Extended Pulse-Powered Humidity-Freeze Cycling for Testing Module-Level Power Electronics

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Goals

We seek to test module-level power electronics (MLPE) in condensing humidity with pulsed power applied to drive degradation mechanisms seen in the field such as:

- Conductive anodic filament (CAF) growth
- Short circuits (including failures in conformal coating)
- Moisture absorption by polymers, gas build-up, popcorning
- Capacitor failure (decrease in dielectric properties, corrosion, and other chemical reactions)
- Corrosion of conductors, including reactions with halogens, pollutants
- Other moisture and bias-induced failures

Motivation

IEC 62093 ed. 1, and IEC 62093 ed. 2 CD (draft), "Photovoltaic System Power Conversion Equipment, Design Qualification Testing," contain 10 cycles of humidity-freeze testing as per IEC 61215 (85°C/85% RH, 20 h, -40°C 0.5 h).

Concerns are:

- This stress test was taken from IEC 61215, the module qualification test, without any adaptation for the construction and requirements of MLPE.
- Testing for moisture ingress takes time. At 85°C/85% RH, the recommended time to test for equivalence in Miami is 612 h to 971 h, and in Chenai, India, is 1,192 h to 3,417 h[1].
- 1000 h of 85°C/85% RH corresponds to <100 demonstrated failures in time (FITs) in 20 years for indoor-use telecom equipment[2].

[1]Depending on use of physics-of-failure or Hallberg-Peck model, from A. Vasan, "Reliability Assessment of MLPE under Humid Environment using Physics-of-Failure Approach," Proceeding of the NREL/SNL/BNL PV Reliability Workshop – Lakewood, CO (Feb. 28–March 2, 2017).

[2] Örjan Hallberg, Stewart Peck, "Recent Humidity Accelerations, A Base for Testing Standards," *Quality and Reliability Engineering International* **7**, 169–180 (1991).

Experiment

Azuray 250 DC-DC optimizer (2 units)

Subject to IEC 62093 ed 1 humidity freeze, additionally with

- Pulsed power (9 A, 28 V) applied in 5-minute 50% duty cycle during ramp-up in temperature
- 2000 h (83 humidity-freeze cycles, 83 days)
- Monitored DC input and DC output (I, V)
- Performance and efficiency measurements after stress testing
- Failure analysis

Results: DC Input and DC Output (I, V)

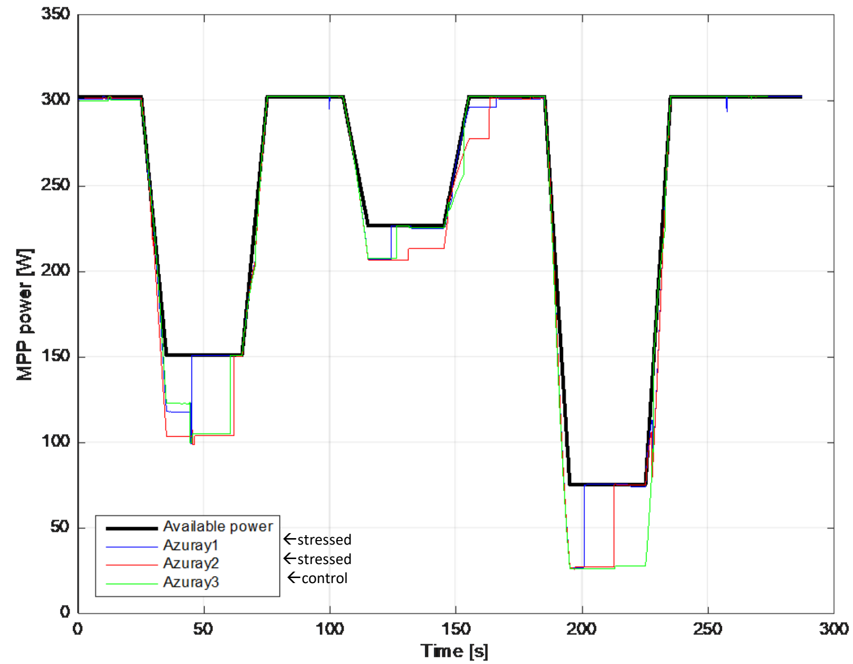
Freeze portion of 24 h humidity-freeze cycle

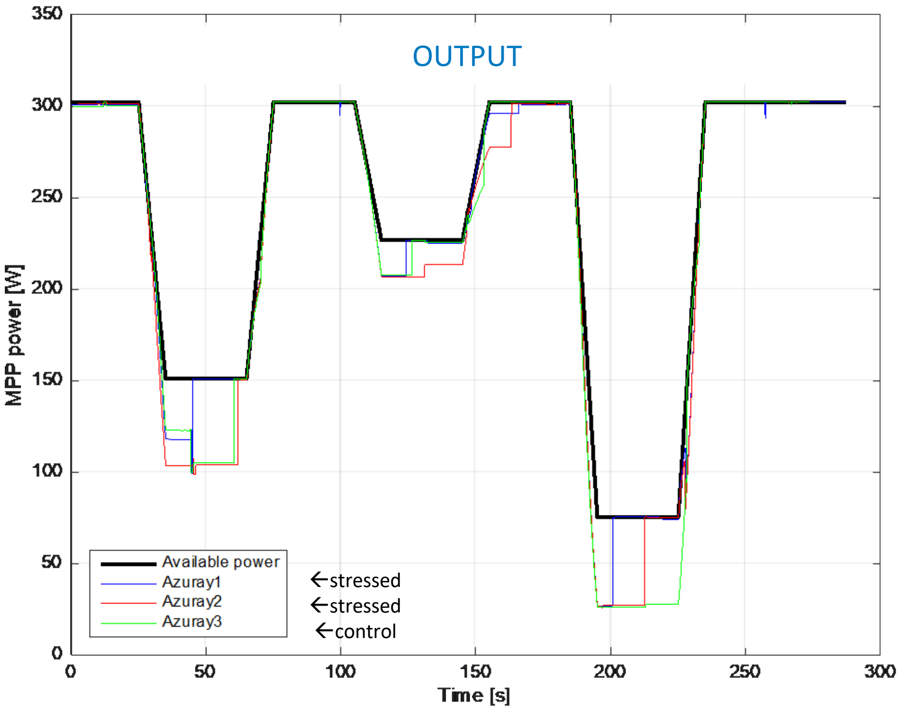
time (h)

Detected no significant change in conversion efficiency over the course of stress testing

Results: Final P_{max} Tracking and Efficiency

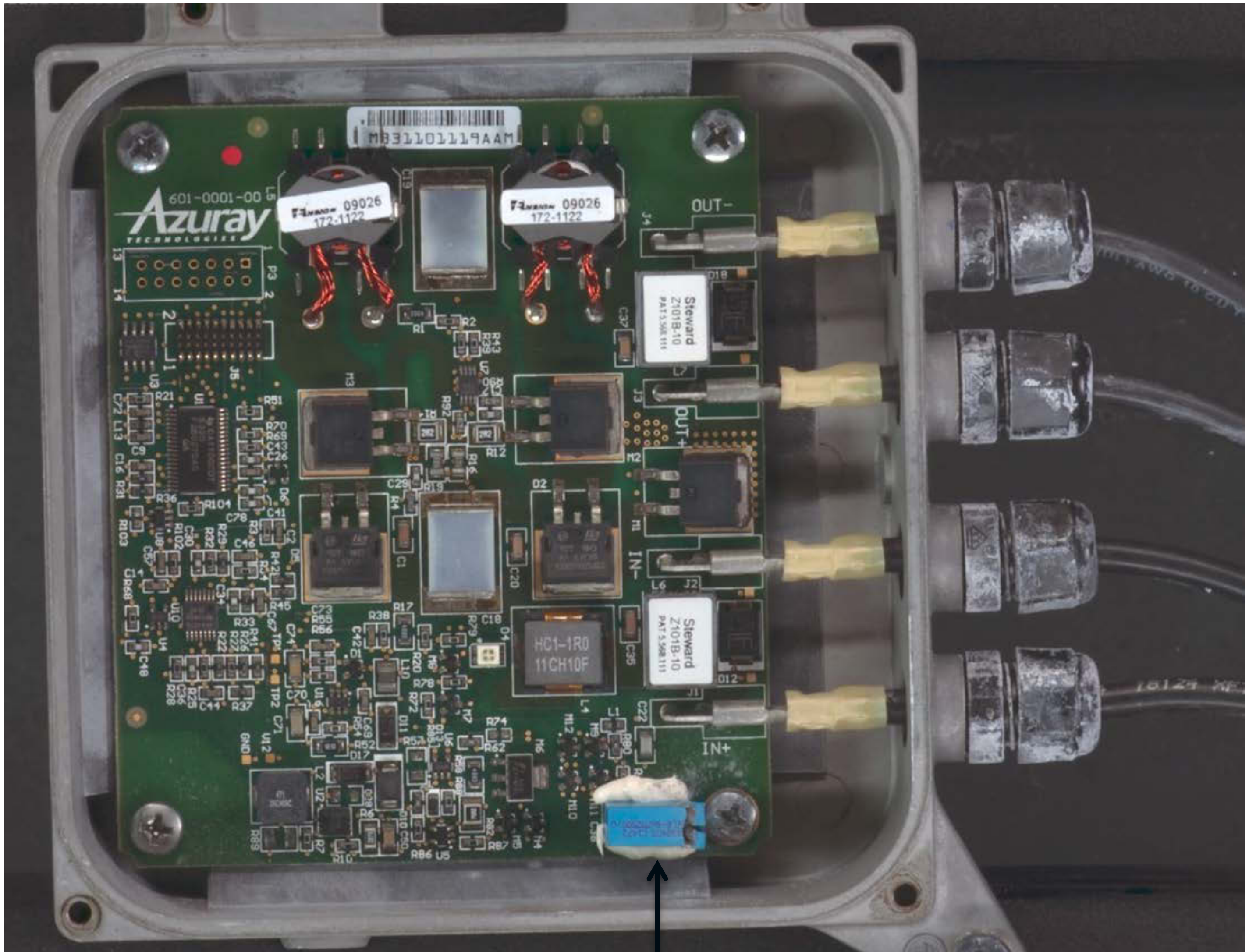
INPUT





No significant difference between stressed and control samples in P_{max} tracking capability and efficiency

Results: Visual Inspection



Failed capacitor

Results: Moisture Ingress Study

Moisture ingress locations:

- O-ring cover plate seal
- Light pipe
- Four wire holes

Part	Thickness (mm)	Area (m^2)	Material	Activation Energy (kJ/mol)	Pre-factor (g·mm/m²/day)	Permeability (g·mm/m²/day)	Permeation (g/day)
O-ring	2	5.00×10^4	Viton	73.2	8.21×10^{12}	1.71×10^2	0.0363
Light pipe	2	4.42×10^5	PMMA	105.2	3.22×10^{18}	1.45×10^3	0.0272
Wire holes (4)	1	3.33×10^4	HDPE	67.7	8.55×10^{10}	11.5	0.0033*

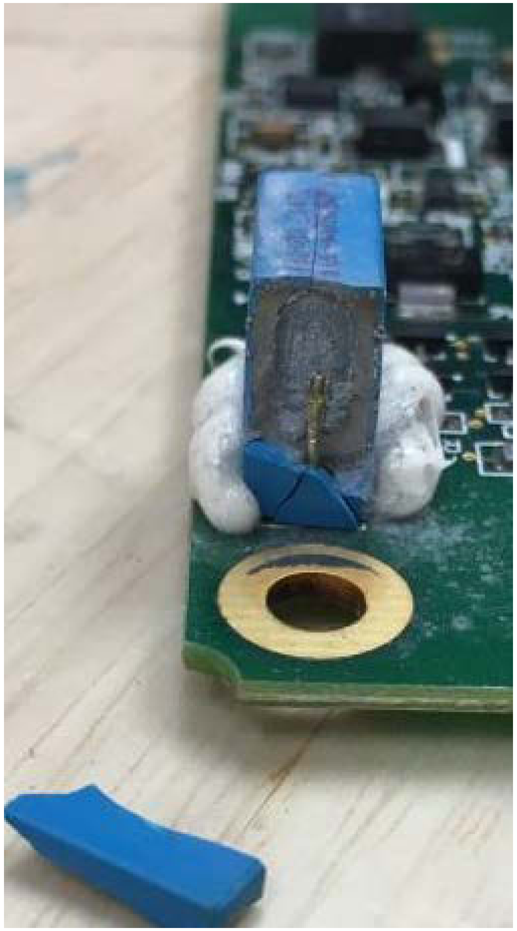
*value may be higher due to imperfections in the wire hole to wire seals

At 85°C, 85% relative humidity:

- Time constant for moisture ingress: 61 h
- Equilibrium reached in about 250 h

Therefore, moisture is calculated to penetrate the MPLE device during test and to not significantly egress during the ½ h °C freeze segment.

Results: Failure Analysis



- Polypropylene film capacitor (MKP)
- EMI suppression
- Capacitor failed in an open circuit
- Appears on the input side, normally functions to suppress interference generated by the device from getting into the wiring
- Cracked open, powder falling out

B 81 122

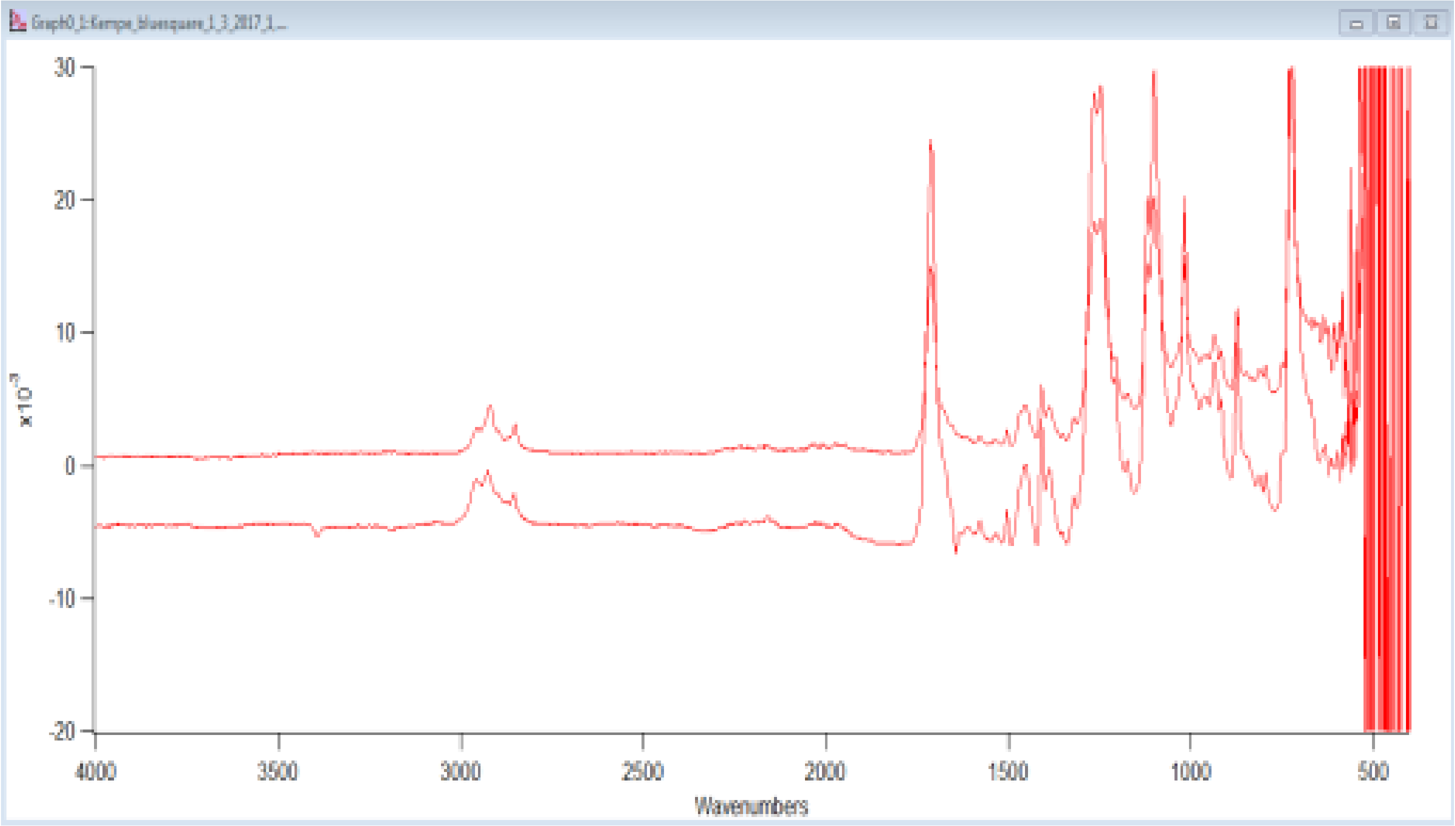
250 Vac

Y2

Technical data

Climatic category in accordance with IEC 60068-1	40/100/21 (e = 10 mm, MKT) 40/085/21 (e ≥ 15 mm, MKP)	
Lower category temperature T_{min} Upper category temperature T_{max}	– 40 °C + 100 °C or + 85 °C	
Passive flammability category in accordance with IEC 40 (CO) 752	C	
Damp heat test	21 days/40 °C/93 % relative humidity	
Limit values after damp heat test	Capacitance change $\lvert\Delta C/C\rvert$	≤ 5 % (e = 10 mm) ≤ 3 % (e ≥ 15 mm)
	Dissipation factor change $\Delta \tan \delta$	for e = 10 mm: $\leq 5 \cdot 10^{-3}$ (at 1 kHz) for (e ≥ 15 mm): $\leq 0{,}5 \cdot 10^{-3}$ (at 1 kHz) $\leq 1{,}0 \cdot 10^{-3}$ (at 10 kHz)
	Insulation resistance R_{is} or time constant $\tau = C_R \cdot R_{is}$	≥ 50 % of minimum as-delivered values

Results: Failure Analysis



- Blue casing possibly poly(diethylene phthalate) (PEP) or polyethylene naphthalate (PEN).
- Sensitive to high temperatures and high humidity.

Results and Next Steps

- EMI suppression capacitor (polypropylene film type) failed by “popcorning” due to vapor outgassing in the pulse powered humidity-freeze cycles.
- No shorts or shunts could be detected despite mildly corroded metallization visible in the failed capacitor.
- Humidity-freeze cycling is optimized to break into moisture barriers. However, further studies will be required on additional MLPE devices to optimize the stress testing for condensation to precipitate any weakness to short circuiting and other humidity/bias failure modes.

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