Potential-Induced Degradation of photovoltaic modules: an automated approach

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Problem

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**:

1. Dark IV measurements *in situ*
2. Data processing with Python
3. Determining %PID from dark IV

Materials & methods

1. Dark IV measurements *in situ*

Laptop with LabVIEW to control setup

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

control

data

HV-source

- -2000 V to 2000 V

Switch matrix

- Reed relays
- Arduino Nano

PV-module

Keithley 2400 (K2400) [1]

- 4-wire dark IV measurements

The switch matrix setup is used to:

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

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.

Results

1. Dark IV measurements *in situ*

Current [A]

Voltage [V]

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

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

The normalized dark IV derived power (Pdark) at 25°C correlates to the normalized power at 25°C : y = x. This equation calculates the Pdark at 25°C from Pdark at stress temperature ➔ the power loss can be calculated from the switch matrix measurements.

Conclusion

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.

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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-sourcemeter. [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.