Evaluating the Durability of Balance of Systems Components Using Combined-Accelerated Stress Testing

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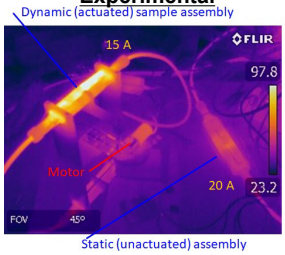
Motivation

-BoS components include cable connectors, cables, branch connectors, fuses (discrete), and fuse blocks.
-The consequences of degradation and failure include offline modules, strings, and inverters; system shutdown; arc fault; and fire! Relative to modules, the underlined items are BoS-centric, with limited publicity.
-*Image: Fiorentini et. al., PVRW 2020. https://www.nrel.gov/docs/fy21osti/80055.pdf*

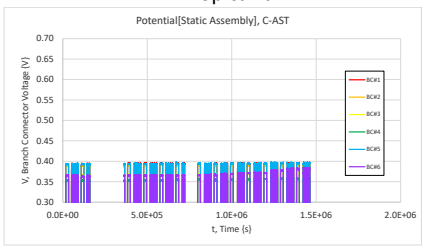
Experimental



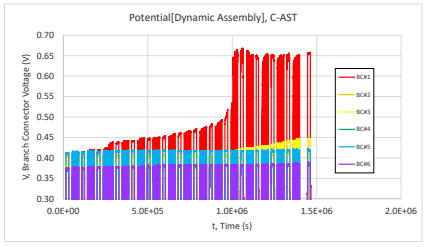
-A utility provider experienced ~30% failure rate in their power transfer chain, attributed to branch connectors.
-"Failure" means overheating, softening, and physical distortion of components.
-The adjoining components were examined as an assembly, including: cable connectors, fuses, and branch connectors.
-Benchtop run: an infrared image compares assemblies in separate circuits. The maximum temperature of the dynamic sample (~100°C, for δ = 1 mm) is greater than that of the static sample (~40°C) with no external mechanical actuation (δ = 0 mm), despite a greater DC current to the static sample.

Results (On-Going C-AST)

Static C-AST run (δ=0mm)
Tropical-b

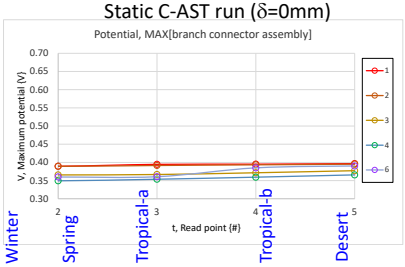


Dynamic C-AST run (δ=0.5 mm)
Tropical-b

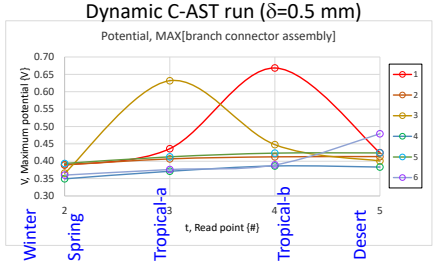


-In benchtop experiments, external mechanical perturbation was found to quickly, stochastically, and greatly affect the results (I_{fail}: 35 A → 15 A, T: ~40 °C → >130 °C). See: *https://www.nrel.gov/docs/fy22osti/81456.pdf*
-Above: specimen voltage was distinguished like in the benchtop experiments in C-AST at a reduced current (10 A) for dynamic specimens relative to static specimens.
-Specimen V and T have been even more distinguished in C-AST for dynamic specimens at the benchtop failure current (15 A) and will be verified next for static specimens.

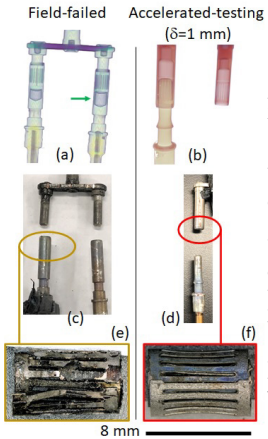
Static C-AST run (δ=0mm)



Dynamic C-AST run (δ=0.5 mm)



-Above: specimen voltage was most distinguished in C-AST at a reduced current (10 A) for the Tropical cycle, which is based on ASTM D7869 for Miami, FL.
-Results to date suggest a combined hot and humid environment is most damaging (e.g. relative to a hot dry environment) when perturbation is applied.
-To date in-situ monitoring (specimen voltage and temperature) during C-AST has given distinguishable feedback relative to read point measurements (between sequences). Watch for: T_{max}, V_{max} as well as rise in the averages.



Failure Analysis (Field and Benchtop Experiments)

-A sequence of non-destructive (IR + optical imaging, R, and XCT), and destructive (morphology and composition after machining) examinations was applied to field-failed and benchtop specimens.
-Example: comparison of field-failed (left) and benchtop-failed (right, for δ = 1 mm) specimens, including: (a) and (b) x-ray computed tomography prior to removing the exterior plastic; (c) and (d) visual appearance of the interior metal components after removing the exterior plastic; and (e) and (f) optical micrographs of the convolute springs extracted from the most externally discolored connections.
-Multiple degradation modes were observed including: melting and reflow of solder; oxidation (with surface discoloration); vaporization (e.g., from localized electrical arcing); corrosion; inelastic deformation (longitudinal and circumferential); and abrasion.
-Localized sample temperature of at least 142 °C is implied from the melted/deformed shape of the polycarbonate plastic. *See: https://www.nrel.gov/docs/fy22osti/81456.pdf*

-Table: comparing the mechanical actuation in the benchtop and C-AST experiments.

EXPERIMENT	SEQUENCE NAME	PERTUBATION DURATION {s}	REST PERIOD (BETWEEN PERTURBATIONS) {s}	CYCLE PERIOD {s}	DUTY CYCLE (ON:TOTAL) {%}	# CYCLES·RUN^{-1} {dimensionless}
benchtop	continuous	1.9	1.9	continuous	50	to failure
C-AST	Winter-1	1	7	8	13	7985
C-AST	Winter-2	2,438	0	2,438	100	5
C-AST	Spring	1,817	0	1,817	100	49
C-AST	Tropical	3	6	9	33	4790
C-AST	Desert	90	0	90	100	2776

Conclusions

-The use of external mechanical perturbation was found to quickly and greatly affect the results of benchtop experiments for cable connector/branch connector/fuse specimen assemblies. Similar results are presently emerging in C-AST.
-Failure analysis diagnosed the hottest location, presumably the location of greatest degradation: the connection between male and female metal pins in both the benchtop (with mechanical perturbation) and field-failed specimens. This is different than the utility provider's originally suggested location – the attachment between the metal pins and cross-connecting bar in the branch connector.
-The validation of the accelerated testing relative to the field installations in this study remains an ongoing effort. The identification of the same degradation location in failure analysis is encouraging.

See Also

-This poster provides an update from C-AST in additional to the manuscript thoroughly focused of the benchtop experiments.
-A journal publication on the benchtop experiments is anticipated in addition to the conference proceedings.
-An on-going effort regarding BoS reliability (cable connectors and cables) is presently underway at NREL and Sandia.
-Please inquire further if you believe you have samples or PV sites of interest or would like to follow the monthly "Balance of Systems Reliability" internet group.
https://energy.sandia.gov/programs/renewable-energy/photovoltaics/pv-systems-and-reliability/pv-connectors/

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