APPLICATION OF ACCELERATED TESTING AND MODELING TO RELIABILITY ANALYSIS OF MICROINVERTERS

T. Paul Parker – SolarBridge Technologies

NREL PV Module Reliability Workshop

February, 2014

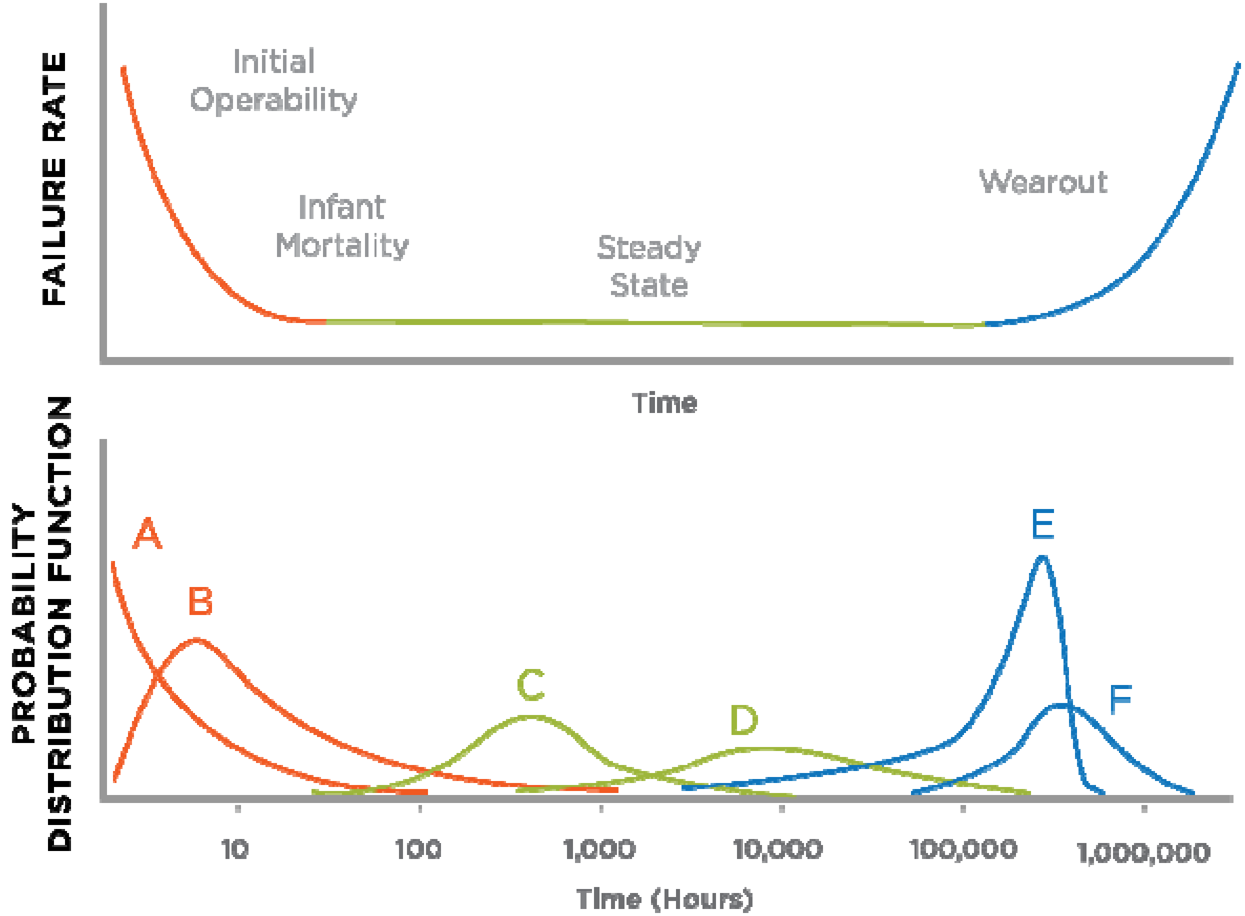
OUTLINE

- Predicting Microinverter Lifetime
- Design Parameters / Field Use Conditions
- Phoenix AZ Case Study
- Reliability Modeling
- Validation using Accelerated Testing

SOLARBRIDGE TECHNOLOGIES™

Predicting Microinverter Lifetime

BATHTUB CURVE AND TYPICAL FAILURE MECHANISMS FOR POWER PRODUCTS



Infant Mortality:

A. Weak Solder Joints

B. Cracked Ceramic Capacitor

Steady State:

C. FET Single Event Burnout

D. Corrosion

Wearout:

E. Electrolytic Capacitor Degradation

F. Non Compliant Solder Joints (BGA,etc.)

PREDICTING PV MICROINVERTER (MI) LIFETIME

- No generic reliability models for Power Electronics Reliability
- Traditional MTBF models (MIL-217, Telcordia SR332, etc)
  - Not applicable to predicting useful life
  - Marginal effectiveness predicting steady state failure mechanisms
- Each MI component has a unique set of failure mechanisms
  - Intrinsic mechanisms limit the lifetime of an inverter
    - 100% of units produced are at risk
    - Cumulative failure of >1% for a given wearout mechanism considered end of life
  - Extrinsic mechanisms are often due to quality excursions of component suppliers or contract manufacturer
    - Small populations at risk, (typically <0.1%)
    - Typical Annualized Failure Rate (AFR) <0.2% for all failure mechanisms

SOLARBRIDGE TECHNOLOGIES

LIFETIME PREDICTION AND TEST VALIDATION

- Step 1: Review all known intrinsic wearout mechanisms
  - Solder joint fatigue, Film / Electrolytic capacitance reduction, PCB via fatigue, Time Dependent Dielectric Breakdown, etc,
- Step 2: Define failure
  - Solder Joint – hard failure or measurable loss of energy harvest
- Step 3: Measure field stresses associated with failure mechanism
  - Solder joint
    - Minimum and maximum temperature
    - Diurnal Δ temperature
    - Ramp rate and dwell times
- Step 4: Identify appropriate solder joint reliability model
- Step 5: Perform accelerated test to validate model

SOLARBRIDGE TECHNOLOGIES™

Design Parameters / Field Use Conditions

DESIGN PARAMETERS / FIELD USE CONDITIONS

- Inverter Electrical Parameters
  - Power dissipation = f(insolation, efficiency, module power)
  - Component Temperature (min, max, ΔT) =
    f(power, ambient temperature, wind velocity, module rooftop gap)
- Material parameters (PCB, solder, components, chassis, potting, etc.)
  - CTE, hardness, Young's modulus, Tg, etc.
- Environmental conditions
  - Ambient Temperature
  - Wind velocity (affects internal component temperature)
  - Relative Humidity
  - Insolation

SOURCES OF DATA

- Inverter reported parameters
  - Voltage, current, power, component voltage / temperature

Date / Time	dc_volts	dc_amps	dc_watts	ac_volts	ac_watts	vbus max	vbus min	vbus avg	FET temp	lte
6/15/2013 6:50	27.99	0.22	6.1	233.17	3.9	376	368	373	10	3354
6/15/2013 6:55	27.69	0.26	7.2	232.72	5	376	368	372	12	3354
6/15/2013 7:05	27.95	0.26	7.5	232.72	5.3	377	369	372	12	3355
6/15/2013 7:10	27.45	0.29	8	232.72	5.7	377	369	373	13	3355
				.						
				.						
				.						
6/15/2013 13:30	26.54	7.81	209.7	248.76	200.5	459	362	400	49	3977
6/15/2013 13:35	25.86	7.82	204.8	246.27	195.8	438	375	416	50	3993
6/15/2013 13:40	25.66	7.92	205.9	249.21	196.9	439	380	422	50	4009
6/15/2013 13:50	26.1	1.77	46.8	234.98	43.3	442	367	389	49	4020
6/15/2013 13:50	26.68	8.68	234.6	249.66	224.5	443	367	405	48	4032
6/15/2013 13:55	18.11	5.7	105.8	241.75	100.2	444	369	386	49	4041
6/15/2013 14:00	26.92	8.9	242.2	251.24	231.9	451	366	429	48	4049
6/15/2013 14:10	26.54	7.92	212.9	249.21	203.5	444	368	408	48	4071
6/15/2013 14:15	26.04	8.54	225.1	249.66	215.3	441	367	420	48	4085
6/15/2013 14:20	21.27	6.82	147.3	245.59	140.3	445	367	386	46	4093
6/15/2013 14:25	26.7	2.02	54.6	235.65	50.8	448	370	386	46	4104
6/15/2013 14:30	26.82	8.15	221.2	249.89	211.6	447	369	405	46	4117

REGIONAL ENVIRONMENTAL DATA

- NREL Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors, Report NREL/TP--463-5607, 1994

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

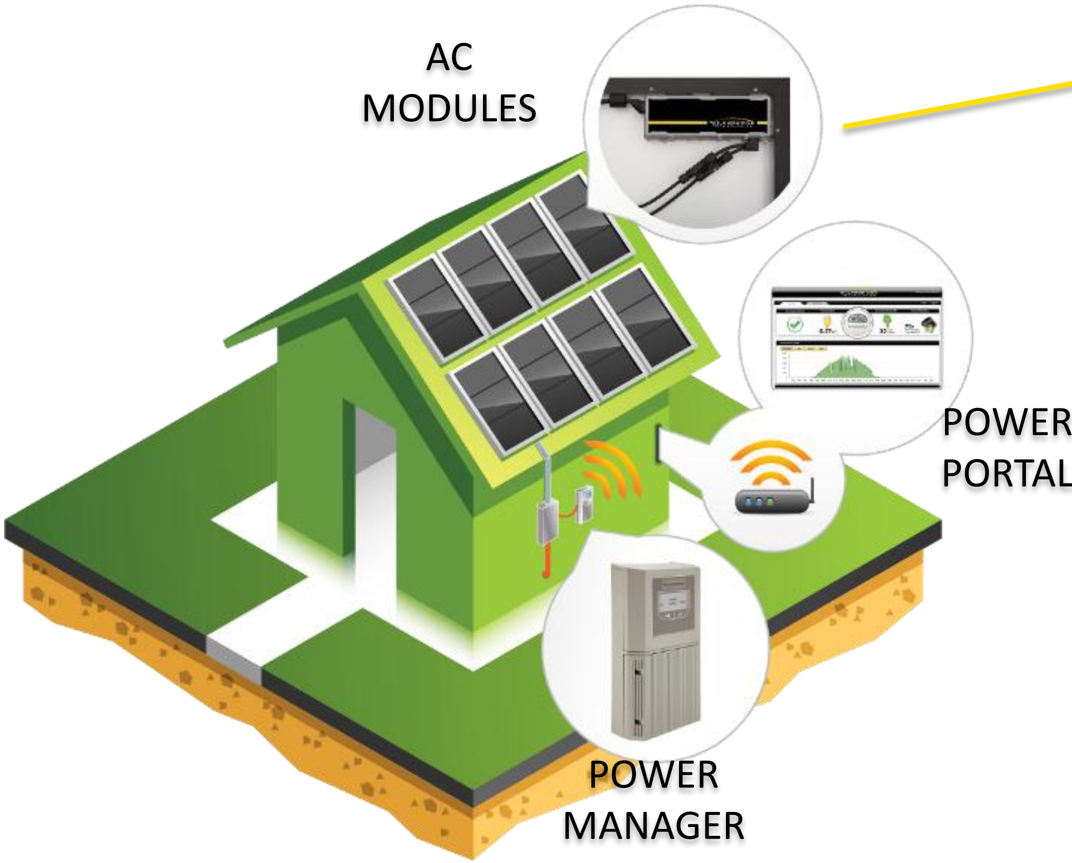
- Atlas Material Testing Technology LLC

Date	Time	Ambient	%RH	Wind Speed M/sec	Wind Direction	Rainfall CM	5° TTL Solar W/m²	5° UV Solar W/m²	34° Total Solar W/m²	34° UV Solar W/m²
6/12/2013	16:44	42	9	4.37	206	0	502	24	406	18
6/12/2013	16:45	41	9	4.86	202	0	497	24	401	18
6/12/2013	16:46	41	10	3.87	225	0	496	24	399	18
6/12/2013	16:47	42	9	2.75	224	0	492	24	395	18
6/12/2013	16:48	41	9	4.51	264	0	488	23	391	18
6/12/2013	16:49	41	9	3.70	244	0	484	23	387	18
6/12/2013	16:50	42	10	2.89	238	0	481	23	384	17

SOLARBRIDGE TECHNOLOGIES

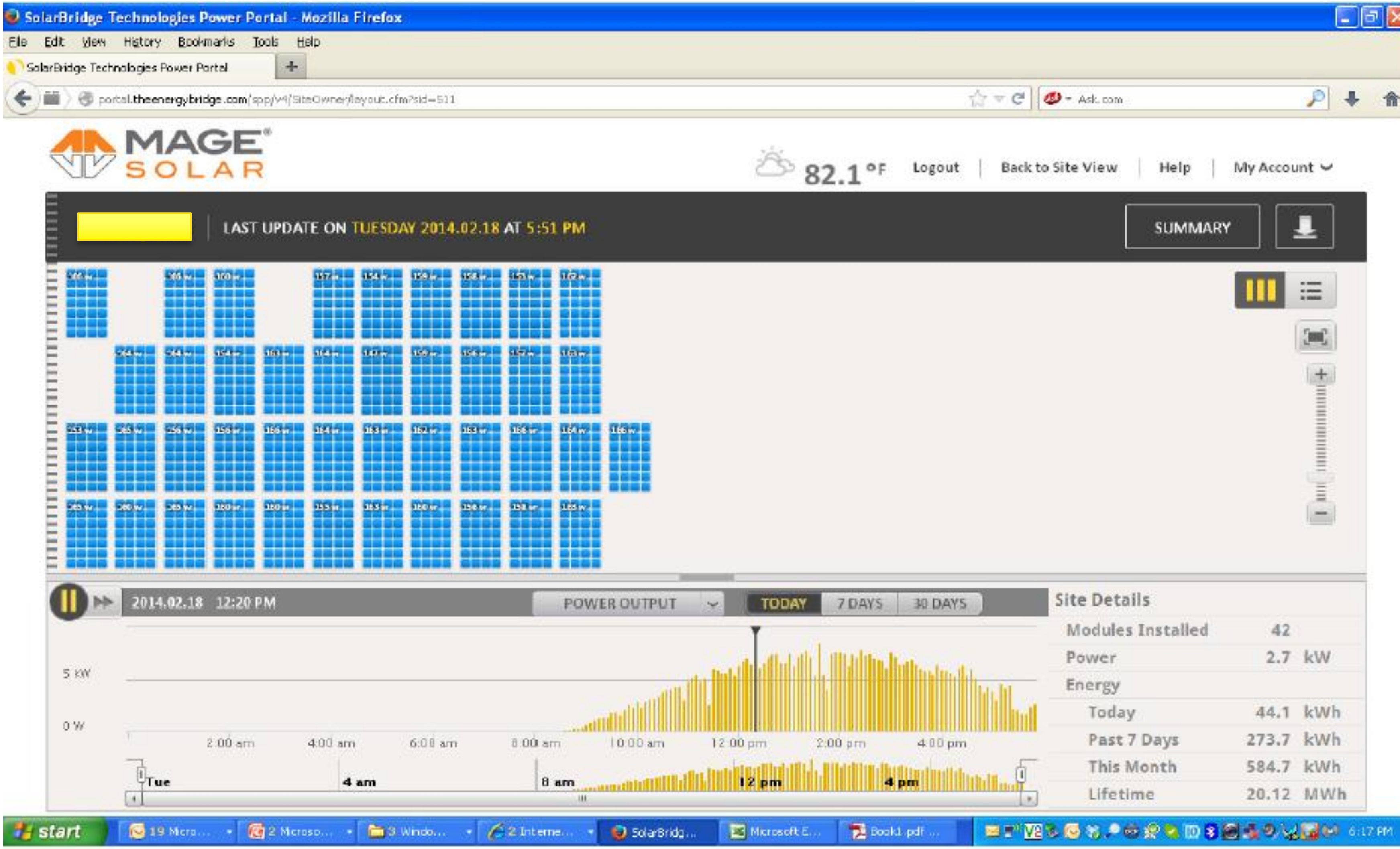
Phoenix AZ Case Study - SolarBridge Microinverter

SOLARBRIDGE AC MODULE

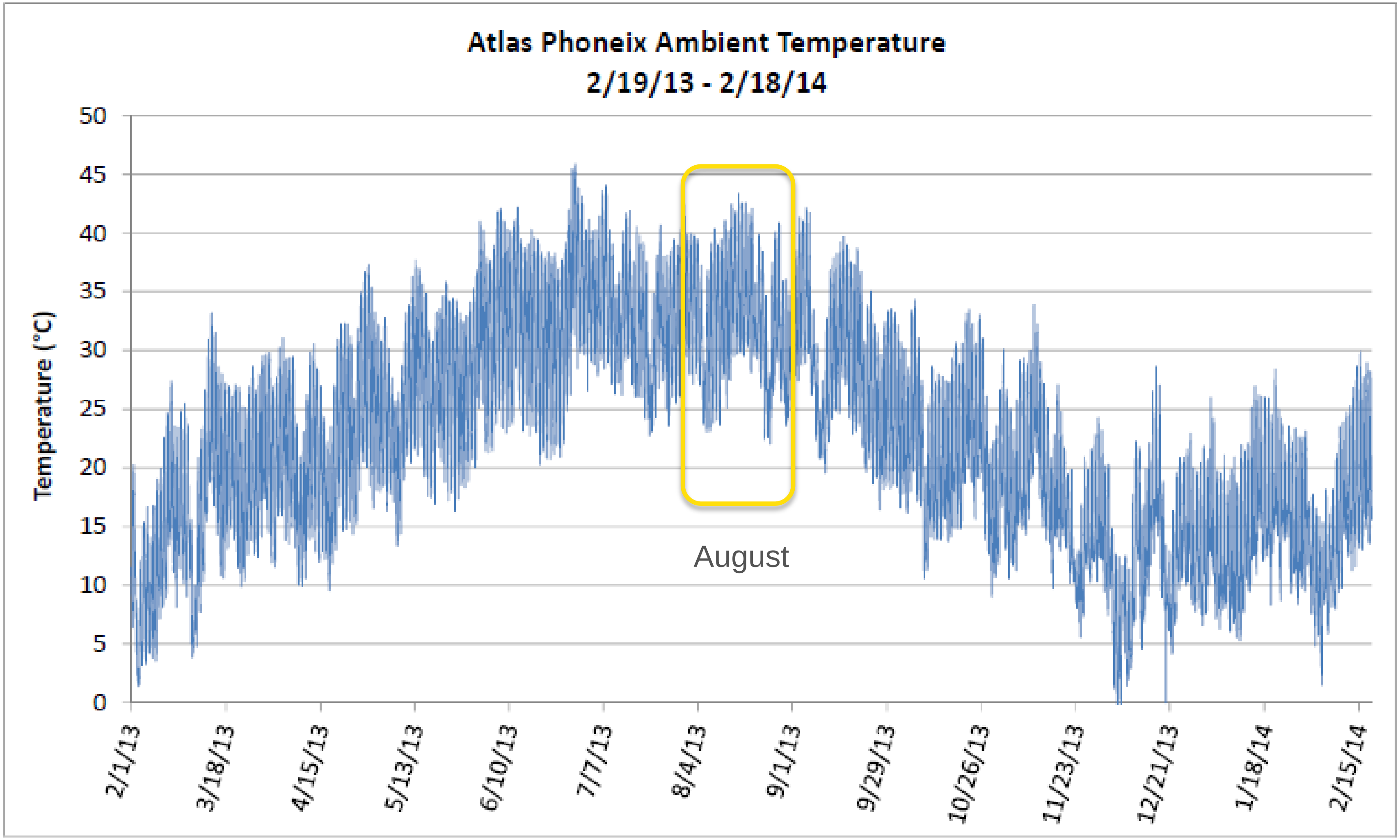


PHOENIX AZ
42 MODULE ACPV INSTALLATION

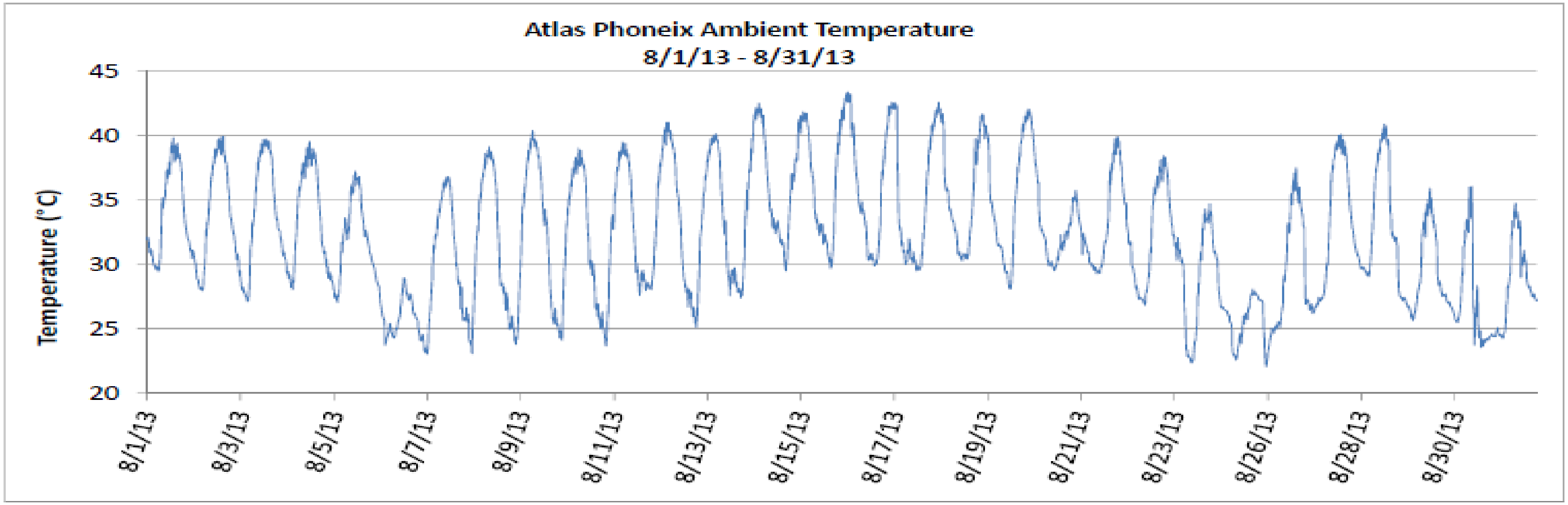
SOLARBRIDGE POWER PORTAL VIEW

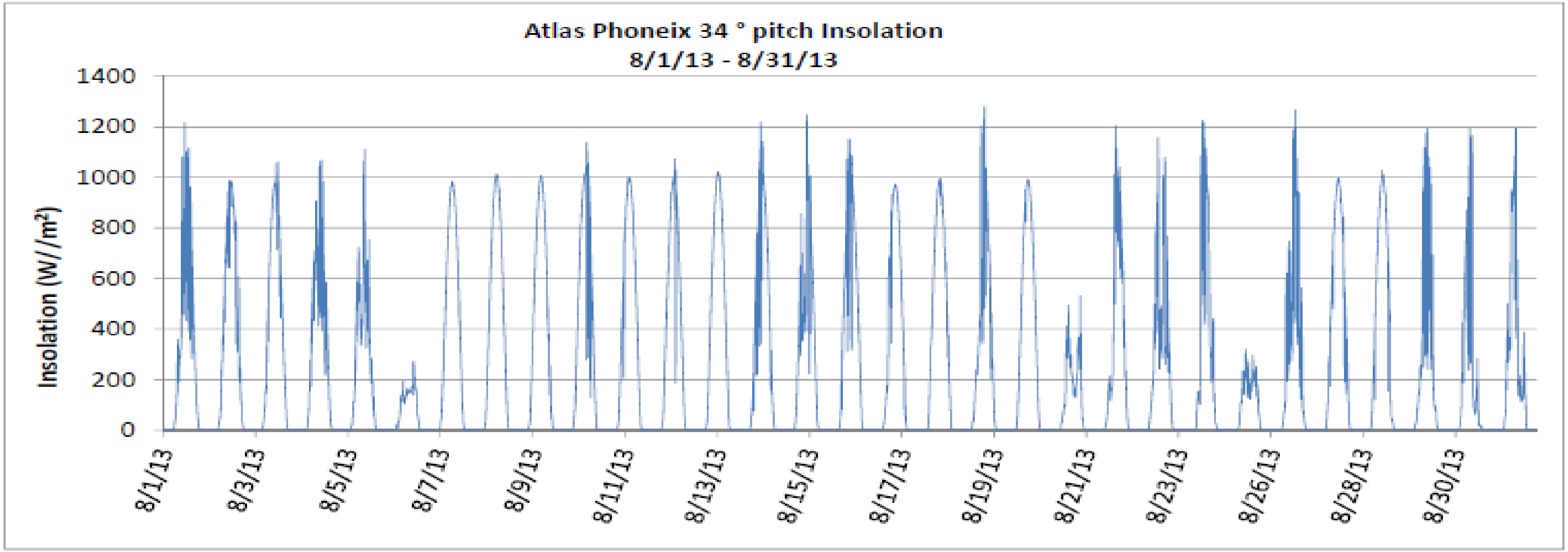


FULL YEAR PHOENIX AZ AMBIENT TEMPERATURE
5 MINUTE SAMPLE INTERVAL (SOURCE – ATLAS)

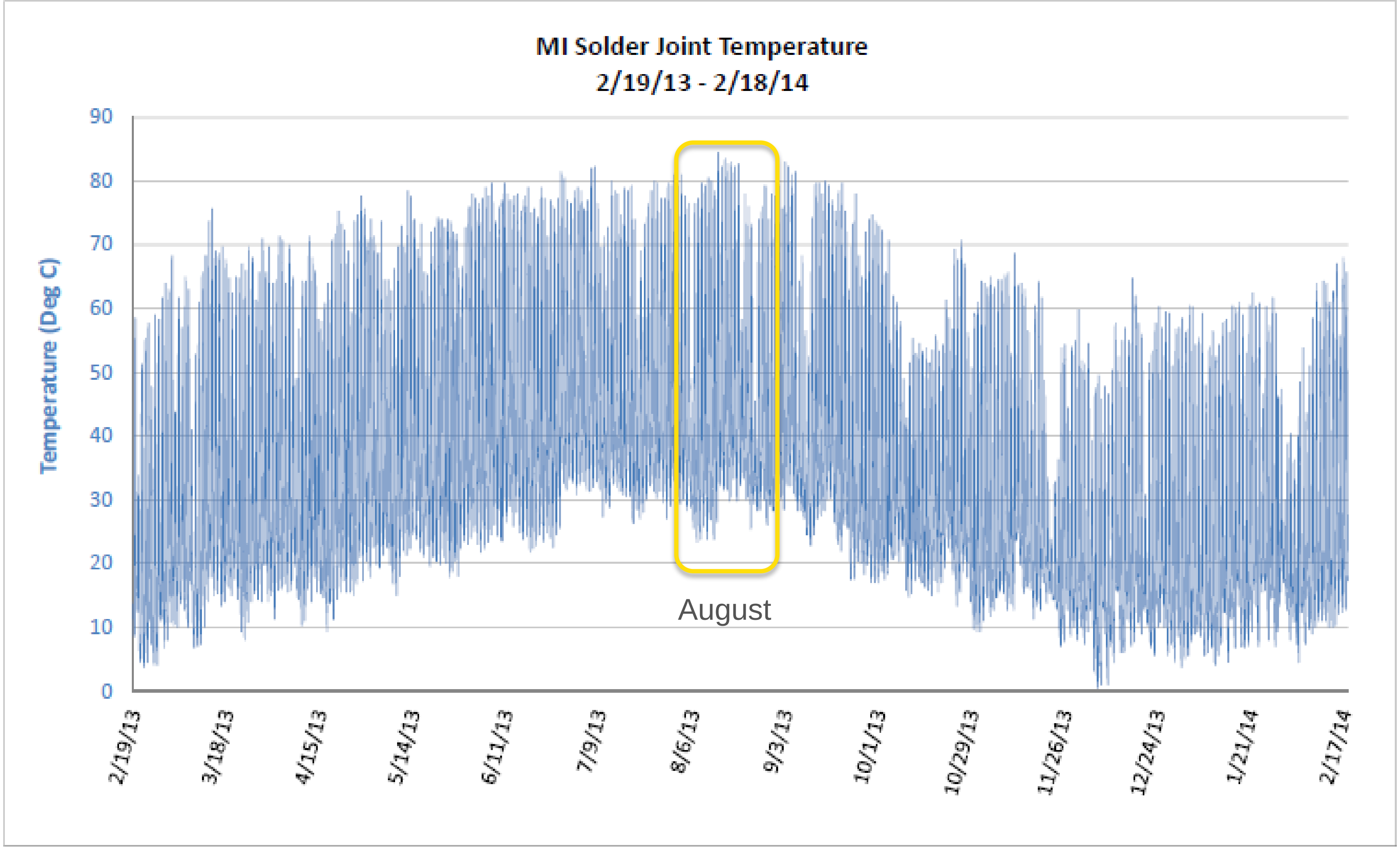


AUGUST '13 AMBIENT TEMP / INSOLATION



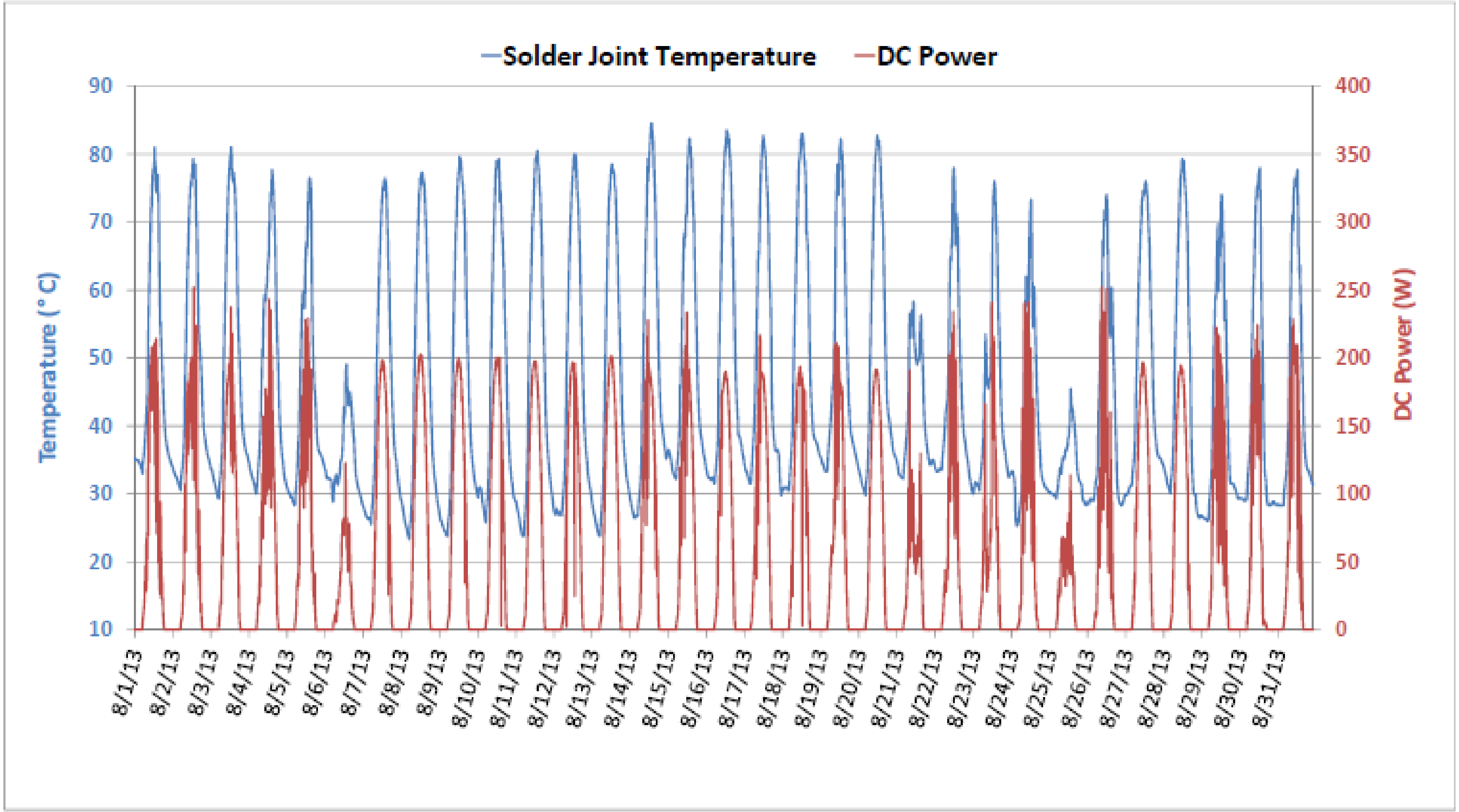


FULL YEAR SOLDER JOINT TEMPERATURE
5 MINUTE SAMPLE INTERVAL

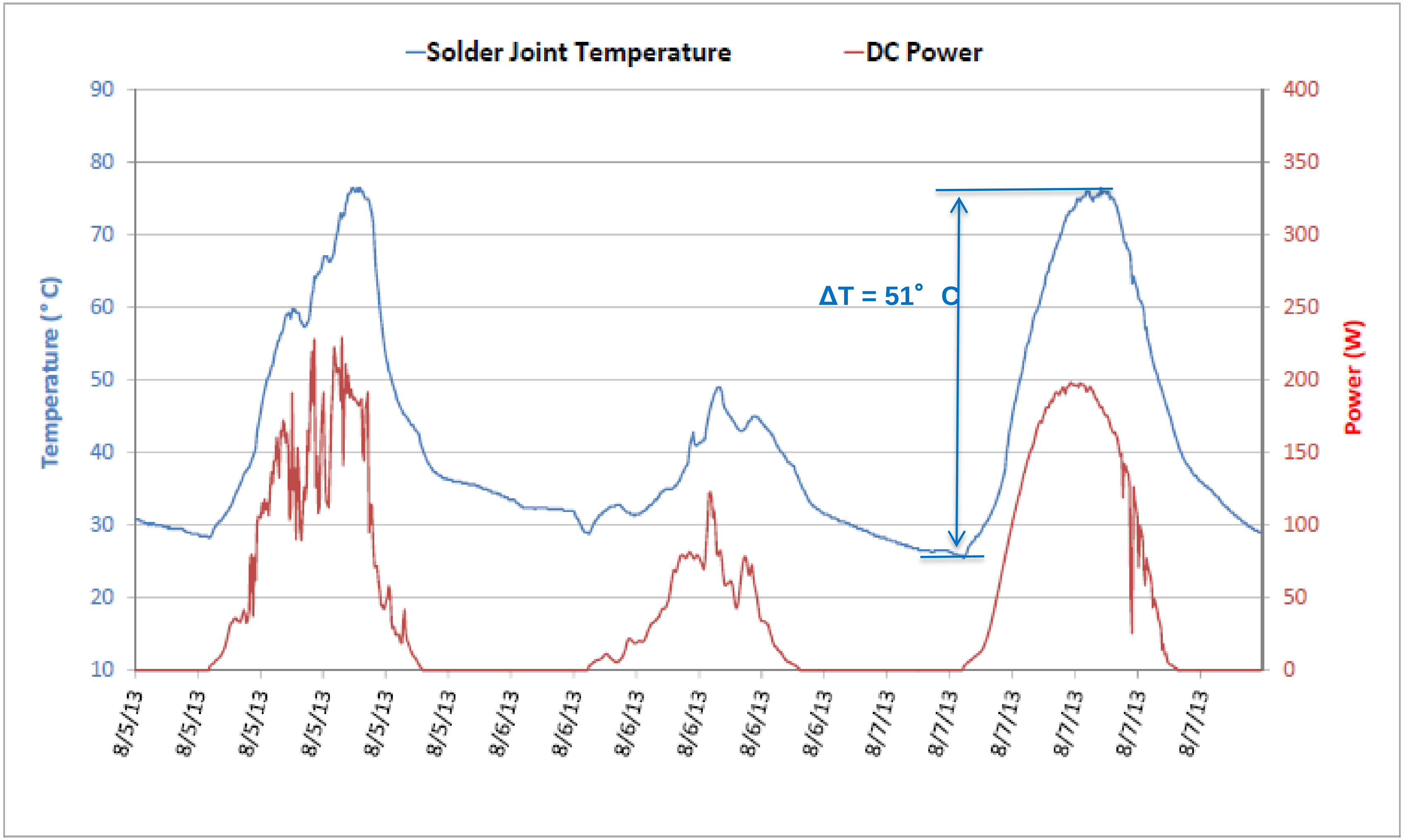


SOLARBRIDGE TECHNOLOGIES

AUGUST '13 MI DC POWER / COMPONENT TEMPERATURE

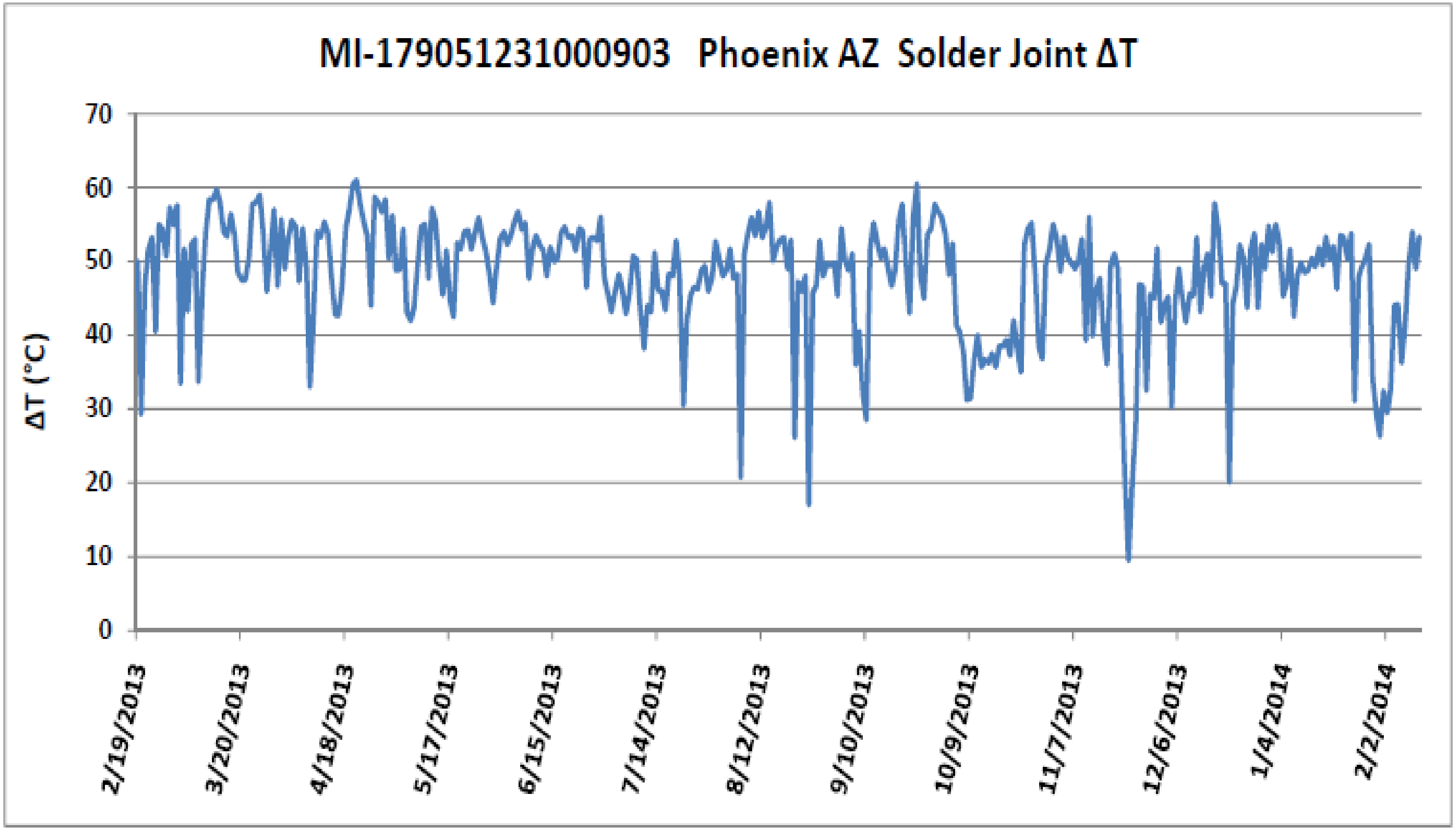


DAILY POWER / TEMPERATURE FLUCTUATION



SOLARBRIDGE TECHNOLOGIES

DAILY SOLDER JOINT ΔT
2/19/13 – 2/18/14



MONTHLY AVERAGE SOLDER JOINT ΔT

Month	Average MIN	Average MAX	Average Delta
Feb '13	5.9	54.7	48.8
Mar '13	12.4	64.4	52.0
Apr '13	15.1	67.2	52.1
May '13	20.5	71.0	50.5
Jun '13	24.9	77.2	52.3
Jul '13	30.3	76.5	46.2
Aug '13	28.3	76.4	48.0
Sep '13	24.8	74.1	49.4
Oct '13	17.1	59.3	42.2
Nov '13	12.9	56.1	43.2
Dec '13	6.9	53.4	46.5
Jan '14	8.5	56.1	47.6
Feb '14	8.9	51.3	42.4
Average	**16.7**	**64.4**	**47.8**

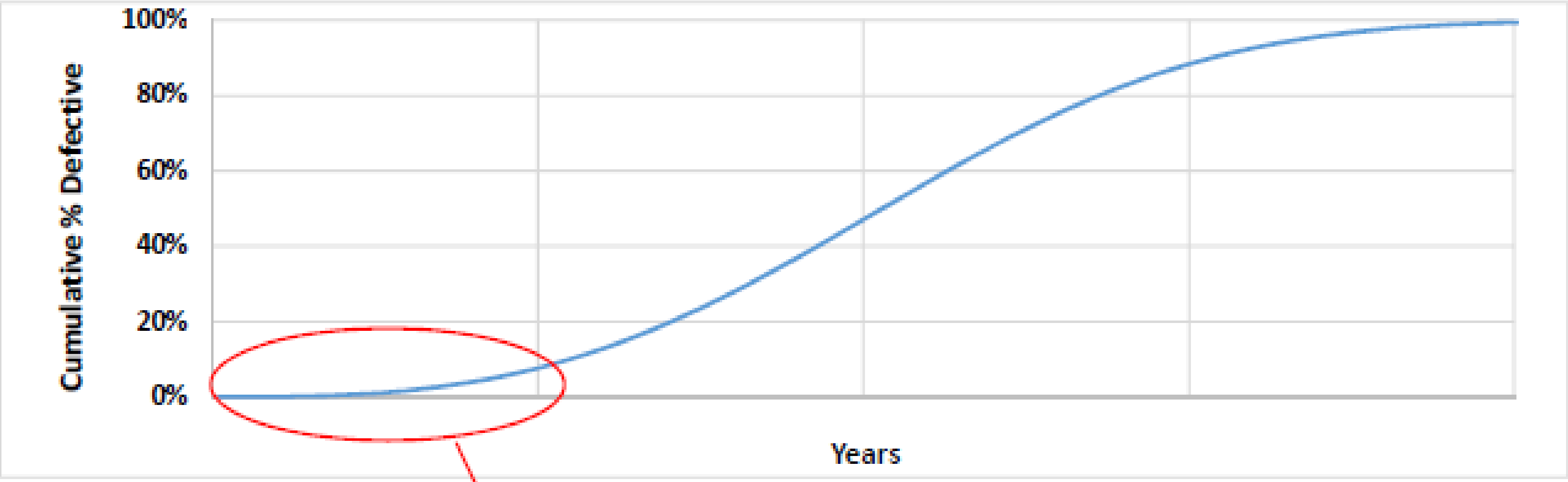
Solder Joint Reliability Modeling

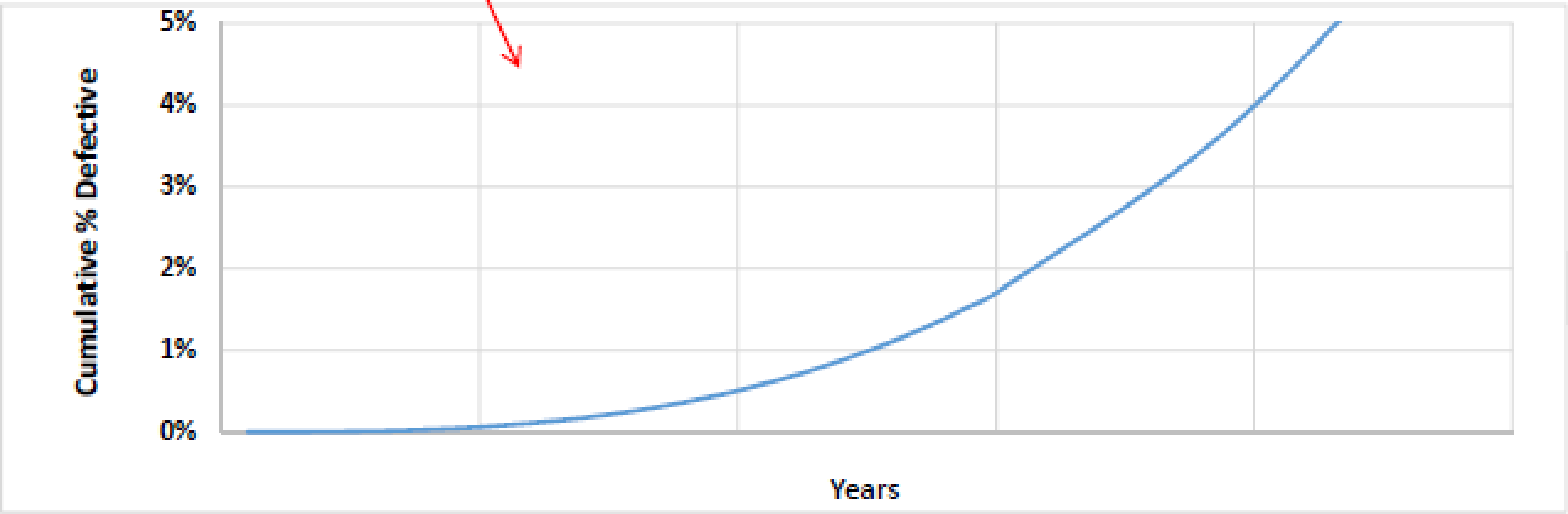
LIFETIME PREDICTION AND TEST VALIDATION

- Step 4: Identify appropriate solder joint reliability model
  - Norris Landzberg
    - N Pan, et.al, “An Acceleration Model for Sn-Ag-Cu Solder Joint Reliability Under Various Thermal Cycle Conditions”, SMTA International, 2005.
  - ANSYS Finite Element Analysis
    - B. Zahn, “Impact of Ball Via Configurations on Solder Joint Reliability in Tape-Based CSP”, ECTC, 2002
  - Cumulative Strain Energy Damage
    - N. Blattau, C. Hillman, “An Engelmaier Model for Leadless Ceramic Chip Devices with Pb-free Solder”, IPC/JEDEC Lead Free Conference, 2006.
  - DfR Solutions Sherlock
    - R. Schueller, C. Tulkoff, “Automated Design Analysis: Comprehensive Modeling of Circuit Card Assemblies, APEX, 2011

SOLARBRIDGE TECHNOLOGIES

SOLDER JOINT FAILURE DISTRIBUTION





Validation Using Accelerated Testing

ACCELERATED TESTING

- Necessary for detection of intrinsic failure mechanisms in a short amount of time
- Requirements:
  - Powering and monitoring to detect intermittents
  - Multiple test environments
    - Thermal cycle
    - High temperature
    - Temperature Humidity
    - Salt Fog
    - Random Vibration
- Requires testing beyond specification
  - Risk of false failures

IEC 62093* PV INVERTER BOS / ENVIRONMENTAL TEST STANDARD

- Thermal Cycle (TC)
  - -40° C to 85° C
  - Purpose: identifies mechanisms related to thermal mechanical cyclic fatigue such as solder joints and PCB vias
  - Acceleration factor 10x – 30x typical
- Highly Accelerated Life Test (HALT)
- High Temperature Operating Bias (HTOB)
- Damp Heat (DH)
- Humidity Freeze (HF)
- Salt Mist
- UV

Notes:
-UL 1741 / IEC 62109 do not have accelerated test requirement,
they address safety only
-Acceleration factors **must** be developed for each failure mechanism;
-Recommend Weibull analysis using multiple stress conditions

SUMMARY

- Confirmation of useful life requires an understanding of all potential intrinsic wearout mechanisms
- Each failure mechanism requires
  - An understanding of physics of failure
  - Appropriate model capable of predicting time to failure
  - Field use conditions
  - Accelerated test method to speed time to detect failure
  - Acceleration factors to predict time to failure
  - Actual field reliability data to validate model and test