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PV Inverter Accelerated Testing for High Humidity Environments

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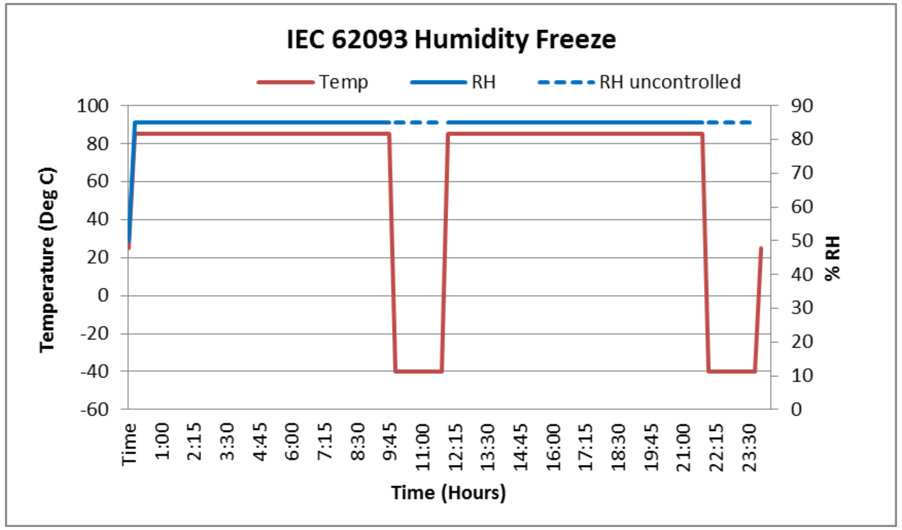
PV Inverter Reliability Workshop

Introduction

- What standards are available for accelerated reliability testing of PV inverters?
- Are PV module humidity test standards applicable to inverters?
- Should we borrow from humidity test standards used in other industries?
- What failure mechanisms are we targeting?
- How do we model acceleration factors?
- How does the product react to the test environment?
- What next?

Industry standards for PV inverters

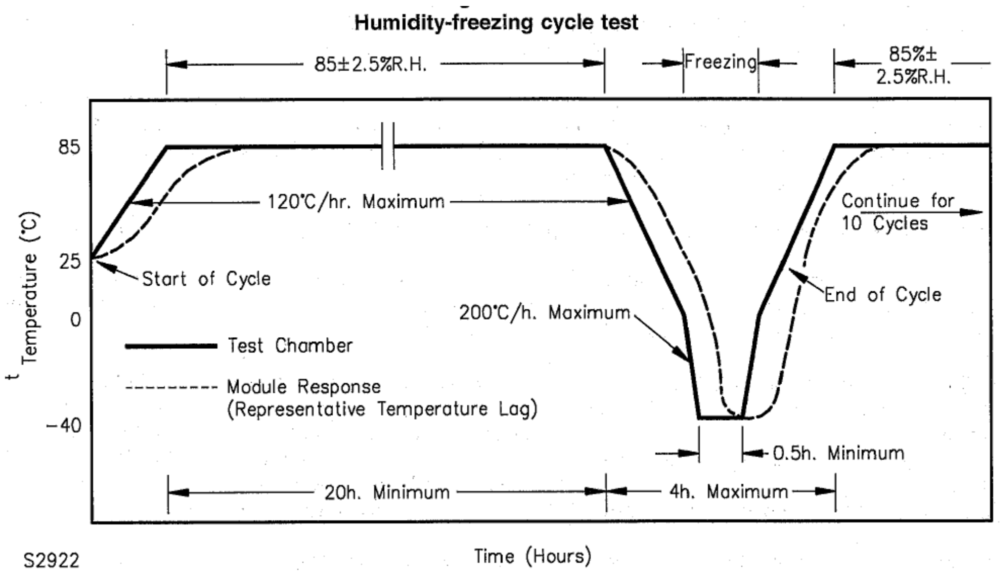
- IEC 62093 (draft)
  - Damp Heat
    - Powered, monitored, light load to reduce internal heating
    - 85C / 85% RH, 1000 hours (42 days)
  - Humidity Freeze
    - Powered, monitored, light load
    - 85C / 85% RH, 10 hours; followed by -40C, 2 hours
    - 20 cycles (10 days)



- ANSI TUV-R 71830 (DOE PREDICTS draft)
  - Microinverters / DC-DC converters
  - Similar to IEC 62093 DH / HF stress levels, duration TBD

Other standards

- PV Module Standards
  - Damp Heat (IEC 61215)
    - 85C / 85% RH, 1000 hours
  - Humidity Freeze (UL 1703 / IEC 61215)
    - 85C/85%, 20 hrs ; -40C, 4 hrs; 10 cycles
- Telecom Power Supplies (IPC 9592)
  - Temperature, Humidity and Bias (THB) *
    - 85C / 85% RH, 1000 hours

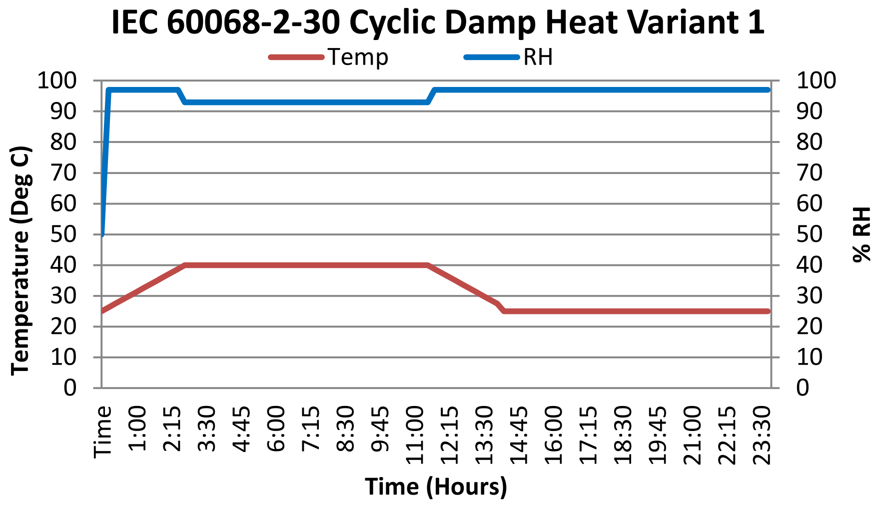


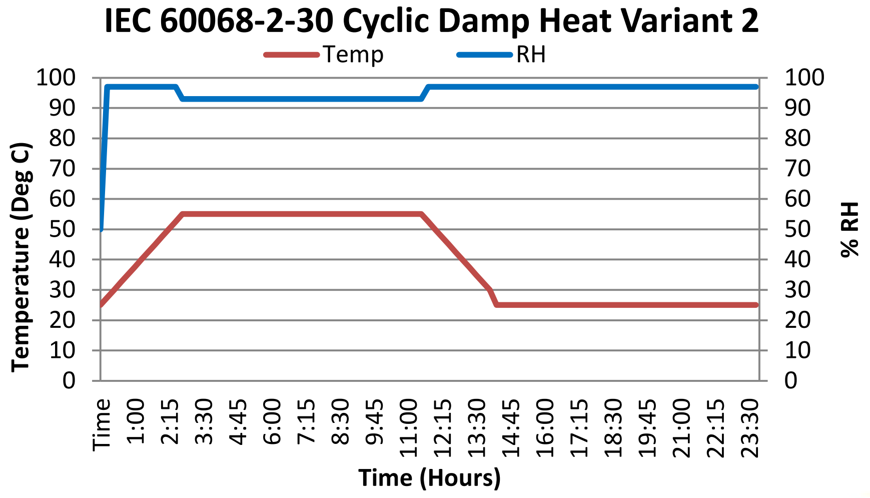
Reference: UL 1703, Figure 36.1

* Similar to IEC 60068-2-67

Other IEC standards

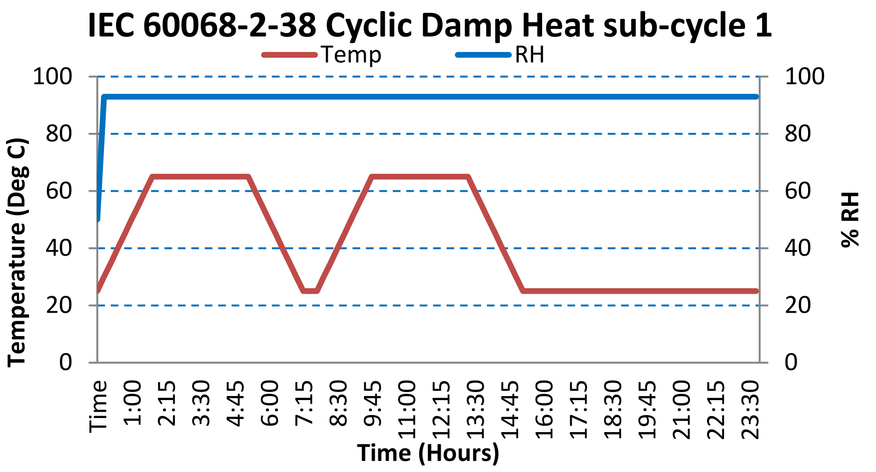
- General Industry
  - Damp Heat (IEC 60068-2-78)
    - 40C / 93%; 1 to 56 days
  - Damp Heat, cyclic (IEC 60068-2-30)
    - Variant 1:
      - 40C / 93%; 12 hr to 25C/97% 12 hr (24 hour cycle) ;
      - 2 to 56 cycles (days)
    - Variant 2:
      - 55C / 93%; 12 hr to 25C /97% 12 hr;
      - 1 to 6 cycles (days)

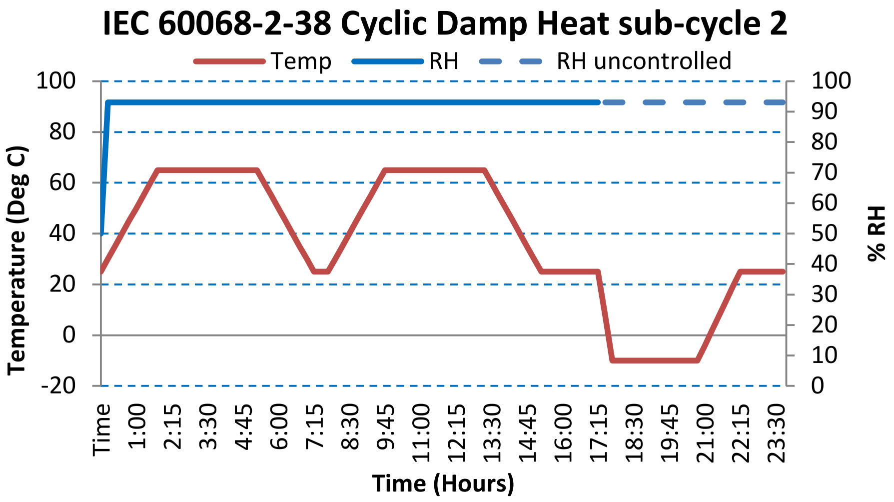




Other IEC standards

- General Industry
  - Damp Heat, cyclic (IEC 60068-2-38)
    - Sub-cycle 1:
      - 65C / 93% to 25C / 93% - 8 hour cycle
      - 2 cycles
      - 25C / 93% - 8 hours
    - Sub-cycle 2
      - 65C / 93% to 25C / 93% - 8 hour cycle
      - 2 cycles
      - 25C / 93% to -10C / uncontrolled RH – 8 hour cycle
    - Each sub-cycle repeated 5 times
    - Test duration – 10 days

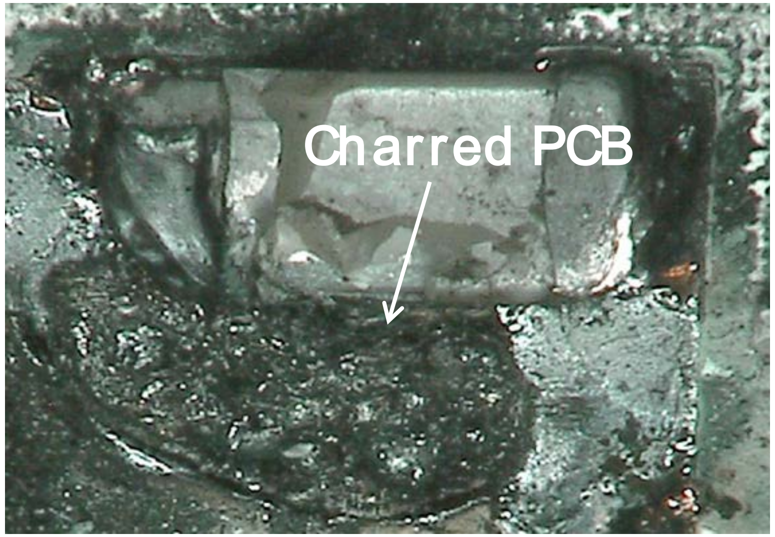


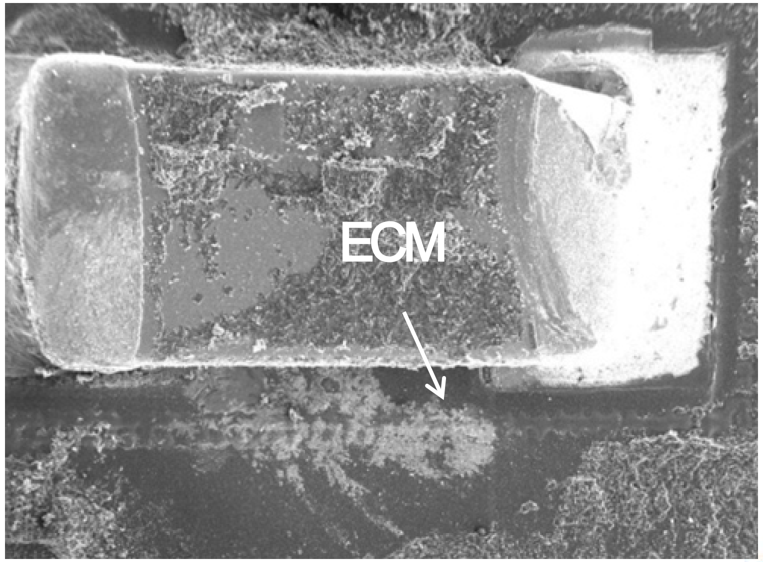


Moisture Assisted Failure Mechanisms

- Electrochemical Migration (ECM) – Dendrite*
  - Metallic ions migrate from anode to cathode, forming treelike structure growing back toward anode
    - Dissolution of Sn, Cu, Ag in the presence of moisture / contaminates
    - Requires Power (Voltage), typically > 1V/mi
  - Typically occurs at PCB surface between 2 conductors joined by an electrolyte medium such as adsorbed moisture
  - Can be highly intermittent, difficult to diagnose, especially in potted assemblies
  - Dependent on available power, evidence can be destroyed
  - Mitigated by cleaning, conformal coating or potting
  - Challenge to model due to hard to predict variables:
    - Amount of moisture adhered to surface of PCB
    - Nature and chemical activity of contaminates, especially flux

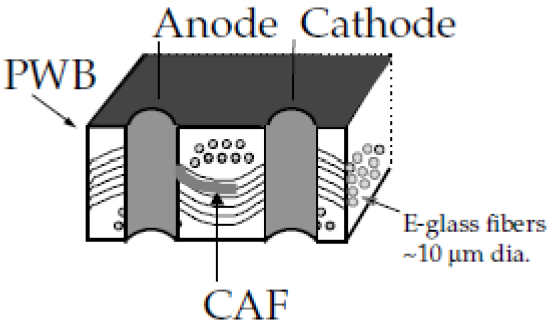
*References 1-3

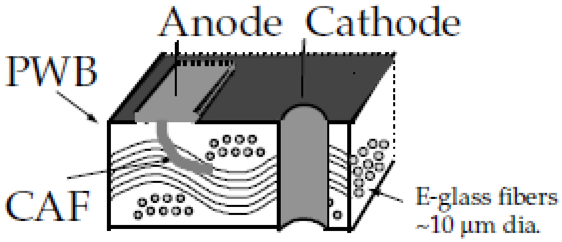


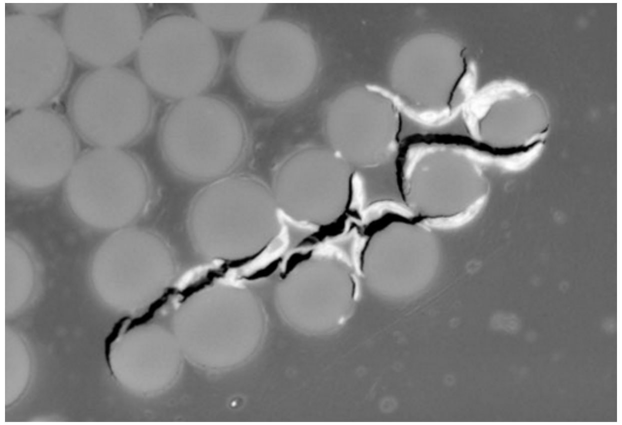


Failure Mechanisms (cont.)

- ECM –Conductive Anodic Filament (CAF) *
  - PCB inner layer only
  - Requires path between points of different potential
  - Path typically provided by glass fiber to resin separation
  - Higher risk in Pb-Free assemblies
  - Similar to dendrite, Cu++ dissolution at anode, migrates along path toward cathode.
  - Can be highly intermittent, often leads to PCB thermal damage
  - Mitigated by proper selection of laminate material, conservative internal spacings
  - Challenge to model due to hard to predict variables:
    - Moisture content of PCB before and after reflow
    - Quality of laminate
    - Process variant: PCB hole drill quality, PCBA reflow profile







* References 4-6

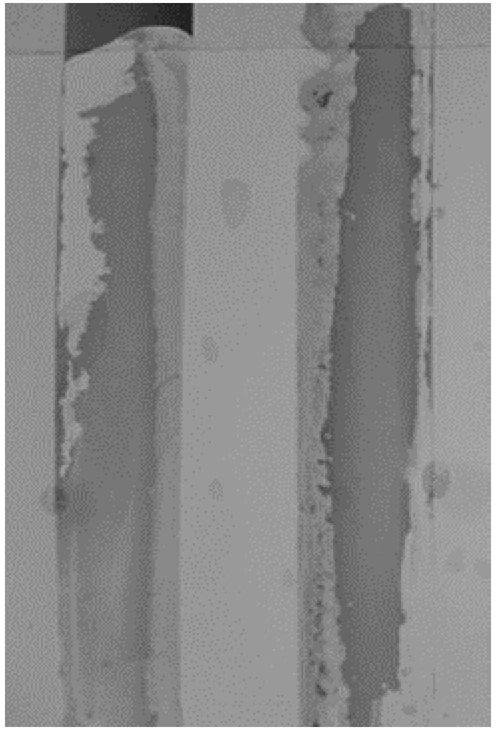
Failure Mechanisms (cont.)

- Film Capacitor corrosion *
  - Corrosion reaction attacking thin metal electrode
  - ZnAl electrodes react with oxygen and water to form non conducting area, reducing capacitance

$$2\,Zn^{\circ} + O_2 + 2\,H_2O \rightleftharpoons 2\,Zn(OH)_2$$

  - Highly accelerated by temperature / RH / voltage
  - Mitigated by with appropriate selection of capacitor case material / pottant
  - Empirical models available from capacitor manufacturers

Before



After

* References 7-8

Modeling – AF: Accelerated Test vs Field Use Conditions

- Identify a region you for which you wish to predict AF
  - Miami Average use environment: 24C / 73% RH (**Reference 9**)
- Identify accelerated test condition:
  - 85C / 85% RH
  - 65C / 85% RH
- Select model: ex: Peck Model (**Reference 10**)
  - $A_T (E_A = 0.7) = 106$
  - $A_H = (85/24)^{2.66} = 1.5$
  - $A_T (E_A = 0.9) = 400$
  - **AF = A_{TH} = 158 – 600x**
- For 25 year life, 50% on time (109.5 khr)
  - Req'd. test time for 85C/85% = 183 – 691 hours
  - Req'd test time for 65C/85%= 1026 – 2647 hours

$$A_T = Exp\left\{\frac{E_a}{K_B}\left[\frac{1}{T_{Use}} - \frac{1}{T_{Stress}}\right]\right\}$$

$$A_H = \left(\frac{R_{Stress}}{R_{Use}}\right)^m$$

$$A_{TH} = A_T A_H$$

$$Ln(t_f) = C + \frac{E_a}{K_B T} - m\ Ln(R)$$

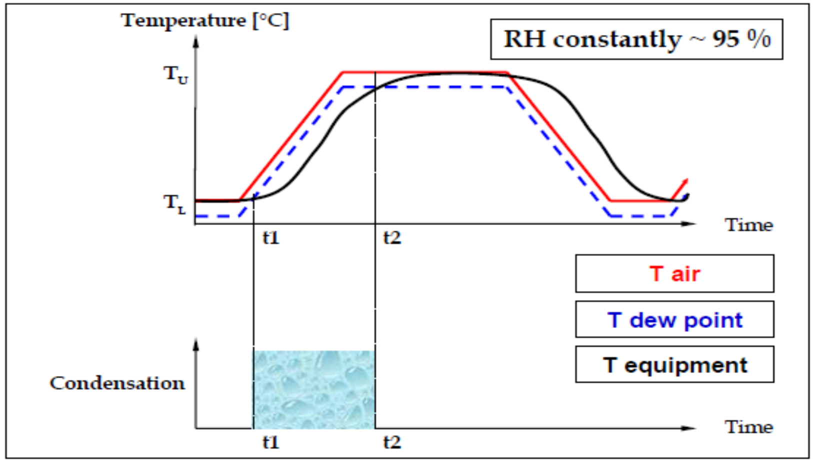
Notation

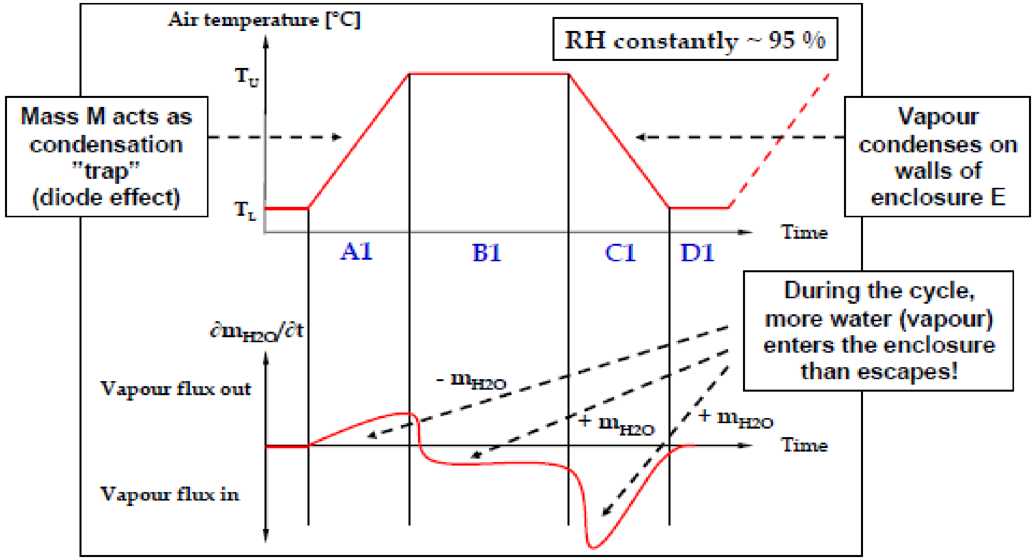
A_H = Humidity acceleration Factor
A_T = Temperature acceleration factor
A_{TH} = Temperature-Humidity acceleration factor
RH_{stress} = Relative humidity of test
RH_{use} = Nominal use relative humidity
T_{stress} = Test temperature
T_{use} = Nominal use temperature
m = Humidity constant
E_a = Activation energy
t_f = Time to Fail
C = Constant

Peck Model

Design Response to T/RH Conditions

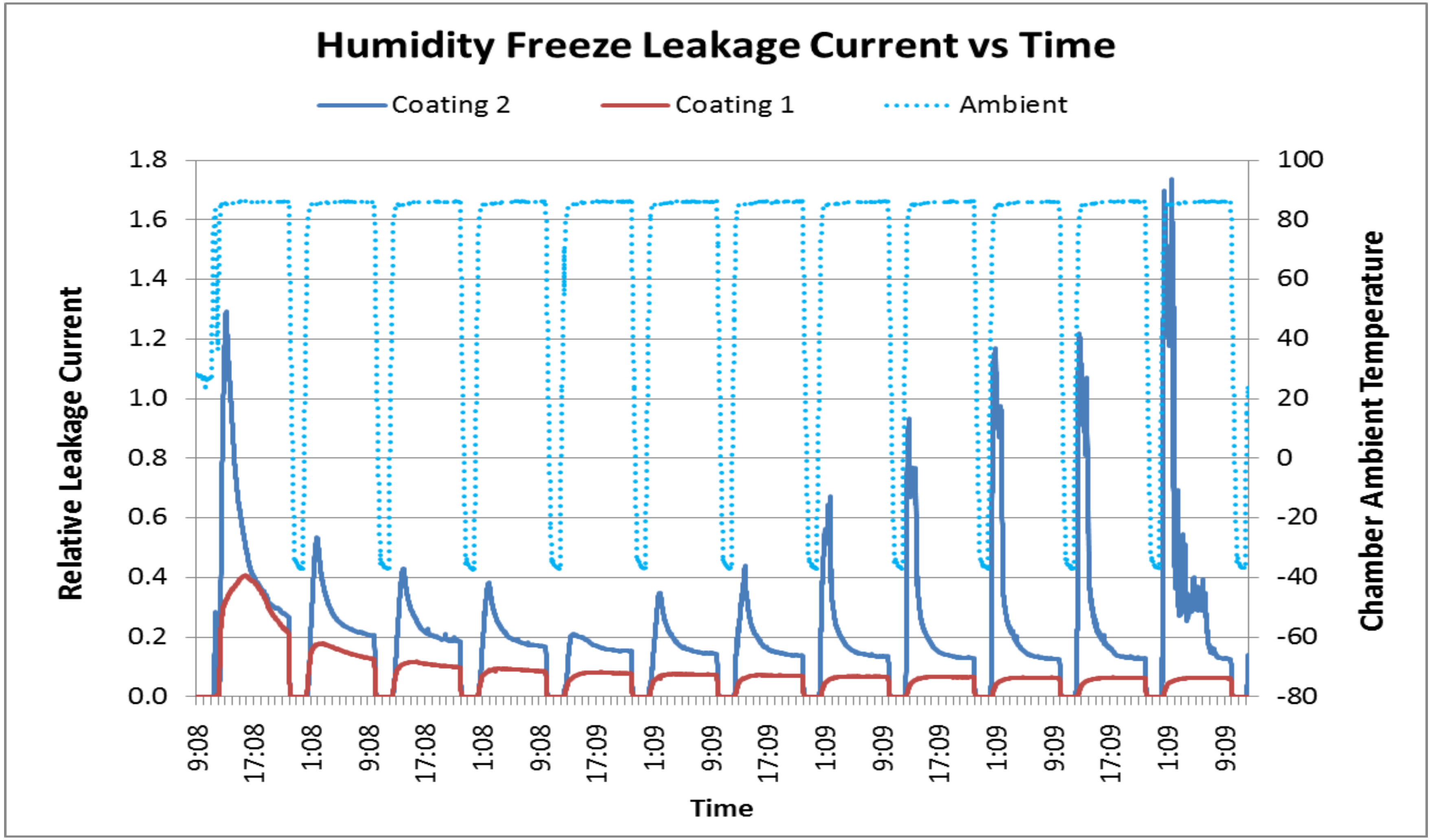
- Unsealed, unpotted assemblies track environment closely
  - For cyclic humidity testing, condensation during temperature ramp up
  - Potential for significant Insulation Resistance (IR) drop
- Sealed, unpotted assemblies vulnerable to “pumping” or “water diode” phenomena
- Potted and conformally coated assemblies may be at risk
  - poor adhesion
  - High moisture content
  - Fast vapor diffusion rate





Reference 11

Real Time Monitoring of Leakage Current / Insulation Resistance



Next Steps

- Survey PV inverter manufacturers for existing humidity test best practices

- Differentiate requirements of Test standard
  - Qualification Test – Pass requirement, no failures allowed
  - Accelerated Life Test– Test to fail, model based on failure mechanism

- Support standards efforts
  - IEC – 62093 needs to be resurrected
  - ANSI TUV-R 71830 (PREDICTS) – See Jack Flicker

References

- ECM: Dendrites
  - (1) C. Hillman, “Contamination and Cleanliness – Developing Practical Responses to a Challenging Problem”, IMAPS – Nordic, June, 2010
  - (2) E Bumiller, et.al , “ A Review of Models for Time-to-Failure due to Metallic Migration Mechanisms”, DfR Solutions
  - (3) X. He, et.al, “Evaluation of Electrochemical Migration on Printed Circuit Boards with Lead-Free and Tin-Lead solder”, Journal of Electronic Materials” June, 2011

- ECM: CAF
  - (4) L Zou, et.al,” How to Avoid Conductive Anodic Filament (CAF), National Physical Lab, January, 2013. Technical Webinar, www.npl.co.uk/ei
  - (5) W.J. Ready and L.J. Turbini, “ Conductive Anodic Filament Formation: A Materials Perspective”, Proceedings of the 3rd Pacific Rim International Conference on Advanced Materials and Processes, 1998
  - (6) L. J. Turbini, “Electrochemical Migration and Conductive Anodic Filament (CAF) Formation”, Tutorial 2, SMTA, October, 2013

References

- Film Capacitor Corrosion
  - (7) M. Michelazzi, et.al, “RFI X2 Capacitors for High Humidity Environments”, 2014 CARTS International
  - (8) HJC White Paper, “Accelerated Lifetime Test for Metallized Film Capacitors”, http://www.hjc.com.tw/cap/pv.pdf

- Modeling
  - (9) NREL “Solar Radiation Data Manual for Flat-Plate and Concentrating Collectors” – Data collected from 239 weather stations from 1961 to 1990. Miami, p 57.

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

  - (10) D.S Peck, “Comprehensive Model for Humidity Testing Correlation, IRPS, 1986.

References

- Humidity Technical Discussion

  - (11) A.B. Kentved, “Humidity Testing of Electronics and Mechanics – How to Select the Right Test Method”, Delta Electronic White Paper, Delta SPM-176, 2008. http://spm-erfa.dk/

Thank You

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