A DECADE OF COMBINED CYCLE ACCELERATED TESTING

Stefan Jarnason, CSG Solar Pty Ltd, 82 Bay St Sydney, NSW, 2019, Australia
Phone: +612 9695-8148, email: stefanj@csgsolar.com.au

CSG Solar produces Crystalline Silicon on Glass (CSG) photovoltaic modules in its research line in Sydney and pilot scale 20 MW factory in Thalheim, Germany. Although CSG modules have been tested outdoors for over ten years, and have passed IEC 61646 and IEC 61730 qualification testing, CSG Solar conducts additional tests to provide confidence that this new thin-film technology will survive 25+ years in the field. To obtain this confidence two things are required: a) in-depth analysis, understanding and rectification of any failure mechanisms, and b) extended accelerated testing to simulate 25+ years outdoor exposure.

COMBINED CYCLE TEST SEQUENCE

Standard qualification testing simulates less than five years of outdoor exposure and is only intended to provide rapid feedback during product development[1,2]. Realising this limitation, in 1999 CSG Solar developed an extended accelerated testing regime, called "Combined Cycle" testing[3]. A single Combined Cycle consists of the standard IEC Qualification tests being applied sequentially to the same module(s), namely 200 temperature cycles from -40°C to 85°C, then 1000h of damp heat at 85°C and 85% RH, then 10 humidity-freeze cycles from -40°C to 85°C/ 85% RH (Figure 1). If these modules survive one such Combined Cycle, which takes about four months of continuous accelerated testing, the Combined Cycle sequence is repeated until the module output drops below 80% of its initial value. Linear interpolation is used to estimate when output drops to the 80% value, giving a numerical value for the modules durability performance in terms of number of Combined Cycles withstood. Multiple modules are tested to increase the statistical significance.

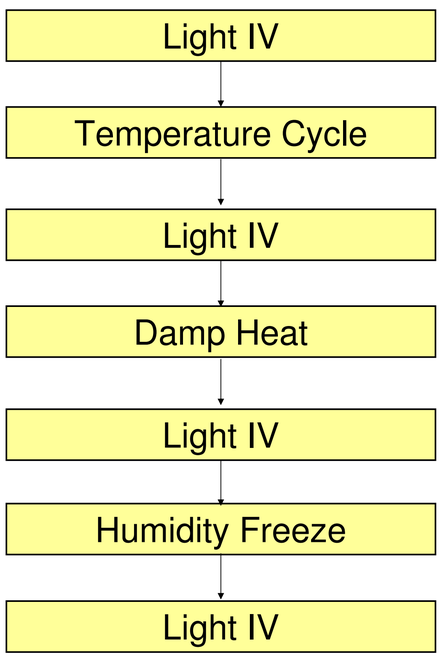

Figure 1: One Combined Cycle sequence.

Advantages of Combined Cycle Testing

- Standard environmental equipment utilised
- Individual exposures well accepted by PV community
- Environmental exposures are within the "normal operating and design conditions" for PV modules
- Continues standard qualification testing for efficient use of durability resources

Limitations of Combined Cycle Testing

- Long test time of 4-12 months required
- No UV or illumination stresses/exposure introduced
- Typically small number of modules under test

COMMERCIAL MODULE COMPARISONS

CSG Solar has more than a decade of results from performing the Combined Cycle sequence on its own modules, and in comparison with other commercially available thin-film modules and traditional crystalline silicon wafer modules. By comparing the results of CSG modules to standard crystalline silicon wafer modules, which have demonstrated their reliability for over 30 years, a relative comparison between the technologies can be obtained. Generally crystalline silicon wafer modules survive approximately 2 Combined Cycles, with remarkable reproducibility between modules from the same manufacturer (Figure 2).

Typically modules from all manufacturers lose some power due to current degradation, however the primary cause of degradation is an increase in the module's equivalent-circuit series resistance. The causes of this increase in series resistance vary between modules, and may be due to delamination, cell cracking, tabbing connections or hot-spots. Although the precise cause of the failure of a laminated module is difficult to diagnose, with the assistance of techniques such as Lock-In Thermography (DLIT)[4], and unique in-module test structures to identify degradation locations, CSG Solar has steadily improved the long term durability of its crystalline silicon on glass modules.

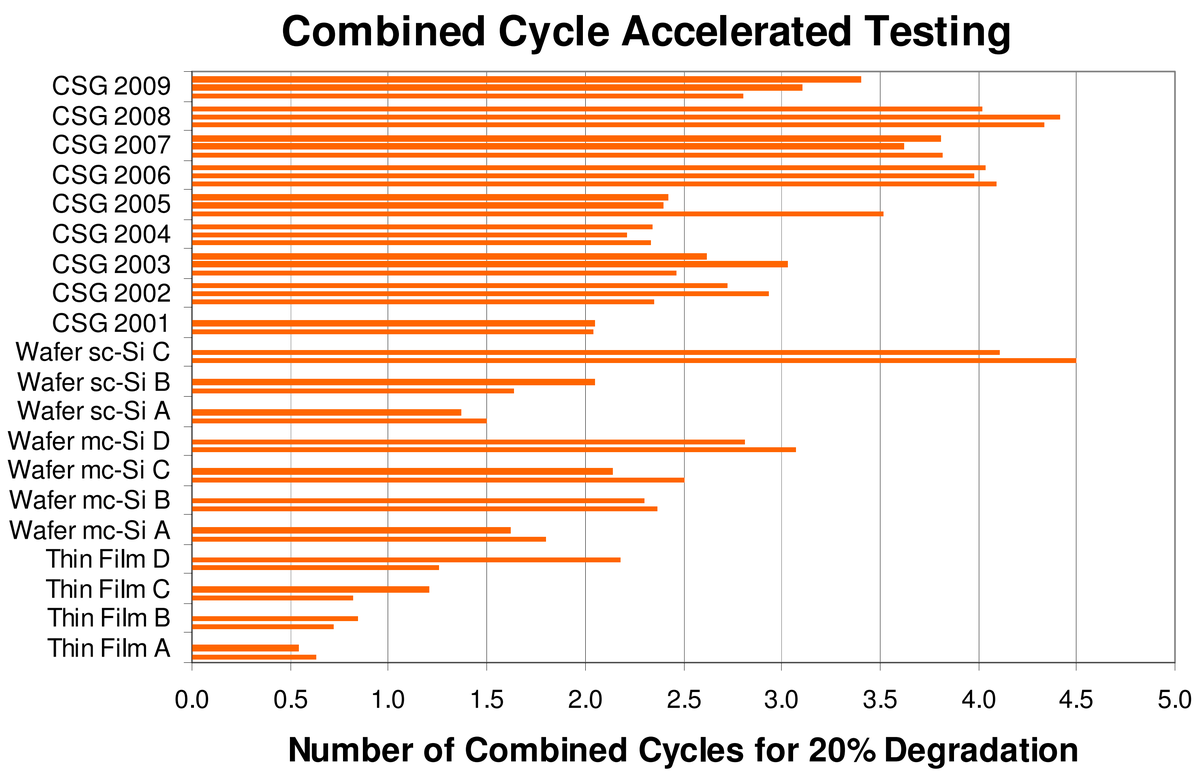

Figure 2: Comparison of commercial and CSG modules in combined cycle testing

DESIGNED EXPERIMENTAL RESULTS

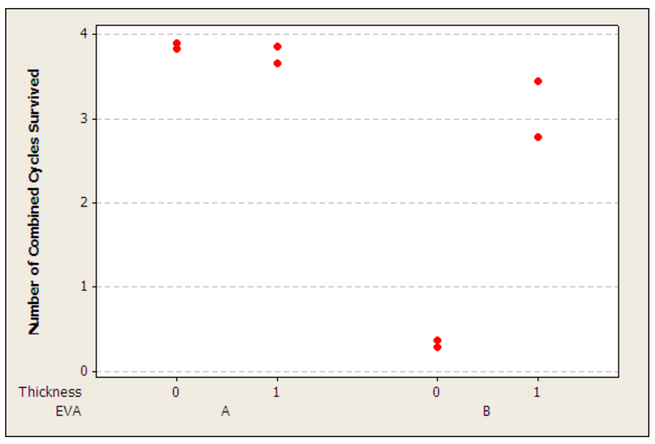

Figure 3: EVA type and thickness experiment

To improve durability a pro-active approach is required to initiate, investigate and test potential module material and process changes. CSG Solar uses a Design of Experiments approach to evaluate proposed module modifications that are based on the previous durability testing results and process advancements,. The results of a typical orthogonal designed experiment comparing two types of EVA in two different thicknesses is given in Figure 3. These results, which were also controlled for material batch, showed that thin EVA B was unable to survive a single combined cycle, while modules with either thickness of EVA type A or with thick EVA type B, were able to achieve 3-4 Combined Cycles before degrading by 20%. Based on this result, EVA type A was the preferred material since it has less susceptibility to thickness and was able to withstand almost 4 Combined Cycles.

Importantly even the poorly performing thin EVA B combination is able to pass the standard IEC 61215/61646 qualification testing, however this combination would be extremely unlikely to survive 25 years in the field. This result demonstrates the advantages of the prolonged Combined Cycle exposure in identifying longer term failure mechanisms.

CONCLUSION

Combined Cycle testing has become the mainstay of CSG Solar's long term durability testing. Over the previous decade this exposure sequence has been demonstrated to consistently identify module degradation that is not detected by the standard qualification testing. The Combined Cycle test sequence is an essential tool in the kit to assess and extend the module lifetime, and is considered a key test that needs to be passed to qualify any significant changes in module processing. The ambitious long term goal of CSG Solar's durability program is to produce modules that consistently achieve survive greater than 4 Combined Cycles, which is primarily achieved by identifying and resolving the identified failure mechanisms.

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