PV module durability testing under high voltage biased damp heat conditions

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Abstract

Ten commercially available photovoltaic module technologies were selected for this study including five thin-film technologies and five silicon wafer based technologies. These modules were subjected to accelerated ageing tests in a dark climate chamber under conditions of 85°C and 85% relative humidity and electrical bias for 650 hours. The bias voltage ±1000V DC was applied between the active circuit of each module and module frame to study the impact of electrical bias on PV module durability under hot and humid conditions. Module performance assessed with a Class A solar simulator under standard testing conditions (STC) showed the biased stressing condition in damp heat test could significantly degrade electrical performance and cause various defects such as delamination, glass surface deterioration, frame corrosion, and metal grid discoloration, depending on module type and bias polarity.

Keywords: Photovoltaic module; durability; damp heat; electrical bias; ion migration

1. Introduction

Durability of PV modules is a topic of great importance for the entire PV community. Electrical output of PV modules could be significantly affected by various environmental factors such as humidity, ultraviolet light, temperature, etc and also internal factors such as module design and materials, system design, etc. Nowadays PV module manufacturers give over 25 years field warranty, with maximum degradation ratio of 20%. Obviously 25 years is a very long time for module performance assessment. Various accelerated stressing tests have been developed to study different failure mechanisms and reveal design weaknesses of PV modules [1]. Among the tests, the damp heat test is especially important for PV...
modules deployed in tropical countries, as this test demonstrates the influence of moisture ingress on the PV modules’ performance. Such ingress was found to be associated with corrosion, delamination, and insulation degradation issues. In this test, PV modules are placed into a damp heat climate chamber under 85°C and 85% relative humidity conditions for 1000 hours or longer. The impact of moisture ingress is evaluated by comparing module performance before and after the damp heat exposure. For tropical countries such as Singapore, moisture ingress is one of the major PV module degradation mechanisms, because of the high ambient temperature and humidity. This makes the damp heat test an important accelerated test to assess module durability in the tropics.

Electrically biased damp heat test introduces another stressing factor into the accelerated test. The test is conducted on the PV modules undergoing the damp heat test, whereby an electrical bias voltage is applied between the module frame and the active circuit. Such a bias condition can occur in real-life PV installations. As PV modules are series and parallel connected in PV arrays, the potential of the active circuit of the last module in series-connected PV module chains could be very high while module frames (usually aluminum material) needs to be grounded as a safety requirement. Such a configuration results in up to 1000 Volts of potential difference. It has been reported that the biased damp heat test revealed similar degradation phenomena as encountered in field applications, such as transparent conductive oxide (TCO) corrosion for thin-film PV modules [2]. The failure mechanism is not well understood, but it was reportedly caused by electro-chemical corrosion associated with sodium ion migration and moisture ingress [2].

In the present study, ±1000 Volt DC was applied in a damp heat (85°C, 85% R.H.) test for 650 hours to different PV modules. Chapter 2 presents the experimental details and Chapter 3 summarizes the results.

2. Experiment

2.1. PV modules

Ten types of commercially available PV modules were selected for this study. Modules were from PV companies in Asia, Europe and USA. Module sizes ranged from 1.0 m × 0.5 m to 1.8 m × 1.1 m. Five of them were thin-film technologies and five silicon wafer technologies. Three with glass-glass construction and seven with glass-backsheet construction. Eight with aluminum frame and two frameless. For each type of module, one module was used for positive bias damp heat test, and one module for negative bias damp heat test. For the frameless modules, aluminum foil (about 30 mm wide) was wrapped along module edges to “create” a pseudo frame connecting with one terminal of the high voltage power supply.

2.2. Equipment setup

The biased damp heat tests were conducted in the dark in a multi-purpose climate chamber set at 85°C and 85% relative humidity. Inside the chamber, PV modules were loaded on a rack with non-conductive spacers and their frames/output cables were connected with a multi-channel high voltage power supply. The power supply applied ±1000 V DC bias voltage during damp heat test for each module. In positive bias test, the “+” terminal of the power supply was connected with the two output cables (shorted together) and the “-” terminal was connected with module frame; In negative bias test, the “+” terminal was connected to module frame and the “-” terminal was connected to the cables of PV module. Test parameters such as voltage and current of each channel were recorded by a computer every minute. The maximum current for each channel was limited to 5 mA.
2.3. Module performance assessment

Before and after the biased damp heat tests, I-V curves were measured with a Class-A flashing-type sun simulator at Standard Testing Condition (STC). A PT100 thermal sensor was attached at the back surface of PV module and the flasher was turned on when module temperature reached 25°C. To ensure the accuracy of the assessment, module surface was cleaned with water to remove dust or contaminants from glass before each I-V measurement.

2.4. Experimental steps

First, all the modules experienced outdoor preconditioning (> 5 kWh/m²) in open circuit mode as suggested in IEC21615 [3]. Initial module performance assessment was done after the preconditioning. Then the modules were loaded into a climate chamber for the 650 hour biased damp heat test. Module performance assessment was done again to obtain the result after the accelerated stress test. After the damp heat test, thin-film modules were preconditioned again outdoors before the subsequent I-V measurement. Visual inspection was also conducted at different stages in this study.

3. Results

3.1. Visual inspection

Each PV module was scrutinized after the damp heat test. Visual defects are summarized in Table 1 and typical defects are shown in Fig. 1 to Fig. 4. Most of the thin-film modules showed signs of delamination. Under positive bias two thin-film modules exhibited “dot-like” delamination under the front glass as shown in Fig. 1, while under negative bias “hair-like” delamination was shown under the glass for three types of thin film modules (see Fig. 2).

Discoloration was also observed on two mono-Si modules only after the positive bias test. The silver metallization turned yellow for the solar cells close to the module frame. Also, the grids beside the tabbing ribbon turned darker (see Fig. 3).

A common defect mode after positive bias test for almost all modules is glass surface deterioration and module frame corrosion. A “milky-white” stain layer emerged on the module glass surface and it was found unable to be removed by scrubbing. Such layers appeared more obvious at the glass surface closer to module frame. Also, all module frames were found to be corroded showing white powder on the aluminium frame surface (see Fig. 4). In contrast, the above-mentioned surface deterioration and frame corrosion was never present in any modules after negative bias damp heat test.
Table 1. Visual defects after 650 hours of ±1000 V 85°C/85% R.H. biased damp heat testing. Notes: “+” indicates positive bias mode and “-” indicates negative bias mode, “§” indicates glass/glass module construction, and “f” indicates frameless module construction.

<table>
<thead>
<tr>
<th>Module type</th>
<th>Delam. under glass</th>
<th>“White Mist” on glass</th>
<th>Frame corrosion / powders</th>
<th>Discolor at cell / metal grid</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>+</td>
<td>-</td>
<td>+</td>
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<tr>
<td>a-Si</td>
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<tr>
<td>a-Si/a-Si tandem</td>
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<tr>
<td>Micromorph tandem</td>
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<td>CdTe §</td>
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<td>CIGS §</td>
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<tr>
<td>Mono-Si</td>
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<td>Multi-Si</td>
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<td>Mono-Si BIPV §f</td>
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<tr>
<td>Mono-Si back-contact</td>
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<tr>
<td>Mono-Si/a-Si hetero.</td>
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</table>

Figure 1. “Dot-like” delamination visible under front glass, and frame corrosion of a-Si/a-Si tandem module after positive-bias damp heat test

Figure 2. “Hair-like” delamination visible under front glass of CdTe module after negative-bias damp heat test

Figure 3. Discoloration of silver metallization on solar cell of Mono-Si module after positive bias damp heat test

Figure 4. Glass surface deterioration of Mono-Si back-contact module after positive bias damp heat test
3.2. I-V measurements

I-V measurements were performed as described in section 2.3. The results are summarized in Fig. 5. Many modules suffered severe efficiency degradation due to the biased damp heat tests. Some of these results are not unexpected. Thin-film module types with TCO layers are known to degrade under negative bias [2], and the mono-Si back-contact module types are known to suffer a surface charging issue under positive bias due to their unique back-contact module structure [4]. However it is surprising to see that the standard mono-Si and multi-Si modules suffered efficiency drops of 63% and 19%, respectively, and that the CdTe and CIGS modules totally lost power after the negative bias test.

Most module types showed more efficiency drop after the negative bias test as compared to the positive bias test, although the latter test resulted in glass surface deterioration that could affect light transmission.

![Figure 5. Module efficiency after bias damp heat tests normalized by the original efficiency before the test. CdTe and CIGS totally lost power output due to shunting problem after the negative bias damp heat test.](image)

3.3. Discussion

The mechanisms of efficiency loss may be different among the modules because of the differences in module structure and PV materials. Ion migration could be an important factor. Sodium ions (Na⁺) are known to be a mobile ion in glass [5]. Under high voltage bias and wet/hot test conditions, we believe Na⁺ migration occurred from the glass to the module frame during the positive bias test, and the glass
surface deterioration was a result of pH value changes at the glass surface which resulted in glass corrosion and also aluminum frame corrosion.

Under negative bias mode, Na⁺ migration would occur in the opposite direction (i.e. from the glass towards the solar cells). Such bias suppressed the occurrence of the glass corrosion issue, however the solar cells could be affected by the mobile ions migrating towards them. Thin-film layers could be susceptible to the “attack” of Na⁺ ions, and the migration could change material properties. For Si wafer modules, the migration could occur through the EVA encapsulation layer. Besides sodium ion migration, there could be other mobile ions inside the modules which contribute to the observed efficiency drops. A detailed study is required to further understand the mechanisms involved.

4. Conclusion

Many PV module types suffered from severe efficiency loss under biased damp heat test conditions. More modules were affected by the negative bias mode as compared to the positive bias mode under the same damp heat test conditions. The cause of the efficiency loss could be associated with ion migration under biased damp heat conditions. Solutions at the module level and system level need to be considered to mitigate the impact of these effects in real-world conditions.

The authors would like to also highlight as a disclaimer that only one module of each type was tested under each bias polarity in this study. These results are therefore not necessarily indicative of each PV technology as a whole.

Acknowledgements

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References

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