Characterizing Fire Danger From Low Power PV Arc-Faults

SAND2014-18427PE

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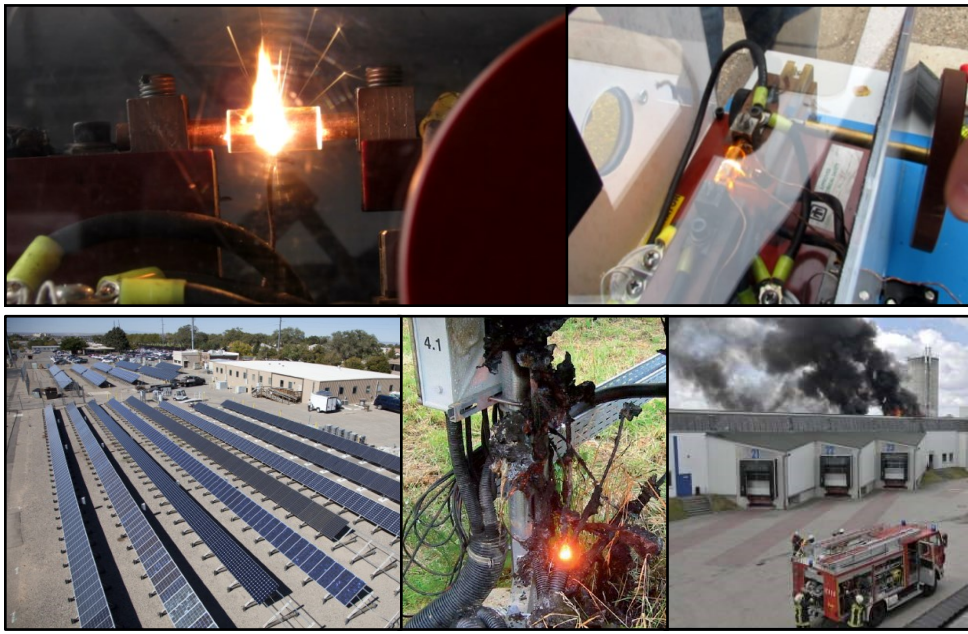

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Sandia National Laboratories, Albuquerque, NM

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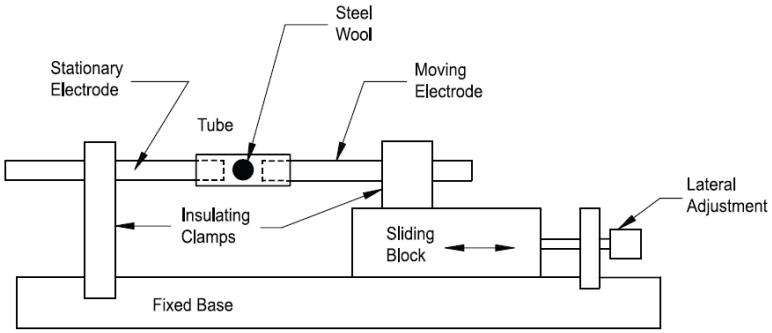
Arc-Fault Codes and Standards

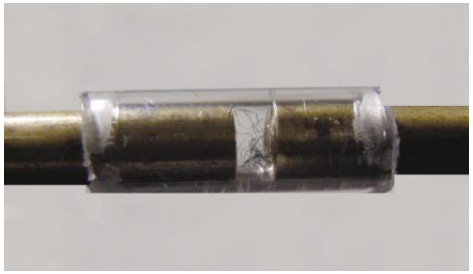
- *National Electrical Code® (NEC)* 690.11
  - 2011 *NEC* requires arc-fault mitigation for PV systems on/penetrating a building
  - 2014 *NEC* requires arc-fault mitigation for all PV systems

- Arc-fault circuit interrupters are listed using Underwriters Laboratories (UL) 1699B, "*Outline of Investigation for Photovoltaic (PV) DC Arc-Fault Circuit Protection*"
  - Not a standard yet! Needs to be improved and voted on by the UL Standards Technical Panel (STP) first.
  - To move UL 1699B to a certification standard, the outline of investigation must be improved.
  - The Sept 2013 STP meeting identified the following areas for development:
    - Arc-fault testing parameters (e.g., inclusion of ballast resistors, capacitors, etc.)
    - DC power supplies for PV simulation
    - Unwanted tripping tests
    - **Arc generation methods**

Arc-fault generation in UL 1699B

- Currently UL 1699B requires the arc to be created with a tuff of steel wool between the ¼” Cu electrodes
- Electrodes are set to a fixed gap
- 4 tests are required with arc powers between 300-900 W





Arc Powers

Trip Times

Arcing current (amps)[a, d]	Arcing voltage[b] (volts)	Average Arcing Watts [a]	Approximate electrode, inches (mm) [b]	Max time (sec) [c]
7	43	300	1/16 (1.6)	2
7	71	500	3/16 (4.8)	1.5
14	46	650	1/8 (3.2)	1.2
14	64	900	1/4 (6.4)	0.8

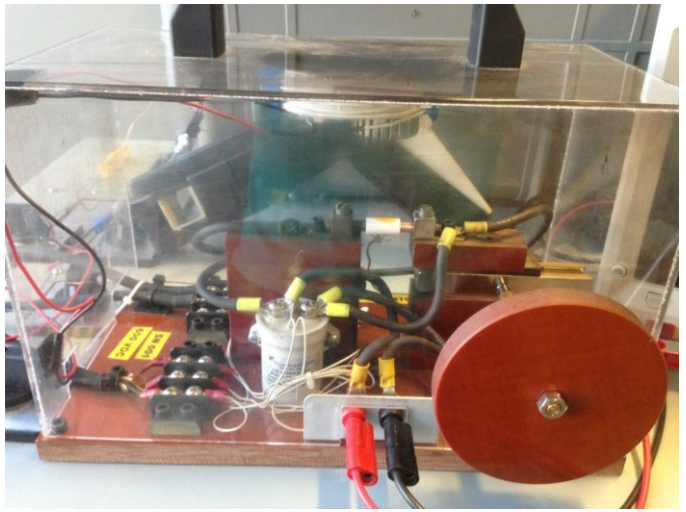
Arc Generation Research Goals

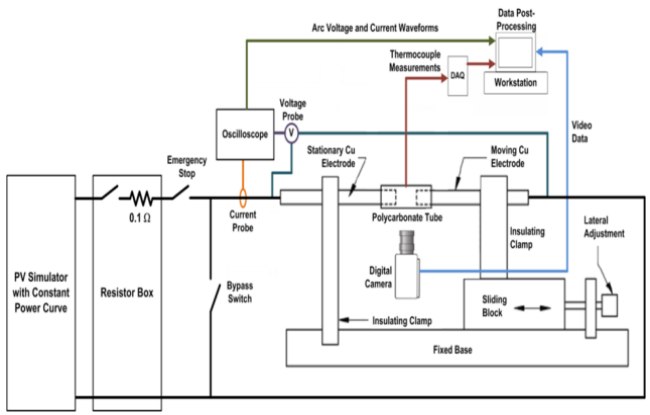
- **Primary Goal:**
  - Determine trip time for low power arc-faults
- **Secondary Goals**
  - Measure arc/sheath temperatures
  - Investigate chemical degradation

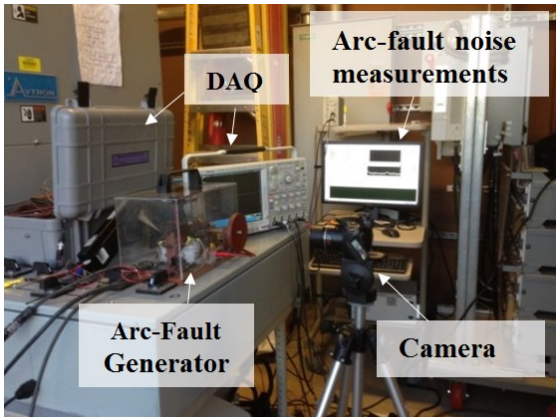
- **Findings:**
  - Results suggest a 16.1% and 22.9% decrease in combustion times for the 100 W and 300 W polycarbonate tests with an oxygen-ingress hole.
  - Electrode geometry can severely impact arc ignition time
  - The “pull-apart” method was found to be more reliable in facilitating stable arcs, however the inclusion of wire mesh according to UL1699B guidelines did facilitate lower ignition times.
  - Recommendations have been made to UL and a revised version of the UL1699B guidelines is underway.

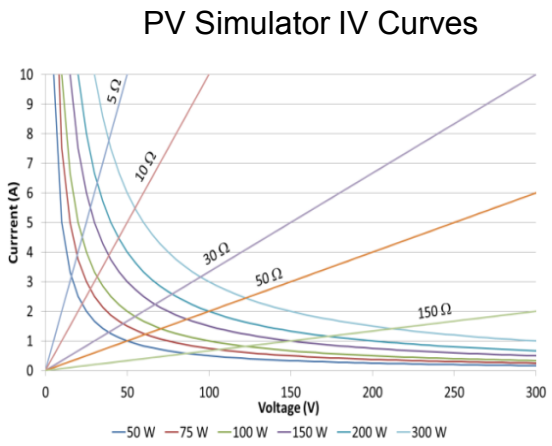
Experimental Setup

- Customized PV Simulator provided power to a developed Arc-Fault Generator.
  - A power resistor was employed to avoid shorting
- The curves programmed into the PV simulator were limited to 600 V and 15 A.
- Smoke detector, thermal measurements and high speed camera used for measuring ignition times.





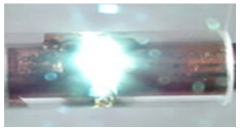




Alternative arc-fault generation methods

The following variables were parameterized:

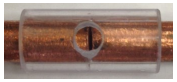
Arc Power



100 W

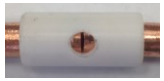
300 W

Sheath Material



Polycarbonate

PET



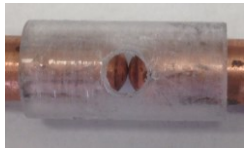
Nylon 6,6

Electrode Diameter

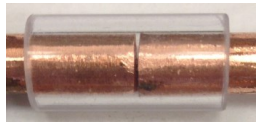
1/8 inch

1/4 inch

Electrode Tip

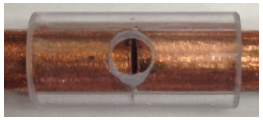


Rounded Tip

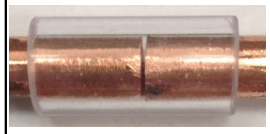


Flat Tip

Hole for O_2 Ingress

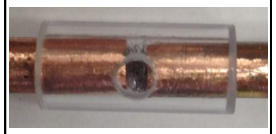


Hole

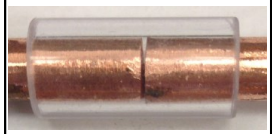


No Hole

Steel Wool Igniter



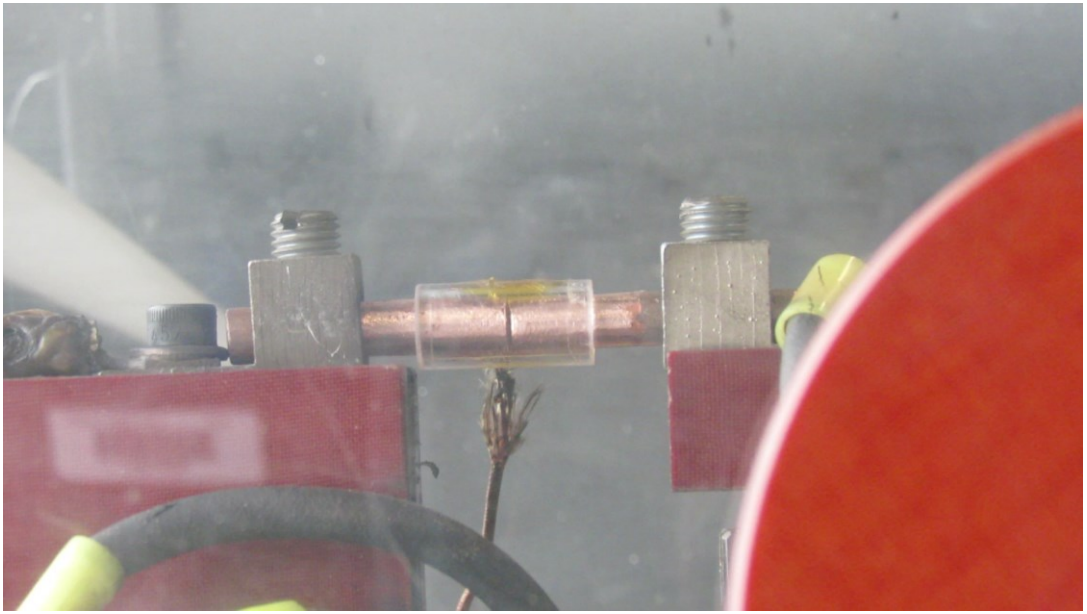
Steel Wool



No Steel Wool

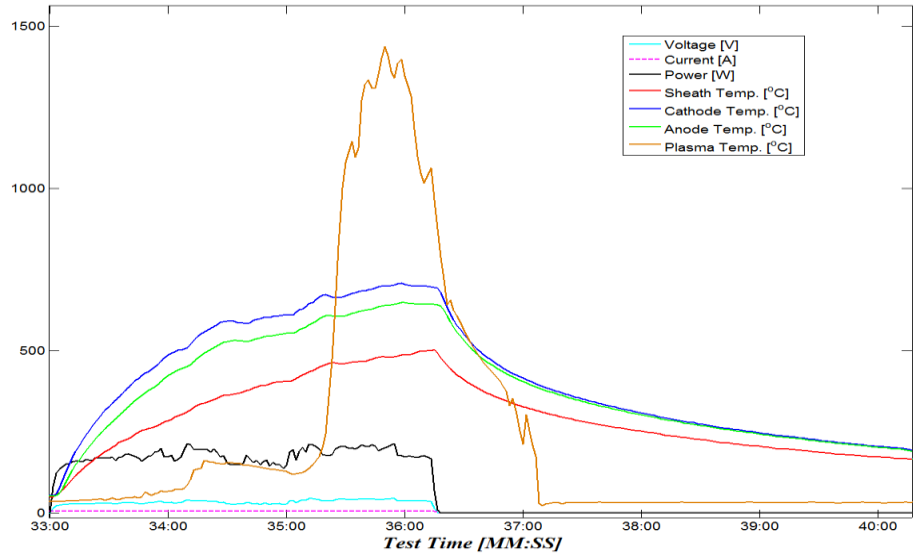
Test Number	Arc Power	Polymer	Electrode Diameter	Electrode Tip	Hole	Steel Wool
1 (UL 1699B)	300 W	Polycarbonate	1/4”	Flat	No	Yes
2	300 W	Polycarbonate	1/4”	Flat	Yes	Yes
3	300 W	Polycarbonate	1/4”	Flat	No	No
4	300 W	Polycarbonate	1/4”	Flat	Yes	No
5	300 W	PET	1/4”	Flat	Yes	No
6	300 W	Nylon 6,6	1/4”	Flat	Yes	No
7	100 W	Polycarbonate	1/4”	Flat	No	No
8	100 W	Polycarbonate	1/4”	Flat	Yes	No
9	100 W	Nylon 6,6	1/4”	Flat	No	No
10	100 W	Nylon 6,6	1/4”	Flat	Yes	No
11	100 W	PET	1/4”	Flat	No	No
12	100 W	PET	1/4”	Flat	Yes	No
13	100 W	Polycarbonate	1/4”	Round	Yes	No
14	100 W	Polycarbonate	1/8”	Flat	Yes	No
15	100 W	PET	1/8”	Flat	Yes	No
16	100 W	Nylon 6,6	1/8”	Flat	Yes	No
17	300 W	Polycarbonate	1/8”	Flat	Yes	No

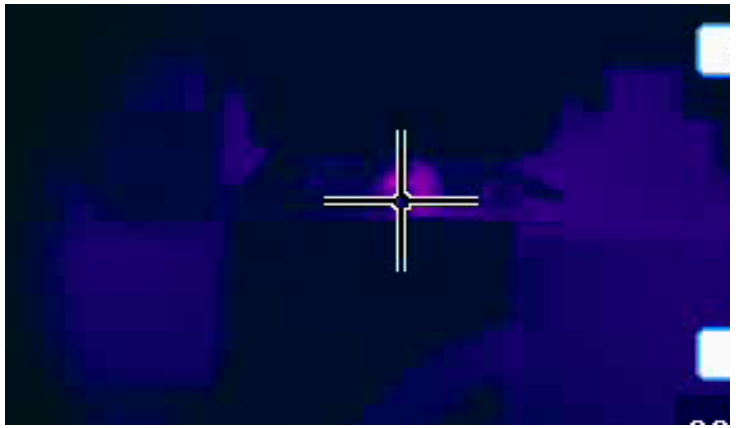
100W Arc-fault Test

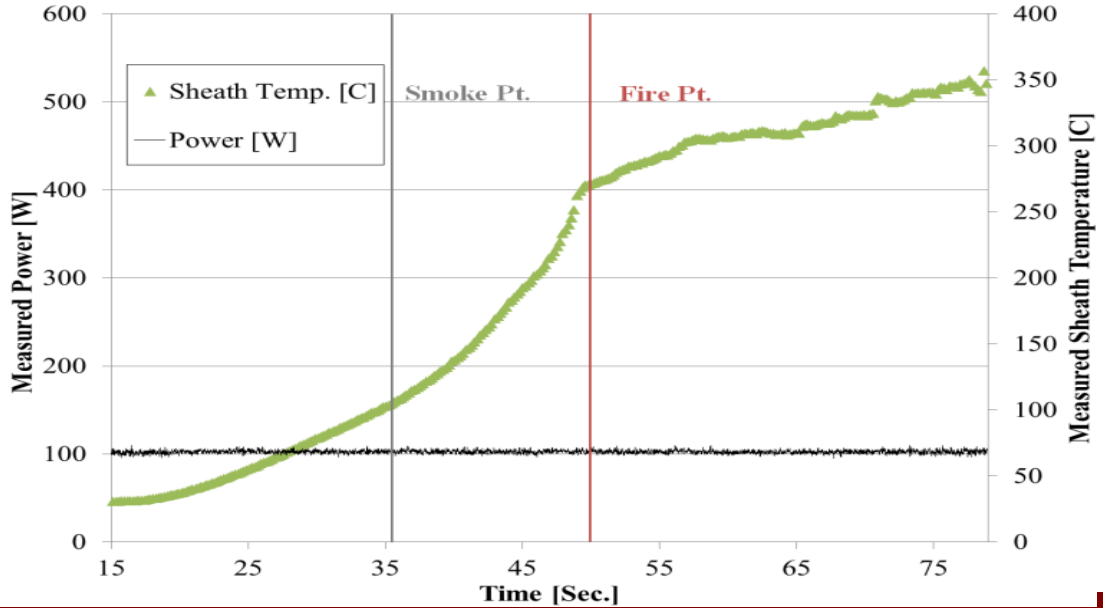


Polycarbonate tube with no hole. Possibly fire at 7.26 s, but no sustained external flame until after 92.04 s.

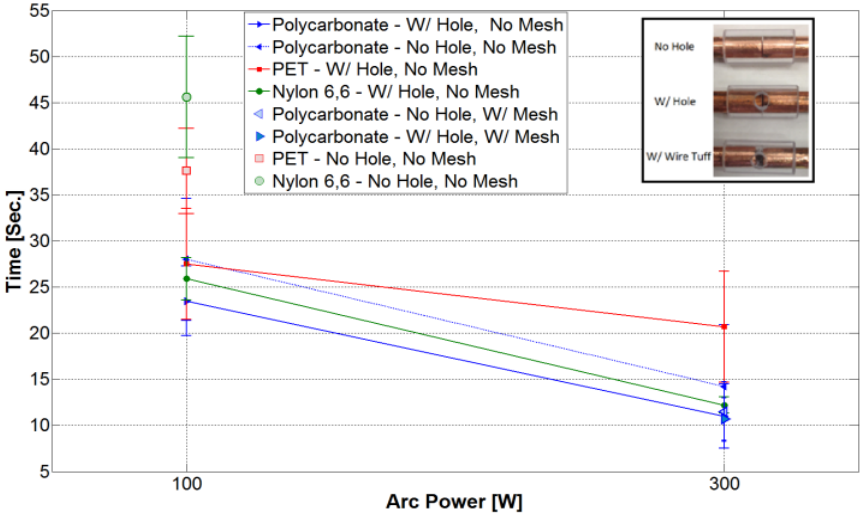
Arc Thermal Degradation Results

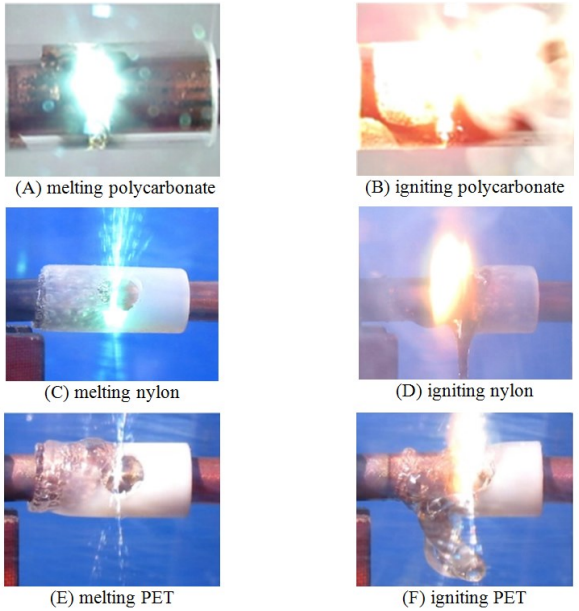


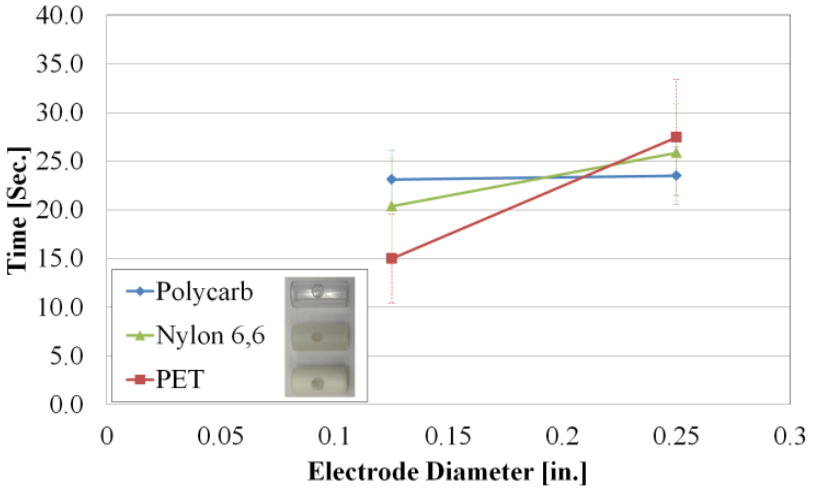


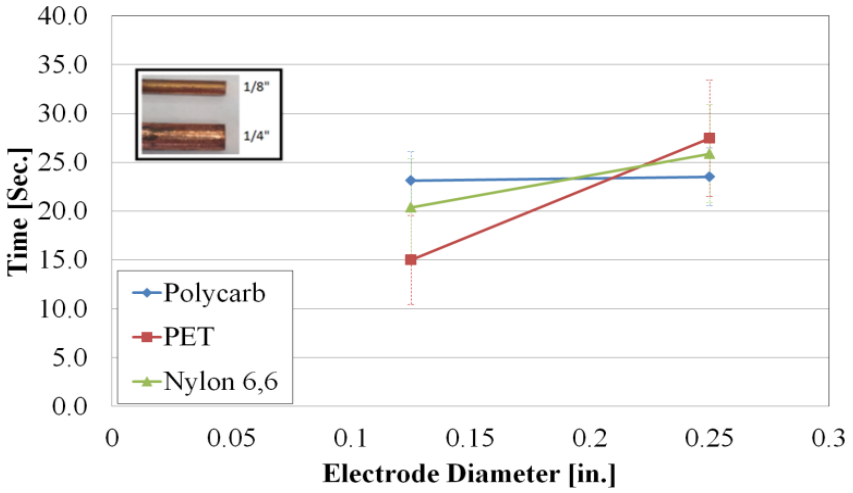


Arc Degradation Results



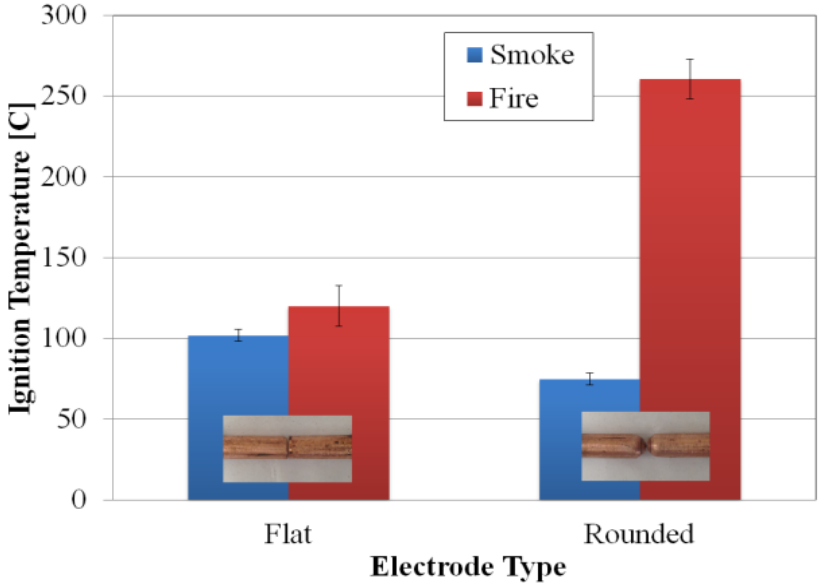


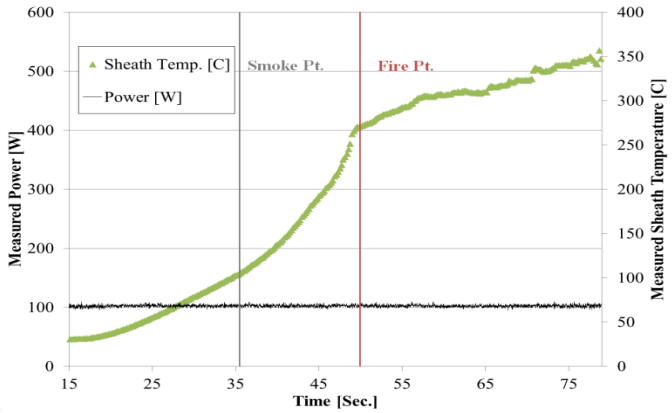


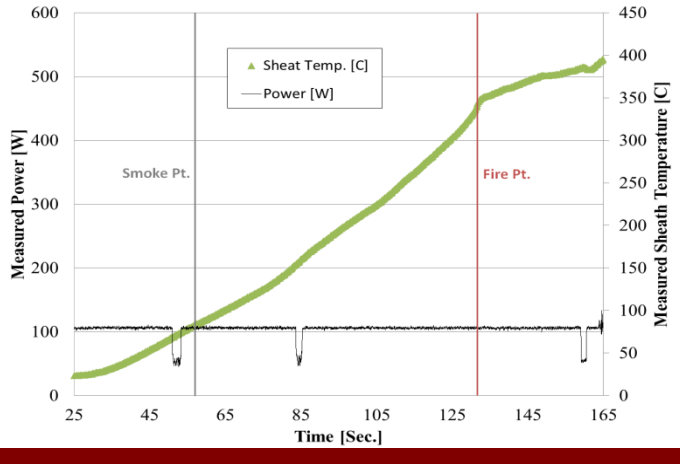


Rounded vs. Flat-Tip Electrodes

- Results found a 17.4% reduction in smoke ignition time, as well as a 26.6% decrease in measured smoke ignition sheath temperatures btw flat and rounded-tip electrodes respectively.
- Rounded-Tip Electrodes increased arc stability but had a lower occurrence of fires due to rapid melting.
  - Holes were included for these tests.

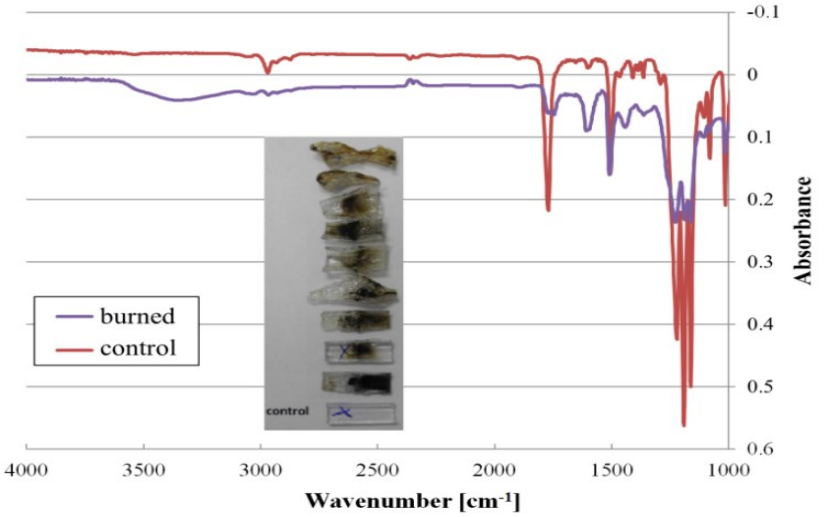


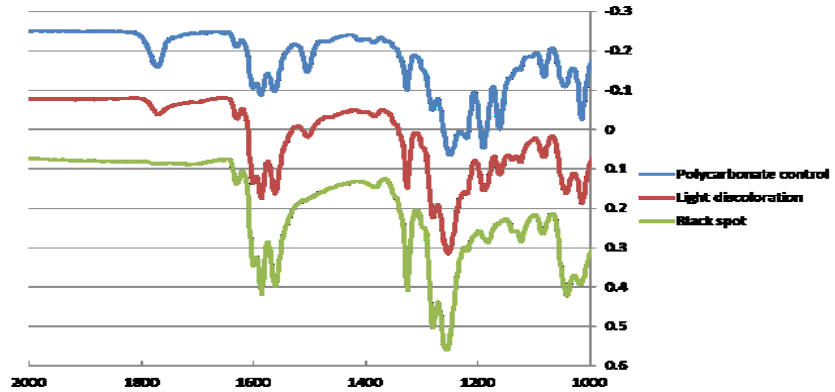


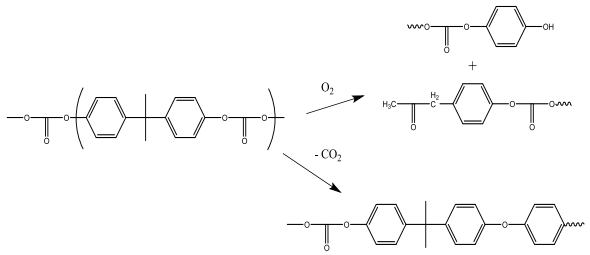


Chemical Degradation Mechanisms

- Chemical analysis showed oxidation reactions (combustion) occur during arc faults and changes in appearance of polymers are not due to just melting.
- Overall, results found similar spectral decomposition between respective grouped samples that experienced fire ignition.
- Some spectral evidence of increased oxidation of the polycarbonate sheaths over the PET and nylon samples were found.
  - This excessive degradation may explain lower ignition times found by polycarbonate sheath materials.







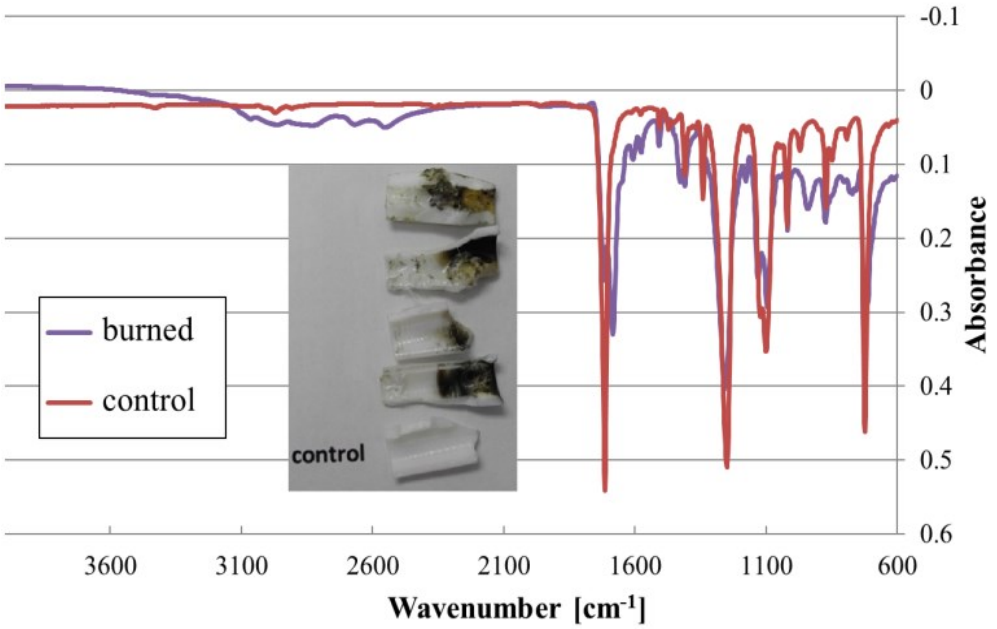
Conclusions

- A parametric study of various geometries, materials, and powers was conducted to determine repeatable arc-fault ignition qualification times and certification tests for UL 1699B.
- The results of this study have determined:
  - Low Power (>100W) arcs cause fires in polymers common to PV systems
  - A trip time of less than 2 seconds is recommended for the suppression of fire ignition during arc-faults.
  - Larger (1/4”) diameter electrodes: Had overall longer ignition times to the 1/8” diameter electrodes.
  - “Pull-apart” generation method (no steel wool): Increased arc stability, though longer ignition times
  - A hole in polymer sheath: Overall decreased ignition times, and greater arc stability.
  - Rounded electrode tips: Increased arc stability, however facilitated longer ignition times.
  - 300 W power: Much lower ignition times overall compared to the 100W arcs.
- Longer ignition times suggest that PET may have enhanced fire suppression over polycarbonate and even the Nylon 6,6 polymer, which is traditionally used in high temperature applications [Pandiyaraj et. al., 2010].
- Stay tuned for 1699B changes after the Sept 2014 STP meeting!

Acknowledgements

- Photovoltaics Solar Evaluation Laboratory
- Distributed Energy Generation Laboratory
- Department of Energy
- Underwriters Laboratory

Questions?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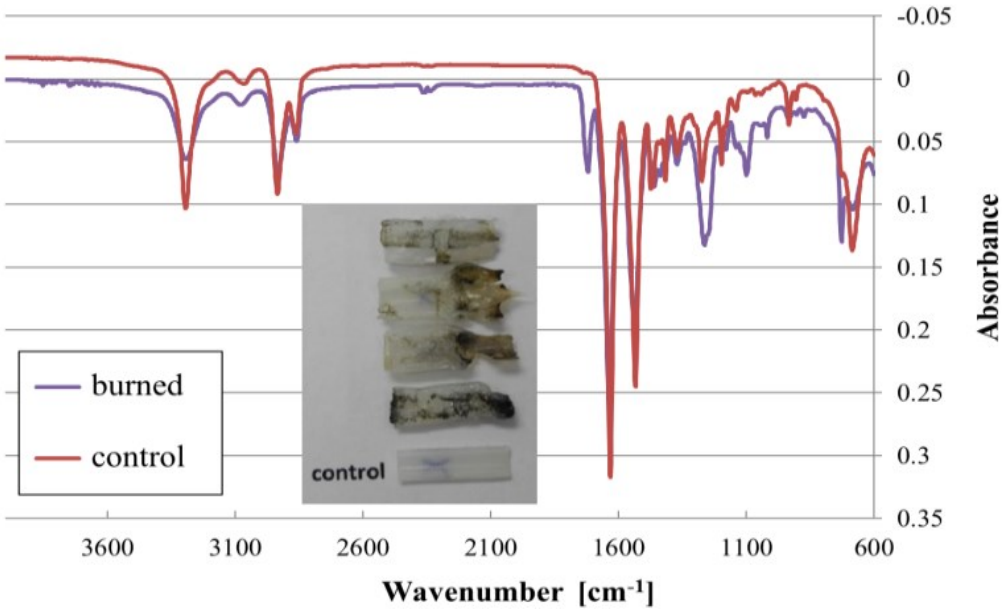
Wavenumber [cm-1]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Wavenumber [cm-1]