Design of Experimental Test Setup for Large-scale Reliability Evaluation of Module Level Power Electronics (MLPE)

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Design of Experimental Test Setup for Large-scale Reliability Evaluation of Module Level Power Electronics (MLPE)

Sai Tatapudi¹, Jack Flicker², Devarajan Srinivasan³, Jigeesha Upadhyaya¹, Kabilan Selvarangan¹, Lakshmi Nandakumar¹, Joswin Leslie¹, Govindasamy Tamizhmani¹

¹ Arizona State University Photovoltaic Reliability Lab (ASU-PRL), Mesa, Arizona, 85212, United States
² Sandia National Labs (SNL), Albuquerque, New Mexico, 87105, United States
³Poundra LLC, Tempe, Arizona, 85281, United States

Abstract — Module level power electronics (MLPE), such as microinverters and DC power optimizers, are power electronic devices integrated or attached with PV modules so that there is one power-conditioning unit per module. This distributed architecture offers significant system benefits, including reduced component electrical stress, partial shading gains, and reduced effect of module failure on array performance. While the majority of MLPE studies have focused on performance, there is a distinct lack of large-scale, time-to-failure reliability studies to determine approximate field-use lifetime. This paper discusses a test setup for the long-term, large-scale, high temperature operating life testing MLPE devices to determine acceleration factor and time-to-failure.

I. INTRODUCTION

Module level power electronics (MLPE), such as microinverters (MI) and DC power optimizers (DCO), are power electronic devices integrated or attached with the module so that there is one power-conditioning unit per module. This sort of power handling topology offers numerous advantages on the system level, such as reduced component electrical stress, partial shading gains, and piecemeal failure of the array via distributed architectures.

However, MLPEs, depending on specific installation configuration (especially the proximity to the PV module), can be subjected to more extreme environments (e.g. higher operating temperatures) during the day than a centralized inverter [1]. Both higher daytime temperatures, as well as larger temperature cycles (combined with little or no active cooling), can result in a negative impact on reliability. While the majority of MLPE studies have focused on performance [2], there is a distinct lack of large-scale, t-to-failure reliability studies (e.g. [3] only conducted testing for 1000 hours units from a single manufacturer). The majority of MLPE reliability studies determine mean time between failure (MTBF) of MLPE units using MIL-HDBK-217 equations [4] to determine failure rates [5]. Previous work by SNL, ASU-PRL, and TUV-PTL researchers tested 140 constant-powered and unpowered units, consisting on various MLPE topologies applying a variety of accelerated stress tests including damp heat, thermal cycling and high static temperatures [6],[7],[8],[9]. The previous testing was meant to be a broad survey of the MLPE market with a large number of different technologies, but small samples sizes from each manufacturer for each stress condition. The current work aims to evaluate the long-term (>12 months), large-scale (60 units), high temperature operating life (HTOL) testing of one device type (MI purchased from the open market) to determine device acceleration factor (AF) and time-to-failure (TTF) of the device.

II. METHODOLOGY

HTOL testing is being carried out at three different temperature stresses, with ambient chamber temperature ranging from just below the derating temperature (range: 85ºC-105º) of the MLPE to the maximum field-use temperature. Field operating temperatures of MLPEs attached to module frames can vary from one location to another on the local climatic conditions. Fig. 1 shows the operating temperature of MLPE (unpowered) from four different manufacturers attached to modules’ frames on rooftop over 19 days in June 2017. Based on the above derating temperatures of MLPEs and field operating temperatures, we decided to perform the accelerated tests between the lower limit of derating temperature of 85ºC and the upper limit of field operating temperature of 65ºC.

At least three accelerated test temperature points are required to determine field-use lifetime using physical models. Once the entire population of the test device has failed, the expected
field-use lifetime from these stress conditions can be extrapolated based on effective equivalent field-use temperature. Testing is currently being carried out simultaneously at ASU-PRL and SNL at different temperatures.

The total population of 60 devices is split into two sub-populations. One sub-population of devices is supplied by a constant power input (rated power) while the second population has a cyclical power profile to more closely mimic field-use conditions. Each sub-population provide lifetime and acceleration factor metrics for the type of power profile (constant or cyclic). Additionally, this enables a direct comparison between constant and cyclic input power testing methods to extract the effect of cyclic power handling on MLPE lifetime. Units are constantly monitored for DC and AC power.

Due to equipment limitations, grid connection restrictions, and test conditions, the test setups at SNL and ASU-PRL differ slightly as explained below.

A. Test Setup at SNL

As shown in Fig. 2, twenty MIs have been mounted on a series of rails inside a walk-in environmental chamber, with each MI being connected to a DC power supply. All microinverters are connected to manufacturer supplied three-phase trunk cable, which is wired to a dedicated distribution panel. The manufacturer’s data gateway system is installed for monitoring the input and output performance at microinverter level. A Python computer script pulls and records the appropriate data streams from the data gateway in 5-minute increments (this time period was chosen as a trade-off in accuracy and tractability). Ambient chamber temperature is maintained consistently at about 75 ±2°C, with individual unit temperatures monitored via the data gateway. Measured individual unit temperature, at constant input power to each of 20 MLPEs, varies from 68 to 81°C (initially it varied from 69 to 82°C). This variation is probably caused by the location of individual unit on the chamber wall rather than at the center of the chamber. The final average temperature of all 20 units is about 76°C.

B. Setup at ASU-PRL

As shown in TABLE I, ASU-PRL’s test setup is designed to test up to 80 MLPE units of both types, microinverters and DC optimizers. In this setup, eight convection ovens are used instead of walk-in environmental chambers. Each oven can accommodate up to 10 MLPE units. Only the test results obtained on forty MIs in four ovens are discussed in this paper.

As shown in Fig. 3, each MI unit is powered by a DC power supply. The 208VAC output of the MI and the power supply AC input are connected to the same AC bus. Hence, the MI power output is fed back to the power supply input, and additional grid power is only used to compensate for circuit losses. This circuit was designed to prevent reverse flow from the microinverters to the grid so the grid stability is not affected by the malfunctioning/degraded MLPE units. In addition, this feedback circuit reduces the total energy usage compared to dissipating the energy, either by using a resistor bank or grid simulator. Any specific test temperature of interest above room temperature can be maintained in each oven. The DC input parameters (V_{DC} & I_{DC}) and AC output parameters (V_{AC}, I_{AC}, I_{RMS}, P_{AC}, \phi, \text{etc.}) of each MI is regularly measured using a set of relays in conjunction with hall effect and voltage sensors. Using external sensors for performance monitoring reduces the occurrence of any random errors caused by degradation of the microinverter’ built-in sensors.

![Fig. 2 Microinverter test station at SNL](image)

![Fig. 3 Microinverter test station at ASU-PRL](image)

**TABLE I**

<table>
<thead>
<tr>
<th>Oven No.</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
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</thead>
<tbody>
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<td>65°C</td>
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<td>10 MI</td>
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<td>10 DCO</td>
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<tr>
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<td>Cyclic Power</td>
<td>Constant Power</td>
<td>Constant Power</td>
<td>Cyclic Power</td>
<td>Cyclic Power</td>
</tr>
</tbody>
</table>
MLPEs inside in each oven at ASU-PRL are powered either constantly or cyclically (6 cycles/day at a 4-hour interval). For MLPEs with constant or fixed power test condition, the ovens are maintained at constant temperature slightly lower than the device target temperatures of 65°C and 75°C to compensate for the heat generation by the MLPEs due to efficiency loss. The power cycling of units inside the oven causes a shallow cyclic temperature profile, compared to the steady-state power, depending whether the power is on (temperature raises) or off (temperature falls). For the MLPEs with cyclic power test condition, the average MLPE temperatures in two ovens are maintained at 65°C (10 units) and 75°C (10 units).

Thermal and performance data are continuously monitored for all 60 units (20 units at SNL and 40 units ASU-PRL) to determine time-to-failure for any of the units in the ovens.

### III. RESULTS

**Raw Data:** Fig. 4 shows the output power of the 20 MIs at SNL over the first 6,000 of testing under constant power condition at 68-82°C. No failure or performance degradation has been observed in any of the units. Discrete changes in power output are due to data acquisition system (DAS) errors or distribution power failures in the laboratory affecting the experimental setup. Fig. 5 shows the inverter efficiency (raw data) over about 5 months for 10 microinverters under cyclic power (CP) profiles at 65°C. Practically, no efficiency loss seems to be observed.

**Efficiency Loss at Cycling Power Condition:** Fig. 6 and Fig. 7 show linear regression trendlines for efficiency measurements of microinverter units over time under cyclic power profiles at 65°C and 75°C, respectively, at ASU-PRL. All the inverters under cyclic power condition at 65°C seem to negligibly small degradation after 5 months of stress testing. This small drop in performance falls within the uncertainty of DAS measurements. Three microinverters (inverters 4, 5 and 7) under cyclic power condition at 75°C have been observed to have lost about 3% after about 5 months of stress testing. In contrast, inverters 1 and 8 appear to have gained about 1%. The average power loss of all 10 units at 75°C under cyclic power condition is about 1%. A continual monitoring is required to ensure that the 3% loss for the three units is not a DAS error.
**Efficiency Loss at Fixed Power Condition:** Fig 8 and Fig 9 show linear regression trendlines for efficiency measurements of the microinverters units over time under fixed/constant power condition at 65°C and 75°C, respectively, at ASU-PRL. All the inverters under fixed power load at 65°C seem to follow about 1% degradation after about 5 months of stress testing with the exception of inverter 2, which appears to have gained about 1%. These small changes in performance could be due to the data acquisition errors. All the inverters under fixed power load at 65 and 75°C seem to have less than 1% degradation after about 5 months of stress testing. This negligibly small drop, if any, in performance could again be attributed to the data acquisition errors.

Fig. 10 shows the final instantly measured power and final instantly measured temperature under fixed/constant power input condition of every one of the 20 units stressed at SNL. The final instant temperatures of these units varied between 68 and 81°C depending on the wall location of the unit inside the walk-in environmental chamber. Again, the results from SNL also indicate that there is no discernable degradation of these microinverters after 6000 hours of operation at 68-82°C under constant power input condition.

**Summary:** The static power conditions at both SNL and ASU-PRL tend to show a relatively constant efficiency with negligible, if any, degradation. The cyclic power condition at 65°C does not seem affect the efficiency. The average efficiency loss under the cyclic power condition at 75°C is about 1% and a continual monitoring is required to ensure that the observed 3% efficiency loss for the three units is not due to a DAS error.

**IV. CONCLUSION**

Large-scale, long-term, accelerated testing of 60 microinverters (identical make and model) at three different temperatures and two different power conditions is currently undergoing. The tested microinverters so far experienced an average efficiency loss of 1% or loss at all temperatures (65-76°C) and power profile conditions (fixed/constant and cyclic). A continual monitoring is required to ensure that the observed average efficiency loss, though less than 1%, is not due to a DAS error. It is encouraging to observe that the microinverters are still operating with no discernable efficiency loss at constant power condition even after 6000 hours of operation at 68-82°C. The testing is being continued for the time-to-failure determination.

**REFERENCES**


