Accelerated Reliability Testing for Commercial and Utility PV Inverters

Ron Vidano

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Abstract

Accelerated testing is an efficient strategy to improve reliability for commercial and utility photovoltaic inverter equipment. The two most often used tests are highly accelerated life testing (HALT) and accelerated life testing (ALT).

HALT is a technique that yields results within a few days due to the nature of the acceleration factors used in the test whereby the unit is subjected to progressively higher stress levels and the inclusion of combined temperature and vibration. HALT is an invaluable method to uncover design weaknesses and is used at both the system as well as assembly level.

Accelerated Life Testing (ALT) is useful to determine wear-out mechanisms or lifetime within confidence limits. ALT is capable of determination for product reliability in a short time period of weeks or months by environmental acceleration factors. ALT can find dominant failure mechanisms and is a valuable tool for the discovery of wear-out failure. In addition, ALT methods can serve as qualification criteria to prescribed lifetime confidence limits.

ALT at the system level involves integration of multiple units such as an inverter and power supply within a large environmentally controlled facility. Subsystem life testing can be completed within smaller environmental enclosures or may be accomplished as a component integrated within the inverter at the unit or system level testing facility.

For ALT, the acceleration factor, length of the test, number of samples, confidence required, and test environment are known. The most common temperature acceleration factor is based upon the Arrhenius model. For PV inverters another acceleration factor is the duty cycle whereby testing may be accomplished continually as opposed to the sun-cycle restrictions for on-site exposure. In addition, inclusion of solar simulation methods provides for inverter cycling experienced during environmental and solar resource extremes. One element of efficient ALT qualification is envelope performance testing at environmental extremes.

It is advantageous to synergize the HALT methods to determine design weaknesses and ALT procedures which provide insight into wear-out lifetimes. Once, it has been determined that the inverter design can attain expected lifetimes, burn-in procedures are developed and used to ensure that the product does not contain process or assembly defects.

Methodology - Reliability Assurance Milestones During Inverter Product Lifecycle

AE uses a closed loop reliability process

Design for Reliability

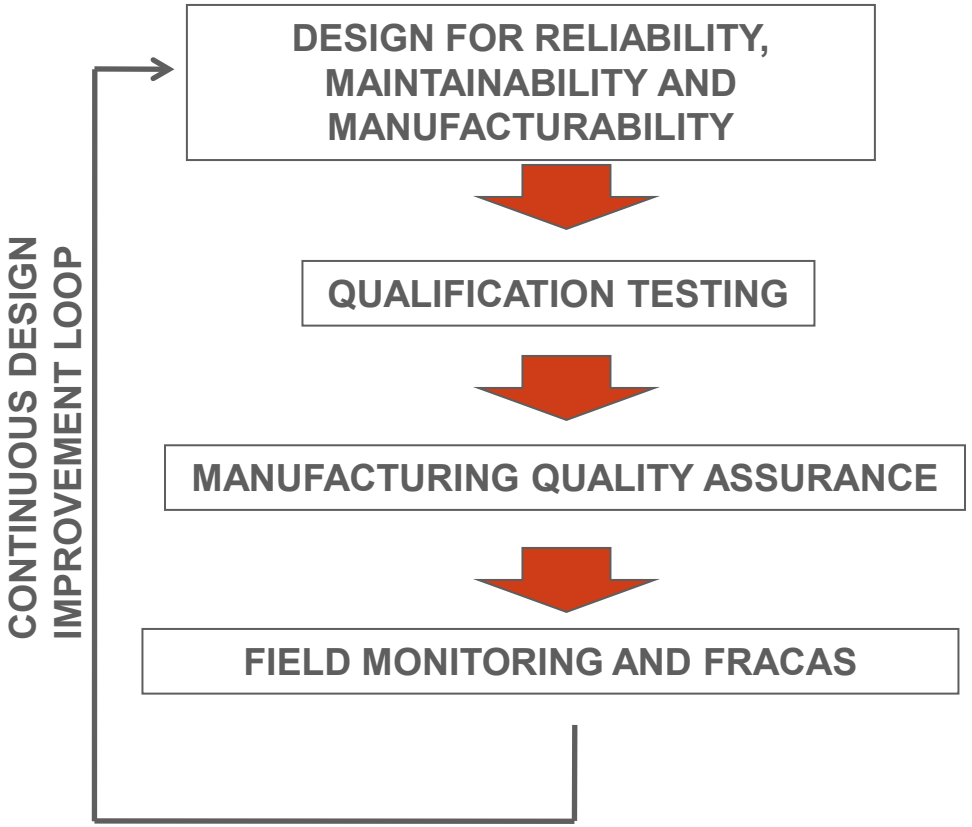
- MTBF, DFMEA, Fault Tree

Reliability Test

- Quantitative: ALT, Thermal
- Qualitative: HALT

Qualification Test

- Power profile, efficiency, harmonics, waveform, modulation, control loop, compliance, WCSA, limits, control & communication, burn-in development



Range of PV Inverters for Accelerated Testing

- String Inverters such as the 3TL Gen3 24kW

- Central Inverters such as the 500TX and 500NX

- Utility Inverters such as the 1000NX

AE Reliability Assurance Background

- AE's Solar and Precision Power Supply customer base requires a reliability focus.
- All products are required to meet a very low AFR

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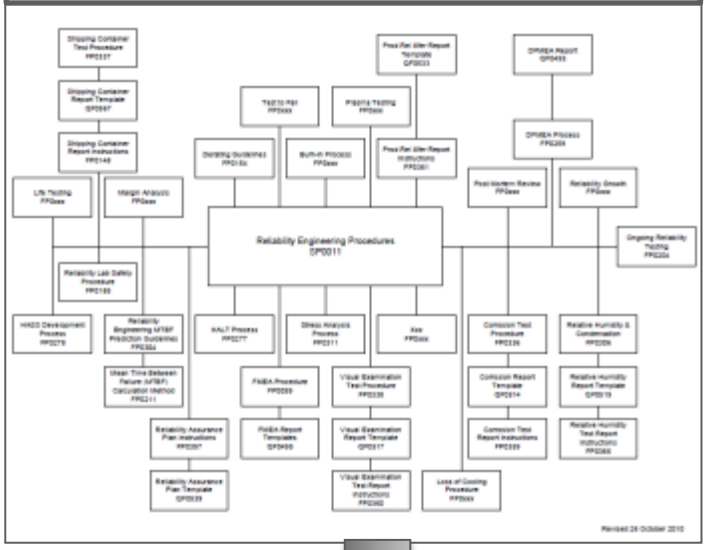
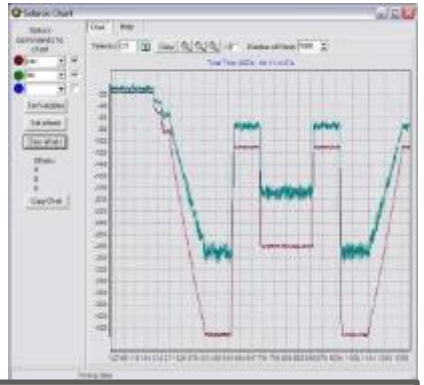
- PV Inverter products have unique challenges
  - Grid and Solar Simulators
  - High Firmware Contact – HIL Methods
  - Harsh Environment
  - Stringent Warranties
  - Monitoring
  - Inverter Reliability Must Compensate for BOE Issues
  - 20-Year Durability
  - >99% Availability
  - High Efficiency

AE Reliability Assurance Program





Advanced Power Supply Infrastructure and Simulation

Inverter Reliability Assurance Program

- Design for Reliability (DfR) Focus Areas
  - Modularity; Improves reliability, repair, test, and manufacturing
  - Derating; Component and subassembly derating to reduce operating stress
  - Temperature Management; Achievement of reduced operating temperatures
  - Predictive Methods – MTBF, DFMEA, Fault Tree Assessments
- Reliability Test
  - **Verification of potential causes based upon DFMEA**
    - **Subassembly ALT, Thermal, Thermal Cycle**
    - **Environmental Testing – Temp/Humidity, Salt Fog**
    - **HALT**
    - **System Level ALT**
- Experience; Reliability Growth
  - Product lifecycle learning experiences into design
    - Improvements based upon assurance testing and field experience

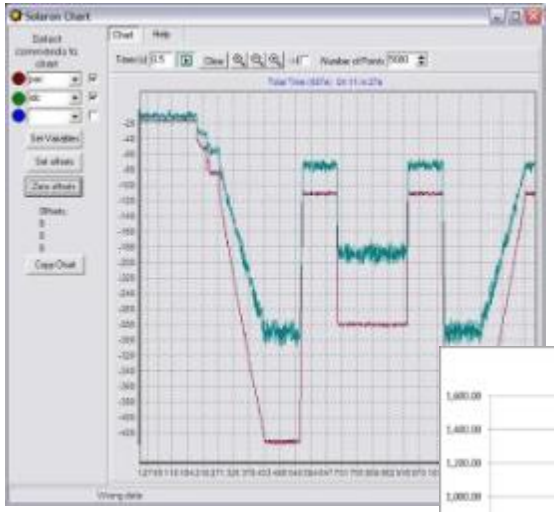
Focus For This Presentation

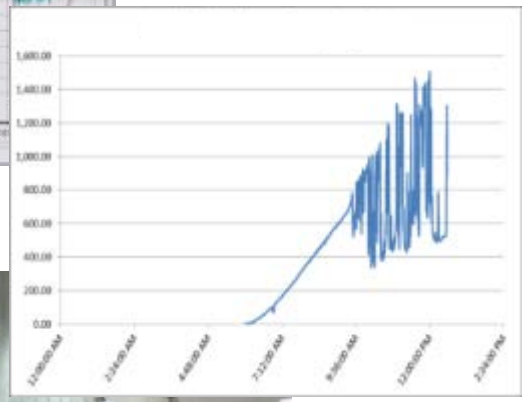
Accelerated Testing Applied to PV Inverters

- **Accelerated Life Testing**
  - **Temperature**
  - Humidity, Temperature-Humidity
  - Voltage
- Temperature Cycling
- Power Cycling
- **Highly Accelerated Life Testing**
  - **Cold step stressing**
  - **Hot step stressing**
  - **Rapid thermal transitions**
  - **Vibration step stressing**
  - **Combined environments**

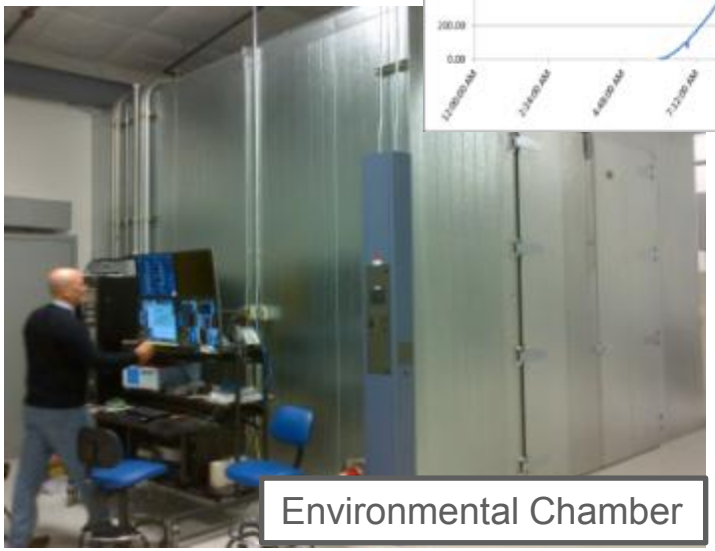
Performance Testing – Solar Simulation

- AE has installed programmable supplies to perform solar simulation testing
- Example of NREL test profile demonstrated with 1000NX inverter
- Example of actual site irradiance data programmed for test





Advanced Power Supply AC2000P



Environmental Chamber

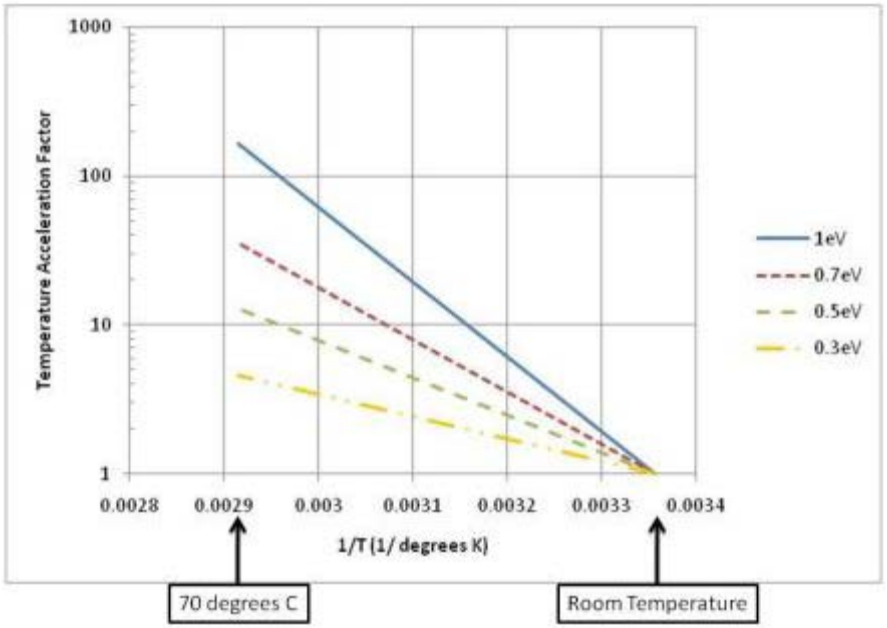
Accelerated Life Test (ALT) – Temperature Acceleration

Durability tests such as subsystem and system level accelerated life testing (ALT) are key tools to qualify the reliability of new designs.

The most common temperature acceleration factor AF(T) is based upon the Arrhenius model

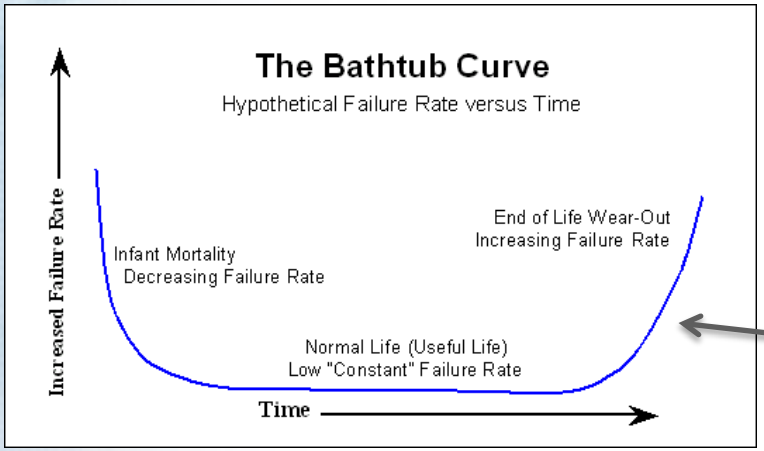
- K_b is the Boltzmann's constant, T_o is the initial ambient temperature in °K, T is the life test temperature in °K, and E_a is the activation energy in eV.

The acceleration factor scales for different activation energies and life test temperatures.



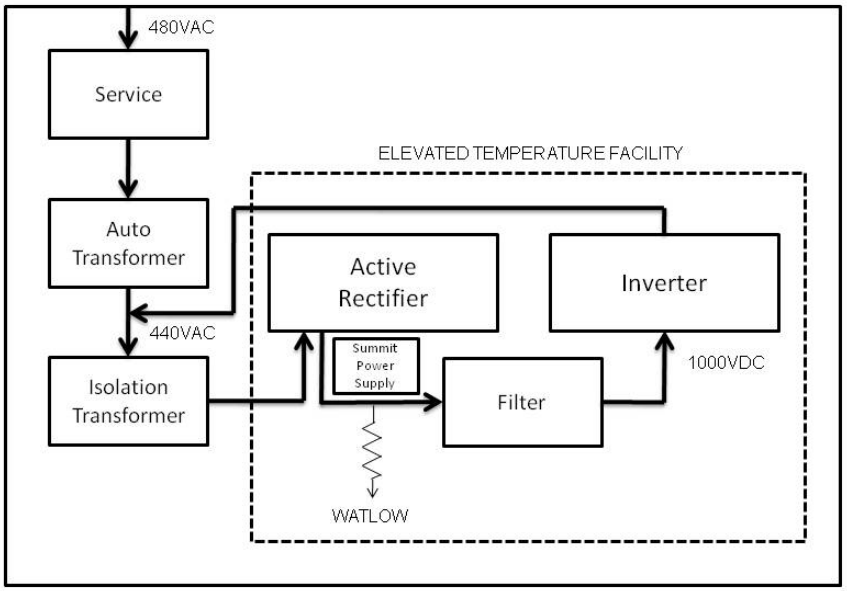
$$\lambda \propto \text{Failures}/(\text{Total Device Hours} \times AF(T))$$

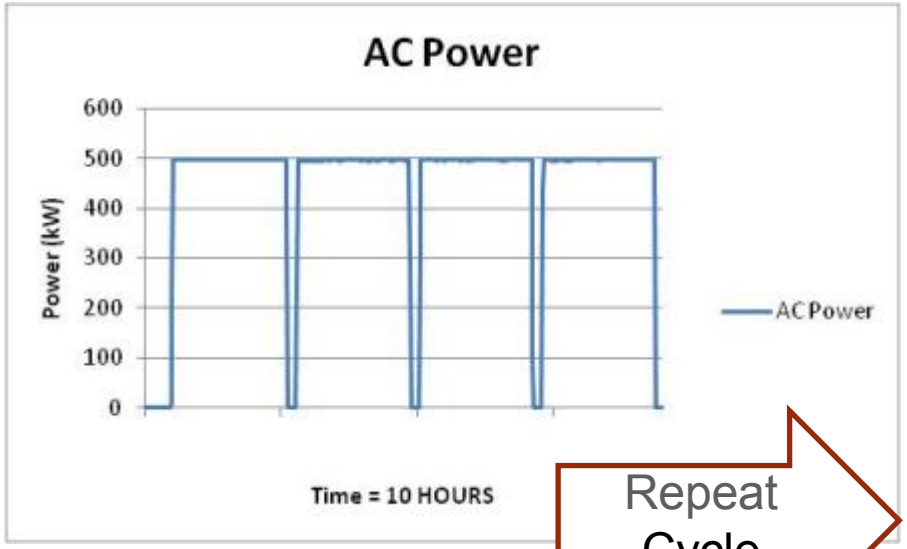
$$AF(T) = \exp[(E_a/K_b)(1/T_o - 1/T)]$$



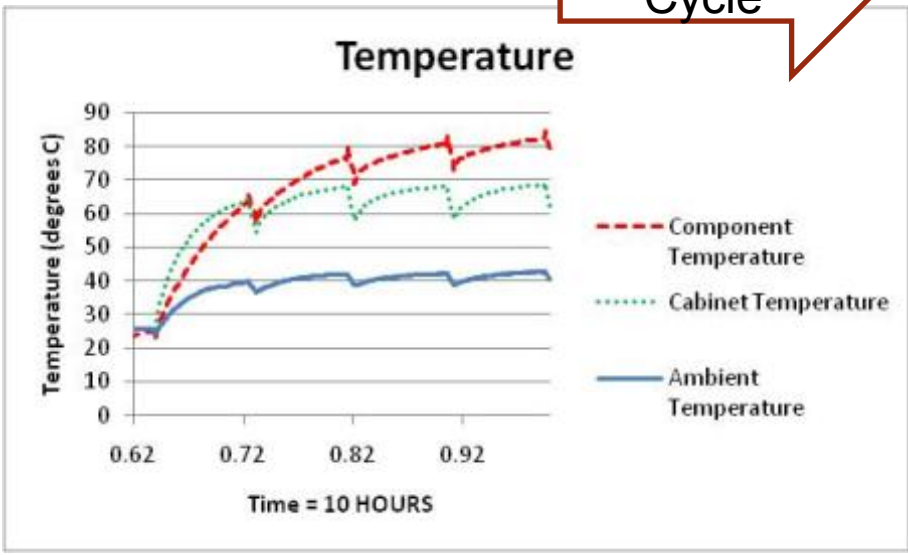
ALT is a gage of the inverter durability to reach end-of-life failure rate region

Long Term Life Test Profile Example; System Level ALT





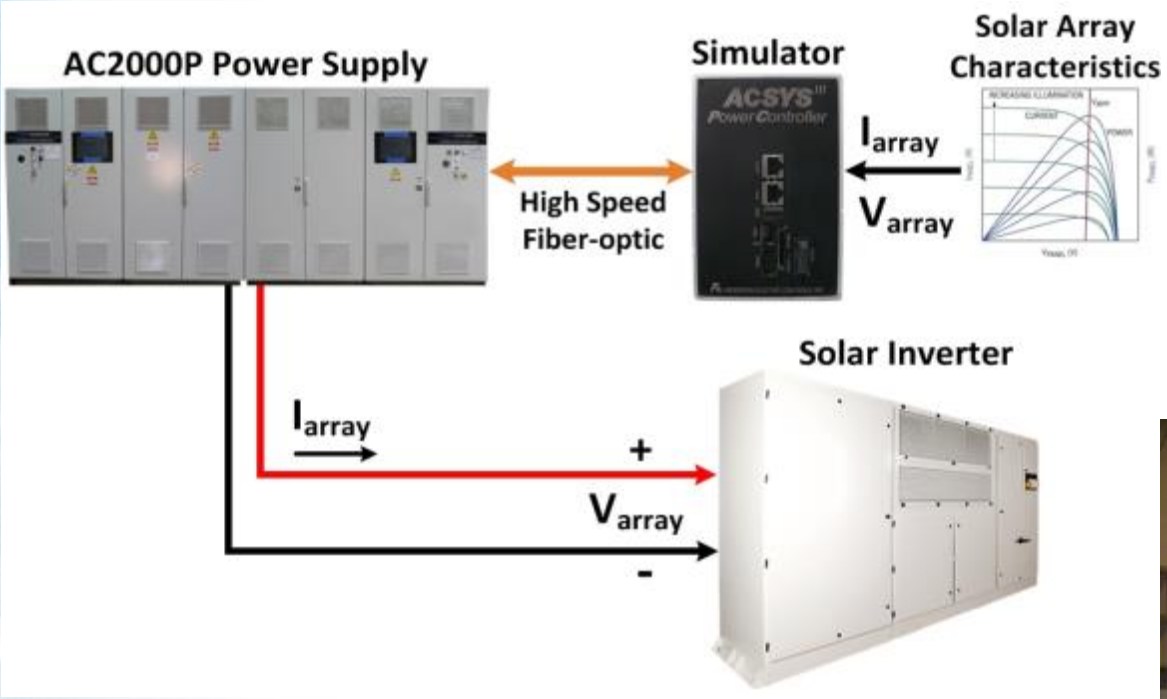
Repeat Cycle



AE has performed ALT for up to two calendar years upon inverters at 50degC, 24X7

Short Term Life Test Profile Example; System Level ALT

AE has developed accelerated life test facilities in Fort Collins, CO and Bend, OR which are capable of grid test simulation at high temperatures using advanced programmable power supplies with solar simulators



Anderson Electric Controls Supply and Solar Simulator Inverter housed within AE environmental chamber

Using solar simulators, AE has performed ALT for up to two calendar months upon inverters at 50degC, 24X7

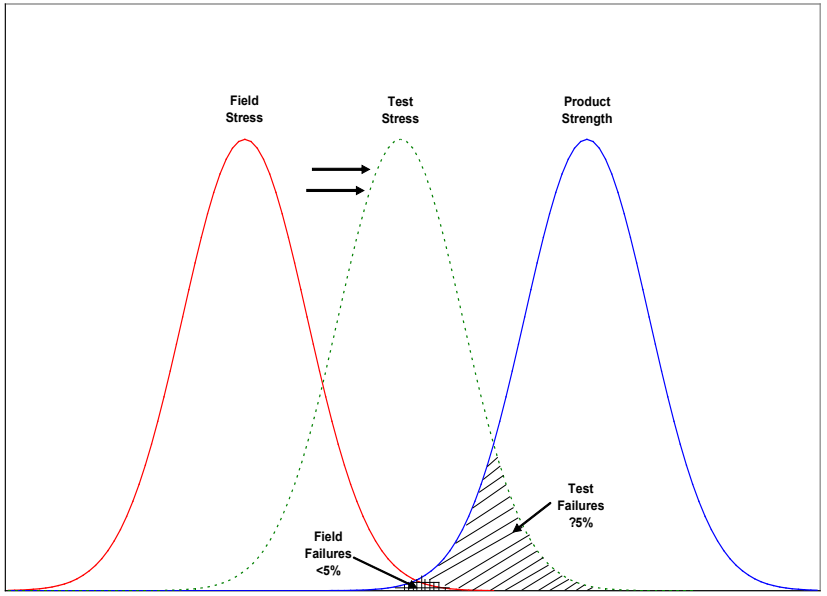
AE Background with HALT, HASS

- Highly accelerated life test (HALT) is a qualitative technique pioneered by leading firms such as HP to develop very reliable printers
- AE adopted the technique to develop reliable precision power supplies used in semiconductor processing
- Several HALT chambers were installed for testing and qualification as well as highly accelerated stress screening (HASS) chambers
- HALT has been used for the past seven years to test and quality PV inverter systems and subsystems

Highly Accelerated Life Test - HALT

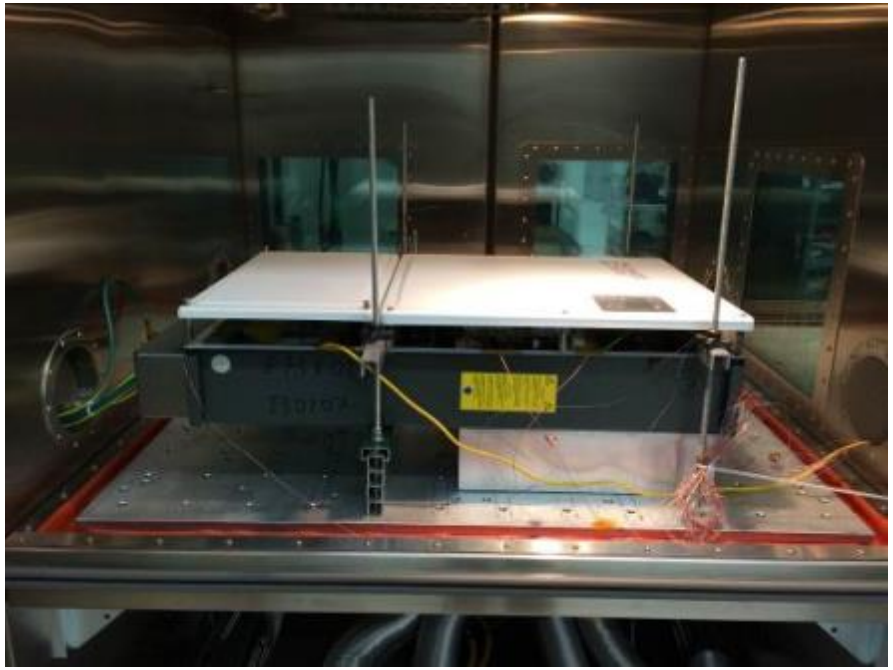
- HALT is intended to uncover design and design margin issues
  - Five stresses
    - Cold step stressing
    - Hot step stressing
    - Rapid thermal transitions
    - Vibration step stressing
    - Combined environments

    in addition to maximum loading the inverters are exercised under power
- Corrective Actions
  - Achievement of acceptable design margins; Temperature margins, Vibration margins, Combined stresses



HALT; PV Inverter Subsystems and Systems

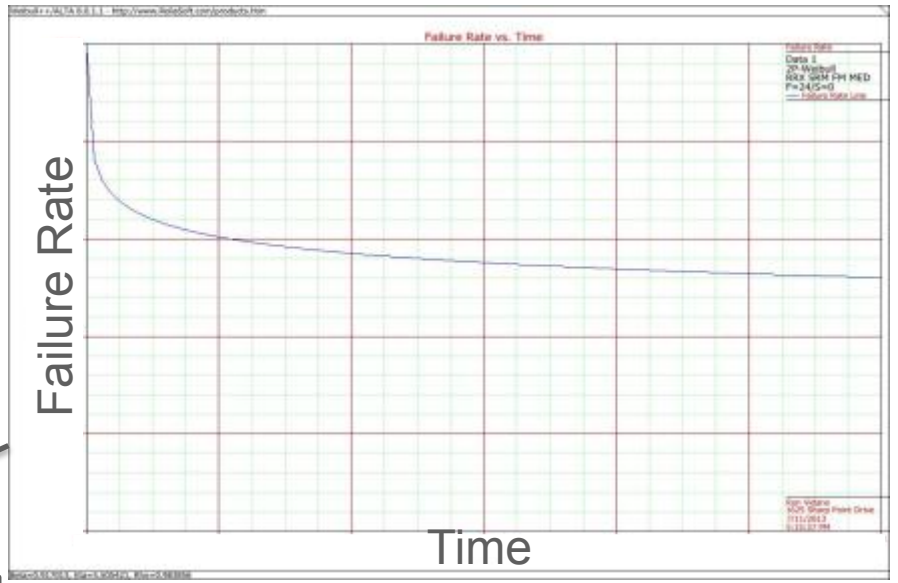
- Utility Inverters
  - Entire Switching Assembly (Engine)
  - DC Contactor Assemblies
  - Aux Power Supplies
  - Cable Assemblies
  - Line Reactors
  - Communication Subsystem
  - PCBAs
    - Digital Control
    - Analog
    - Sensor Control
- String Inverters
  - Entire 3TL 24kW
  - Entire 3TL 48kW



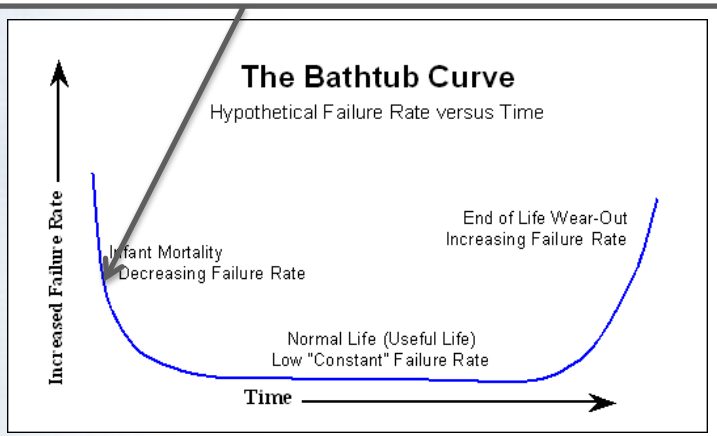
System Level Burn-In for Utility Inverters

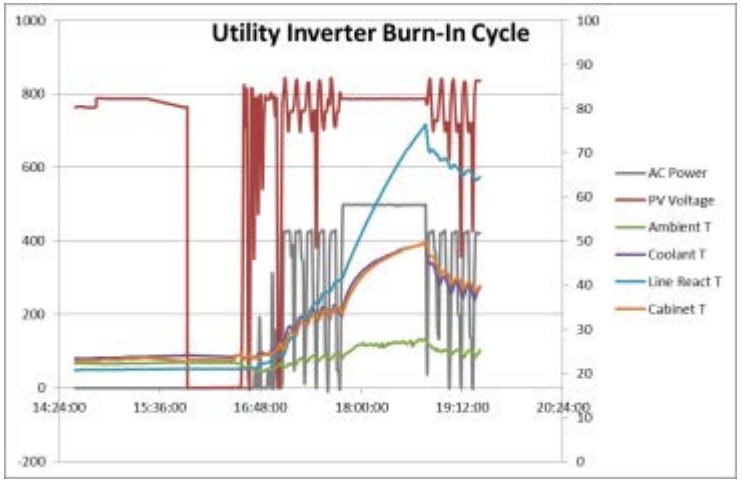
- Burn-in testing takes place at the unit level to stress the components for a designated period time to precipitate component early lifetime mortality - Temperature and Voltage Acceleration Factors
- The burn-in cycle contains voltage and power cycling which is done to ensure that power connections such as the bolted-joint assemblies are robust as well as to test low power electrical connector interfaces

Weibull statistics are accumulated to assess the burn-in cycle



Production Burn-In reduces the number of failures in the early (decreasing failure rate) lifetime region





Conclusions

- Accelerated life testing can be effectively employed for both subsystem and system level qualification of central, utility and string inverters
- HALT qualification is most effective at the subsystem level for central and utility inverters
- For string inverters, HALT qualification offers a unique approach for reliability improvement of the entire product

AE World Headquarters
1625 Sharp Point Drive
Fort Collins, CO 80525

800.446.9167
970.221.4670
sales.support@aei.com

www.advanced-energy.com