Polarization Type Potential Induced Degradation under Positive Bias in a Commercial PERC Module

Preprint

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Polarization type Potential Induced Degradation under Positive Bias in a Commercial PERC Module

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***Abstract* — Potential induced degradation of the polarization type (PID-p) can reduce module performance in a relatively short period of time. PID-p can occur at both voltage polarities, but most studies are focused on degradation under a negative bias. This paper uses commercial bifacial passivated emitter and rear contact (PERC) cells within a monofacial glass-backsheet module construction to evaluate the impact of PID-p under a positive bias on the front side. Using the aluminum-foil (Al-foil) method, the module was stressed for PID in an environmental chamber. After the stress, the maximum power (Pmax) showed a decline of 3.1% at 1000 W/m² and 6.2% at 200 W/m². Recovery under light was also investigated. Complete recovery was observed at high irradiance, while a partial recovery was seen at lower irradiance. The outcomes of this study can help in understanding PID-p degradation under a positive bias and its recovery under the light.**

***Keywords* — potential induced degradation, polarization, positive bias, PERC, recovery**

I. Introduction

PV modules are connected in series in commercial systems with high absolute system voltages ranging from 1000V to 1500V. The high voltage difference and elevated temperature/humidity cause leakage currents to flow between the grounded module frame and the cell. These leakage currents can be an indicator of PID [1]. Studies have shown that PID can reduce module performance by up to 30% [2]. Three main types of PID phenomenon have been reported in the literature, i.e., PID-shunting (PID-s), PID-polarization (PID-p), and PID-corrosion (PID-c) [1].

When understanding the PID-p effects in PV modules, most studies focus on the degradation under a negative bias on the rear side of the p-PERC bifacial modules. Yamaguchi et al. reported a rapid degradation due to PID-p when PV modules were stressed at -1000V and -1500V [3], [4]. Janssen et al. suggested minimizing PID-p by modifying the dielectric antireflection/passivation stack composition while using stress conditions of -1000V for PID [5]. Similarly, Luo et al. studied the impact of illumination on PID-p in PV modules by stressing them at -1000V [6]. In another study, they stressed the modules at +1000 V but report little to no degradation. Moreover, the samples used in these studies were all one-cell modules instead of commercial ones [7].

Therefore, in this paper, we use a commercial p-PERC PV module to study the effect of PID-p under a positive bias on the module front. Using the Al-foil method in an environmental chamber, the module was stressed for PID. Recovery under sunlight was also carried out after the PID stress. Pre- and post-characterization tests such as Flash IV and electroluminescence (EL) were performed to understand the changes in performance, post-PID and post-recovery.

II. Experimental Setup

This study used one commercial monofacial glass-backsheet (white backsheet) module employing 144-half-cut bifacial PERC cells. The cell dimensions were 78 x 156 mm, and the module dimensions were 2141 x 994 mm. The encapsulant used in the module was ethylene vinyl acetate (EVA). Kapton tape was used to cover the perimeter of the module frame to prevent contact of the Al-foil with the frame. The Al-foil was placed on the front glass, and 3M Al-tape (0.028 mm) was placed between the foil pieces to ensure electrical connectivity. An additional layer of thick insulating roofing membrane was put on top of the Al-foil to ensure a good contact between the glass and Al foil. The module was placed horizontally on a rack inside the environmental chamber, and extra weight was put on the module front to ensure proper contact between the foil and the front glass.

The module terminals were shorted and connected to the positive end of the power supply, while the front Al-foil was connected to the negative terminal of the power supply. So, the cell was at a positive bias with respect to the front side under stress. The module was stressed at +1500V, 25°C, and 54% relative humidity (RH) (to closely match with typical climatic condition) for 168 hours as per International Electrotechnical Commission (IEC) standard 62804-1. Leakage current was monitored for the duration of the stress. For recovery, after PID, the module was placed under sunlight with an average dosage of 19 kWh/m² at open circuit conditions on the front side.

Characterization tests, including Flash IV and EL, were performed pre-PID, post-PID, and post-recovery to measure the change in performance parameters. The Flash IV was done using a Spire 5600 at standard test conditions (STC) (1000W/m² and 25°C) and low irradiance of 200W/m² (also at 25°C) at SolarPTL. The IV parameters such as Pmax, short circuit current (I_{SC}), open circuit voltage (V_{OC}), fill factor (FF), maximum current (I_{MAX}), and maximum voltage (V_{MAX}) were acquired using the IV sweep. The EL was performed at 100% I_{SC} with an exposure for 30 seconds. The average gray value for the EL images was also obtained using an image analysis tool.

III. Results and Discussions

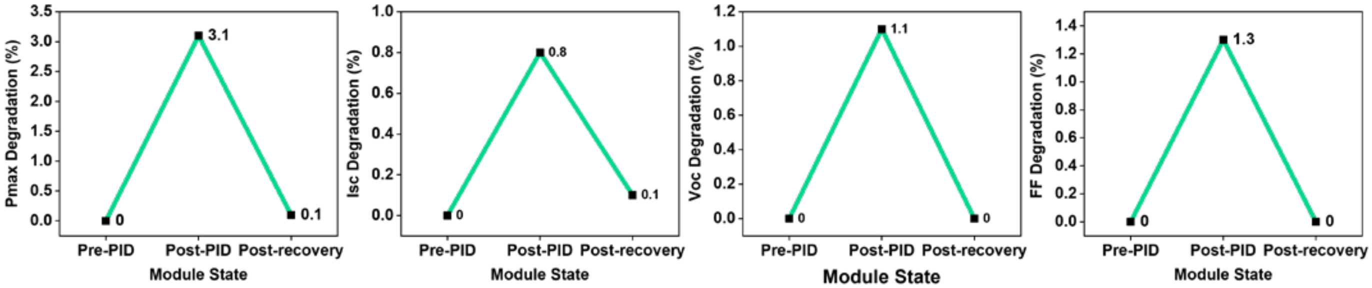

Fig. 1. Evolution of Pmax, FF, $I_{SC,}$ and V_{OC} for pre-PID, post-PID, and post-recovery using Flash IV performed at 1000W/m^2

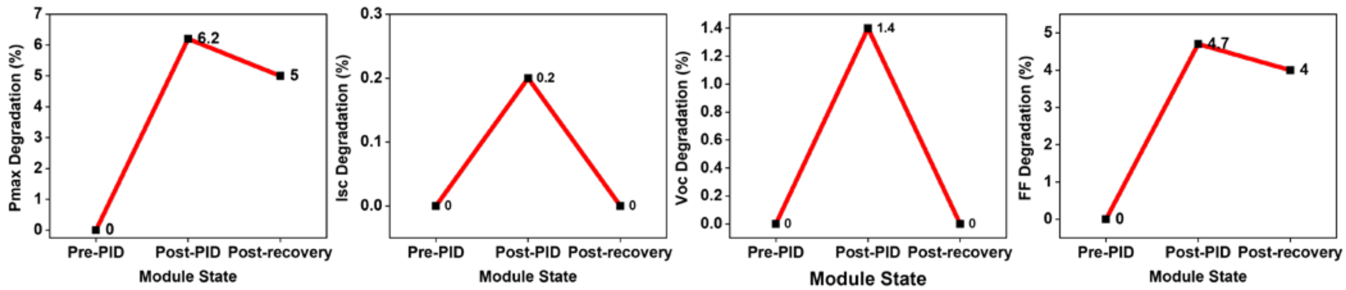

Fig. 2. Evolution of Pmax, FF, $I_{SC,}$ and V_{OC} for pre-PID, post-PID, and post-recovery using Flash IV performed at 200W/m^2

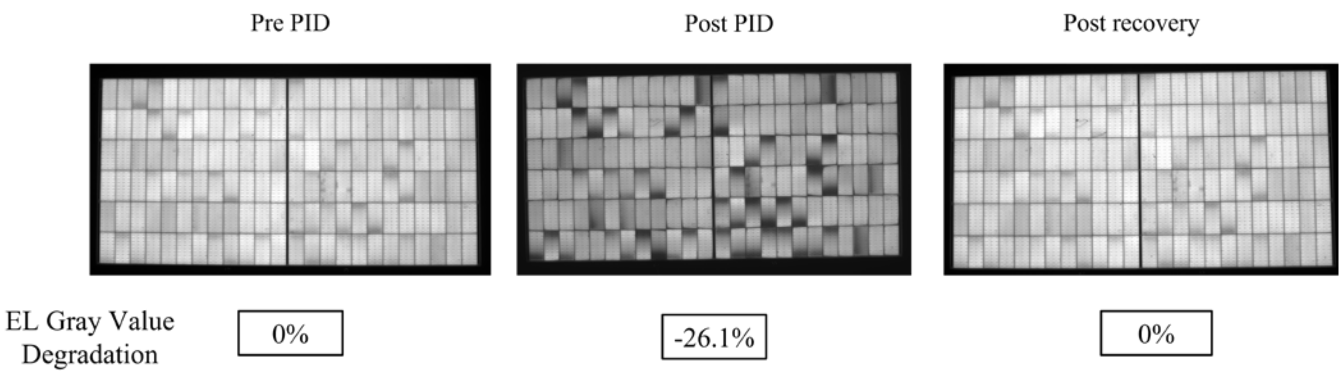

Fig. 3. EL images for pre-PID, post-PID, and post recovery

Fig.1 shows the % degradation in Pmax, I_{SC}, $V_{OC,}$ and FF at high irradiance at different states for the tested module. Similarly, Fig. 2 shows the % change for the same parameters at low irradiance at various states for the module. Higher levels of degradation and partial recovery for Pmax and FF are seen at lower irradiance. Fig. 3 shows the EL images with gray values at 100% I_{SC}. Moreover, post-recovery EL images suggest a complete recovery from PID.

We believe that the degradation in this module under a positive bias is due to PID-p. Since PID-s involve the movement of Na^+ ions to the cell junction, the positive ion migration to the positive electrode cannot occur under a positive bias [8]. So, the decline in Pmax should arise either due to PID-p or PID-c. PID-c is not recoverable under light exposure [9]. Since the stressed module almost completely recovers under sunlight, we believe that the observed degradation may be attributed to the PID-p mechanism [9].

The PID-p mechanism occurring in PERC (with AlO_x and SiN_y passivation) cells has been explained by Sporleder et al. [10] using the K center model (for negative bias on the rear side, for positive bias on the front, a mechanism has not been reported in the literature). A Si dangling connection linked to three N atoms forms a K center. K centers (K^0, K^-, or K^+) can have a neutral, negative, or positive electrical charge. Under a voltage bias, the K^+/K^0 can accept electrons, or K^-/K^0 can release electrons. Pre-PID, the passivation layer has a negative charge, and the K-center charge states within SiN_y are arbitrarily dispersed. When the PID stress is applied, K^-/K^0 releases electrons causing the K-center charge states within SiN_y to become positive (under positive bias, as in this study, we believe the K-center charge states would become negative). This leads to an approximately zero charge for the passivation layer, increasing the surface recombination velocity (SRV). The increase in SRV reduces the intrinsic field effect passivation of the AlO_x layer (for the module under study, we are not sure about the passivation layer, and therefore the mechanism presented is based on the current literature), and the module power decreases [10]. Positive bias applied to the cell repels positive charge from the front passivating dielectric. Said another way, it attracts net negative charge to the passivating layer. When the net charge in the front passivating layer becomes more negative, it attracts more minority carrier holes from the n+ emitter layer at the front of the n+/p PERC structure. When the industry moves toward more selective emitters, the sensitivity to this effect increases because the selective emitter, with lower phosphorus doping, provides less front surface field screening the minority carriers from cell front recombination at the dielectric interface with the Si emitter. When exposed to sunlight, almost full recovery is observed because photogenerated electrons are captured by K^+ centers and nullify them. This changes the K^+ charge to a mobile hole that sinks via the SiN_y layer leading to fewer K^+ centers that can draw the minority carrier electrons to the dielectric interface. Hence, the SRV decreases, and recovery is seen [11].

Furthermore, higher degradation level at lower irradiance is linked to the shift in surface recombination injection-level dependency caused by the PID-p progression, which alters the surface charge density of the AlO_x/SiN_y layer [12]. Incomplete recovery of PID at lower irradiance is reported by other works [13], [14]. However, the mechanism is still not clearly understood and will be the topic of future studies.

IV. Conclusions and Future Work

PID-p mechanism can quickly degrade under voltage bias and recover under light in PV modules compared to other types of PID mechanisms. Moreover, most PID studies target degradation under a negative bias, whereas PID-p can also happen under a positive bias in PERC modules, as observed in this study. Using the Al-foil method for PID testing, we see a 3.1% and 6.2% degradation in Pmax at high and low irradiance levels, respectively. Under sunlight, complete recovery is seen when the module is tested at STC. However, recovery is only partial when IV is measured at lower irradiance. The results of this study can help the PV community understand PID-p in PERC cells under a positive bias and its recovery under sunlight.

Future studies may need to be focused on understanding the mechanisms behind incomplete recovery at low irradiance and how outdoor field conditions can propagate or recover PID-p.

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References

[1] F. I. Mahmood and G. TamizhMani, "Impact of Anti-soiling Coating on Potential Induced Degradation of Silicon PV modules," in *2022 IEEE 49th Photovoltaics Specialists Conference (PVSC)*, 2022, pp. 1198–1200.

[2] M. Dhimish and G. Badran, "Recovery of photovoltaic potential-induced degradation utilizing automatic indirect voltage source," *IEEE Trans. Instrum. Meas.*, vol. 71, pp. 1–9, 2021.

[3] S. Yamaguchi, K. Nakamura, A. Masuda, and K. Ohdaira, "Rapid progression and subsequent saturation of polarization-type potential-induced degradation of n-type front-emitter crystalline-silicon photovoltaic modules," *Jpn. J. Appl. Phys.*, vol. 57, no. 12, p. 122301, 2018.

[4] S. Yamaguchi, B. B. Van Aken, M. K. Stodolny, J. Löffler, A. Masuda, and K. Ohdaira, "Effects of passivation configuration and emitter surface doping concentration on polarization-type potential-induced degradation in n-type crystalline-silicon photovoltaic modules," *Sol. Energy Mater. Sol. Cells*, vol. 226, no. February, p. 111074, 2021.

[5] G. J. Janssen *et al.*, "Minimizing the polarization-type potential-induced degradation in PV modules by modification of the dielectric antireflection and passivation stack," *IEEE J. Photovoltaics*, vol. 9, no. 3, pp. 608–614, 2019.

[6] W. Luo *et al.*, "Investigation of the Impact of Illumination on the Polarization-Type Potential-Induced Degradation of Crystalline Silicon Photovoltaic Modules," *IEEE J. Photovoltaics*, vol. 8, no. 5, pp. 1168–1173, 2018.

[7] W. Luo *et al.*, "Elucidating potential-induced degradation in bifacial PERC silicon photovoltaic modules," *Prog. Photovoltaics Res. Appl.*, vol. 26, no. 10, pp. 859–867, 2018.

[8] V. Naumann *et al.*, "Explanation of potential-induced degradation of the shunting type by Na decoration of stacking faults in Si solar cells," *Sol. Energy Mater. Sol. Cells*, vol. 120, pp. 383–389, 2014.

[9] K. Sporleder *et al.*, "Local corrosion of silicon as root cause for potential-induced degradation at the rear side of bifacial PERC solar cells," *Phys. status solidi (RRL)--Rapid Res. Lett.*, vol. 13, no. 9, p. 1900163, 2019.

[10] K. Sporleder, V. Naumann, J. Bauer, D. Hevisov, M. Turek, and C. Hagendorf, "Time-resolved investigation of transient field effect passivation states during potential-induced degradation and recovery of bifacial silicon solar cells," *Sol. RRL*, vol. 5, no. 7, p. 2100140, 2021.

[11] B. M. Habersberger and P. Hacke, "Impact of illumination and encapsulant resistivity on polarization-type potential-induced degradation on n-PERT cells," *Prog. Photovoltaics Res. Appl.*, vol. 30, no. 5, pp. 455–463, 2022.

[12] W. Luo *et al.*, "Elucidating potential-induced degradation in bifacial PERC silicon photovoltaic modules," *Prog. Photovoltaics Res. Appl.*, vol. 26, no. 10, pp. 859–867, 2018.

[13] J. Oh, S. Bowden, and G. S. TamizhMani, "Potential-

Induced Degradation (PID): Incomplete Recovery of Shunt Resistance and Quantum Efficiency Losses," *IEEE J. Photovoltaics*, vol. 5, no. 6, pp. 1540–1548, 2015.

[14] J. Oh, S. Bowden, and G. TamizhMani, "Application of reverse bias recovery technique to address PID issue: Incompleteness of shunt resistance and quantum efficiency recovery," in *2014 IEEE 40th Photovoltaic Specialist Conference (PVSC)*, 2014, pp. 0925–0929.