**Background**

**MOTIVATION:** PV system arc faults have led to a number of rooftop fires which have caused significant property damage and threatened the safety of building occupants. In response, Article 690.11 was approved for the 2011 National Electrical Code® requiring new PV systems on or penetrating a building to include a listed arc fault protection device.

**Discovery:** Failing modules change frequency content transmitted by PV modules.

**Bad News: Arc Fault Signatures Can Be Masked from Arc Detectors**

Frequency-dependant attenuation through the intermittent module varies depending on the orientation of the external cable connected to the failed solder bond.

**Good News: Health Monitoring and Prognostics Opportunities**

Electrical intermittency is a precursor to arcing in PV systems, so frequency response analysis or impedance spectroscopy measurements could be used as a prognostic or health monitoring technique to identify conditions which lead to arc faults.

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**The Bad: Arc Fault Signal is Attenuated by Damaged Modules**

1. An arc fault initiates at a connection in a module and generates AC noise on the PV string. This signal travels down the line through the PV system.
2. As the signal passes through the modules and connectors, some of the frequency content of the electrical AC arc noise may be attenuated. (Focus of this study.)
3. Depending on the system line lengths, antenna effects and other RF phenomena, the spectral content of the arc signature will change.
4. The modified arcing signal reaches the arc fault detector within the arc fault circuit interrupter. Detection of either the current or voltage content could be performed by the AFCI. Depending on the cell technology, system topology, meteorological conditions, and health of the modules, the signal reaching the AFCI will be different than the original arcing signal—possibly allowing an arcing condition to go undetected.
5. Inverter switching generates additional noise in the system at a few kHz to 100 kHz.

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**Conclusions**

- The module electrical response changed based on the connection quality of a failed solder bond in the junction box.
- Four orientations of the junction box wire were tested and produced different frequency responses.
- Frequency-dependent attenuation in PV strings could have severe consequences because AC filtering may mask the arc fault signature from arc fault circuit interrupters.
- Unfortunately, conditions which cause arcs—i.e., discontinuities in the electrical conductors—are also responsible for AC attenuation on the line.

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**The Good: Impedance Spectroscopy and Frequency Responses Identify Arc Fault Conditions**

- Impedance spectroscopy, resistance or reactance health monitoring and prognostics could indicate degraded strings or modules before they initiate an arc fault.
- While the module attenuation is a challenge for arc fault detectors, the frequency response changes could be used to identify module damage prior to catastrophic failure.

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**PLOT 1:** Frequency response of a single intermittent module for different orientations of the bad junction box wire.

**PLOT 2:** The AC frequency content of the arcing detector is affected by the intermittent module for orientations 1, 3, and 4 of the damaged junction box wire.

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**Conclusion:**

- Impedance spectroscopy results for four different orientations of the bad junction box wire. Orientation 2 is typical of healthy modules.

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**CHARACTERIZING PV ARCING CONDITIONS WITH IMPEDANCE SPECTROSCOPY AND FREQUENCY RESPONSE ANALYSIS**

Jay Johnson, Jason Strauch, Scott Kusznmaul, Ward Bower, David Schoenwald - Sandia National Laboratories

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**Connection intermittency attenuates arc fault signatures. Arc fault conditions can be detected with frequency response analysis and impedance spectroscopy.**