RELIABILITY CHALLENGES FOR SOLAR MICROINVERTERS

T. Paul Parker

Principal Reliability Engineer

&

Terence Parker

Applications Engineering Manager

SOLARBRIDGE TECHNOLOGIES™

INTRODUCTION

- Overview of SolarBridge and SolarBridge Products
- Overview of Photovoltaic (PV) Systems
- Reliability of Inverters in PV Systems
- Microinverter Design for Reliability
- PV Reliability Test Standards applied to PV inverters and integrated ACPV

COMPANY INFORMATION

- Founded in 2004 to commercialize power electronics technologies created at the University of Illinois
- Organization creating a platform of related products for the efficient conversion of energy
- Renamed the company SolarBridge Technologies (formerly SmartSpark Energy Systems®) to reflect revised strategy to focus exclusively on the solar market
- Locations in Champaign, IL and Austin, TX
- Substantial IP base
- 50 employees/consultants

SOLARBRIDGE TECHNOLOGIES™

SOLARBRIDGE AC MODULE SYSTEM

Integrated Pantheon™ microinverter

PV-Dock™

Power Manager

Power Portal

SOLARBRIDGE PANTHEON MICROINVERTER

HIGH RELIABILITY

- SolarBridge™ is designed to match the life expectancy of a typical PV module
- Eliminates failure prone components
- 25 year warranty

MAXIMUM PERFORMANCE

- Distributed MPPT
- 235W input, 225W output
- 95.5% max efficiency

LOWEST LCOE

- Lowest installation costs – comes preinstalled
- 5 – 25% increase in energy harvest
- No inverter replacements
- No single point of failure

SOLARBRIDGE TECHNOLOGIES™

SOLARBRIDGE POWER MANAGER

FLEXIBLE

- Outdoor or indoor mounting location
- Onboard display and two-button interface
- AC or battery power source

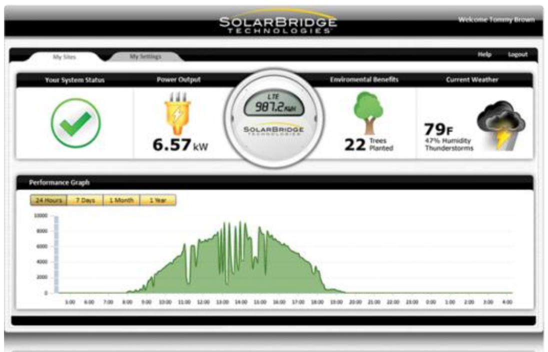
POWERFUL

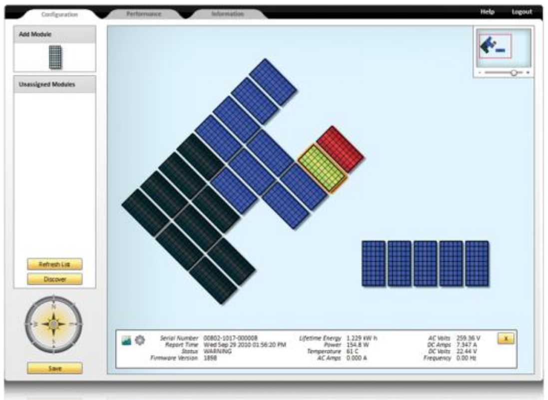
- Wired and wireless communications
- Full-featured site management software

EXPANDABLE

- Smart-grid ready ZigBee networking
- USB expansion port

SOLARBRIDGE POWER PORTAL





SITE DASHBOARDS

- 24/7 web-based access
- Detailed analytics
- Proactive alerts

MODULE CANVAS

- Module-level performance visibility
- Intuitive GUI for site layout

MULTISITE DASHBOARDS

- Portfolio-level indicators of system health

SOLARBRIDGE TECHNOLOGIES

GO-TO-MARKET STRATEGY

- Partnership with PV module manufacturers to develop and distribute an integrated AC module
- Initial focus on residential/small commercial
- Advantages:
  - Utilizes existing sales/distribution channels established by the module manufacturer
  - The SolarBridge™ microinverter will help to differentiate PV modules
  - Revenue/margin expansion for module manufacturer

INTEGRAL ACPV : QUANTITATIVE AND QUALITATIVE ADVANTAGES

- Compelling economics
  - 20 to 30% LCOE reduction
  - Without higher up-front costs
- Highest confidence customer experience
  - Integrated 25 year warranty from a single entity
  - Best system safety
- Net market expansion
  - More sites qualify
  - More companies can do installation

Integral ACPV mandates disruptive innovation :
Unprecedented microinverter reliability for module-compatible service life

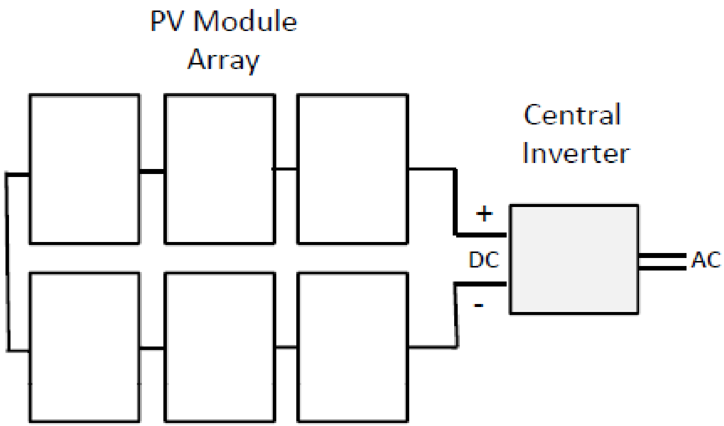
SOLARBRIDGE TECHNOLOGIES

OVERVIEW OF PV SYSTEMS

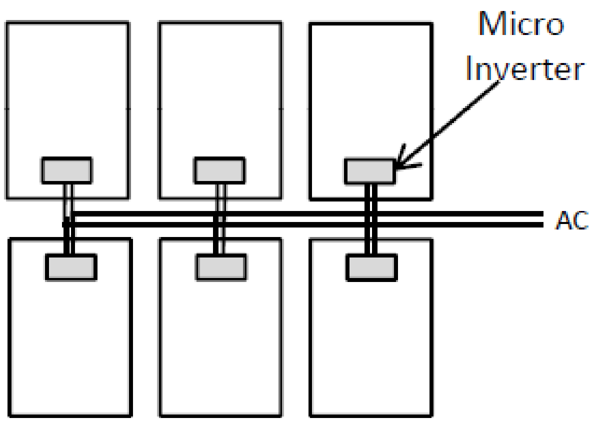
- PV Modules (Panels)
  - Convert solar radiation to DC Power
  - Typically Single Crystal or Polycrystalline Silicon
  - Size: ~3' x 5'
  - Typical Power: 150W – 230W
  - Typical Output Voltage: 20V to 40V
- Inverters
  - Convert PV DC input to grid compatible AC
  - Central inverter: >2.5kW
  - Microinverter: 175W – 230W

SERIES VS. PARALLEL SYSTEMS

- Series (String) Connected
  - 1 Central Inverter
  - High DC Voltage
  - Single Points of Failure

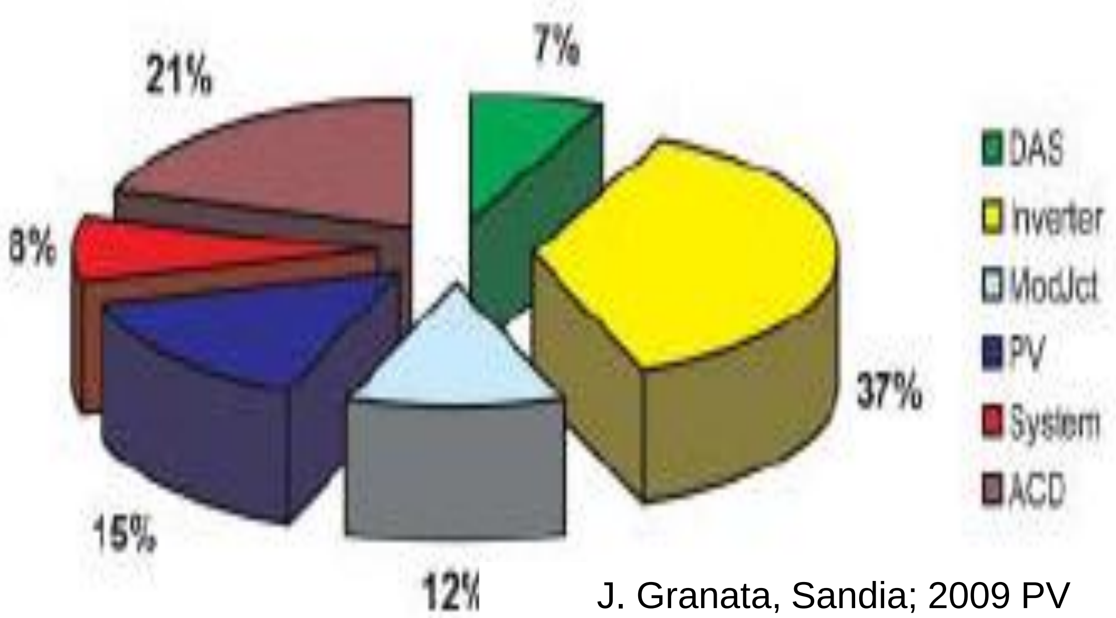


- Parallel Connected
  - 1 Microinverter / module
  - Low DC Voltage
  - No Single Point of Failure



CENTRAL INVERTERS VS. MICROINVERTERS

- Central Inverter
  - 5 - 10 year warranty typical
  - Leading cause of PV system failure



J. Granata, Sandia; 2009 PV Reliability Conference

CENTRAL INVERTERS VS. MICROINVERTERS

- Microinverter
  - Rooftop Installation
  - 15 to 25 year warranty
- System Design Using Microinverters
  - Detached (mounted to PV support infrastructure)
    - Exposed DC cables
  - Integrated (attached to bottom of PV module – ACPV)
    - No exposed DC cables

ADVANTAGE OF MICROINVERTERS OVER CENTRAL INVERTERS

- Reliability – Critical
  - No single point of failure
  - Longer warranty
- Lower DC Voltages, less vulnerable to arcing
- Improved Energy Harvest
  - Optimized Maximum Power Point Tracking (MPPT)
  - Better accommodates shading, module mismatch
- PV Module level monitoring

SOLARBRIDGE TECHNOLOGIES™

SOLARBRIDGE MICROINVERTER RELIABILITY / SAFETY OBJECTIVES

- 25 Year Warranty
  - No wear-out mechanisms during useful life
- 200 FIT max (0.2%/yr, 5M hr MTBF)
  - For 20 module installation, 1 service call in 25 year lifetime
- Safety
  - Risk mitigation for arc faults
  - No exposed DC, capability to remove AC in case of fire (in series PV systems, firefighters cannot disconnect HV DC, presents safety hazard)

SOLARBRIDGE TECHNOLOGIES™

ACHIEVING 25 YEAR WARRANTY

- Understand use Environment
  - Solar Insolation
  - Temperature Distributions
  - Qty/Magnitude Temp Cycles
  - AC Grid Disturbances / Lightning
  - Humidity, Salt, Pollution,…

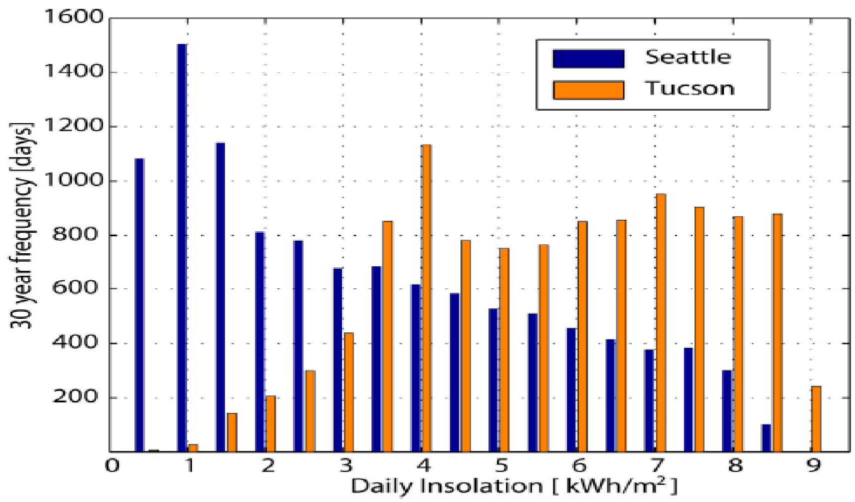
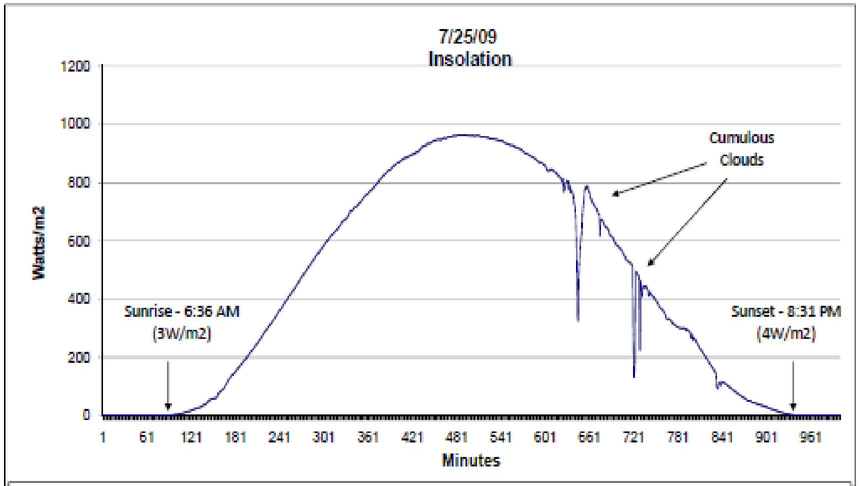
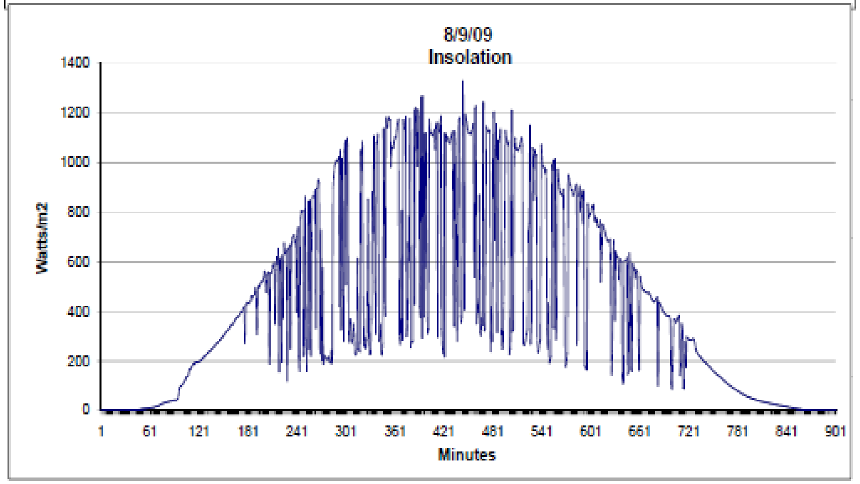


Fig. 2: 30 year histogram of daily insolation.





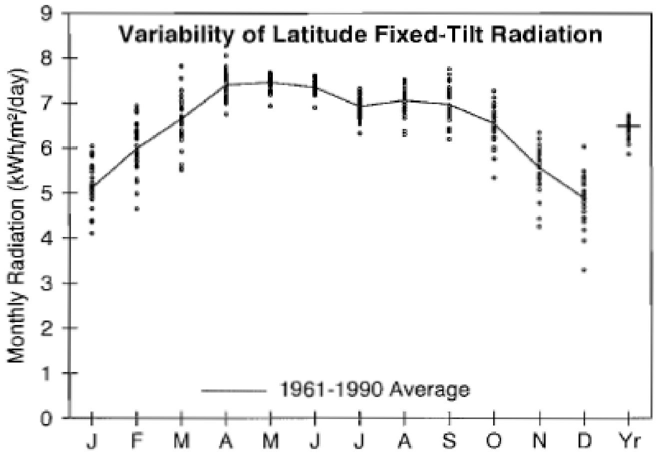
NREL SOLAR IRRADIANCE DATA – PHOENIX, AZ

Phoenix, AZ

WBAN NO. 23183

LATITUDE: 33.43° N
LONGITUDE: 112.02° W
ELEVATION: 339 meters
MEAN PRESSURE: 974 millibars

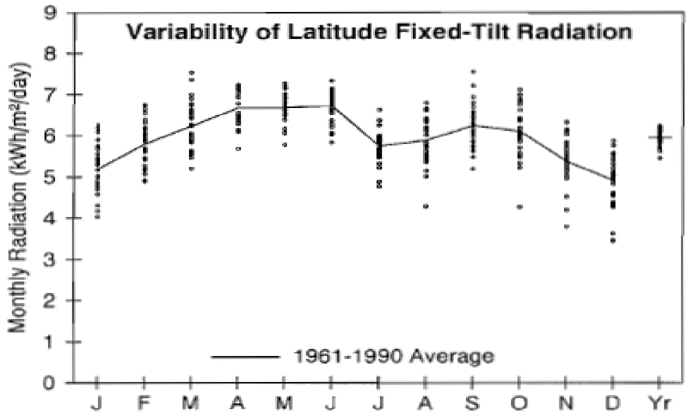
STATION TYPE: Primary



Average Climatic Conditions

Element	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Temperature (°C)	12.0	14.3	16.8	21.1	26.0	31.2	34.2	33.1	29.8	23.6	16.6	12.3	22.6
Daily Minimum Temp	5.1	7.1	9.3	12.9	17.7	22.7	27.2	26.2	22.7	16.0	9.4	5.4	15.2
Daily Maximum Temp	18.8	21.5	24.2	29.2	34.2	39.7	41.1	39.8	36.8	31.2	23.8	19.0	29.9
Record Minimum Temp	-8.3	-5.6	-3.9	0.0	4.4	10.0	16.1	15.6	8.3	1.1	-3.9	-5.6	-8.3
Record Maximum Temp	31.1	33.3	37.8	40.6	45.0	50.0	47.8	46.7	47.8	41.7	33.9	31.1	50.0
HDD, Base 18.3°C	201	126	101	42	4	0	0	0	0	9	74	192	750
CDD, Base 18.3°C	4	12	53	123	242	387	491	457	343	173	23	4	2312
Relative Humidity (%)	51	44	39	28	22	19	32	36	36	37	44	52	37
Wind Speed (m/s)	2.5	2.8	3.2	3.4	3.4	3.2	3.4	3.2	3.0	2.8	2.6	2.5	3.0

NREL SOLAR IRRADIANCE DATA – FLAGSTAFF, AZ



Flagstaff, AZ

WBAN NO. 03103

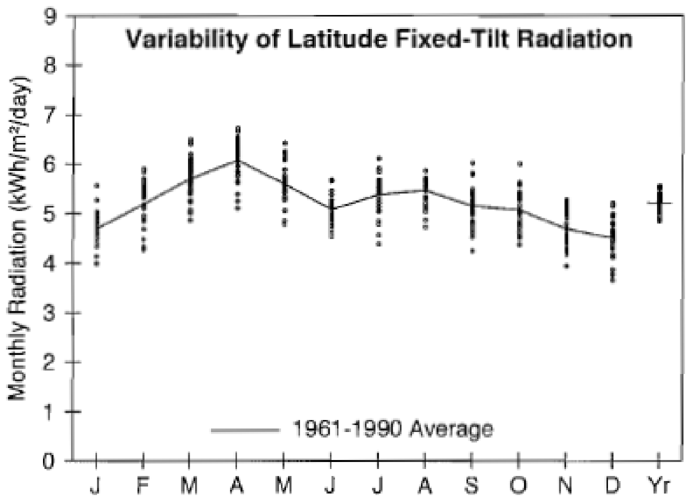
LATITUDE: 35.13° N
LONGITUDE: 111.67° W
ELEVATION: 2135 meters
MEAN PRESSURE: 788 millibars

STATION TYPE: Secondary

Average Climatic Conditions

Element	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Temperature (°C)	-1.8	-0.3	1.8	5.7	10.2	15.4	19.1	17.8	14.1	8.4	2.7	-1.3	7.7
Daily Minimum Temp	-9.3	-7.9	-5.9	-2.9	0.7	5.2	10.3	9.4	5.1	-0.6	-5.3	-9.0	-0.8
Daily Maximum Temp	5.7	7.4	9.6	14.3	19.7	25.7	27.7	26.3	22.9	17.4	10.6	6.3	16.1
Record Minimum Temp	-30.0	-30.6	-26.7	-18.9	-10.0	-5.6	0.0	-4.4	-5.0	-18.9	-25.0	-30.6	-30.6
Record Maximum Temp	18.9	21.7	22.8	26.7	30.6	35.6	36.1	33.3	32.2	29.4	23.3	20.0	36.1
HDD, Base 18.3°C	625	521	512	378	252	104	16	36	132	307	470	609	3962
CDD, Base 18.3°C	0	0	0	0	0	17	39	21	3	0	0	0	81
Relative Humidity (%)	62	60	56	47	40	33	51	58	55	53	57	61	53
Wind Speed (m/s)	2.9	2.8	3.1	3.3	3.2	3.0	2.3	2.0	2.3	2.4	2.8	2.6	2.7

NREL SOLAR IRRADIANCE DATA – MIAMI, FL



Miami, FL

WBAN NO. 12839

LATITUDE: 25.80° N
LONGITUDE: 80.27° W
ELEVATION: 2 meters
MEAN PRESSURE: 1017 millibars

STATION TYPE: Primary

Average Climatic Conditions

Element	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Temperature (°C)	19.6	20.3	22.1	24.0	25.9	27.4	28.1	28.2	27.7	25.7	23.1	20.6	24.4
Daily Minimum Temp	15.1	15.8	17.9	19.9	22.3	23.9	24.6	24.8	24.4	22.3	19.3	16.4	20.6
Daily Maximum Temp	24.0	24.7	26.2	28.0	29.6	30.9	31.7	31.7	31.0	29.2	26.9	24.8	28.2
Record Minimum Temp	-1.1	0.0	0.0	7.8	11.7	15.6	20.6	20.0	20.0	10.6	3.9	-1.1	-1.1
Record Maximum Temp	31.1	31.7	33.3	35.6	35.0	36.7	36.7	36.7	36.1	35.0	31.7	30.6	36.7
HDD, Base 18.3°C	49	28	8	0	0	0	0	0	0	0	3	23	111
CDD, Base 18.3°C	87	83	123	170	236	273	303	307	282	229	147	93	2332
Relative Humidity (%)	73	71	69	67	72	76	75	76	78	75	74	72	73
Wind Speed (m/s)	4.3	4.7	4.9	4.8	4.4	3.8	3.7	3.7	3.8	4.4	4.5	4.3	4.2

ACHIEVING 25 YEAR WARRANTY

- Eliminate known high failure rate components / wear-out mechanisms / De-rate
  - Electrolytic Capacitors (E-Caps)
    - Electrolyte vaporization
    - Major industry field recalls due to poor quality
  - Optoisolators
    - Current Transfer Ratio (CTR) Degradation
  - Non compliant solder joints
    - BGA
    - Large Ceramic body parts
  - Corrosion
    - Salt, industrial pollution
  - MOV / fuses
    - Limit to number of high energy transient discharges

ELECTROLYTIC VS. FILM CAPACITOR LIFETIME

- Using Industry accepted reliability models and fixed temperature, Film caps have >10x longer lifetime than Electrolytic Capacitors

Capacitor Description	End of Life Failure Criteria	$T_{operating}$ (Cap Core)	
		60°C	70°C
5000 Hour, 105C Rated Electrolytic Capacitor	20% drop in Capacitance or doubling ESR	8 Years	4 Years
10000 Hour, 105C Rated Electrolytic Capacitor	20% drop in Capacitance or doubling ESR	16	8
SolarBridge Film Capacitor	5% drop in Capacitance	136	68

Voltage derating = 80% in all cases

Device	BellCore	CNET	HRD4	M217	Siemens
Aluminum Electrolytic Capacitor	210	22	120	16	120
Film Capacitor	17	4	6	1	14
FIT Ratio E-Cap / Film	12.4	5.5	20.0	16.0	8.6

Using 120 FIT electrolytic, five capacitors in a system leads to 600 FITs or 0.5% E-cap failures/yr
Using 6 FIT film cap, five capacitors in a system leads to 30 FITs or 0.03% film cap failures /yr

* Jones, et.al, “A Comparison of Electronic Reliability Prediction Methods”, IEEE Trans. on Reliability, June 1999, p 127 – 143.

ACHIEVING 200 FIT RELIABILITY

- Design For Reliability
  - Component de-rating
  - Proven component technology
  - Careful vendor selection / management
- Outdoor Testing
- Accelerated Testing
- Manufacturing Yield Management
- Closed Loop Feedback

RELIABILITY TEST STRATEGY

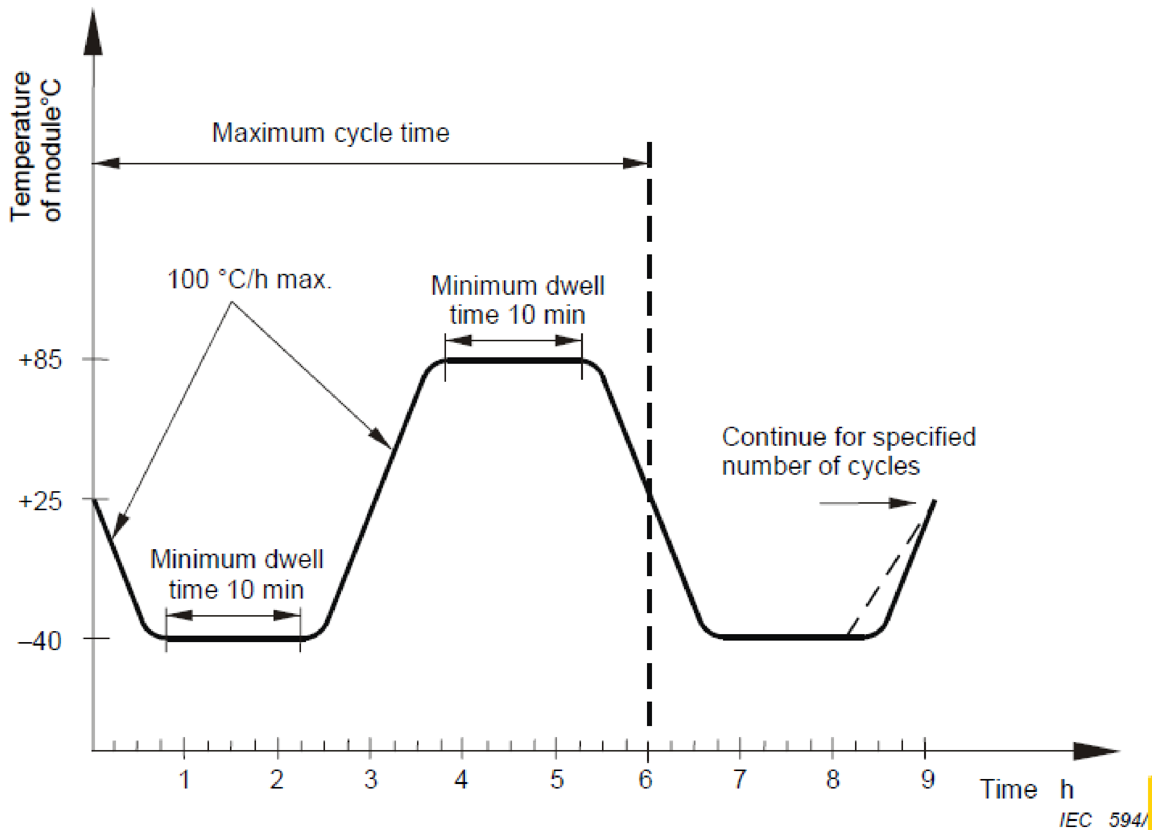
- No standards currently available which focus on PV Microinverter Reliability
- Custom tests
  - Component level accelerated testing
  - HALT/HASS
- UL1741 Standard for Safety– *PV inverters*
- UL1703 / IEC61215 Standard for Safety– *Flat Plate Photovoltaic Modules and Panels*
  - Designed to apply to PV modules only
  - Integrated Microinverter must pass UL1703
  - Contains combinations of Regulatory and Reliability tests
- IPC-9592 - *Requirements for Power Conversion Devices for the Computer and Telecommunications Industries*
  - Does not cover Inverters
  - Does not apply to typical PV use environment

UL 1703 GENERAL REGULATORY COMPLIANCE TEST REQUIREMENTS

- Temperature
- Leakage Current
- Cable Strain Relief
- Mechanical Loading Test
- Dielectric Withstand
- Wet Insulation Resistance
- Impact Test
- Fire Test
- Water Spray

THERMAL CYCLE

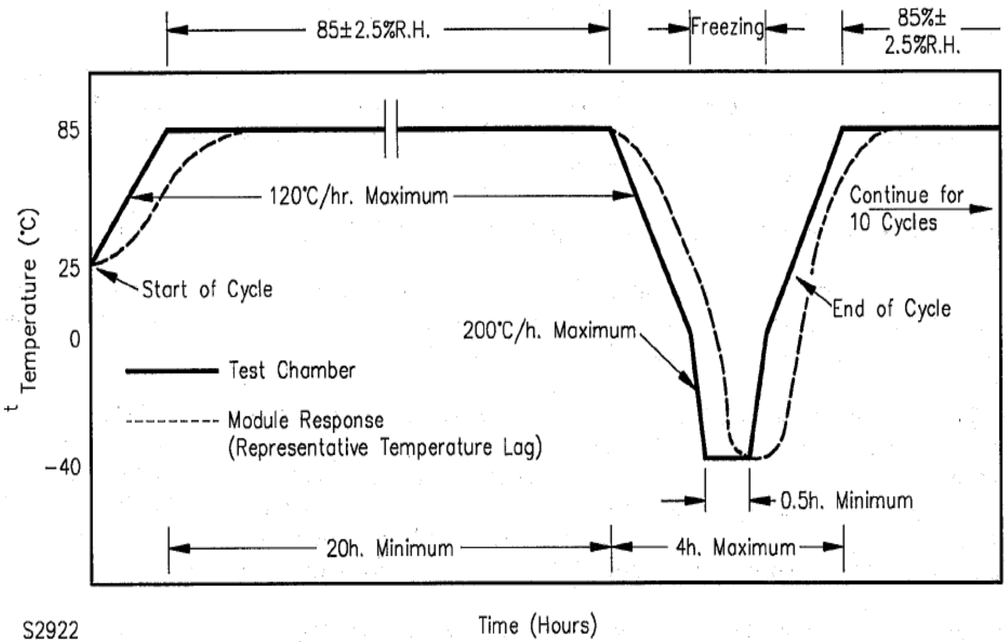
- Unpowered / Static Continuity Monitoring
- Sample Size = 3
- Delta T = 125° C
- Ramp = 2° C/min
- 200 cycles
- 1200 hours



HUMIDITY FREEZE

- Unpowered
- Sample Size = 3
- Delta T = 125° C
- RH = 85% @ 85° C
- Ramp = 3° C/min
- 10 cycles
- 240 hours

Figure 36.1
Humidity-freezing cycle test



WEAKNESS OF TESTING TO EXISTING STANDARDS

- No correlation to actual field use conditions, no accelerated test models applied
  - Solution: Perform separate highly accelerated tests for specific failure mechanisms, model according to industry best practices
- Weak on Shock & Vibration
  - Solution: Apply methods from IPC-9592 / IEC 60068-2
- Weak on AC Line Disturbances
  - Solution: Apply methods from IPC-9592 / IEC 61000-4

SOLARBRIDGE TECHNOLOGIES™

CONCLUSION

- PV Microinverters provide an innovative solution to existing challenges in Residential and Small Commercial Solar applications
- High reliability is key to the success of Microinverter technology
- Currently no test standards available which adequately demonstrate Microinverter reliability

SOLARBRIDGE TECHNOLOGIES