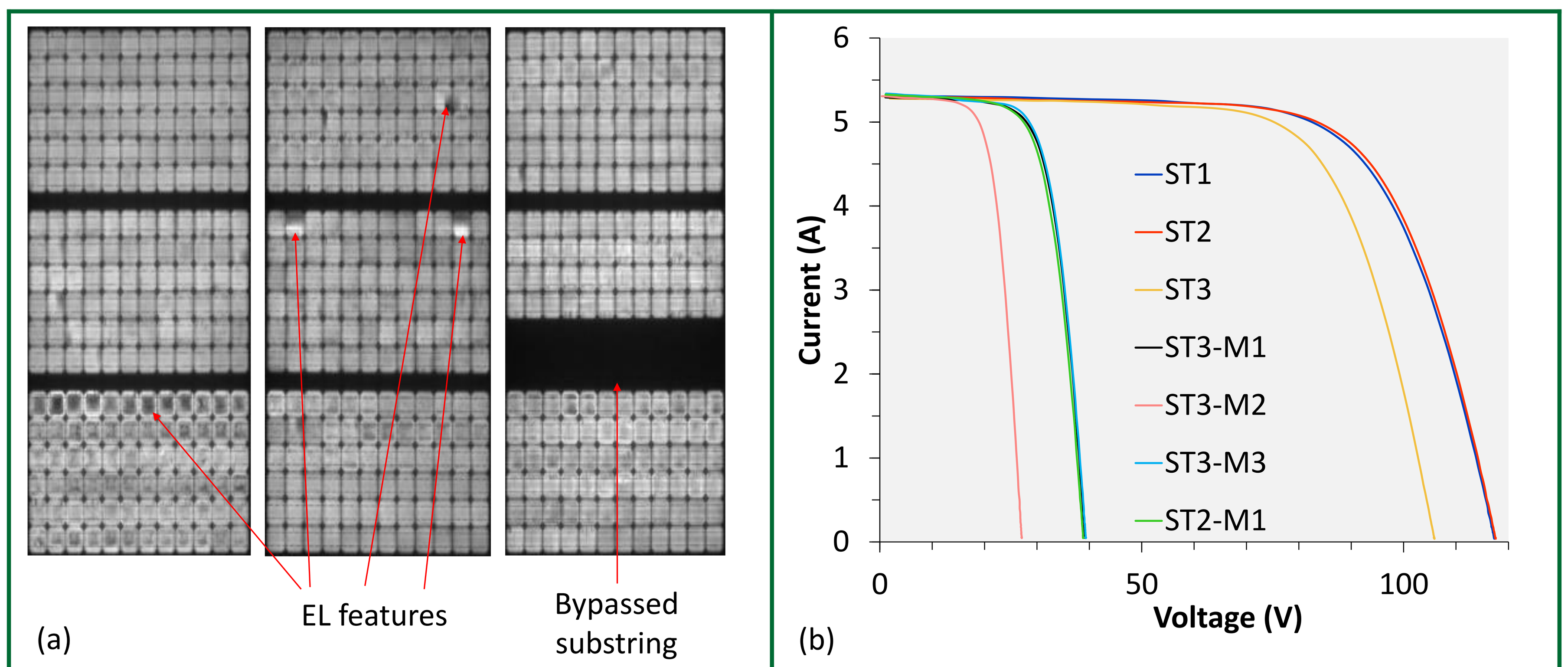

Fig 5: (a) EL image and (b) I-V characteristics of the monocrystalline array.

- EL and I-V measurements reveal that one substring is problematic.
- Other EL features could not cause significant current mismatch to appear as hot spots on TIR images.
- The substring appears dark since it was bypassed when the string ST3 was biased for EL imaging.
- The abnormalities in the substring caused a drop in V_{OC} of ~ 12 V between good and bad strings and modules, and resulted in power loss of 18% on module level which translate to 9% on string level, indicated in Table 1.
- No bump on the I-V curves of the underperforming string ST3 and module ST3-M2 since the bypass diode across the substring is faulty (shorted).

Table 1: Performance parameters of the strings and modules in the monocrystalline array.

String / Module	I_{SC} (A) ±1.2%	V_{OC} (V) ±0.8%	I_{MP} (A) ±1.4%	V_{MP} (V) ±0.9%	P_{MAX} (W) ±4.2%
ST2-M1	5.3	38.7	4.7	29.9	139.3
ST3-M2	5.3	27.1	5.2	22.0	114.4
ST2	5.3	117.6	4.9	86.6	424.3
ST3	5.3	105.9	4.7	82.1	385.9

Conclusions

- TIR imaging can quickly identify underperforming cells in operational PV plant and facilitate decision making.
- Partial soiling on crystalline silicon cells can affect TIR images and mislead decisions during PV module inspections and result in only cleaning the soiled modules, yet other non-visual anomalies may be hidden.
- TIR imaging of damaged cells is inhibited if one substring is sufficiently mismatched and if the substrings are equally mismatched.
- TIR imaging conducted on clean PV modules give a better picture on the operational temperature of cells.
- Incorporation of other testing techniques, such as I-V measurements and EL imaging add valuable information on the state of the modules.
- Accumulation of knowledge regarding the dynamic TIR imaging on operational PV modules can improve and develop PV inspections for long-term reliability and hence an improved return on investment of the modules.

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