

# Potential-Induced Degradation of photovoltaic modules: an automated approach

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**Potential-induced degradation (PID) reduces the efficiency of PV-modules, increasing the levelized cost of energy (LCOE), thus PID research is necessary.**

**Time consuming PID measurements**

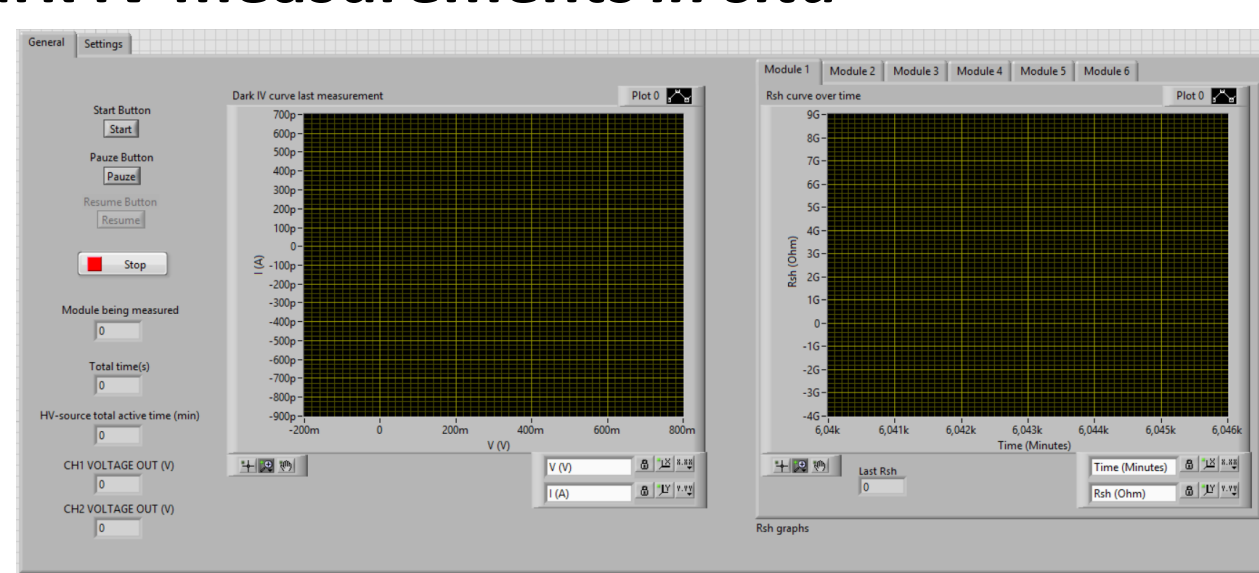
- > 2h
- Manual data processing

↓

The solution is **automating**:

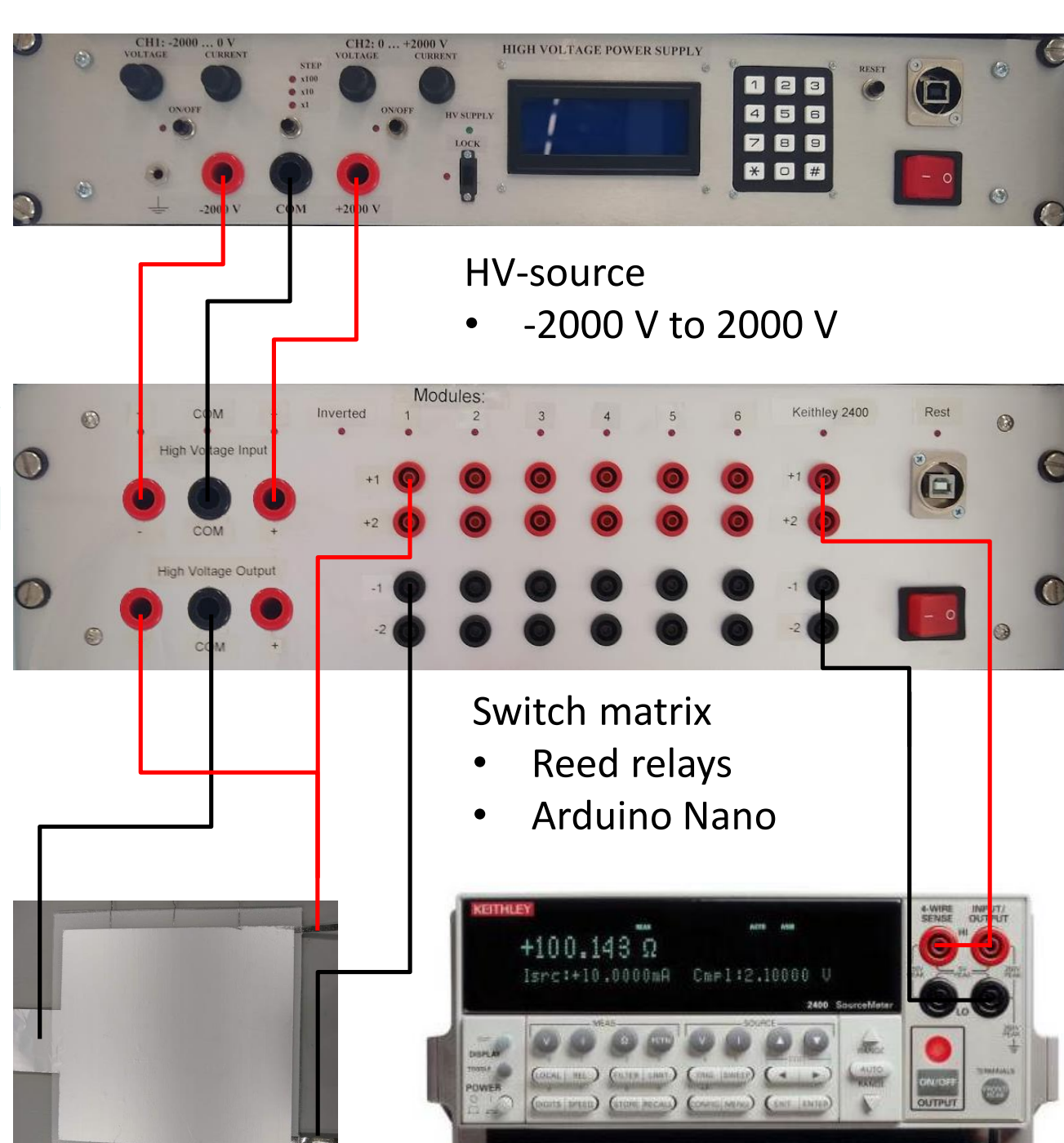
- Dark IV measurements *in situ*
- Data processing with Python
- Determining %PID from dark IV

### 1. Dark IV measurements *in situ*



Laptop with LabVIEW to control setup

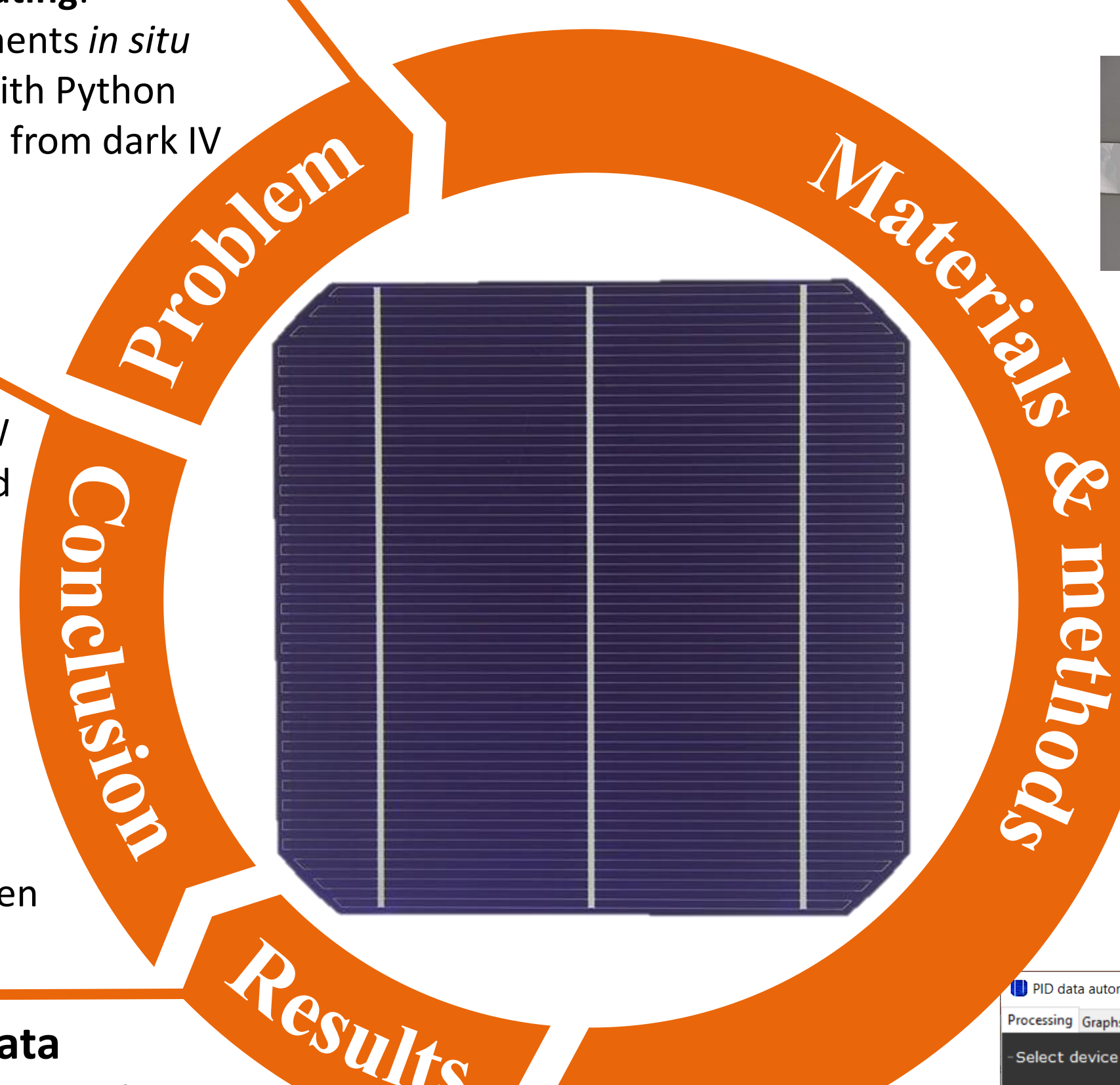
- Voltage of HV-source
- Number of modules
- Stressing time



HV-source  
• -2000 V to 2000 V

Switch matrix  
• Reed relays  
• Arduino Nano

Keithley 2400 (K2400) [1]  
• 4-wire dark IV measurements



### 1. Dark IV measurements *in situ*

The switch matrix setup induced PID in the stressed samples. Therefore, it can be concluded that the custom-made LabVIEW software correctly controls the HV-source and switches the K2400 correctly.

### 2. Data processing

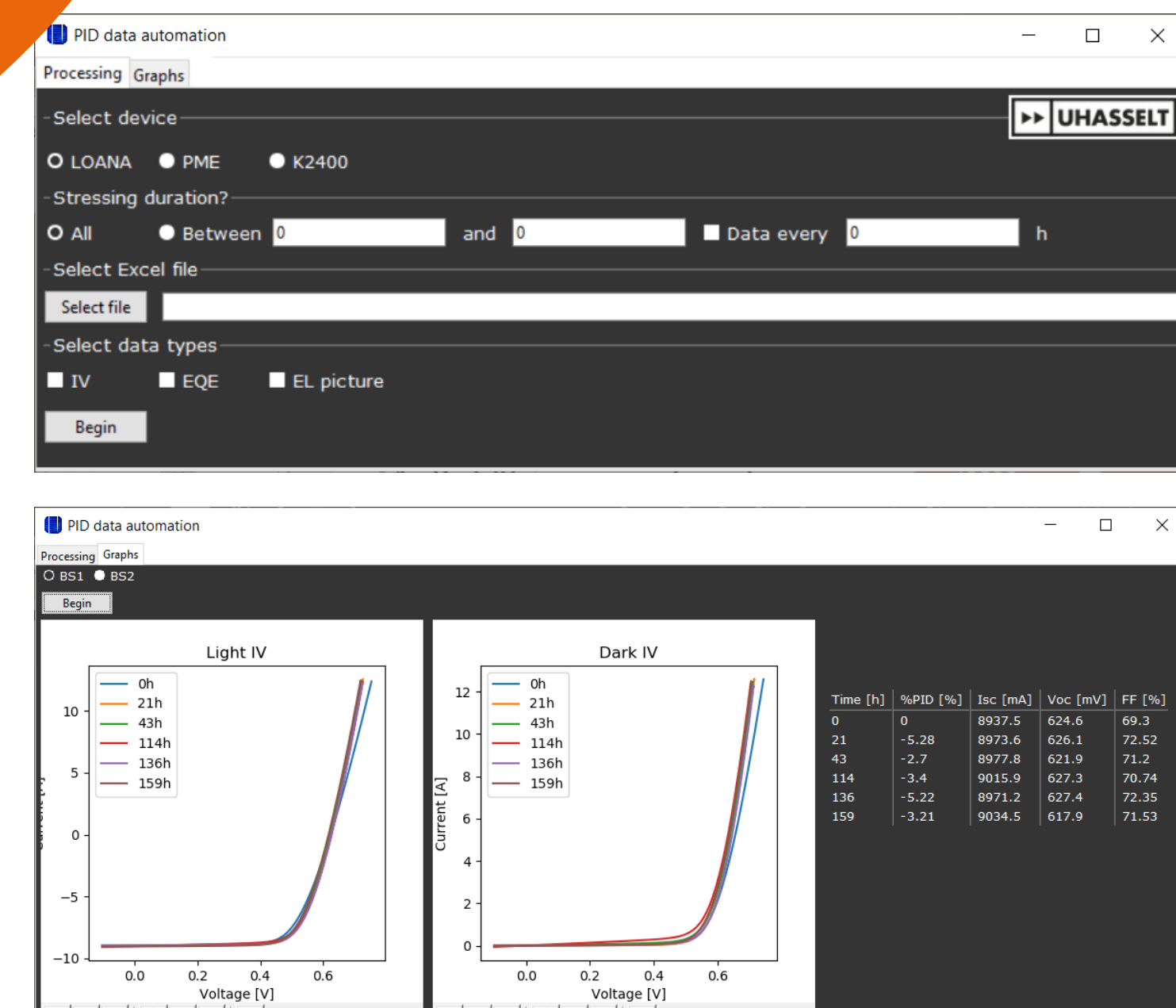
Python program processes the data correctly.

### 3. Determining %PID from dark IV

The method to calculate the power at 25°C from the dark IV measurements at stress temperature was used. The difference between the calculated and actual power is negligible.

### 2. Data processing

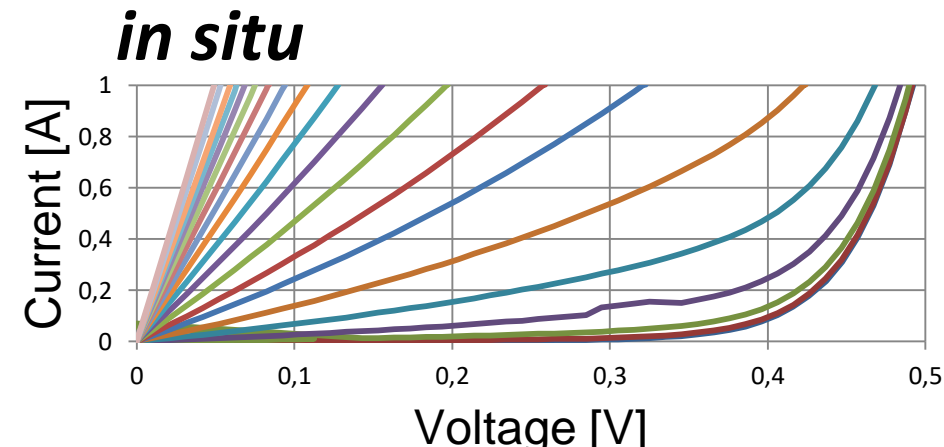
Python application processes data and EL-images. In the processing tab, some settings are controlled. In the graphs tab, the IV curves and cell parameters are displayed.



The switch matrix setup is used to:

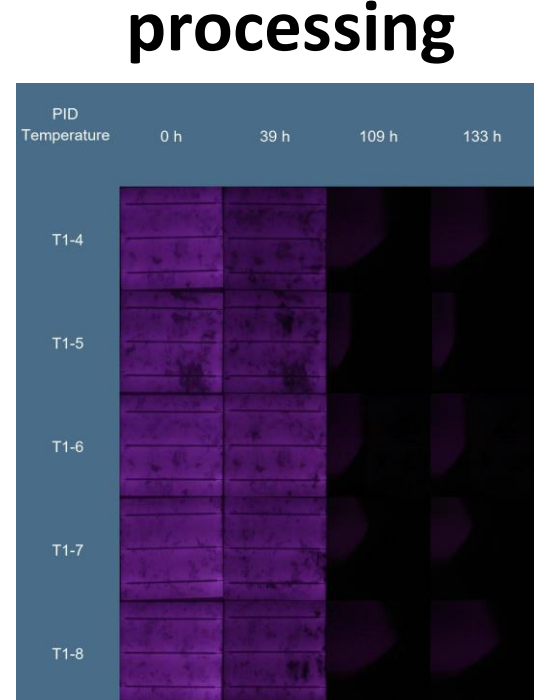
- PID stress or cure PV-modules
- Measure dark IV characteristics *in situ*

### 1. Dark IV measurements *in situ*



20 dark IV measurements from the switch matrix setup from 0 hours (right curve) to 114 hours of PID-s stressing (left curve).

### 2. Data processing



The brightness of the EL-images decreases, new dark spots are visible which indicates PID-s.

### 3. Determining %PID from dark IV

The normalized dark IV derived power ( $P_{dark}$ ) at 25°C correlates to the normalized power at 25°C:

$$y = x. \text{ This equation calculates the } P_{dark} \text{ at } 25^\circ\text{C} \text{ from } P_{dark} \text{ at stress temperature } \rightarrow \text{ the power loss can be calculated from the switch matrix measurements.}$$

$$P_{dark}(25^\circ\text{C}, t) = \frac{P_{dark}(T_s, t)}{1 + (1 - k_{estimated} (1 - \frac{P_{dark}(T_s, t)}{P_{dark}(T_s, 0)}) * \gamma_{dark}(0) * (T_s - 25))} \quad [2]$$

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[1] „Keithley 2400 SourceMeter SMU Instruments,” Tektronix, [Online]. Available: <https://www.tek.com/keithley-source-measure-units/keithley-smu-2400-series-source-meter>. [Accessed 13 May 2019].  
 [2] W. Luo, P. Hacke, J. P. Singh, J. Chai, Y. Wang, S. Ramakrishna, A. G. Aberle and Y. S. Khoo, "In-Situ Characterization of Potential-Induced Degradation in Crystalline Silicon Photovoltaic Modules Through Dark I-V Measurements," IEEE Journal of Photovoltaics, vol. 7, no. 1, 2016.