Standardization and Reliability Testing of Module-Level Power Electronics (MLPE)

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Outline

- Development of qualification standard for MLPE
- FMEA survey on MLPE failures
- Reliability evaluation of 17-year old AC modules
- Summary

Development of qualification standard for MLPE

ANSI/TUV-R 71830

Microinverters and Microconverters – Design Qualification and Type Approval

Potential References:

- IEC 61215: Crystalline silicon terrestrial photovoltaic (PV) modules – Design qualification and type approval
- IEC 61646: Thin-film terrestrial photovoltaic (PV) modules - Design qualification and type approval
- IEC 62093: Balance-of-system components for photovoltaic systems - Design qualification natural environments
- ECN-C-04-032: Design qualification of inverters for grid-connected operation of photovoltaic power generators
- TUV-2PfG 2305: Test program for junction boxes with active electronics
- California Energy Commission (CEC) List of Eligible Inverters per SB1 Guidelines
  http://www.gosolarcalifornia.ca.gov/equipment/documents/Sandia_Guideline_2005.pdf
- IEC 61683: Photovoltaic systems - Power conditioners - Procedure for measuring efficiency
- UL 1741: Standard for Inverters, Converters, Controllers and Interconnection Systems for use with Distributed Energy Resources

[The profiles of stress tests for MLPE qualification test standard need to be adjusted - without compromising the intent of the standard - to match the qualification and safety standards of modules and inverters (IEC 61215/61746, UL 1741, IEC 61730 & UL 1703) so they can be combined to reduce the testing cost and time]

Qualification Testing: What it is and isn't

What it is

- Qualification test standard complements the safety standard but not a safety standard
- Qualification tests are a set of well defined accelerated stress tests
- They utilize accelerated stress tests to duplicate failure modes observed in the field
- They incorporate strict pass/fail criteria
- The stress levels and durations are limited so the tests can be completed within a reasonable amount of time and cost
- The goal for qualification testing is that a significant number of commercial products will pass (If not there will be no commercial market.)
- Qualifies the design and helps to eliminate infant mortality (later we will look at the bathtub curve)

The Qualification testing is performed to qualify the design and packaging of a product. It provides a baseline for subsequent acceptance testing, comparative testing and lifetime prediction testing. In other words, qualification testing is the minimum requirement before initiating acceptance testing, comparative testing and lifetime testing. The qualification testing is typically completed before the production decision is made, and all other tests are typically completed after the initiation of production.

All the above should be considered as ground rules to develop qualification standard!

Adopted from: IEC 61215: What it is and isn't, J. Wohlgemuth, PVMRW 2012; Accelerated Lifetime Testing, G. Tamizhmani et. al., SolarABCs.org

Qualification Testing: What it is and isn't

What it is not

Qualification testing is not intended to:

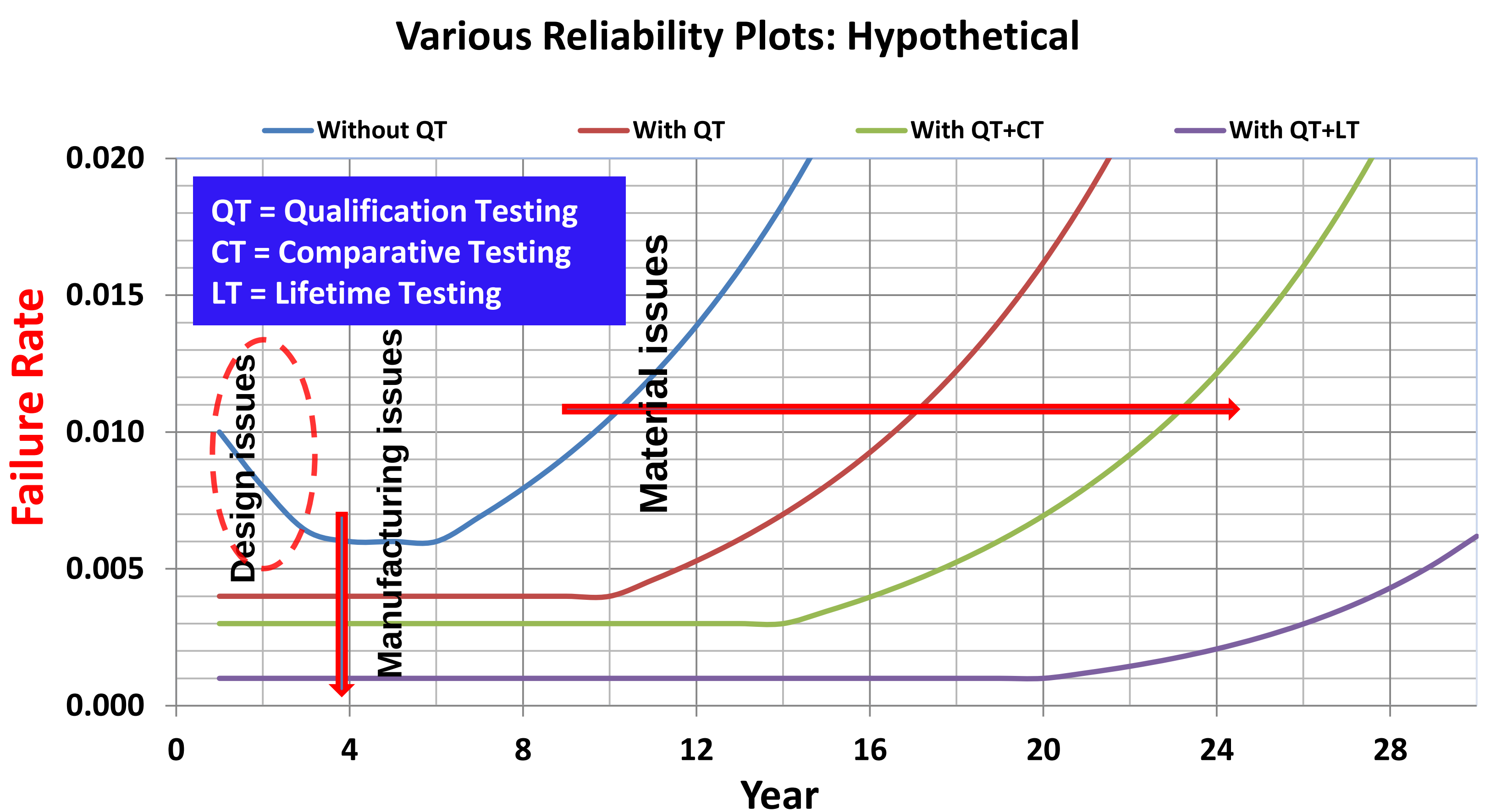
- Differentiate between products that may have long and short lifetimes (later we will look at the bathtub curve)
- Identify and quantify wear-out mechanisms (later we will look at the bathtub curve)
- Address all failure mechanisms in all module designs
- Address failure mechanisms for all climates and system configurations
- Quantify lifetime for different applications or climates.

All the above should be considered as ground rules to avoid distraction from the goal!

Adopted from: IEC 61215: What it is and isn't, J. Wohlgemuth, PVMRW 2012; Accelerated Lifetime Testing, G. Tamizhmani et. al., SolarABCs.org

Qualification Testing: What it is and isn't

	Qualification	Comparative	Lifetime
Purpose	Minimum design requirement	Comparison of products	Substantiation of warranty
Quantification?	Pass/fail	Relative	Absolute
Mechanisms studied	Infant mortality	Wear out	Wear out
Climate or application	No differentiation	Differentiated	Differentiated

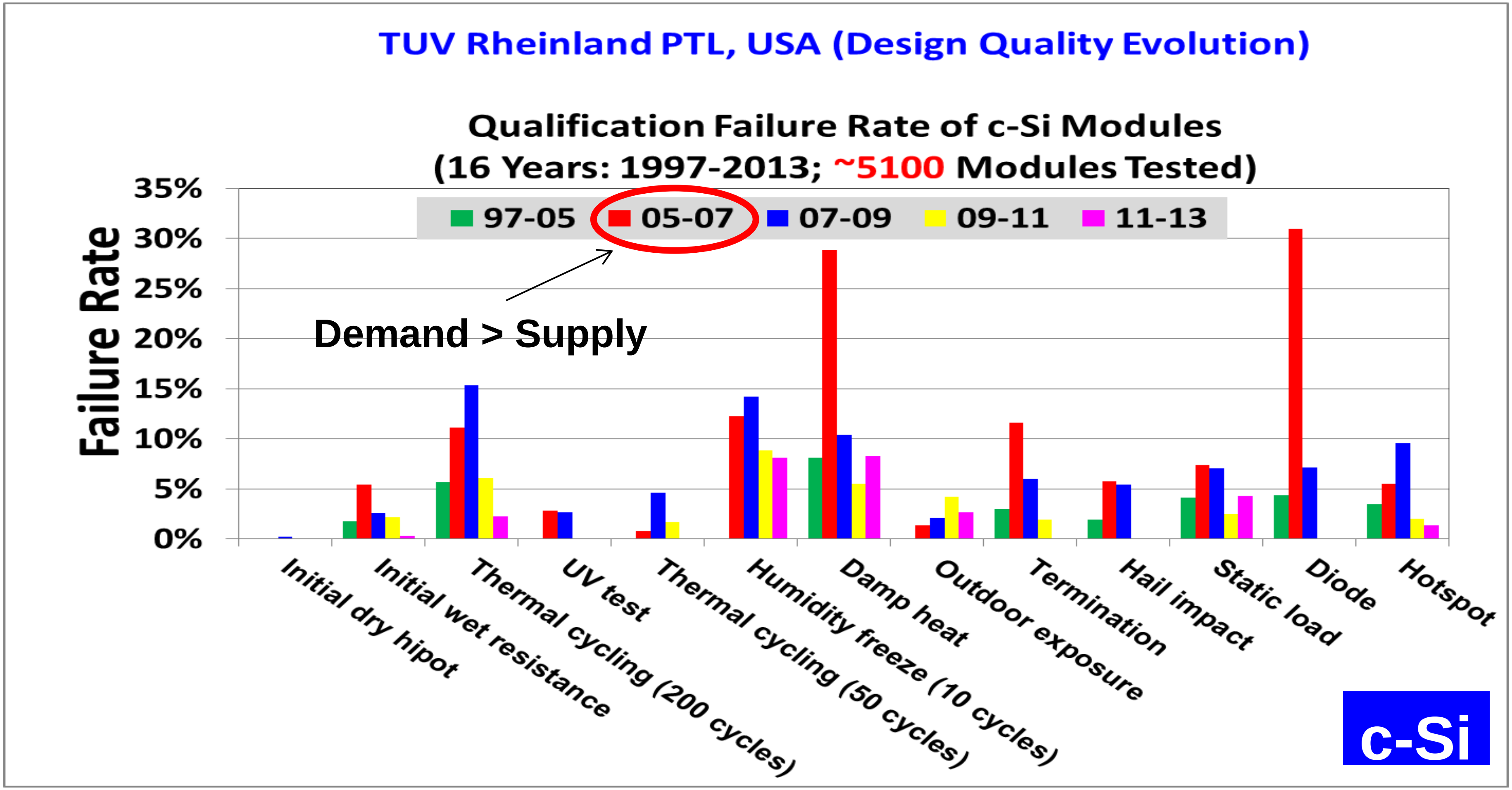


Source: TamizhMani and Kuitche, SolarABCs.org

Adopted from: Kurtz and Wohlgemuth, NREL; Accelerated Lifetime Testing, G. Tamizhmani et. al., SolarABCs.org

PV Module Design Quality Evolution: 1997-2013

Demand and supply may influence the design quality!

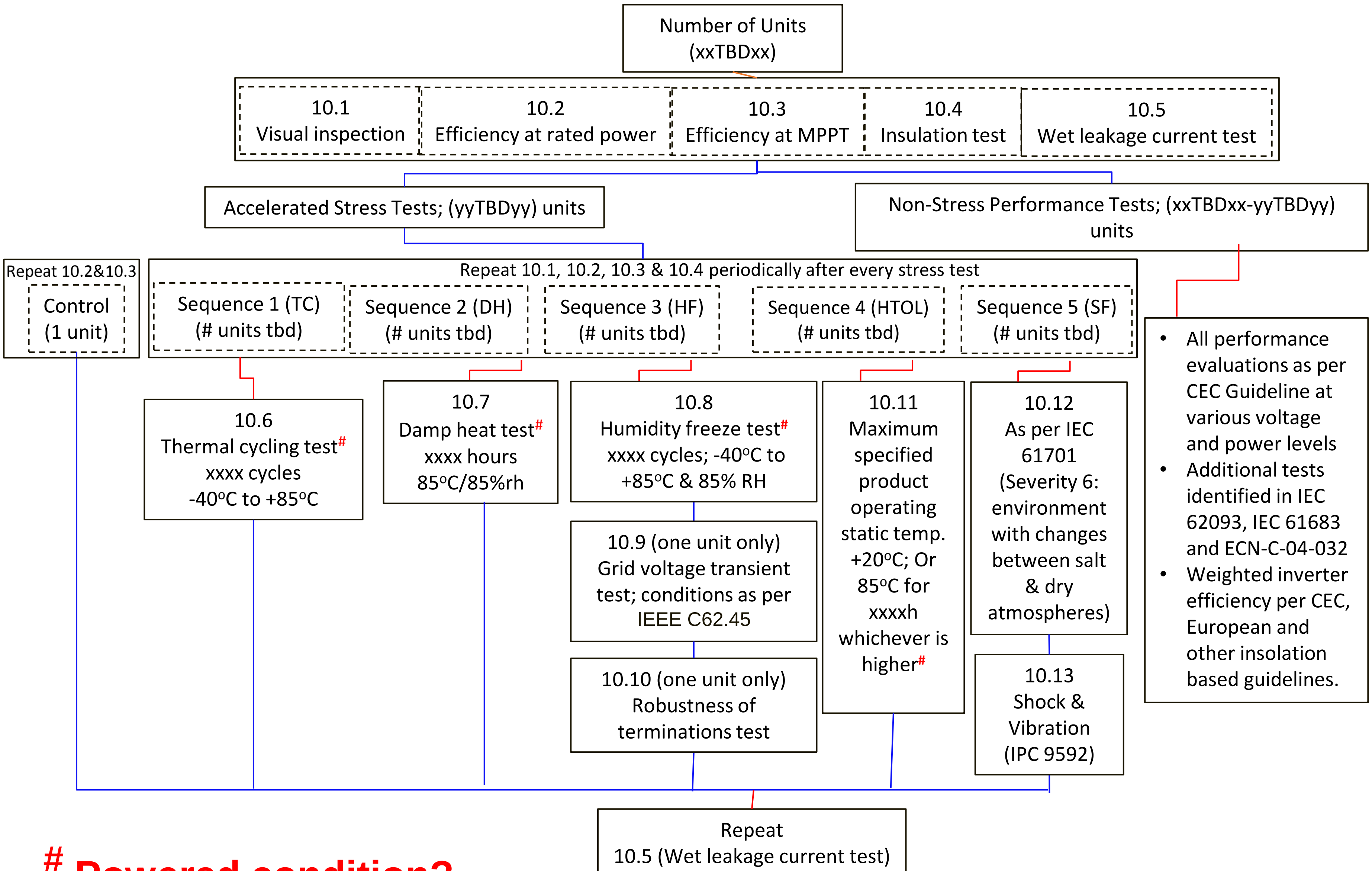


- Overall design quality evolution in the 1997-2013 period: WORST period is 2005-2007
- Design quality in the latest period of 2011-2013: Generally speaking, BEST period!
- Initial wet resistance failure in the 2011-2013 period: Lowest!

We need to monitor the design quality of MLPE over time!

ANSI/TUV-R 71830 Standard (Nov2014-v1)

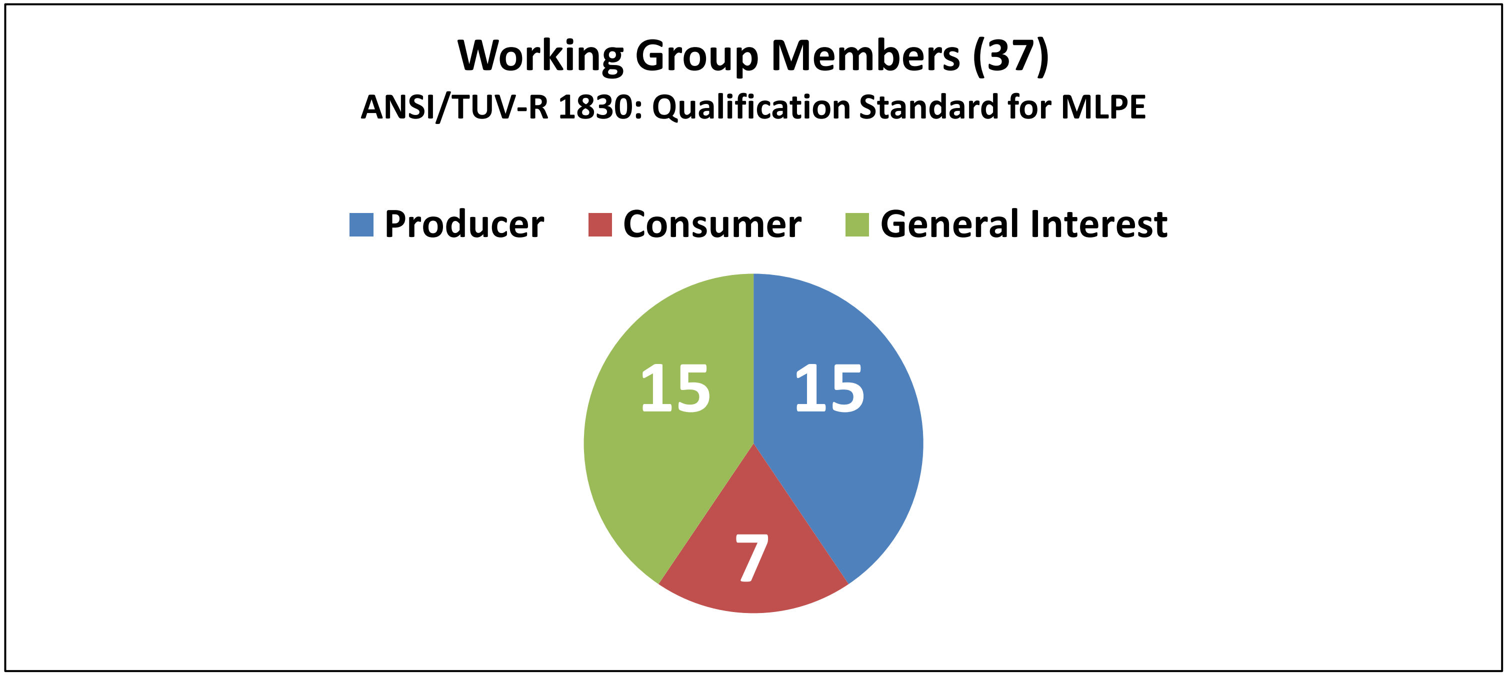
MLPE Qualification Standard Test Sequence



* Pass/Fail TBD for the sequence and individual stress test: No changes from initial?; Retest when one or more units fail

** Number of units = 1 (IEC62093-ed1); 2 (IEC61215); 3 (UL1741); 5 (Qual PLUS); 8 (IEC62093-draft ed2)

ANSI/TUV-R Standards: Applying for Membership



Applying for Membership

http://education.tuv.com/join-ansi-working-groups/

Or

Contact: Jerome Novacek, JNovacek@tuvptl.com

FMEA Survey

RPN = S * O

S = Severity; **O** = Occurrence

S = how strongly the effects of the failure will affect system

O = probability of a failure mode for a predetermined time period

RPN is a numeric/statistical ranking approach for each failure mode

Survey on the probability of occurrence of a specific failure mode
In a list of major sources for critical failures for MLPE products, please rank each component based on their probability of occurrence: MOSFETs, diodes, electrolytic capacitors, multilayer ceramic capacitors, film capacitors, interconnects, AC and DC disconnects and fuses, GFID device, MOSFET gate circuitry, control and other micro electronic circuitry, solder fatigue, PCB, surge suppression device, auxiliary power supply, inductor and transformers and potting compound.

The top 5 at-risk components as identified by the survey are (as per S*O metric):

Item	Failure	Cause
DC Input-DC Input Connection	Intermittent contact	loose connection
AC Output-AC Connectors	Intermittent contact	loose connection
Power Conversion-Low Voltage DC to High Voltage DC	Open & Short circuit failures of DC Link Capacitor	Wear out of electrolytic capacitor in DC Link
AC Output-Protection against OV due to grid disturbances	short circuit	Varistor failure-short from surge
Power Conversion-Low Voltage DC to High Voltage DC	Open & Short circuit failures of MOSFET/Diode	Device degradation (threshold voltage, leakage current)

The survey also asked respondents to list their top three reliability concerns or environments for the system as a whole.

Top 3 reliability concerns	Number of responses
Temperature cycling	9
Solder joint fatigue	7
Humidity corrosion	2
Component quality	4
Moisture Ingress	2
External Grid events	2
Lightning	1
Poor rack/ module grounding	1
High Wind causing the mounts to fail	1
Communications	1
Effects of Potting compound on magnetics and other components	1

These survey results will need to be taken into account during the standard development

Reliability evaluation of 17-year old AC modules

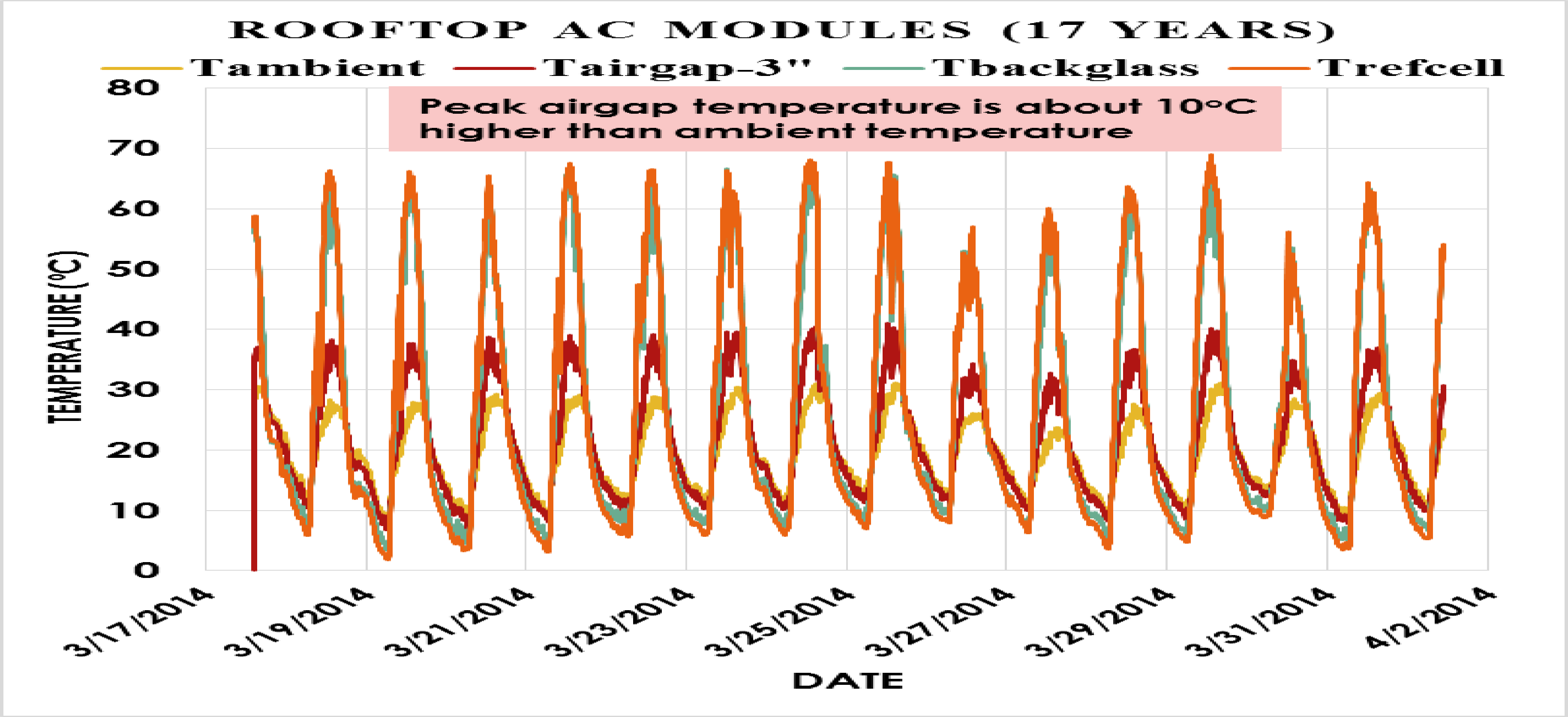
Characteristics of 17-year old AC modules operated in a hot-dry climate

PV Module STC Rating	
Pmax	285 W
Voc	62.8 V
Isc	6.3 A
Vmp	50.3 V
Imp	5.7 A

Ascension Microinverter	Parameter
Rated Voltage	120 V ac
Output Current	0-2.5 A ac
Output Power	0-300 W ac
Maximum ambient temperature	60°C

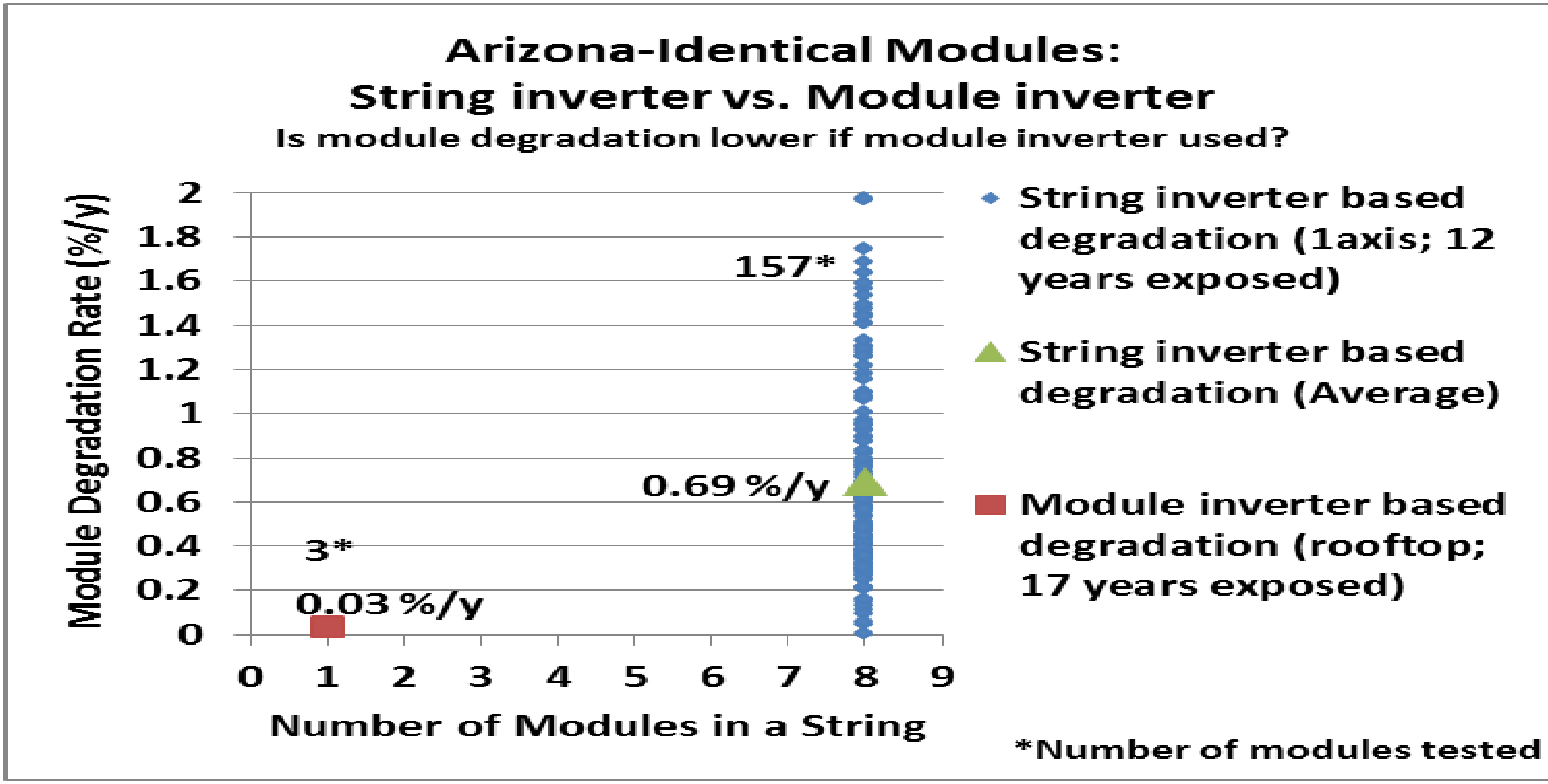
- All four DC modules were determined to be functional
- 2 out of 4 microinverters were determined to be fully functional
- All four DC/AC conversion units were determined to be functional but only 2 out of 4 controller units were determined to be functional

Operating conditions of 17-year old AC modules



- Various temperatures were monitored before removing AC modules from rooftop
- Peak air gap temperature is about 10°C higher than ambient temperature for 3” air gap modules
- Peak air gap temperature will be much higher than 10°C if the air gap is reduced or air flow is restricted (module backsheet temperature as high as 95°C is possible!)
- Record high ambient temperature for this site is 52°C

DC power output of 17-year old AC modules



- Degradation of individual-AC modules is compared with degradation of stringed-DC modules (8 modules per string inverter)
- Identical modules from same manufacturer and identical climatic condition for both systems (Tempe and Chandler, AZ)
- 1 axis system - 12 years of field operation – String inverter – 8 modules in a string – 157 modules in total tested
- Rooftop system - 17 years of field operation – Individual AC Modules – 3 modules in total tested
- Only 3 AC modules have been tested – Statistically insignificant to make any conclusion!

Summary

- Development of qualification standard for MLPE
  - ➢ Potential tests and test sequences have been identified
  - ➢ All major environmental stress may need to be performed under powered conditions

- FMEA survey on MLPE failures
  - ➢ Based on the survey results, the identified tests may need to be revised

- Reliability evaluation of 17-year old AC modules
  - ➢ Ambient operating conditions for MLPE units identified
  - ➢ Current topology is changed but the lessons learned (conversion unit vs. control unit) from the 17-year old AC modules may be useful to develop robust designs

Thanks for your attention!

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