



Understanding Potential Induced Degradation for LG NeON Model



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Revisions Table

Date	Version	Description of change	Remark
2016.03.04	1.0 (1 st edition)		
2016.05.23	1.1	Add the leakage test results	

1. Introduction

In recent years, more and more instances of PV modules failures, while operated under high potential, were observed. These failures were found to be caused by Potential Induced Degradation (hereafter, PID), one of the most prominent forms of degradations occurring in c-Si PV modules[1].

The mechanisms of PID can be explained by two phenomena: Electrochemical Corrosion and Polarization Effect. Because both electrochemical corrosion and the polarization effect are dependent on PV Module characteristics, either one or both conditions may be present within the PV Module. Although the former does not show the recovery characteristics, the latter shows reversible characteristics under irradiance conditions, especially in LGE n-type Modules. However, PV Modules do not reflect any reversible characteristics, while under the PID test as proposed by the IEC working group.

As a result, they do not fulfill the requirements of lifetime warranty test [2].

This paper will elaborate on the reversible characteristics of the n-type LGE Modules in real environmental conditions, as well as prove that the n-type LGE Modules do not experience any adverse effects associated with PID.

We will explain two topics in this paper:

- Verify that there is no PID Effect on LGE N-type module during illumination.
- Figure out recovery characteristics after PID occurrence on LGE n-type modules.

2. PID(Potential Induced Degradation)

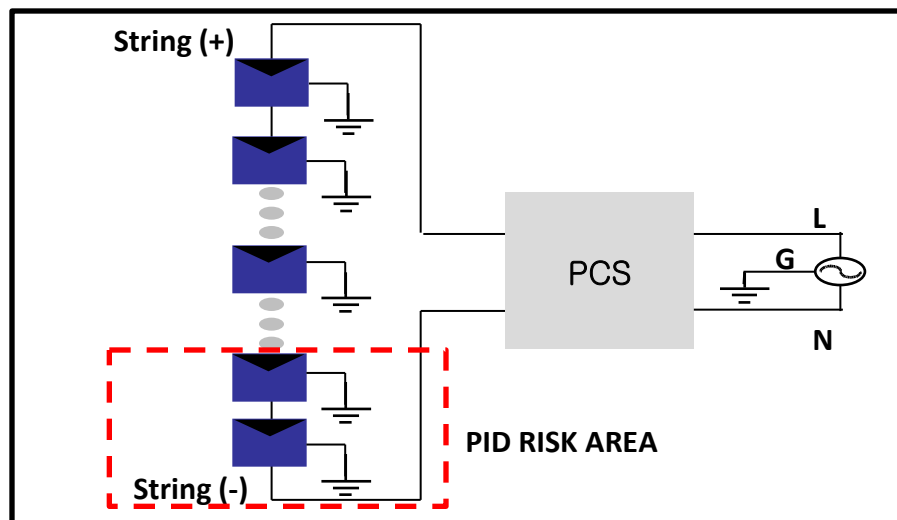
2.1 Potential Induced Degradation

- Power degradation due to the exposure to the external potential
- External potential = Potential relative to the ground → High voltage stress
 - ※ Dependent on magnitude and sign of external potential
- Two Cases : Polarization (reversible) / Electro chemical corrosion (irreversible)

2.2 History

- First addressed by Hoffman and Ross – Jet Propulsion Laboratory (1978) [3]
 - : Bias humidity test as a candidate for module qualification
- Different types of PID were reported in other PV technologies
 - Polarization (reversible)
 - Electro chemical corrosion (irreversible) [4]
 - : the transport of ionic elements in the presence of applied electric field
- PID of c-Si solar cells was first observed by SunPower (2005) : Polarization Effect
- Evergreen reported PID for front-junction p-type c-Si solar cells (2008)
 - ※ Long-term degradation by system bias voltage is not presently captured in IEC or UL standards

Figure 1 : PID risk area



There are two causes for PID to occur in a PV Module: Electrochemical Corrosion and Polarization Effect. (See Figure 2.)

First, Electrochemical Corrosion can be verified with a Corona Discharge Test, in which the cause of PID is not dependent on the type of ion. One prevalent ion found in the glass to cause PID is the sodium ion (Na). Because the Na carries a positive ion (+), the electrochemical Corrosion caused by the Na⁺ ion creates a destructive effect on the P-N Junction of the solar cells, resulting in power degradation of the solar module. This degradation is irreversible.

However, the + ion cannot shunt LG n-type cells, which have a p-type emitter on its top surface, as opposed to the n-type emitter that most p-type modules have on their top surfaces. As a result, Electrochemical Corrosion cannot be found on LGE n-type modules.

Second, Polarization cumulates charges around the SiNx ARC and can disrupt the minority carrier movement and the junction electrical field, resulting in the power degradation of the cells.

[5]

However, the polarization effect is a reversible reaction, and modules can recover from polarization. The solar cells naturally recover to its normal condition after PID had been occurred, and recovery is accelerated while under high temperature or opposite polarity.

Generally, the cell itself is consisted of two components: a capacitor and a resistor, that link together in parallel. The capacitor represents the charges accumulated on and around the insulating ARC layer, and the resistor symbolizes conductive channel allowing for the dispersion of charges. To prevent PID behavior, the goal is to prevent charges from building up in the capacitor. [5]

Although LG n-type cells do show the power degradation under normal PID Test condition, they naturally prevent the charge from building up while under irradiance, eliminating any effects from polarization.

As a result, LG n-type cells do not show any effects from PID under real environmental conditions.

We would like to test and verify LG n-type cells' performance under PID in this paper.



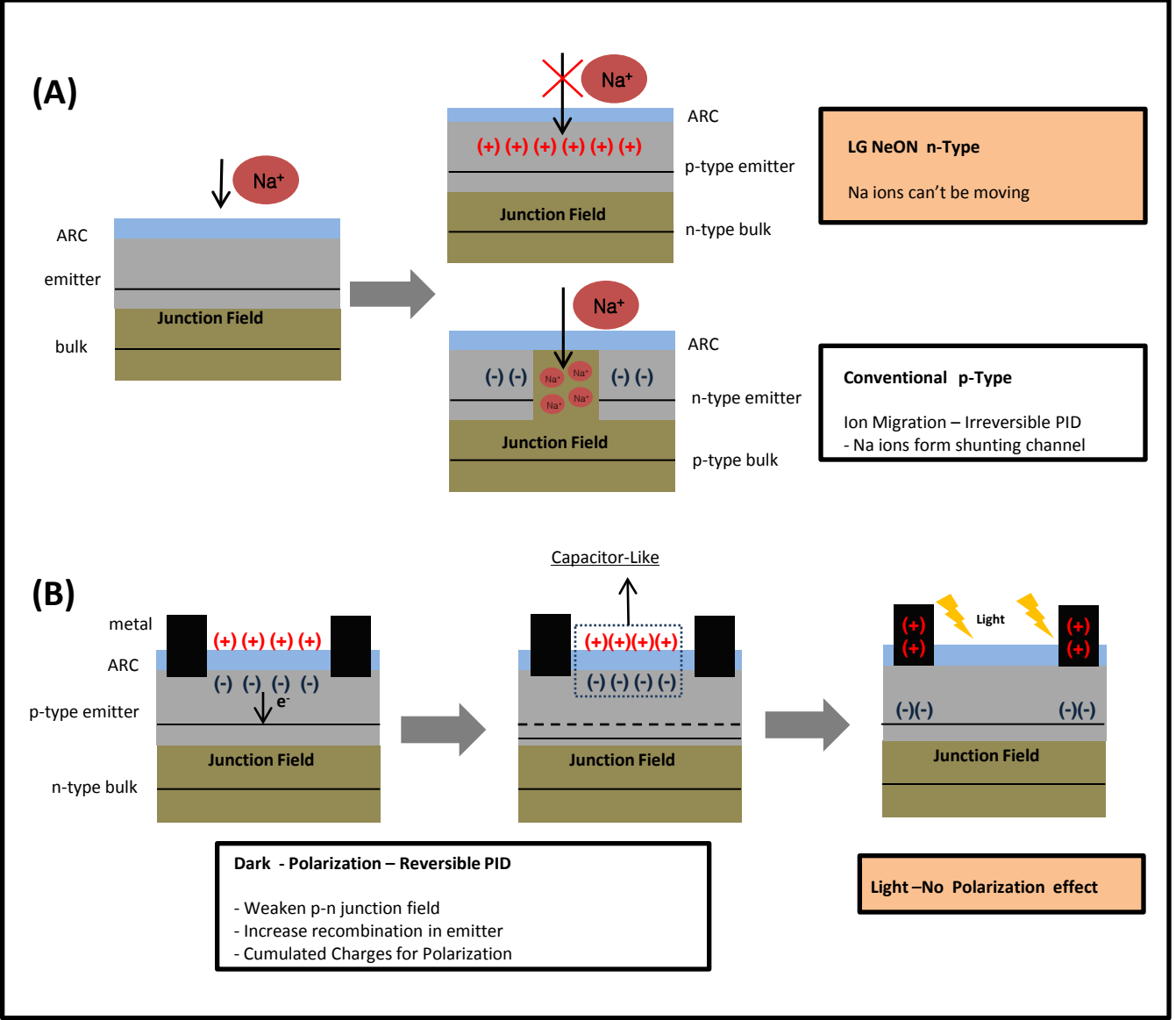


Figure 2 : (A) Electrochemical Corrosion, (B) Polarization Effect

4. Description

4.1 Characterization Measurements

Characterization measurements are conducted before and after each stress test. These measurements provide an evaluation of the module's resistivity against the applied stresses. Step 1 and 2 were tested by Fraunhofer ISE, Germany.

4.1.1 Performance at STC according to IEC 60904 (-1 and -3)

The specific module parameters are determined by taking an I-V curve by means of a pulsed solar simulator at standard test conditions (STC):

Irradiation: 1000 W/m²

Module temperature: 25 °C

Spectrum of solar simulator: AM 1.5

Class of solar simulator (according to IEC 60904-9): AAA

The measured values will be compared to the specifications given on the data sheet.

4.1.2 Electroluminescence Imaging

An electroluminescence (EL) image is taken while applying a current to the module and collecting the emitted radiation from the module.

EL images can reveal inhomogeneities and defects such as micro-cracks on the cell or defective electrical interconnections. PID affected cells can also be visualized.

4. Description

4.2 Step 1: PID Test acc. to IEC TC 62804 ed. 1

The PID test was performed by connecting the modules to a positive / negative potential between cells and frame and exposing them to warm and humid climate in a climate chamber. The test conditions were taken from the IEC TS 62804 ed. 1 – ‘System voltage durability test for crystalline silicon modules’.

The test conditions are:

- Application of a voltage of 1000 V (-/+) between cells and frame
- Ambient temperature of 60 °C
- Ambient humidity of 85 %
- Test time: 96 hours

4.3 Step 2 : PID- / Light-Recovery Sequence

Potential induced power degradation in a PV module can be reversible to a certain extent. Experience shows, that power, lost due to PID, can partly be regained due to changing ambient conditions.

During the PID-/ light-recovery sequence, ten cycles of changing ambient conditions are subsequently completed. During the first five hours of each cycle, the front side of the modules is exposed to an illumination of roughly 1000 W/m² at ambient conditions of 20 °C and 50 % relative humidity in the climate chamber (similar to daylight conditions). During the following 3 hours the ambient conditions are set to 40 °C and 90 % relative humidity without illumination (similar to night conditions).

During the ten cycles, a voltage of -1000 V is applied on modules M03 and M04 and +1000 V on modules M05 and M06.

Several power measurements are conducted during the time of illumination.

Figure 3 and Figure 4 show the graph of the actual and set ambient conditions in the climate chamber.

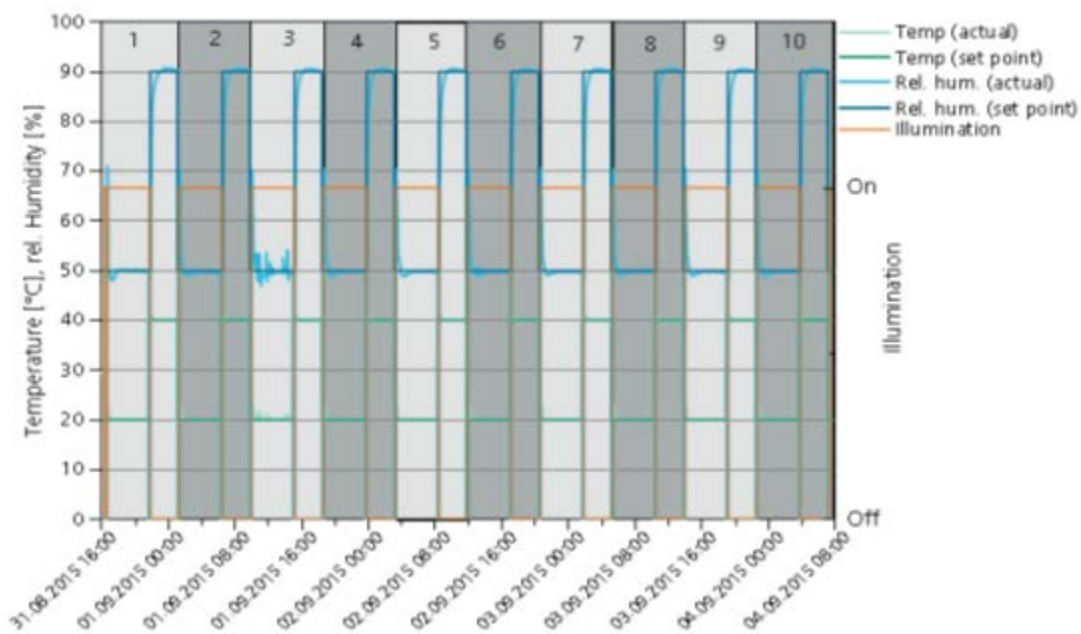


Figure 3 : Climate chamber characteristic – modules M03, M04

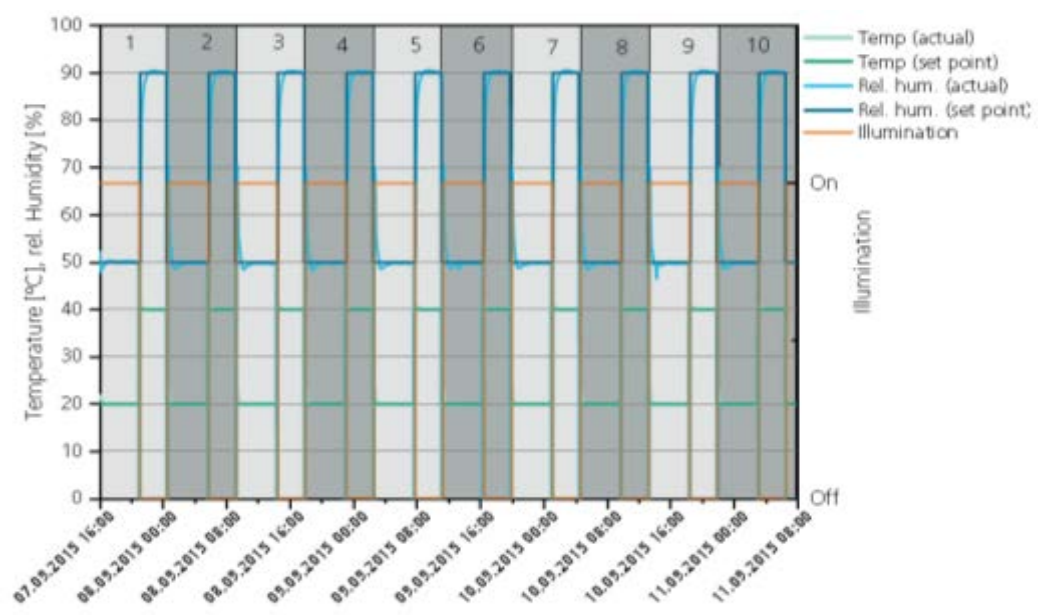


Figure 4 : Climate chamber characteristic – modules M05, M06

4. Description

4.4 Step 3 : PID- / With Light Source, Leakage Current Monitor

In order to verify PID effect under illumination, Step 1 was tested under a light source. The was tested under irradiance with intensity as high as 1000 W/m² and as lows as 200W/m² to simulate conditions on a fine sunny day and a cloudy day, respectively.

Figure 5 shows PID Test condition with a light source.

Figure 6 shows the scheme of PID test to observe the leakage current. The module is placed in an environmental chamber so as to control module temperature, relative humidity and irradiance. The leakage current is compared in dark and light state, respectively.



Figure 5: PID Test with Light source

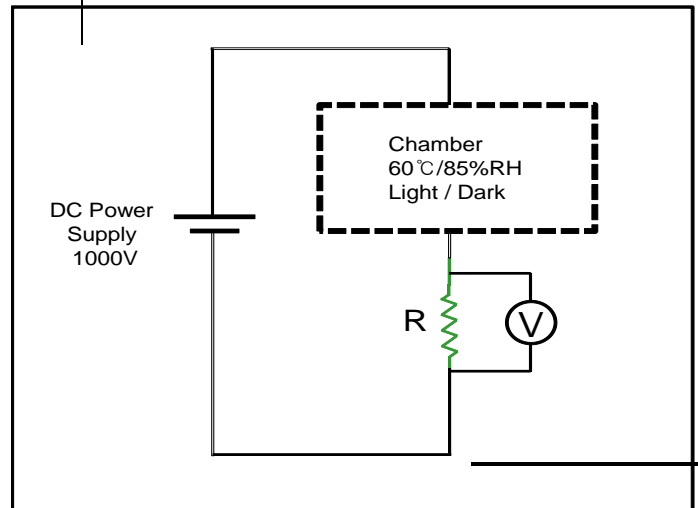


Figure 6: Schematic of leakage current measurement system

5. Test Results

5.1 Step 1,2 Performance Measurement

In this chapter, the results of the performance measurements at STC are given. Table 1 and 2 list the results of the measurements before and after the PID test and the final measurement after the recovery procedure. The deviation from the initial measurement is also given.

Table 1: Performance measurement at STC, PID test with -1000 V

M03

	Isc [A]	Voc [V]	Imp [A]	Vmp [V]	Pmax [W]	FF [%]	eff [%]
Initial Measurement	9.93	40.64	9.32	33.11	308.68	76.49	18.82
PID Test 96 hours at -1000 V							
After 96 hrs PID Test	9.76	40.14	9.16	32.34	296.24	75.59	18.06
Deviation to initial [%]	-1.70	-1.20	-1.80	-2.30	-4.00	-1.20	-4.00
Recovery Procedure at -1000 V							
After Recovery	9.99	40.64	9.34	33.00	308.26	75.91	18.80
Deviation to initial [%]	0.60	0.00	0.20	-0.30	-0.10	-0.80	-0.10

M04

	Isc [A]	Voc [V]	Imp [A]	Vmp [V]	Pmax [W]	FF [%]	eff [%]
Initial Measurement	9.99	40.66	9.36	33.00	308.80	76.06	18.83
PID Test 96 hours at -1000 V							
After 96 hrs PID Test	9.87	40.39	9.24	32.64	301.73	75.70	18.40
Deviation to initial [%]	-1.20	-0.70	-1.20	-1.10	-2.30	-0.50	-2.30
Recovery Procedure at -1000 V							
After Recovery	10.00	40.70	9.38	33.05	310.00	76.20	18.90
Deviation to initial [%]	0.10	0.10	0.20	0.20	0.40	0.20	0.40
Measurement Uncertainty [%]	± 1.9	± 0.6	± 2.2	± 1.2	± 2.1	± 1.6	± 2.2

5. Test Results

Table 2 : Performance measurement at STC, PID test with +1000 V

M05							
	Isc [A]	Voc [V]	Imp [A]	Vmp [V]	Pmax [W]	FF [%]	eff [%]
Initial Measurement	9.98	40.60	9.38	33.16	311.19	76.82	18.98
PID Test 96 hours at +1000 V							
After 96 hrs PID Test	9.93	40.46	9.36	32.90	307.99	76.64	18.78
Deviation to initial [%]	-0.50	-0.30	-0.20	-0.80	-0.10	-0.20	-1.00
Recovery Procedure at +1000 V							
After Recovery	9.98	40.53	9.41	32.98	310.19	76.65	18.91
Deviation to initial [%]	0.10	-0.20	0.20	-0.50	-0.30	-0.20	-0.30
M06							
	Isc [A]	Voc [V]	Imp [A]	Vmp [V]	Pmax [W]	FF [%]	eff [%]
Initial Measurement	9.94	40.67	9.39	33.22	311.87	77.13	19.02
PID Test 96 hours at +1000 V							
After 96 hrs PID Test	9.94	40.52	9.38	33.00	309.40	76.78	18.87
Deviation to initial [%]	0.00	-0.40	-0.10	-0.70	-0.80	-0.50	-0.80
Recovery Procedure at +1000 V							
After Recovery	9.96	40.58	9.40	33.06	310.91	76.91	18.96
Deviation to initial [%]	0.20	-0.20	0.20	-0.50	-0.30	-0.30	-0.30
Measurement Uncertainty [%]	± 1.9	± 0.6	± 2.2	± 1.2	± 2.1	± 1.6	± 2.2

5.2 Step 1,2 Electroluminescence Imaging

In case of PID, either the pn-junction is shunted (ion migration) or an increased surface recombination (polarization) occurs. Both cases cause a decrease of shunt resistance (R_{sh}) of the solar cell and module. A low value R_{sh} on the other hand causes power loss by providing an alternate current path through the solar cell junction and reduces the voltage from the solar cell. The effect of R_{sh} is particularly severe at low light levels, since there will be less light-generated current and a lower open circuit voltage (V_{oc}). In an EL image, a change in R_{sh} after a PID test can be very well observed when applying a much lower current than ISC, which represents a low light level.

The PID affected area of a solar cell or even the whole cell appears dark in the image and PID affected cells can be identified. Tables 3 to Table 6 show the EL images of the tested modules before and after the PID test and after the PID-/ light-recovery sequence.

Table 3 : Electroluminescence images of module M03

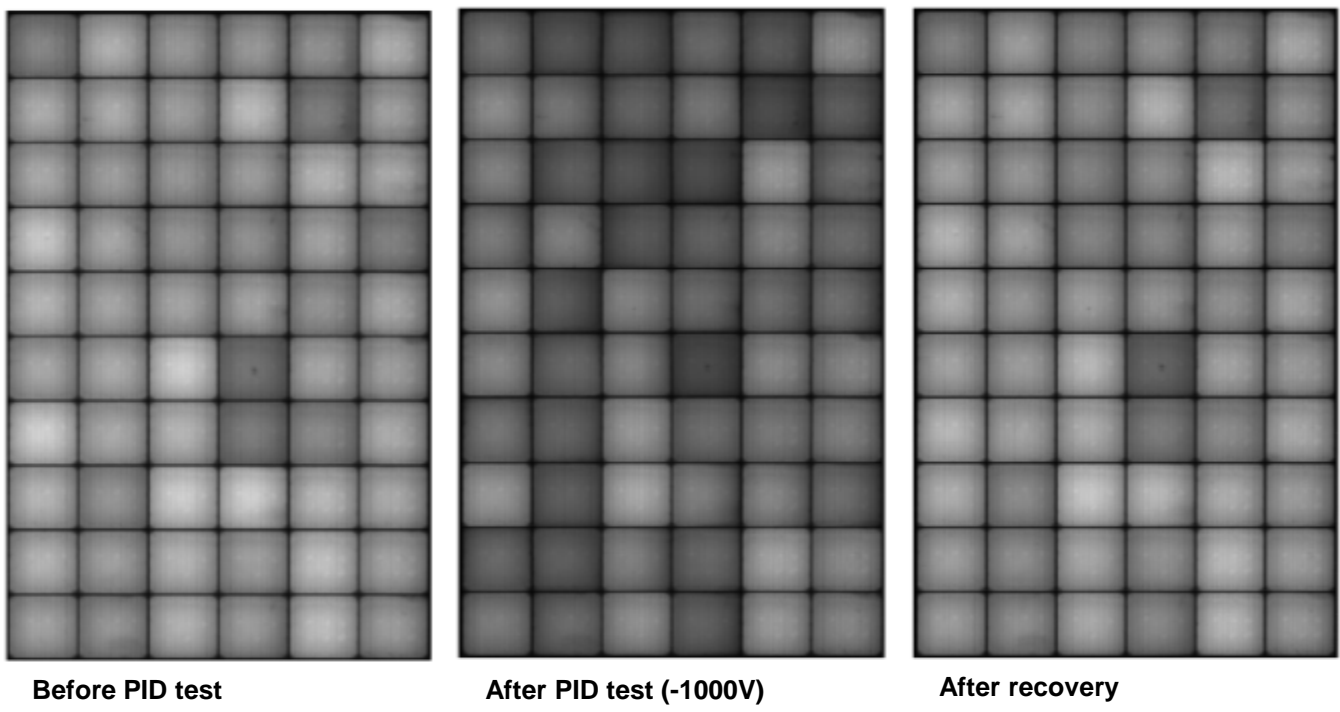


Table 4 : Electroluminescence images of module M04

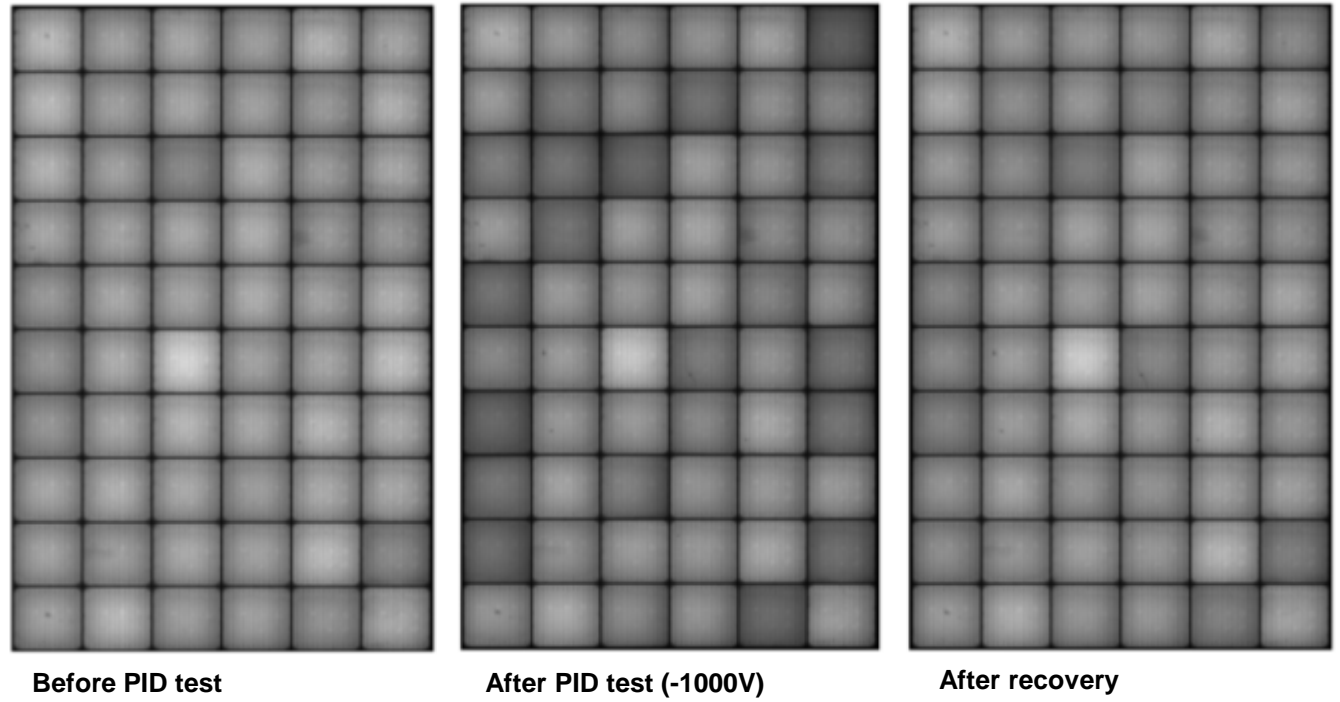


Table 5 : Electroluminescence images of module M05

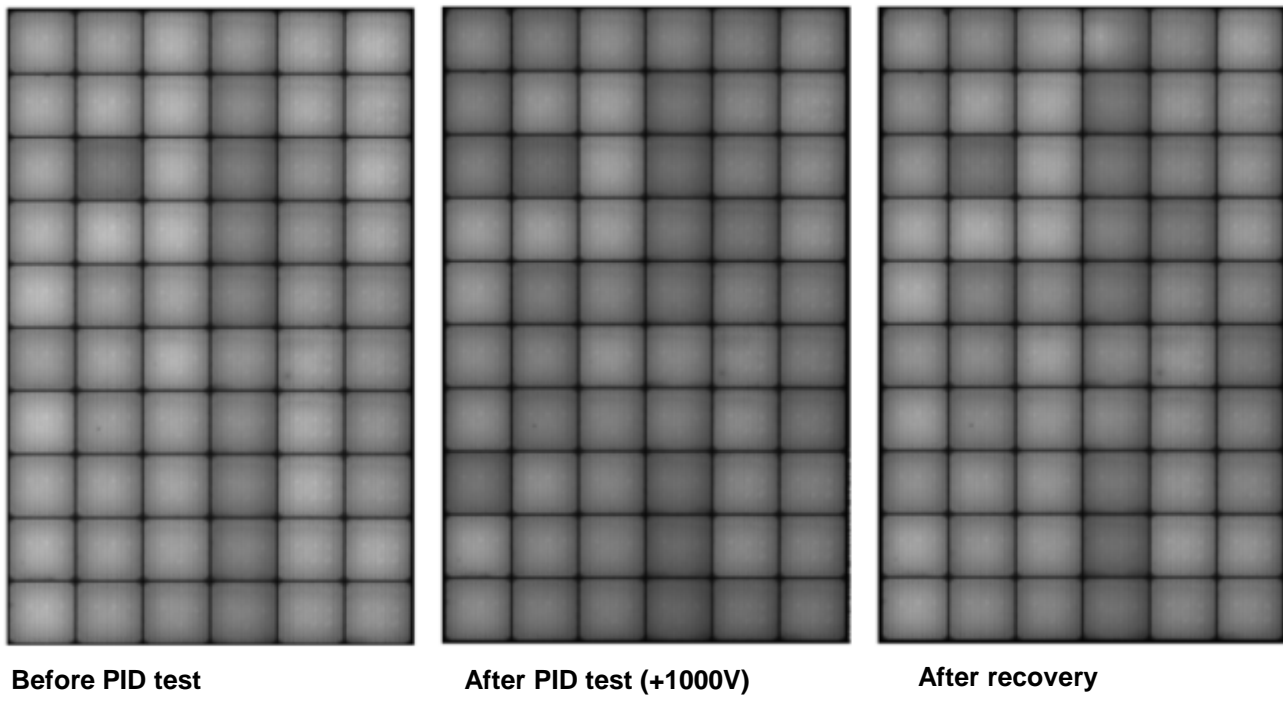
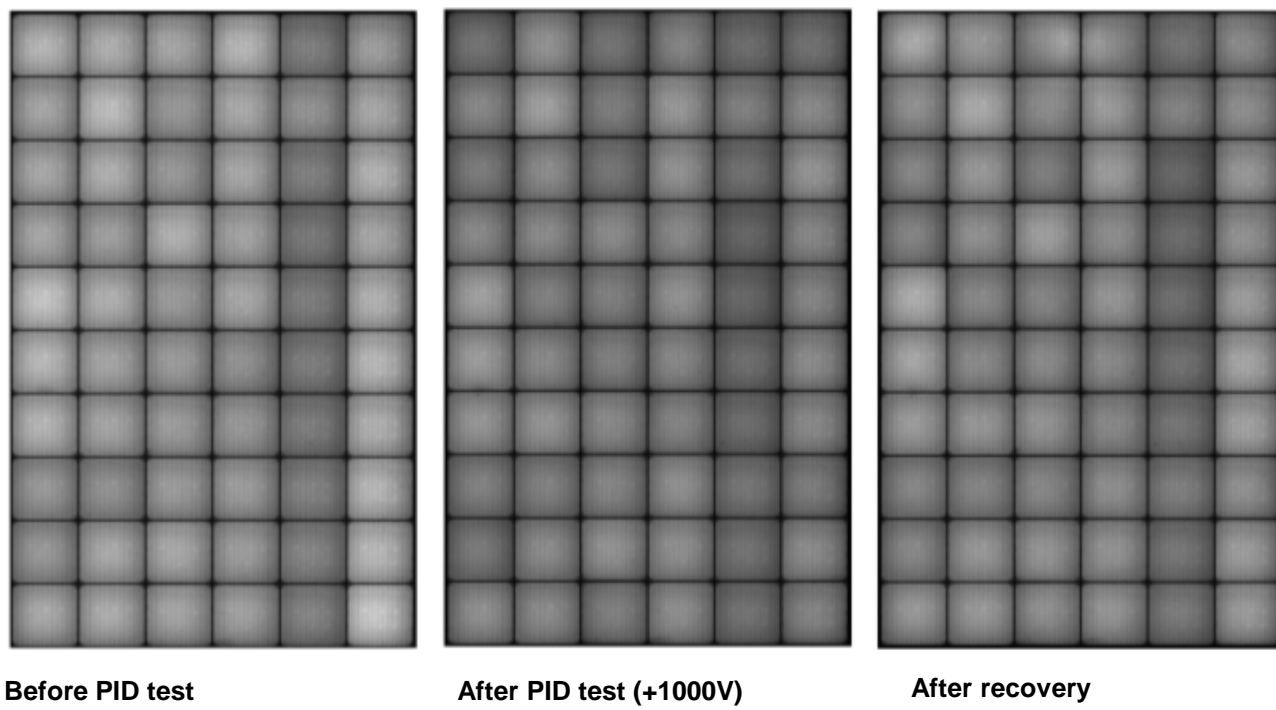


Table 6 : Electroluminescence images of module M06



5.3 Step 3 Performance Measurement and Electroluminescence Imaging

In this chapter, the results of the performance measurements at STC are given. Table 7 list the results of the measurements before and after the PID test. The deviation from the initial measurement is also given. Tables 8 to Table 9 show the EL images of the tested modules before and after the PID test

Table 7: Performance measurement at STC, PID test with -1000 V with light source M07

	Isc [A]	Voc [V]	Imp [A]	Vmp [V]	Pmax [W]	FF [%]	eff [%]
Initial Measurement	10.07	40.52	9.56	32.76	313.24	76.76	19.10
PID Test 96 hours at -1000 V with light (200W/m²)							
After 96 hrs PID Test	10.09	40.43	9.65	32.46	313.30	76.76	19.10
Deviation to initial [%]	0.21	-0.21	0.94	-0.92	0.02	0.00	0.00

	Isc [A]	Voc [V]	Imp [A]	Vmp [V]	Pmax [W]	FF [%]	eff [%]
Initial Measurement	10.07	40.48	9.57	32.75	313.26	76.86	19.10
PID Test 96 hours at -1000 V with light (1,000W/m²)							
After 96 hrs PID Test	10.04	40.41	9.48	32.85	311.36	76.76	19.00
Deviation to initial [%]	-0.33	-0.16	-0.92	0.30	-0.61	-0.13	-0.53

5.4 Leakage Current Comparison

Examining the leakage current during PID test, a current profile of the dark state’s module similar to that of a capacitor is observed, on the other hand a current of the light state’s module is not observed. (see Figure 7)

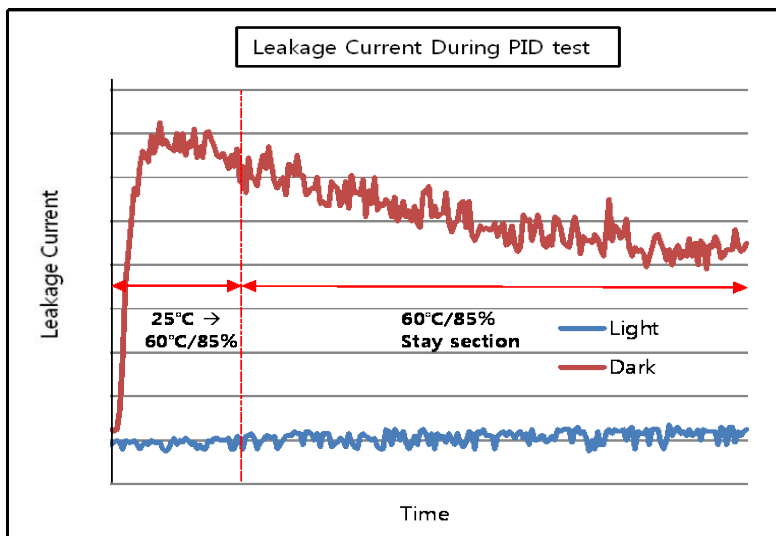
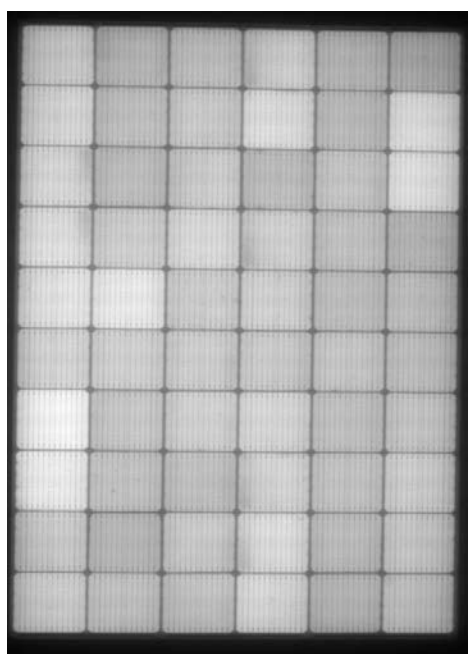
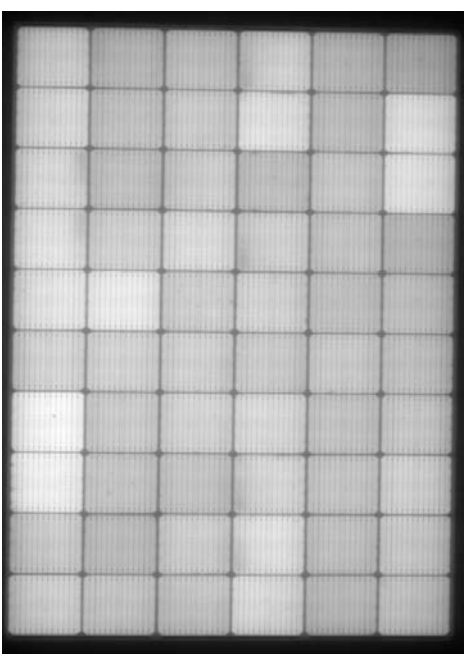


Figure 7: Leakage current comparison (light / dark)

Table 8: Electroluminescence images of module M07

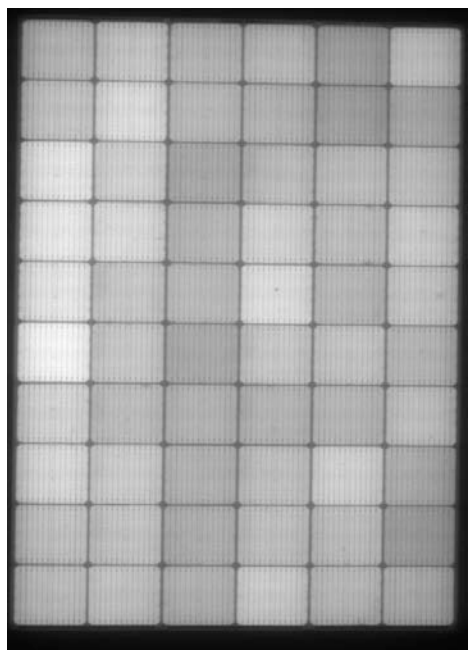


Before PID test

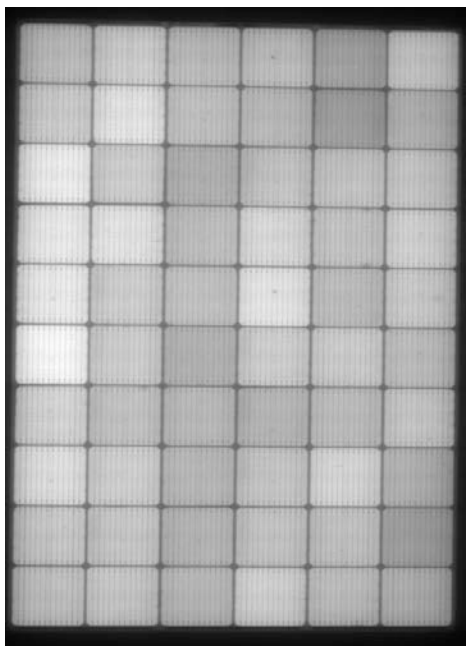


After PID test (-1000V)

Table 9: Electroluminescence images of module M08



Before PID test



After PID test (-1000V)

6. Summary and Conclusion

Summary:

The results given in this report are valid for the case of a potential of 1000 V (-/+) lying on the cells, while the module frame is grounded.

After the first PID test (acc. to IEC TS 62804 ed.1), a negative deviation of output power was recorded for the four modules. While for modules M03 and M04 the power loss was -4.0 % and -2.3 %, for modules M05 and M06 it was only -1.0 % and -0.8 % and therefore nearly negligible. All modules are not rated as sensitive to PID assuming a pass/fail criterion of max. 5 % power loss. However, exposed at negative potential, the power loss is slightly higher than at positive potential, which indicates a slight sensitivity to negative ground potential. The EL images support this impression, as some slightly darker cells can be found on modules M03 and M04 after the first PID stress treatment.

During the PID-/ light-recovery sequence, all four modules regained power fast after first light exposure, although the 'critical' ground potential was continuously applied to the modules. The modules remained on a high level during the dark-light phases in PID-light recovery treatment. The power measurements conducted after the PID-/light sequence show, that the initial power could be fully regained.

And the second PID test (acc. To IEC 62804 ed.1 with light source), a negative deviation of output power was recorded for the two modules. While for modules M07 and M08 it was only 0.02% and -0.61%.

Conclusions:

The behavior described above shows clearly that the modules recover fast when exposed to light and that a simulated day-night sequence, as applied in the scope of this project, does not lead to a continuous decrease in power. The test result indicates that the PID effect will be equalized in the field to the largest extent.

- [1] S. Pingel et al. "Potential Induced Degradation of Solar Cells and Panels", Conference Paper 35th IEEE, 2010
- [2] H. Nagel et al. "Lifetime Warranty Testing of Crystalline Silicon Modules for Potential-Induced Degradation", 27th EUPVSEC 2012
- [3] Hoffman et al., "Environmental qualification testing of terrestrial solar cell modules", 13th IEEE PVSC, pp. 835-842, 1978
- [4] Ross et al., " Measurement and Characterization of voltage- and current-induced degradation of thin-film photovoltaic modules", Solar Cells, Vol. 27, Issue 1-4, pp. 289-298, 1989
- [5] Chen-Wei et al., "Potential Induced Degradation Mechanism Observed at Module Level", 28th European Photovoltaic Solar Energy Conference and Exhibition



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