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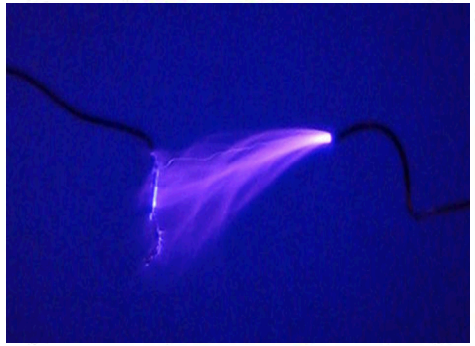


PV Arc-Fault Degradation Phenomena & Model Development for Photovoltaic Connectors

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U.S. DEPARTMENT OF ENERGY

National Nuclear Security Administration

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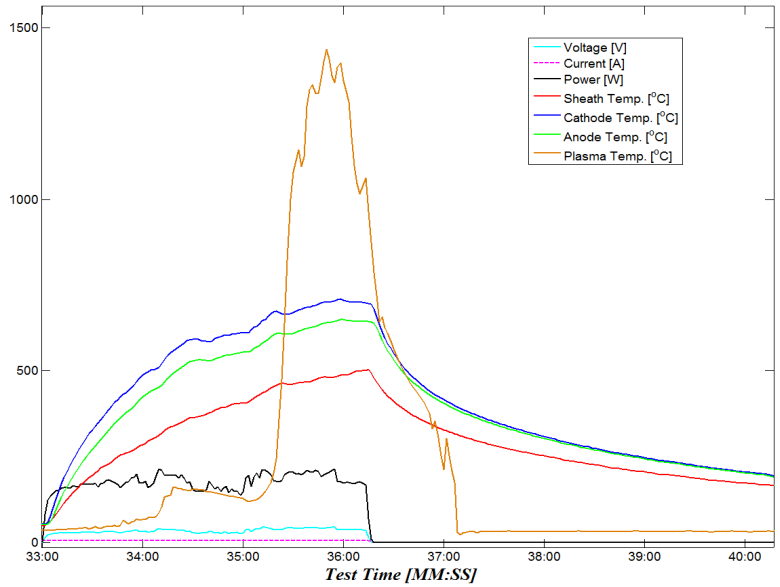
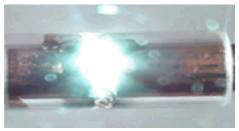
Thermal Arc-Fault Research

- As the worldwide installed capacity of photovoltaic systems continues to grow and age, the number of arc-faults in PV systems is expected to increase.
- Arc-fault events arise due to PV cabling degradation & other reliability issues.
- Lack of fundamental understanding for arc-faults and AFCI tripping has given rise to the need for better characterization, sensing methodologies and Standards.
- This work provides novel methods for arc-fault characterization, detection and mitigation.

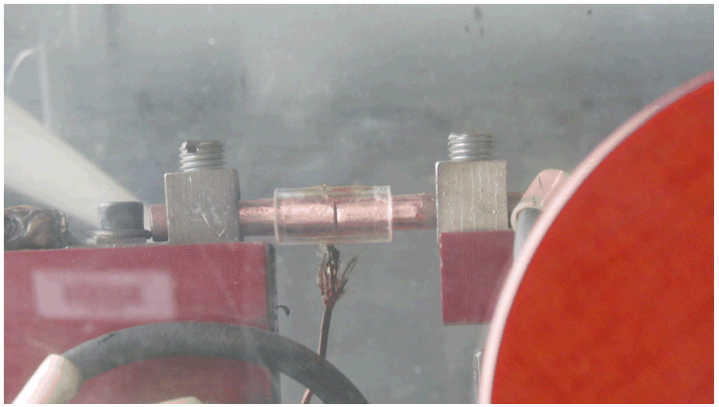


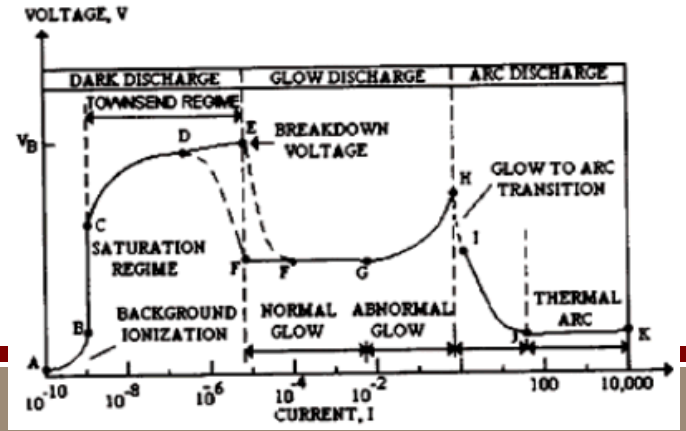
Arc Power



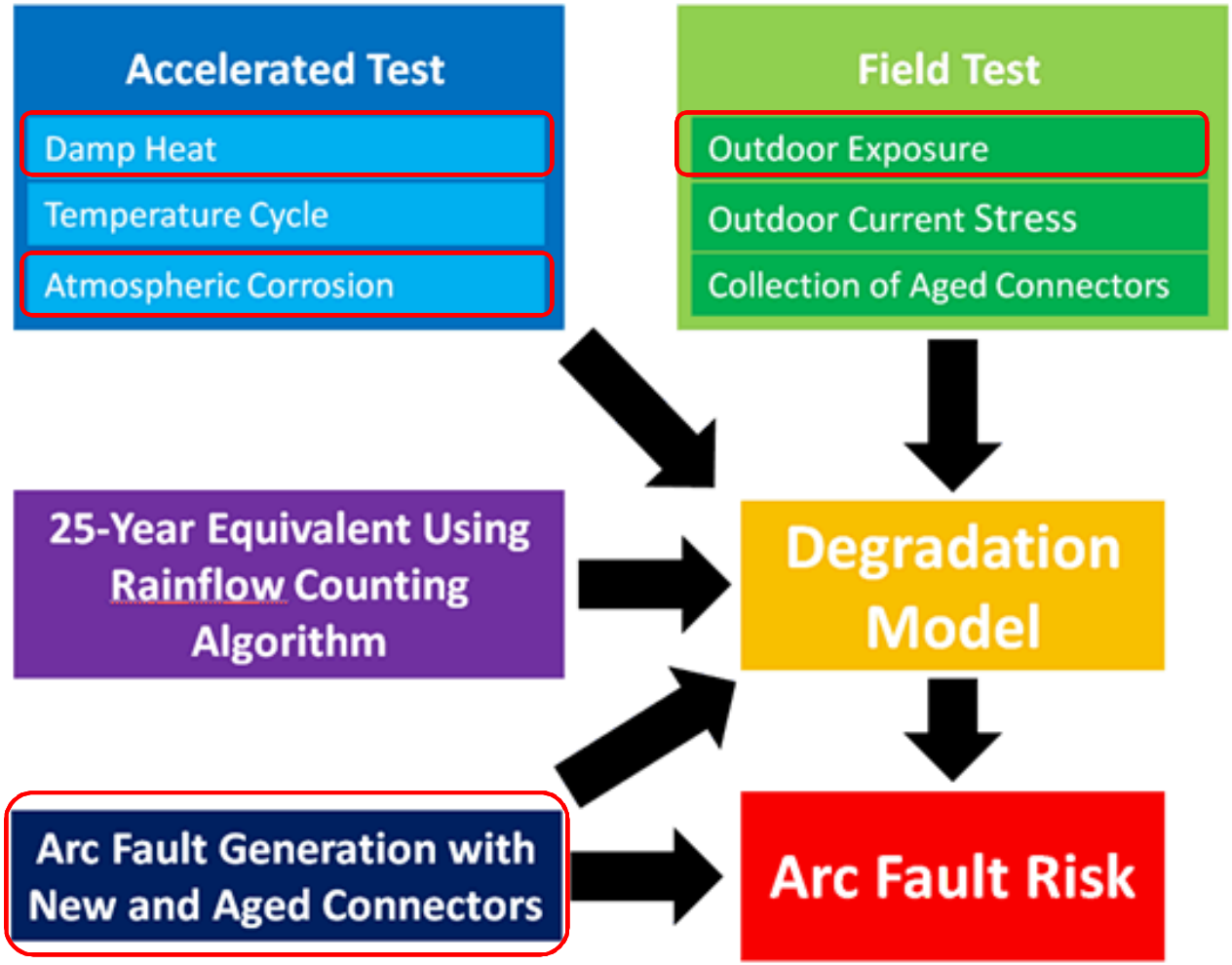
100 W

300 W





Research Overview



Connectors are Robust to Damp Heat and MFG Tests

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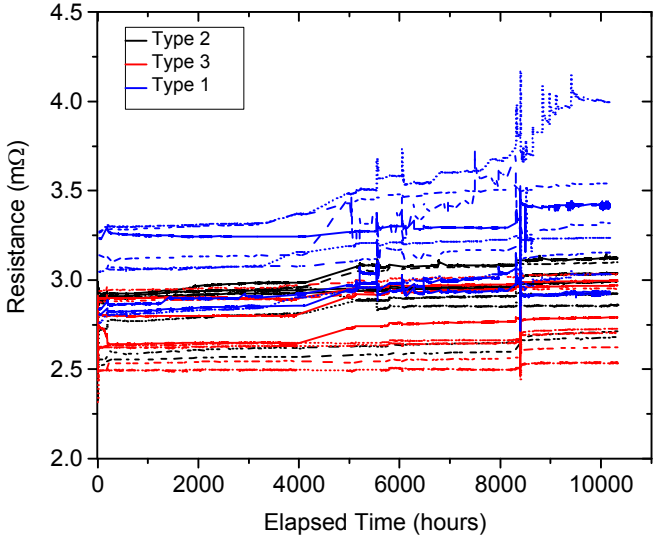
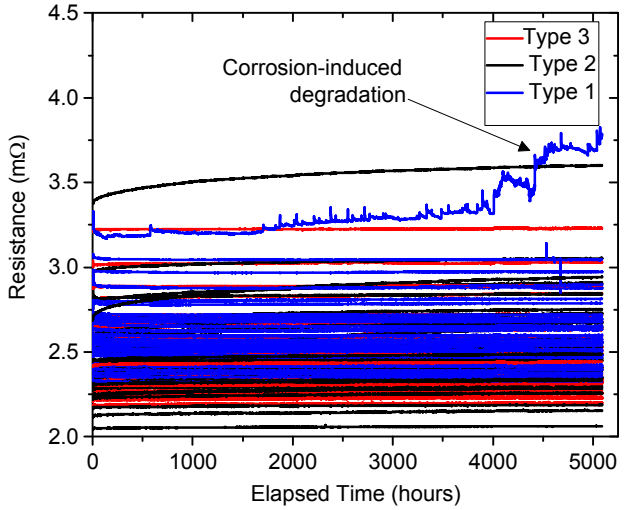
Damp Heat 85°C/85% RH



Class II Corrosion Chamber ppb H_2S, Cl_2, NO_2, 70% RH,30°C



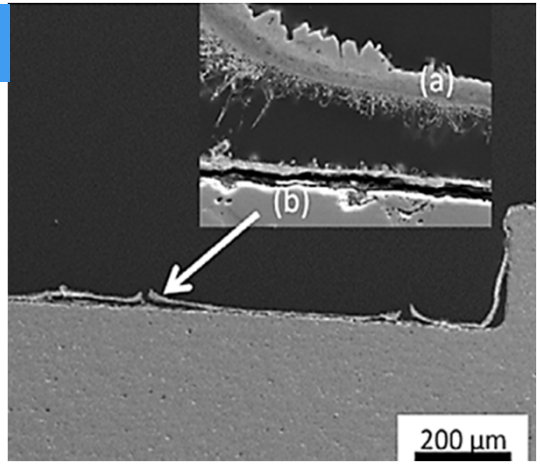
- While some degradation was observed, connectors were overall robust to corrosion and damp heat.
- Type 1 connectors showed greatest resistance increase.

Materials Analysis Revealing of Degradation

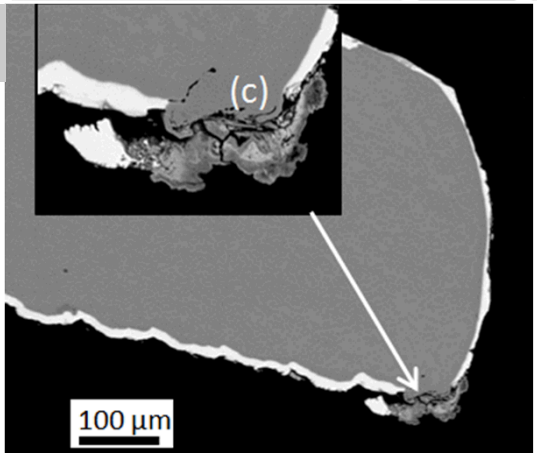
Type	Base Alloy	Underplate, Thickness (µm)	Overlayer, Thickness (µm)
I	Cu-Zn-Pb	Cu, 1	Ag, 3-4
II	Cu	--	Sn, < 1 -8
III	Cu	Ni, 1	Sn, 5-9

Pins and Sockets Boldly Exposed to MFG

Type 1

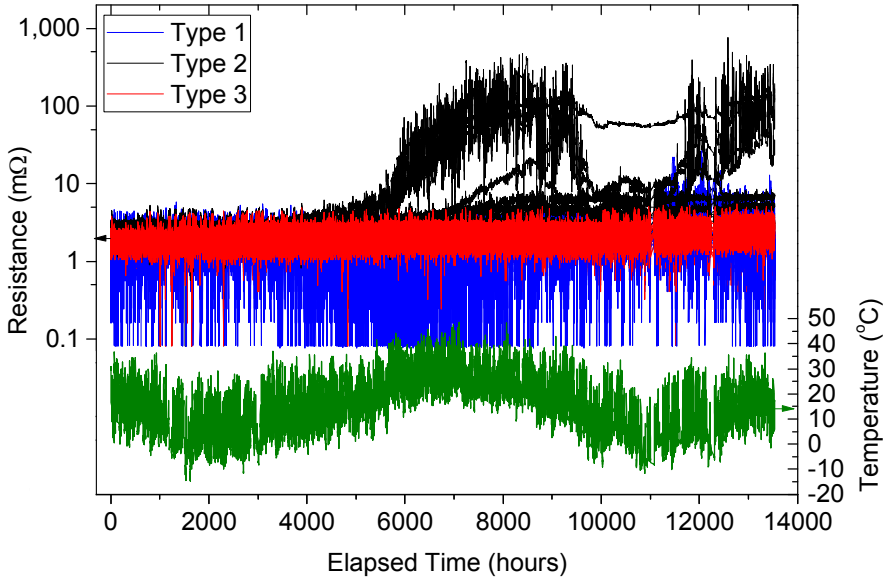


Type 2



- Disparate materials of construction linked to variance in corrosion response and resistance
- Ag plating vulnerable to sulfide-rich environments

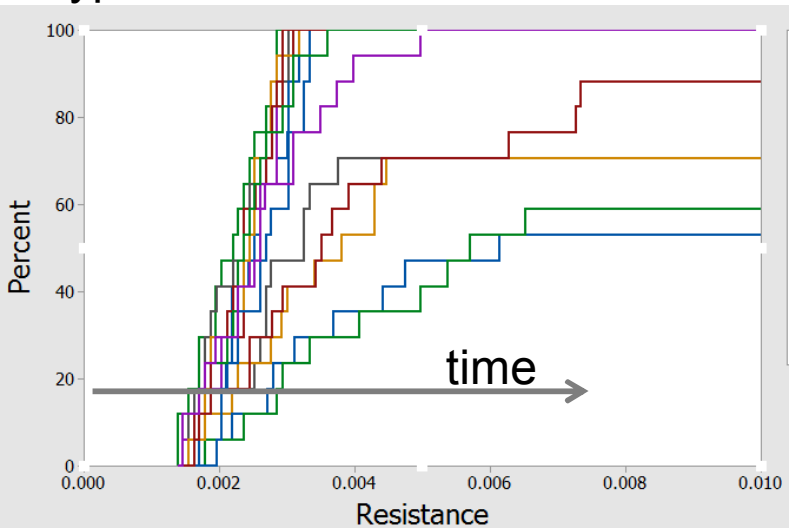
Enhanced Degradation of Type 2 connectors undergoing over 13,000 Hours of Outdoor exposure



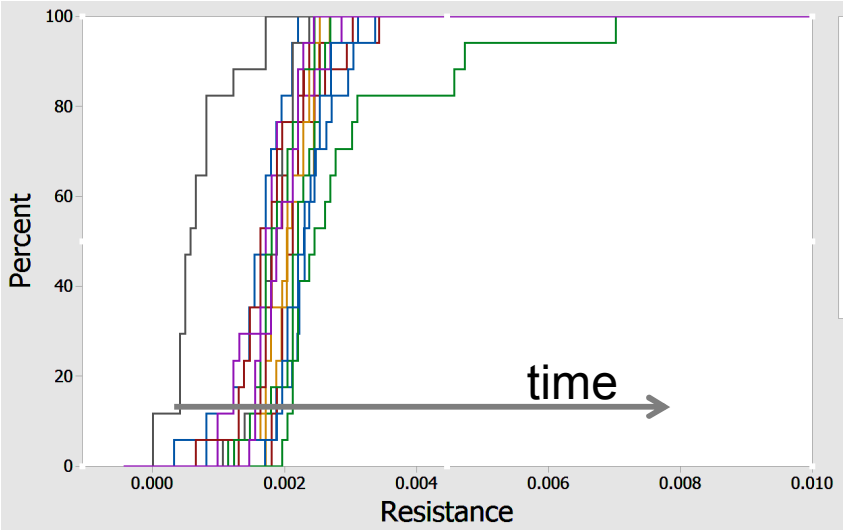
- Failures of Type 2 observed after 13,000 hours of long-term passive outdoor exposure test involving 51 connectors.
- Variance in connector performanace across exposure environments reflective of inconsistent stresso factors

Enhanced Degradation of Type 2 connectors undergoing over 13,000 Hours of Outdoor exposure

Type 2



Type 1



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Translating Degradation into Arc Fault Risk

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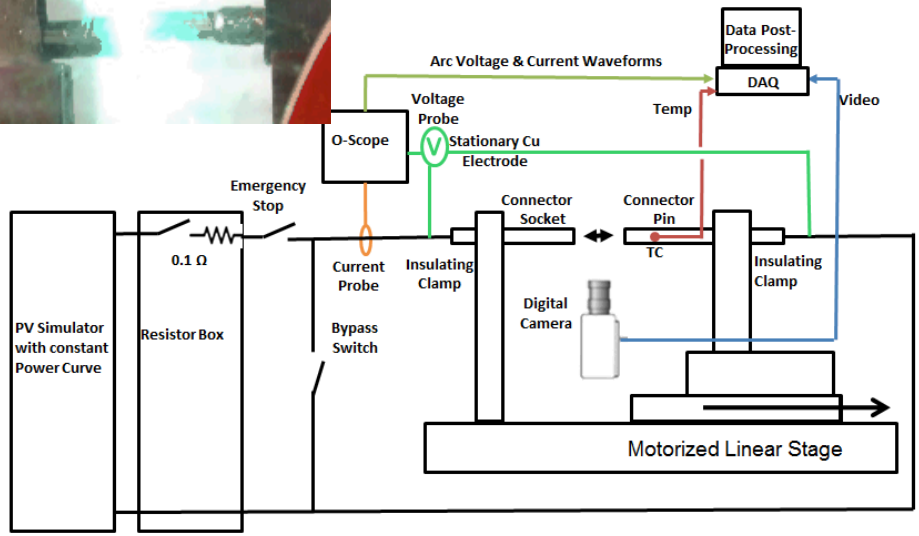
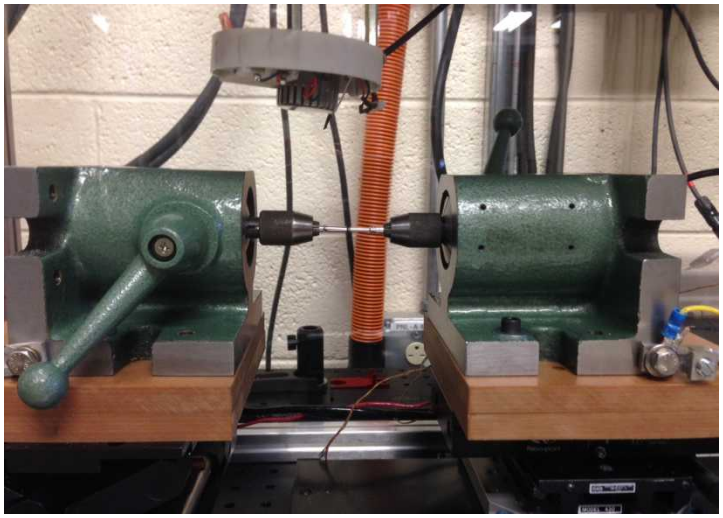
Connector separation distance necessary for arc ⟷ Resistance increase necessary for arc ⟷ Arc fault risk

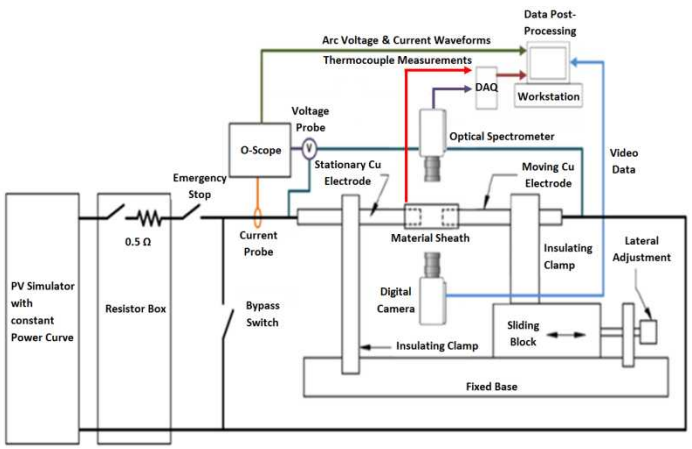
- Connector separation distance prior to arc tested as a proxy for arc fault risk.
- Temperature can potentially be a method for arc fault prognostics.

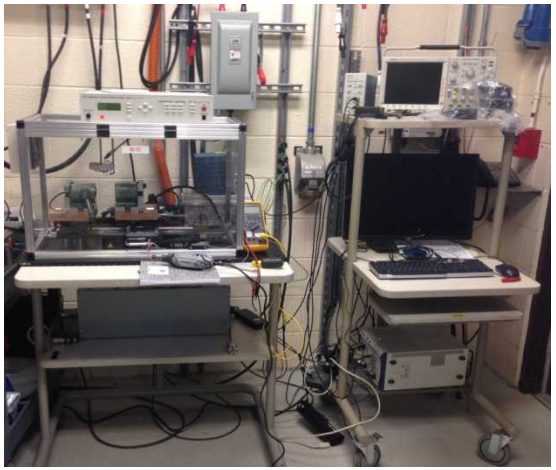


Arc-Fault Experimental Setup

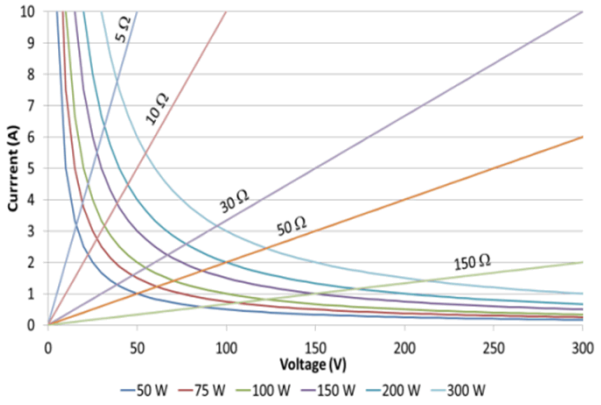
- Customized PV Simulator provided power to a developed Arc-Fault Generator.
  - A power resistor was employed to avoid shorting
- Smoke detector, thermal measurements and high speed camera used for measuring ignition times.
- Spectral Analysis Performed
  - J. Johnson and K.M. Armijo, 29th EU PVSEC, **2014**, Amsterdam, Netherlands.
  - B. Yang, et. al., 40th PVSC, **2014**, Denver, CO.
  - J. Johnson and K.M. Armijo., 40th PVSC, **2014**, Denver, CO.



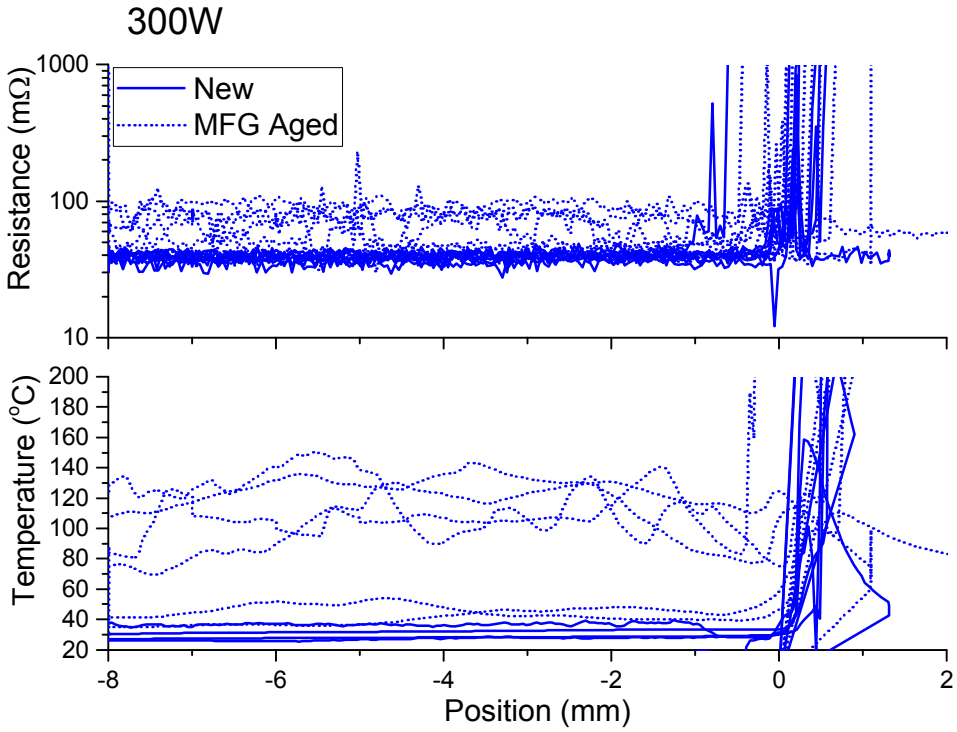


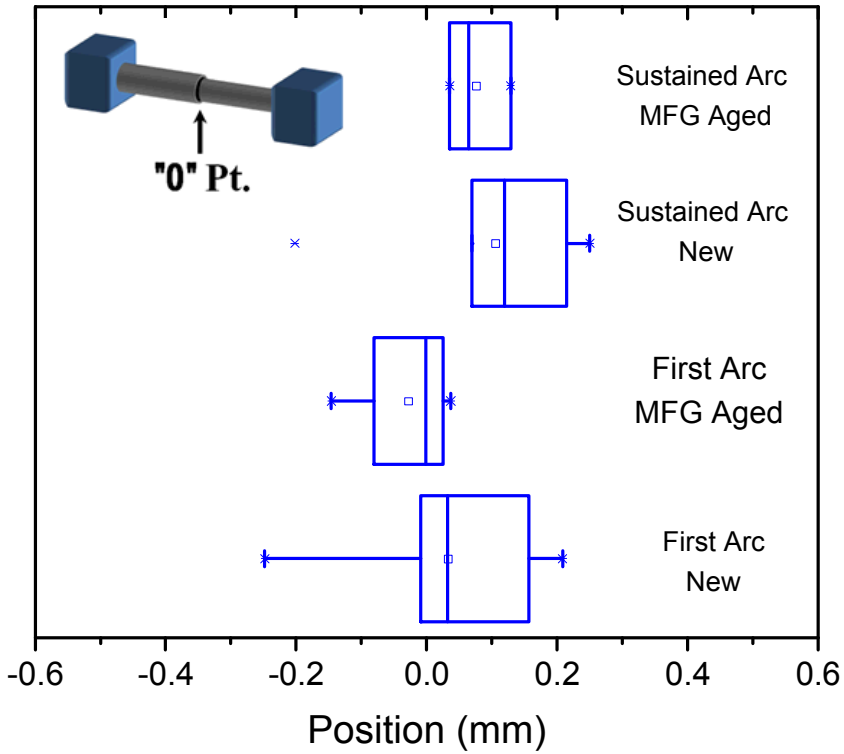


PV Simulator IV Curves



Arc Fault Separation Tests- Type1, MFG and New





- Joule heating of aged connectors
- No apparent difference in visually observed first and sustained arc as a function of position between new and aged

Effect of Corrosion On Arc Fault Risk Depends on Several Factors

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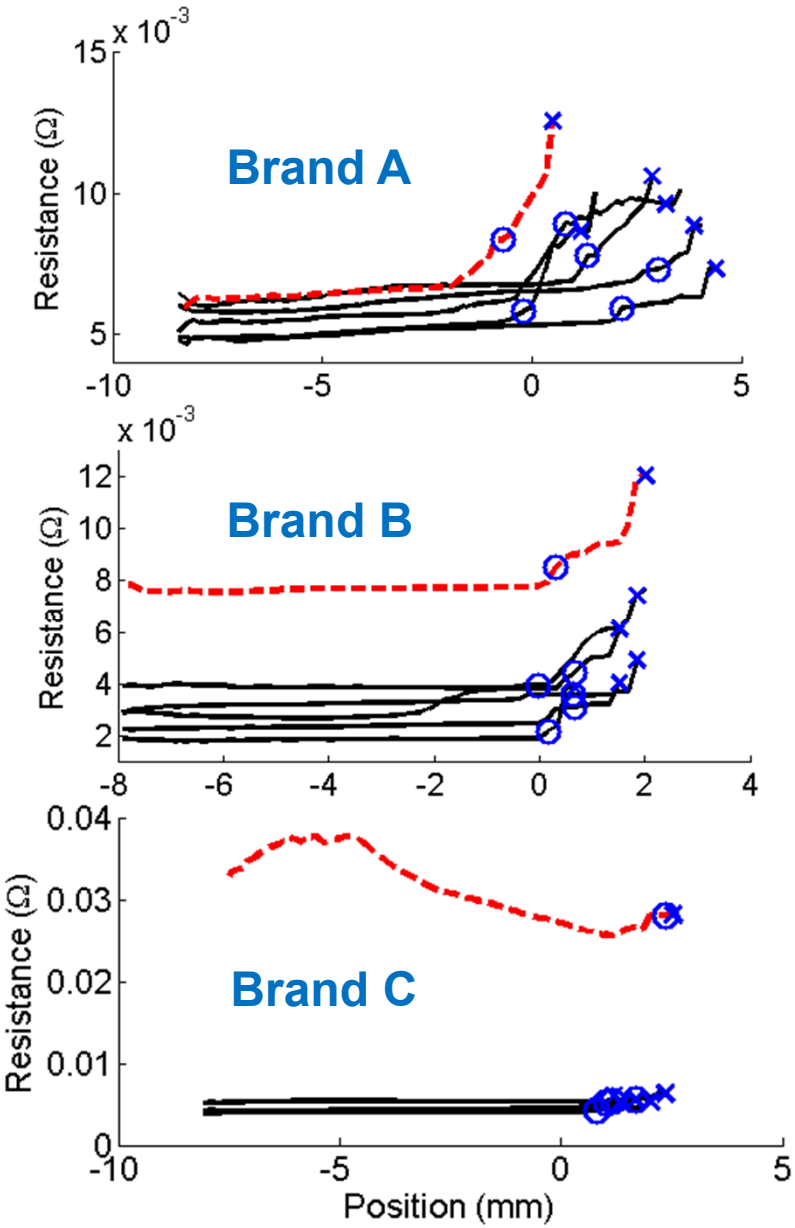
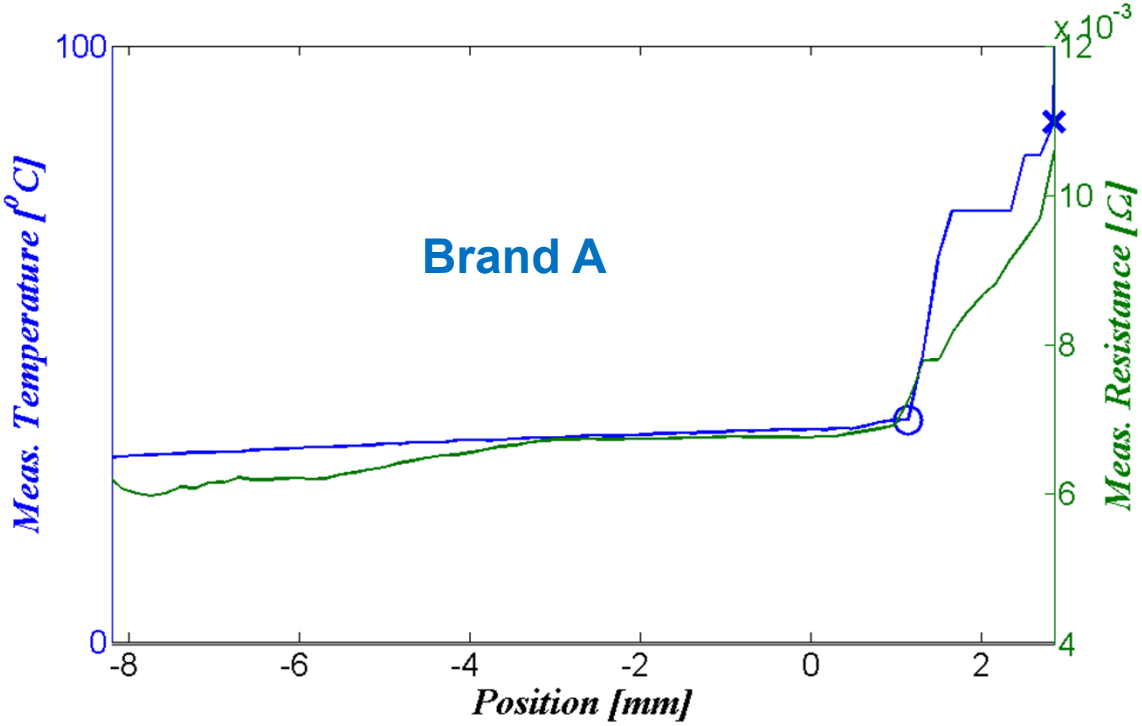


Legend:
- : degraded connector
- : fresh connector
- o : First observed spark
- x : Sustained arc

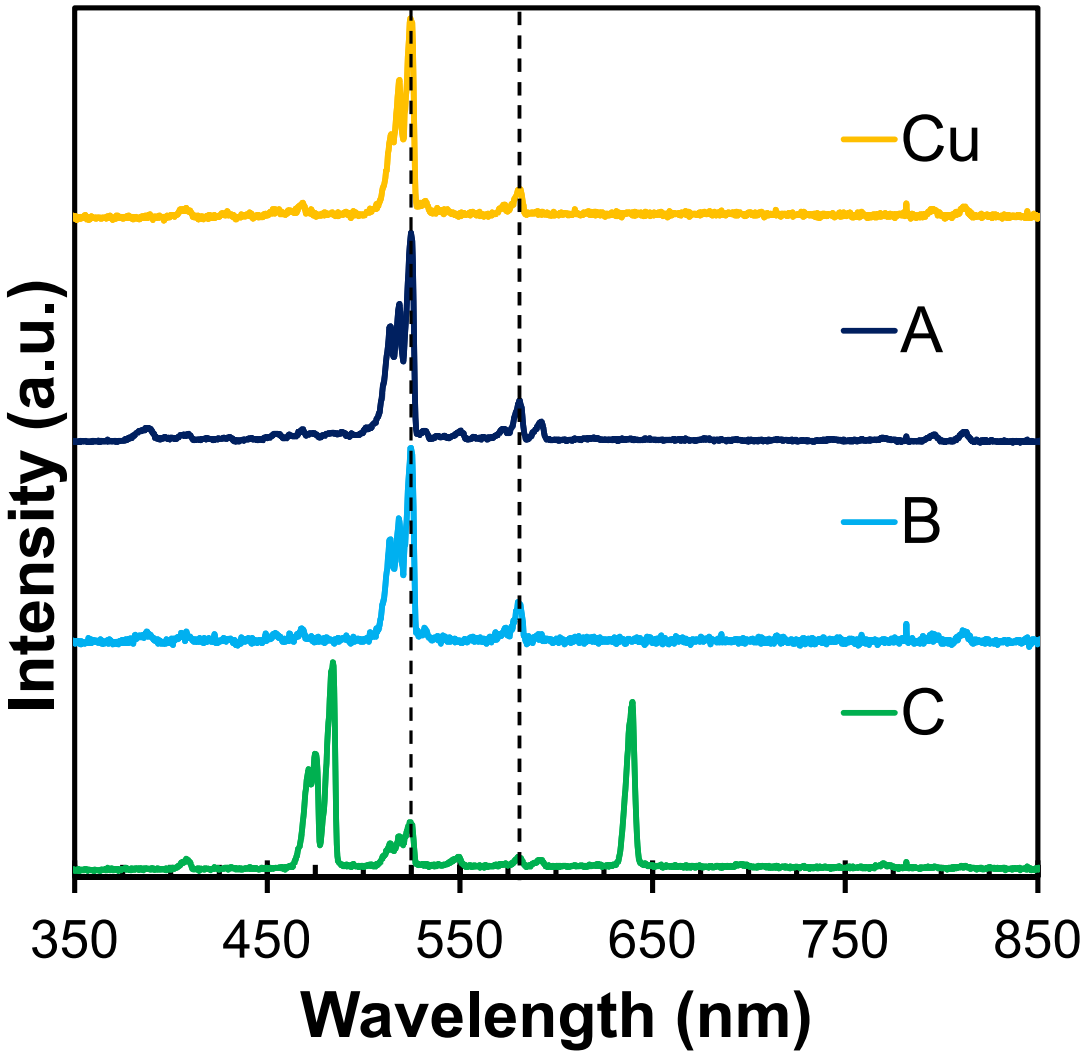
- Arc fault risk likely depends on materials and geometry:
  - **A:** Corrosion results in similar resistance but higher arc fault risk.
  - **B:** Corrosion results in higher resistance but minimal effect on arc fault risk.
  - **C:** Corrosion results in much higher resistance but lower arc fault risk.

Arc Fault Temperatures



- Temperature increases measurably between first spark and sustained arc.
- This phenomenon could be used for arc fault prognostic applications.

Arc Fault Spectra Can Provide Additional Useful Data



- Optical emission spectroscopy was used to evaluate the arc fault.
- Spectrum can identify connectors with similar composition (A and B) and those that don't (C).
- Can potentially measure material vs. depth and temperature.

Conclusions

- BOS connectors were found to be robust to corrosion-related accelerated tests.
- A procedure to evaluate arc fault risk of new and degraded connectors was developed.
- Outdoor exposure invoked considerably higher resistance increase at faster rates
- Performance disparity across connector designs may be linked to materials of construction - further work necessary
- Temperature and emission spectrum analysis can reveal additional information about the underlying degradation and arc fault processes.
- Joule heating due to corrosion was demonstrated to be potential issue for arcing.

Acknowledgements

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- Underwriters Laboratories

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Questions?