Potential induced degradation (PID) study on accelerated stress tested PV modules

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Potential Induced Degradation (PID) Study on Accelerated Stress Tested PV Modules

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Abstract — High system voltage could increase the leakage current from the active cells/circuit to the grounded module frame. The leakage current could then lead to performance degradation, called potential induced degradation (PID). This study presents the PID results obtained on the fresh modules as well as the modules which were previously subjected to accelerated damp heat test (85°C/85%rh; 1000 hours) and thermal cycling test (-40°C to 85°C; 200 cycles). The PID test was conducted in an environmental chamber by stressing the modules at 85°C, for up to 35 hours at +600V or -600V. Electrical performance and electroluminescence studies were also carried out on the pre- and post-PID tested modules.

Index Terms — grounding, durability, potential induced degradation, reliability, system voltage

I. INTRODUCTION

The levelized cost of energy ($/kWh) due to photovoltaic (PV) modules is dictated not only by the initial price of the modules ($/W) but also by the reliability (distribution of surviving units over time) and durability (distribution of degradation rates over time) of the modules. Just a few failed modules (reliability) or underperforming modules (durability) can make a serious negative impact at the string level and system level performances. The PV module components including cells and polymeric materials must be protected from degradative failures (soft issues; causing durability losses) and catastrophic failures (hard failures; causing reliability failures) caused by various stresses including temperature, humidity, ultraviolet radiation, wind, hail, and high system voltages, and various effects including corrosion, broken interconnects, hotspots, delamination and encapsulant discoloration.

The qualification testing standards of IEC 61215 and IEC 6146 [1]-[2] for the flatplate PV modules include various accelerated tests for the stresses identified above except the system voltage stress. High system voltage increases the leakage current from the active cells/circuit to the grounded module frame, through encapsulant, glass surface and/or interfaces of cell/encapsulant and encapsulant/glass. This leakage current due to high system voltage could lead to performance degradation, called potential induced degradation (PID). Recently, a few research groups have published PID results on the fresh modules [3]-[5]. This study presents the PID results obtained on the fresh modules as well as the modules which were previously subjected to accelerated damp heat test (85°C/85%rh; 1000 hours) and thermal cycling test (-40°C to 85°C; 200 cycles).

### TABLE 1

<table>
<thead>
<tr>
<th>PID test on Monocrystalline Silicon Modules</th>
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<tbody>
<tr>
<td>Test Modules</td>
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<tr>
<td>+600V (Phase-I)</td>
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<tr>
<td>-600V (Phase-II)</td>
</tr>
<tr>
<td>Reverse +600V (Phase-III)</td>
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II. METHODOLOGY

Five monocrystalline silicon modules from a single model were used for this investigation. The modules were initially tested for the baseline performance to determine the initial performance after light conditioning for the light induced degradation. Two of these modules were thermal cycling (-40°C to 85°C; 200 cycles) stressed as per IEC 61215, two other modules were damp heat (85°C/85%rh; 1000 hours) stressed as per IEC 61215 and the last module was not stressed (fresh module). The system voltage of 600V was applied between the shorted module leads and the frame. The glass surface was covered with a conductive carbon paint extending to the frame. The PID test was conducted in an environmental chamber by stressing the modules at 85°C, for up to 35 hours at +600V or -600V with an intermittent evaluation for the determination of activation energy using Arrhenius equation. All the five modules were subjected to PID tests in three phases as shown in Table 1 and Fig 1. Pre- and post-characterizations of performance, infrared scans and electroluminescence scans were carried out after the PID tests.
III. RESULTS AND DISCUSSION

As shown in Fig 2, the power outputs of all the three phase I modules (control 1A; TC200-2A; DH1000-3A) after 35 hours at +600V and 85°C dry heat were within 5% of initial power outputs. However, as shown in Fig 2, the power outputs of all three phase II modules (control 1A [same module after phase 1 testing]; TC200-3B; DH1000-3B) after just 5 hours at -600V and 85°C dry heat lost approximately 85% of their initial power. In order to see if this degradation mechanism can be reversed and the lost power can be recovered, a reverse polarity of +600V was applied for 5 hours in phase-III to the modules from phase-II. As shown in Fig 2 and Fig 3 for Phase III modules, the control module (control 1A) recovered about 60% of its original power and the thermal cycling module (TC200-2B) recovered about 71% of its original power. However, the damp heat module (DH1000-3B) recovered only about 28% of its original power. It appears that there are both reversible and irreversible degradation mechanisms operating during the negative bias. The reversible mechanism appears to be dominant in the control and TC200 modules whereas the irreversible mechanism appears to be dominant in the DH1000 modules. The loss recovery trend (TC200 > Control > DH1000) of these results appears to indicate that the extent of irreversible mechanism increases as the amount of moisture present in the module package increases.

![Fig 2: Power loss or recovery after various bias conditions](image)

The activation energies determined for the positive biased modules at various stress durations using Arrhenius plots are shown in Table 2.

<table>
<thead>
<tr>
<th>PID Test Module</th>
<th>Activation Energy (eV)</th>
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<tbody>
<tr>
<td>Control-1A</td>
<td>0.71 0.65 0.61 0.58</td>
</tr>
<tr>
<td>TC 200-2A</td>
<td>0.55 0.69 0.68 0.68</td>
</tr>
<tr>
<td>DH1000-3A</td>
<td>0.76 0.39 0.38 0.37</td>
</tr>
</tbody>
</table>

As can be seen in Table 2, the Control-1A module has undergone a gradual decrease in the activation energy. For the TC200-2A module, after an initial increase, the activation energy stays constant. For the damp heat accelerated stressed module DH1000-3A, the activation energy dropped dramatically from 0.71eV to 0.38eV after the first cycle and stayed constant for the successive PID stress cycles. Based on the measured leakage currents and activation energies determined in this study, it may be speculated that the DH1000-3A module might have had some trapped moisture from 1000hrs of damp heat accelerated stressing, which might have contributed to high leakage currents in the early stages of PID test. It is speculated that ingressed moisture in the glass coated with carbon conductive paste, might be providing a conducting pathway from the solar cells to glass superstrate to frame.
This high resolution electroluminescence (EL) imaging technique provides important information on the defects in crystalline silicon solar cells. It is useful in locating the damaged finger contacts, electrical shunts, broken fingers, broken cells and micro cracks. Fig 4 shows an EL image before and after 35 hours of PID (+bias), corresponding to Control-1A module. As it can be seen the crack length seems to be practically not affected by 35 hours of PID stress test, and correspondingly shows no major change in module performance. The EL images corresponding to before and after 5 hours of high voltage negative bias are shown in Fig 5. From this Fig 5 it can be observed that active area has reduced significantly due to negative bias stress. This observation is consistent with the performance drop discussed earlier in this paper. The EL images corresponding to before and after 5 hours of high voltage reverse positive bias are shown in Fig 6. From this Fig, it can be observed that active area has improved significantly due to reverse positive bias stress. This observation is consistent with the dramatic performance recovery discussed earlier in this paper.

IV. CONCLUSIONS

To obtain a very high surface conductivity, the glass surfaces of the PV modules were covered with a conductive carbon paint extending to the frame. A potential induced degradation (PID) study at both positive and negative bias voltages on both accelerated stressed and unstressed modules have been successfully carried out at 85°C dry-heat. Less than 5% power degradation has been observed during the positive bias whereas about 85% power degradation has been observed during the negative bias. This study also indicates that the power lost during the negative bias can be recovered by reapplying positive bias but the extent of power recovery drastically varies depending on the history of the original modules (fresh, TC200 stressed or DH1000 stressed). A very high surface conductivity layer of carbon extending all the way to the frame has been used; in reality, this type of high surface conductivity in the field condition could happen only on sunny/cloudy days during heavy salt-loaded (marine/costal conditions) rains. Therefore, this study needs to be extended with lower surface conductivity layers or methods in order to better simulate the field conditions. An extension of this study is currently underway at ASU Photovoltaic Reliability Laboratory (ASU-PRL).
REFERENCES


