As of 2011, the National Electrical Code® (NEC) has required arc-fault circuit interrupters (AFCIs) to be incorporated into photovoltaic (PV) systems to prevent fires. Some manufacturers are designing AFCIs to consist of arc-fault detectors (AFD) incorporated into inverters or combiner boxes in order to take advantage of the DC switching functionality of the existing hardware. Since AFCIs and AFDs are safety devices, it is critical to ensure the long-term functionality of AFD devices in these harsh environments. Sandia National Laboratories (SNL) has performed accelerated life tests on 10 AFDs. The devices were tested after being subjected to the thermal damage equivalent of 1.7-year increments in an inverter until 77.6 equivalent years of solder fatigue damage. 30% of the boards experienced component failures but there were no solder failures, indicating solder fatigue is not the primary failure mode. Based on these results, Sandia recommends an appropriate burn-in process for production of arc-fault devices.

**Solder Accelerated Life Testing Process**

While the primary failure mode for AFD devices is unknown, microelectronic and discrete component solder bonds are known to fail on printed wiring boards as a result of harsh thermal environments. Specifically, thermo-mechanical solder fatigue failure is common in thermal cycling environments (e.g., automotive applications), so it was believed solder fatigue would be one of the leading causes of AFD failure in outdoor inverters which experience diurnal and seasonal cycling. To determine the lifetime of the solder joints, the following process was employed:

1. Collect data before study.
2. Collect thermal profiles from the field.
3. Extract test data using methodology.
4. Perform finite element analysis (FEA) on collected data.
5. Extract test data using methodology.
6. Perform life-time prediction for each test configuration.
7. Compare results to expected life.

**Modeling the Thermal Environment of an Inverter**

To find the number of accelerated thermal cycles which produce 1-year of equivalent inverter exposure, a SNL-developed finite element analysis (FEA) code with Unified Creep Plasticity Damage (UCPD) models for solder was run for rainflow count binned inverter thermal profiles and compared to simulations of -55 to 125°C cycles. The number of equivalent accelerated cycles was determined for the following thermal histories:

1. Ambient temperature within a 5 kW inverter at the Florida Solar Energy Center (FSEC).
2. Ambient temperature within a 3 kW inverter at the Southwest Region Experiment Station (SWRES) at the New Mexico State University in Las Cruces, NM.
3. Integrated circuit heat sink temperature within a 3 kW inverter at SWRES (theoretical comparison only).

Calculations indicated that the fatigue damage rate was highest in the clock solder joints. The FSEC ambient inverter thermal history was the most damaging internal ambient environment, so it was used to find the expected life and equivalent number of accelerated life cycles.

**Solder Joint Failure Analysis**

Solder fatigue damage calculations for the joints of the gull-wing 16-lead small outline integrated circuit (SOIC), 6-joint leaded ceramic chip carrier (LCCC) clock, and 1206 capacitor were performed.

**Results and Discussion**

All 10 of the AFD boards were exposed to 225 thermal cycles. After every five cycles, the boards were tested using the internal diagnostic self test function; and after 45 cycles (15.5 years of equivalent solder damage using the 100% solder crack failure criteria), physical arc-fault tests were conducted at the Distributed Energy Technologies Laboratory at SNL. After all the accelerated cycles, there were no failures from solder fatigue. Rather, there were infant mortality failures of 30% of the AFDs; and therefore, the expected lifetimes of those parts could not be calculated using the FEA model. In all the failed boards, visual inspection of the solder joints was performed and all joints were in excellent condition.

**Conclusions:**

1. The on-board diagnostic self test function of the AFDs works well to indicate when the functionality of the boards is lost.
2. Solder fatigue is an unlikely AFD failure mode when installed in an inverter.
3. Since the AFDs are required to operate for long periods of time in harsh environments, using a burn-in (stress screen) process to identify faulty components will be used in the future.