

# DEVELOPMENT AND APPLICATION OF ACCELERATED TEST METHODS SPECIFIC TO CPV SYSTEMS

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**Abstract:** Accelerated test methods are essential to prove the life of CPV products within an acceptable amount of time. This paper describes two separate accelerated test programs SolFocus is conducting on its 300 Watt SF1100 CPV product. One program is a traditional temperature / humidity step test with results extrapolated to field conditions through a use-condition model of the interior of the panel. The other program is a field study with the CPV receiver components operating at elevated temperature levels while operating in grid-connected systems. The methodology of both programs is detailed along with initial data and results.

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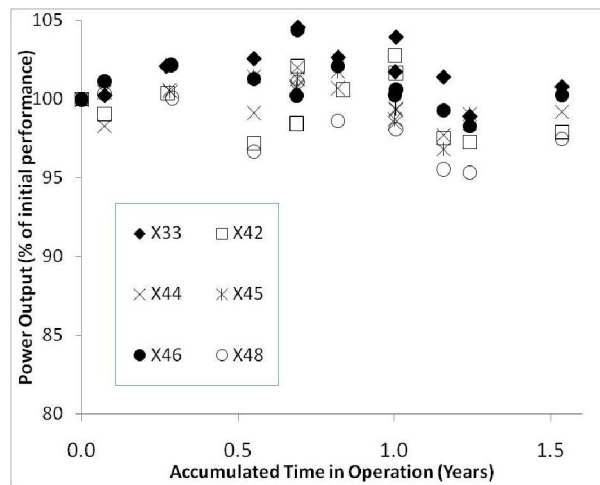
## INTRODUCTION

The SolFocus SF1100 300 Watt CPV panel has passed the IEC 62108 qualification standard which establishes a level of product safety, performance and reliability. Unfortunately, the weathering and on-sun durability tests conducted for IEC 62108 are insufficient to determine the expected life of CPV systems. Thus the IEC 62108 qualification is only a part of the overall SolFocus reliability program which also includes predictive lifetime studies at the component and system levels.

In order to quantify the expected life of CPV systems it is required to determine the effects of operating under high solar fluxes and photo-current generation as well as temperature and humidity. While running long-term field durability tests, as has been described previously (1), is essential, certain failure modes may only become evident after multiple years operating in the field. Accelerated test methods are required to catch and quantify the long term effects of failure modes within a reasonable amount of time.

Standard reliability goals within the solar industry are to obtain 20% or less power degradation over the 20 to 25 year life of the product or less than 1% degradation per year assuming linear degradation. Measuring power output with high precision and high reproducibility is very difficult for CPV in the field due to environmental variation. So far SolFocus believes it has obtained approximately  $\pm 3\%$  reproducibility over measurements taken repeatedly over multiple years. Refining normalization techniques should soon improve that to  $\pm 2\%$ . Yet even at that level, it's possible that failure modes

which significantly shorten the life of the product are not even detectable until multiple years have passed. This is not acceptable. Figure 1 is an example where, even after monitoring prototype SF1100 panels for over 1.5 years, the measurement noise still dominates over any actual change in performance. Thus it is impossible to draw any long-term life trends on this data alone.



**FIGURE 1.** On-sun performance measurements on 6 prototype SF1100 panels over 1.5 years of on-grid operation.

The weathering tests required for IEC 62108 are a useful gauge to establish a minimum expected life, but are inadequate to provide a quantitative life estimate due to moisture / temperature related failure mechanisms. Two additional aspects are required to obtain this. Tests need to be conducted over multiple

levels of both temperature and humidity in order to obtain enough data to fit into a multiple stress relationship. Most of these relationships are either variants of the Eyring, Arrhenius and/or the inverse power law relationships. The next requirement is a use-condition model that predicts the temperature and humidity level of your equipment in different field locations, assuming it is different than the conditions outside the CPV equipment.

Temperature / humidity weathering tests do not adequately stress components within CPV systems that are exposed to concentrated solar fluxes where thermal gradients and photo-induced current flows exist. Thus a whole set of failure modes can be missed entirely unless an attempt to characterize and capture these mechanisms is included. The most fundamental aspect of this is to have a robust field monitoring program. Due to the difficulty of making field measurements with high reproducibility as well as the long expected product lives, it is further required to quantifiably accelerate aging mechanisms while under CPV operating conditions.

SolFocus is currently involved in two separate accelerated test efforts, a traditional temperature / humidity step test and an accelerated field study, to quantify the long term life of its SF1100 CPV product. SolFocus believes that results from these accelerated tests along with the ongoing monitoring of non-accelerated systems operating in the field are capable of quantifying the life of its product to acceptable accuracy in approximately 1 year of testing. These tests have been underway for approximately 6 months for the SF1100. This paper details the accelerated test methodology used, presents some preliminary test results and links those results to standard operating conditions.

## METHODOLOGY

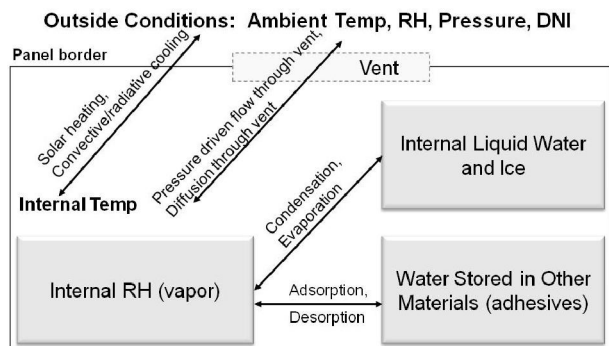
The first accelerated test program is a traditional step test study in which scaled down SF1100 ‘mini-panels’ have been stressed at different temperature / humidity levels in environmental chambers. Each ‘mini-panel’ has all materials as a complete panel, except they consist of only a single 15 watt power unit. Two or three mini-panels were assigned to each test condition. The mini-panels were on-sun tested at initial state and after every 1000 hours of applied stress using the standard ‘side-by-side’ on-sun test methods defined in IEC 62018 with an unstressed control mini-panel. In addition to 7 different constant temperature and humidity conditions detailed in Table 1, a ‘condensing cycle’ was also included. The ‘condensing cycle’ cycles between 65°C/85%RH for 6 hours and 10°C/50%RH for 3 hours and is designed to

cause liquid water to condense onto all surfaces internal to the panel for the majority of the cycle.

**TABLE 1.** Temperature / Humidity conditions in ‘mini-panel’ study.

Condition	Quantity of mini-panels in test
125°C / dry	2
100°C / dry	2
85°C / 85%RH	2
85°C / 60%RH	2
85°C / 30%RH	3
65°C / 85%RH	2
55°C / 60%RH	3

Once the mini-panels have degraded to the point where end-of-life can be projected, the results will be fitted to a temperature-humidity acceleration model for the overall CPV system. SolFocus typically uses the Reliasoft ALTA software package to fit similar data sets. Since the SolFocus CPV panel is an enclosed space with limited flow into and out of the enclosure it was required to generate a model which predicts interior temperature / humidity conditions based upon the exterior conditions. The use-condition model, diagrammed in Figure 2, is used as a design tool to optimize conditions inside the panel as well as for reliability purposes. The output from the use-condition model is an hourly list of the internal temperature and % RH conditions for a representative year. The temp-humidity acceleration model is then integrated over that representative year to get the expected life of the panel at that particular climate zone.



**FIGURE 2.** Use-condition model of SF1100 CPV panel.

To attempt an accelerated stress field test, SolFocus generated non-standard panels with CPV receivers modified to run at elevated conditions. The modification was made by varying the thermal interface material (TIM) located between the receiver heat sink and backpan. This results in the receiver assembly operating under nominal solar flux levels and photocurrent flows while at temperatures significantly above a standard panel. The heat sinks

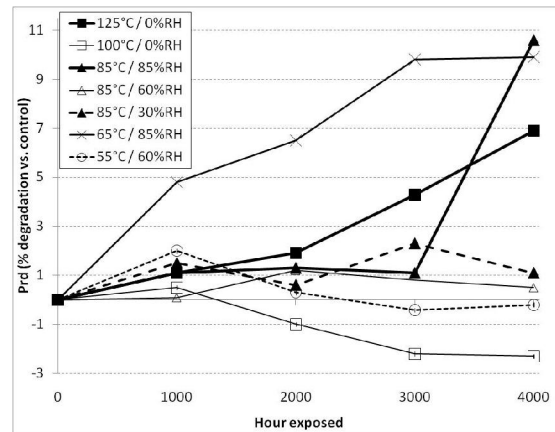
are instrumented with thermocouples and temperatures recorded continually every 10 minutes during operation. These accelerated test panels are integrated into grid connected 12 panel 3.6kW arrays. The panels are taken off-grid and the individual on-sun power output is measured at the start of the test program and after every 2 months of operation. The DOE test matrix under investigation is as follows:

- Temperature, 3 levels: Normal operating temperature, +20C target, +40C target.
- Climate zone, 2 levels: Desert (Tempe, Arizona), Tropical (Nelha, Hawaii).
- Cell type, 2 levels: Cell type A, Cell type B. Both III-V triple junction cells.

A separate condition was investigated where a thermal/power cycle has been induced on an entire 3.0kV grid-connected CPV array by continually moving the array on and off axis, 20 minutes per cycle and approximately 24 cycles per day. This simulates the thermal transients common for CPV due to tracking irregularities, shading and cloud cover. The results will be used to establish acceleration rates over the normal use case. While the exact acceleration factor cannot be determined, it is approximately 8x if it's assumed that under normal conditions an average of 3 on/off cycles per day occur.

## RESULTS

The results of the mini-panel step test, shown in Figure 3 after 4000 hours, so far are inconclusive. The intention is to continue the tests out until the mini-panels reach the official fail point of 20% degradation at which time the panels will be dismantled and each individual component tested. None of the panels run at constant T / %RH conditions has reached that fail point. The 65°C/85%RH and 85°C/85%RH panels are both at about 10% degradation, the former condition has linear degradation while the latter is non-linear. To attempt to explain this, the calibrations of the environmental chambers were re-checked after completion of 4000 hours and found to within 0.5% of the target temperatures and humidity. In addition, the mini-panels in each condition were visually checked to verify that no condensed liquid water was forming on the glass or mirror surfaces. The other constant temperature condition where degradation is evident is the 125°C/0%RH condition with 6% degradation. Note that with the 100°C/0%RH condition, there is actually an improvement in performance. The other lower humidity conditions have shown no change after 4000 hours.

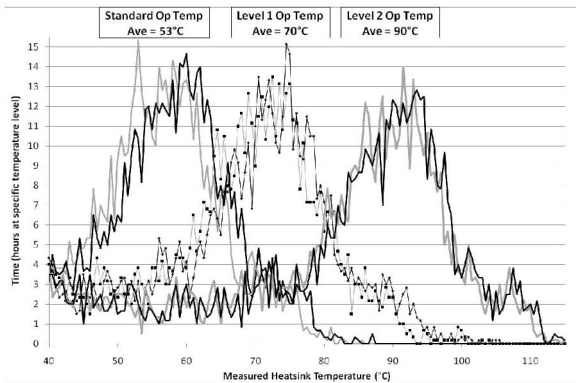


**FIGURE 3.** Relative degradation of 'mini-panels' after 4000 hours in various weathering conditions.

Where the trends were evident, the degradation was extrapolated out to 'end-of-life' and input into the ALTA software package. Unfortunately, no meaningful T/%RH relationship could be determined. This is due to two main factors: 1) similarity between the 65°C/85%RH and 85°C/85%RH degradation values, and 2) no trends yet evident in the 60% or 30%RH cases. The tests are ongoing and it is hoped that a model can be generated after degradation has progressed further.

The mini-panels exposed to the condensing cycle degraded 30% after 92 cycles. The total accumulated time at each dwell point during these cycles was 500 hours at 65°C/85%RH and 300 hours at 10°C/50%RH. The panels were dismantled and individual components tested. It was found that the majority of the degradation occurred due to a decrease in light transmission through the front glass sheet. The condensing cycle has been identified as an effective tool to determine susceptibility to effects of surface condensation. Note that the IEC62108 defined humidity freeze test causes a much lower response to this particular degradation mechanism. The front glass sheet has now been replaced with a more water resistant glass which is being used for full-scale manufacturing.

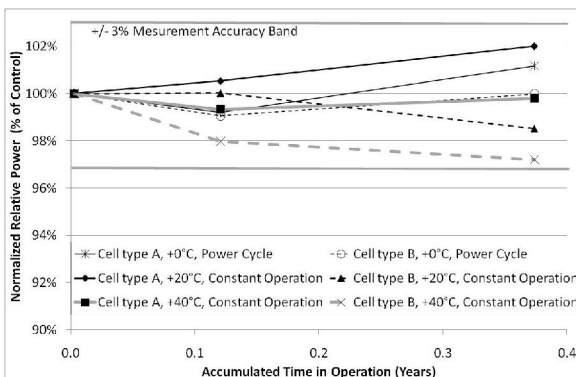
The accelerated field test has been underway for approximately 5 months. Figure 4 shows the receiver heat sink temperature distribution for the accelerated test panels at the Tempe, Arizona field site. The average value for the accelerated temperature panels is 17°C and 37°C higher than the standard design panels indicating that the DOE thermal targets were obtained. Note that the thermal data shown is over the fall and winter seasons and the overall distributions will trend higher over the remainder of the year.



**FIGURE 4.** Heat sink temperature distributions over the Oct '09 to March '10 time span.

Only three sets of panel on-sun performance data have been collected to date. Figure 5 gives the normalized performance over time for the elevated temperature panels relative to the standard thermal configuration panels. The elevated temperature panels do output less power due to the cells running hotter, but so far no output degradation from initial performance is evident above the +/-3% noise level. It's possible there has been some power loss with the +40°C, cell type B accelerated panel, but it is unclear if that trend is actual or just variation within the noise range. It is hoped that by the end of one year of operation there will be clear signs of degradation in at least one of the elevated temperature levels.

The relative performance of the panels stressed with the power cycle is also presented in Figure 5. As of March 3rd, 2010, when the last performance measurements were made, 1800 cycles had been completed with no degradation evident.



**FIGURE 5.** Panel level test results for the Accelerated Field Test panels in Tempe, Arizona after 3 months. All data is relative to the control (non-accelerated) panels.

## CONCLUSIONS

SolFocus has designed a series of accelerated tests that are intended to quantify degradation rates associated with standard temperature, humidity stresses as well as stresses associated with operating under concentrated conditions. These system level accelerated tests are a critical portion of the overall SolFocus SF1100 reliability program. Additional components of this program include component level accelerated life tests and detailed performance monitoring of panel populations operating in the field under non-accelerated conditions. When all components of this program are brought together, product life spans in the 20 to 25 year life range can be determined within approximately 1 year of testing.

The system level accelerated tests described in this paper for the SF1100 are incomplete so definite conclusions are not yet possible. One product weakness, degradation due to condensed water on the interior of the front glass sheet, was identified early in the program and was mitigated by changing the source glass.

SolFocus believes that system level accelerated stress tests are essential to the introduction of a new CPV product into the solar power market place. Applying accelerating stress while under operation in the field in addition to traditional temperature / humidity weathering tests assures that all possible failure modes have been encompassed. Results from these tests can be used to improve methods and protocols for ongoing reliability testing and point to where industry – wide standards should be employed.

## REFERENCES

1. M. Spencer and M. Finot, "Field Testing for Reliability Assessment of New CPV Technologies", ICSC5 conference, November 16 - 19, 2008. Palm Desert, CA.