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Overview of Arc-Faults and Detection Challenges

Jay Johnson

Sandia National Labs

(505) 284-9586, jjohns2@sandia.gov

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Arcing in PV Systems

- **How are PV fires created?**
  - Discontinuities in the PV conduction path initiate electrical arcing
  - The arc creates a high temperature plasma which ignites surrounding materials
- **What are the dangers?**
  - Loss of property
  - Injury or death for building occupants, business owners, and firefighters
  - Reduced PV market penetration due to bad publicity for the PV industry
- **How prevalent is the problem?**
  - Difficult to quantify the number of PV-initiated fires
    - Solar companies do not publicize arcing events
    - No widespread reports on residential fires
    - Few documented fires - typically commercial installations
      - Buerstadt, Germany – Commercial building
      - Mont Soleil, Switzerland – 560 kW plant
      - Bakersfield, CA – Target store
- **What is being done about it?**
  - 2011 National Electric Code Article 690.11: Arc-Fault Circuit Protection (Direct Current)
    - 80 V or greater PV systems on or penetrating a building must have a listed Arc-Fault Circuit Interrupter
  - UL 1699B: Photovoltaic (PV) DC Arc-Fault Circuit Protection
    - Provides the Arc-Fault Circuit Interrupter (AFCI) testing methodology

Rooftop fire in Buerstadt, Germany.

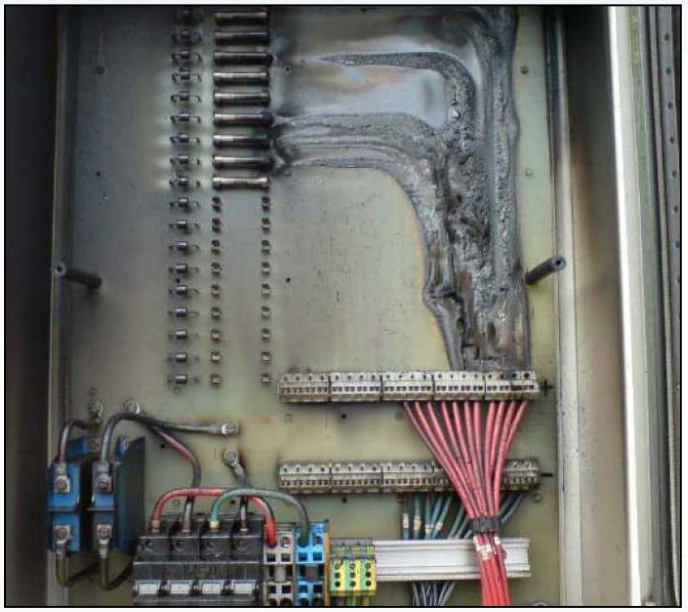
Arcing at the combiner box [1].

[1] Kremer, P. "Arcing potential in fuses: missing standards for adequate testing of fuses in PV application," International Workshop: Arcing in Photovoltaic DC-Arrays, Burgdorf, Switzerland, 8-31-2007,

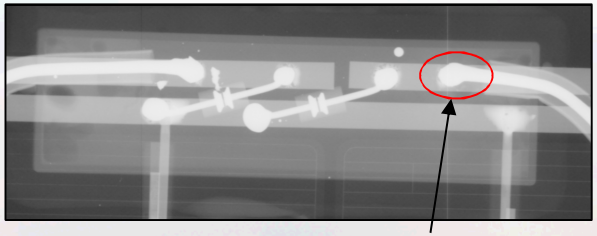
Arcing in PV Systems

- **Why are PV systems susceptible to arcing?**
  - PV systems have high DC voltages (600+ V)
  - No zero-crossing like AC systems – PV arcs do not self-extinguish
  - More systems are aging and exposed to wind, weather, rodents, trees, etc.
- **Where does arcing occur?**
  - Connections in the array
    - Fuses
    - Inter-module connectors
    - Inverters
  - Connections in the module
    - Junction boxes
    - Bypass diodes
    - Cell-to-cell connections
    - Cell-to-busbar connections

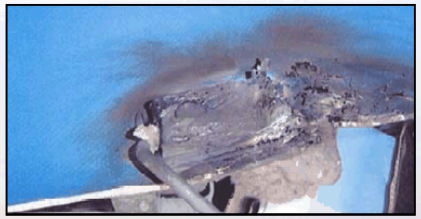
Burned Busbar [3]



Combiner box in Burgdorf [2]



Failed Bond in Junction Box

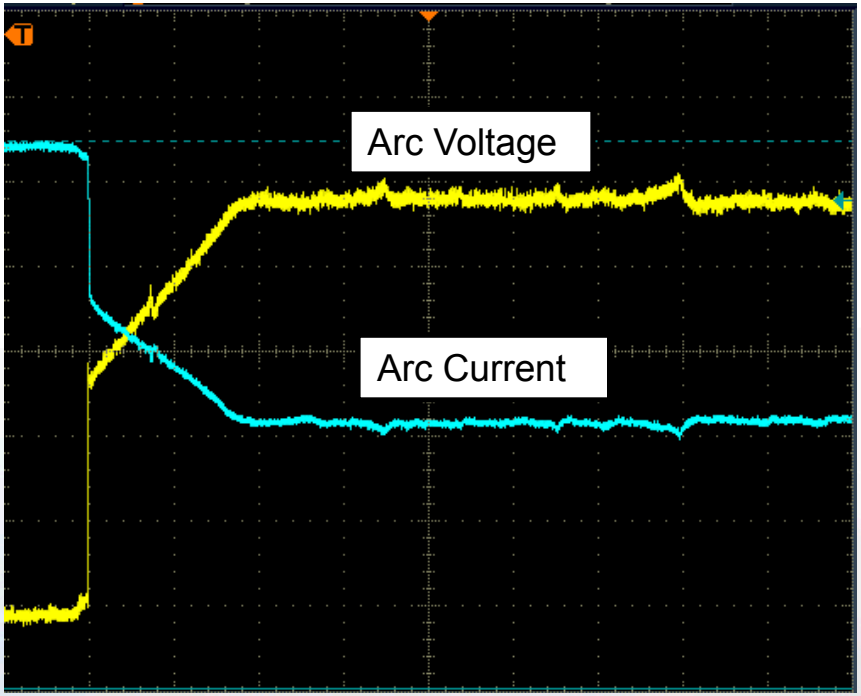


Destroyed Junction Box from Arc [2]

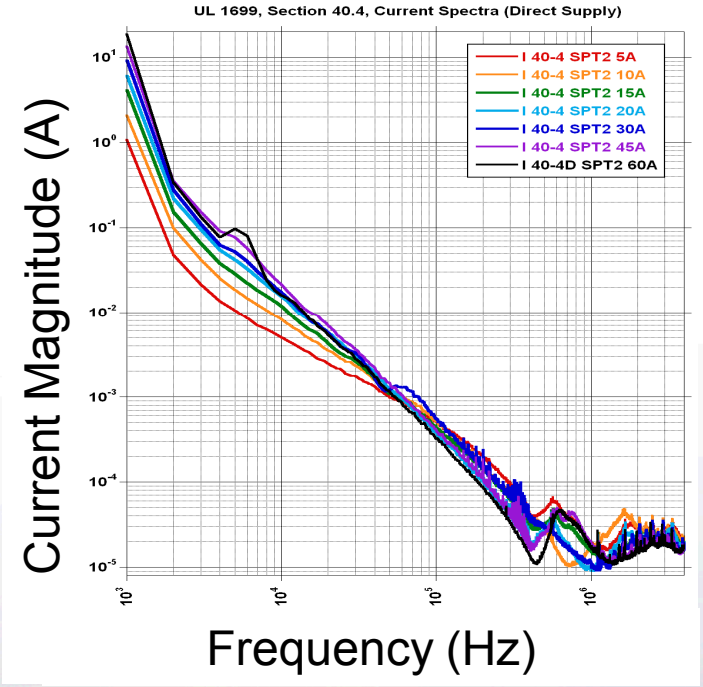
[2] Haeberlin, H. "Arc Detector for Remote Detection of Dangerous Arcs on the DC Side of PV Plants," International Workshop: Arcing in Photovoltaic DC-Arrays, Burgdorf, Switzerland, 8-31-2007.
[3] Cotterell, M. "Arcing potential within PV Module contacts and solutions," International Workshop: Arcing in Photovoltaic DC-Arrays, Burgdorf, Switzerland, 8-31-2007.

Electrical Arcing Behavior

- **What is the electrical behavior of an arc?**
  - In series arcs, voltage surges and current drops [4]
  - The arcing frequency content is approximately 1/f (pink) noise.



Series Arcing Behavior in Time Domain with Increasing Air Gap [4]



Arcing in Frequency Domain [5]

[4] Hastings, J. K., Zuercher, J.C. and Hetzmannseder, E., "Electrical Arcing and Material Ignition Levels," SAE 2004 World Congress & Exhibition, Detroit, MI, March 2004.
[5] Brazis, P. W. Jr., Private Transaction with Underwriters Laboratories.

Detection Difficulties

- **Many proposed AFCIs use frequency content of the string for detection**
- **Two challenges with remote arc detection**
  1. Missed or delayed detection due to filtering in PV components (e.g., modules, connectors, bypass diodes)
  2. Nuisance tripping due to noise from electromagnetic coupling (crosstalk), inverter switching, and radio frequency (RF) effects