CHARACTERIZING PV ARCING CONDITIONS WITH IMPEDANCE SPECTROSCOPY AND FREQUENCY RESPONSE ANALYSIS

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

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**.

Arcing at the combiner box.

PV arc fault-initiated fire on a warehouse in Buerstadt, Germany.

Discoloration indicating arcing at the busbar and collector ribbon.

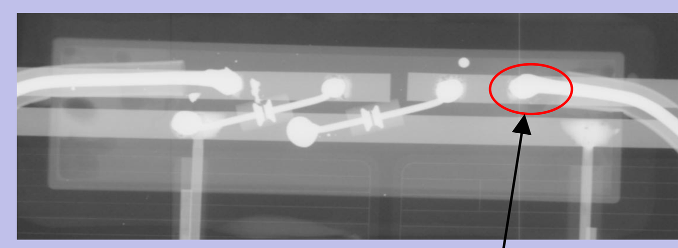
Discovery: Failing modules change frequency content transmitted by PV modules.

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.

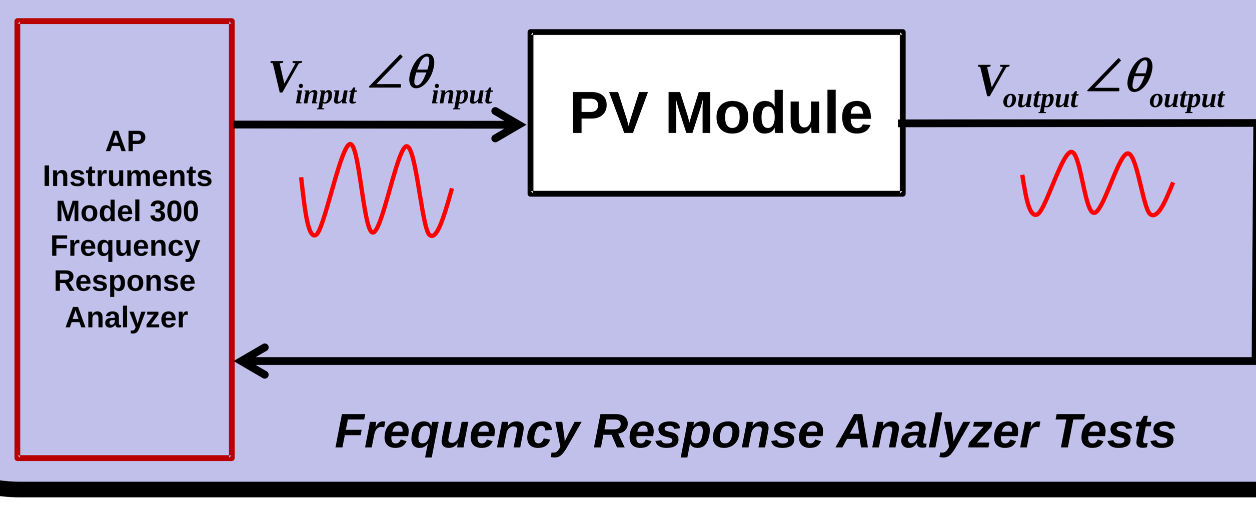
Experimentation

PURPOSE: Sandia National Laboratories is investigating the effect of module degradation on string arcing frequency content. For this study, the arc fault frequency characteristics through an intermittent 80 W polycrystalline Si module are investigated. The intermittent module failed from a solder joint in the junction box.



Failed Bond in Junction Box

PROCEDURE: The AC response and impedance of an intermittent 80 W polycrystalline Si module under no irradiance was measured with a Frequency Response Analyzer. The input signal was swept from 1 Hz to 10 MHz at 250 mV AC. The attenuation of the AC signal was determined by V_{output}/V_{input} for each frequency.



Frequency Response Analyzer Tests

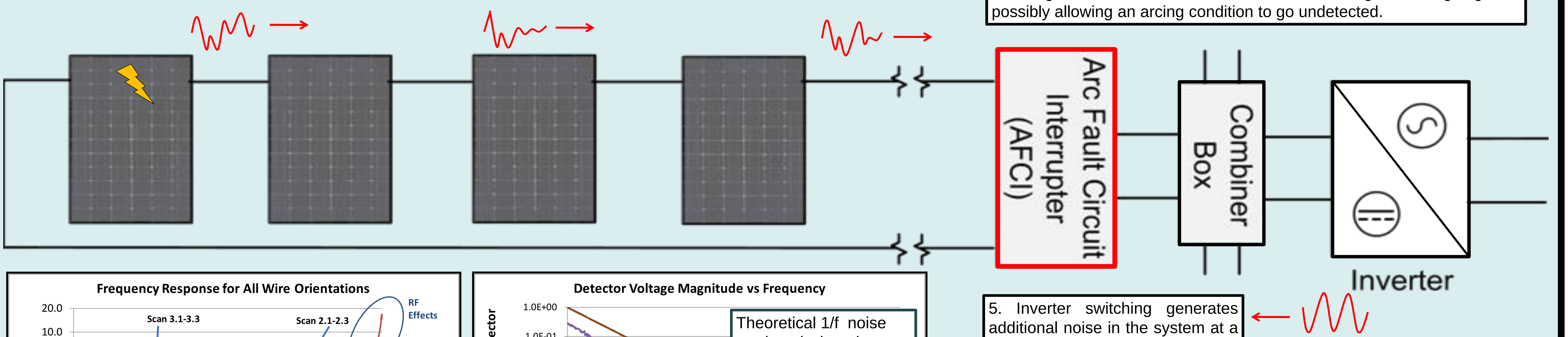
The Bad: Arc Fault Signal is Attenuated by Damaged Modules

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.

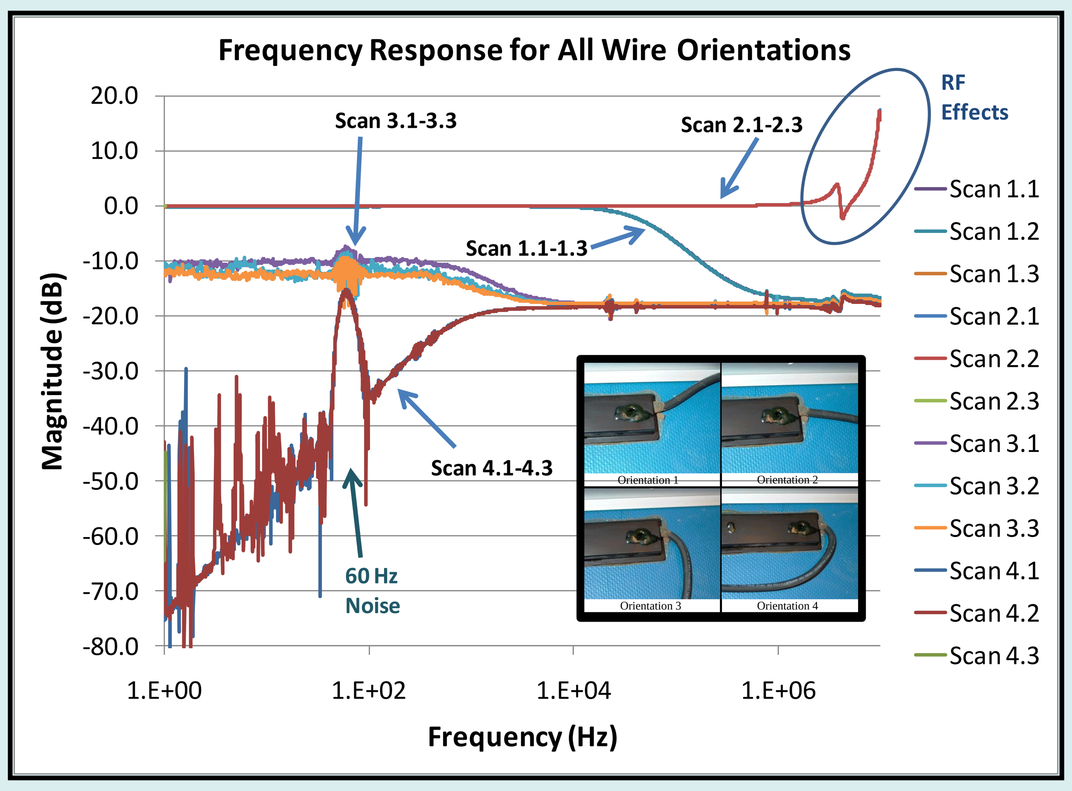
2. As the signal passes through the modules and connectors, some of the frequency content of the electrical AC arc noise may be attenuated. **(Focus of this study.)**

3. Depending on the system line lengths, antenna effects and other RF phenomena, the spectral content of the arc signature will change.

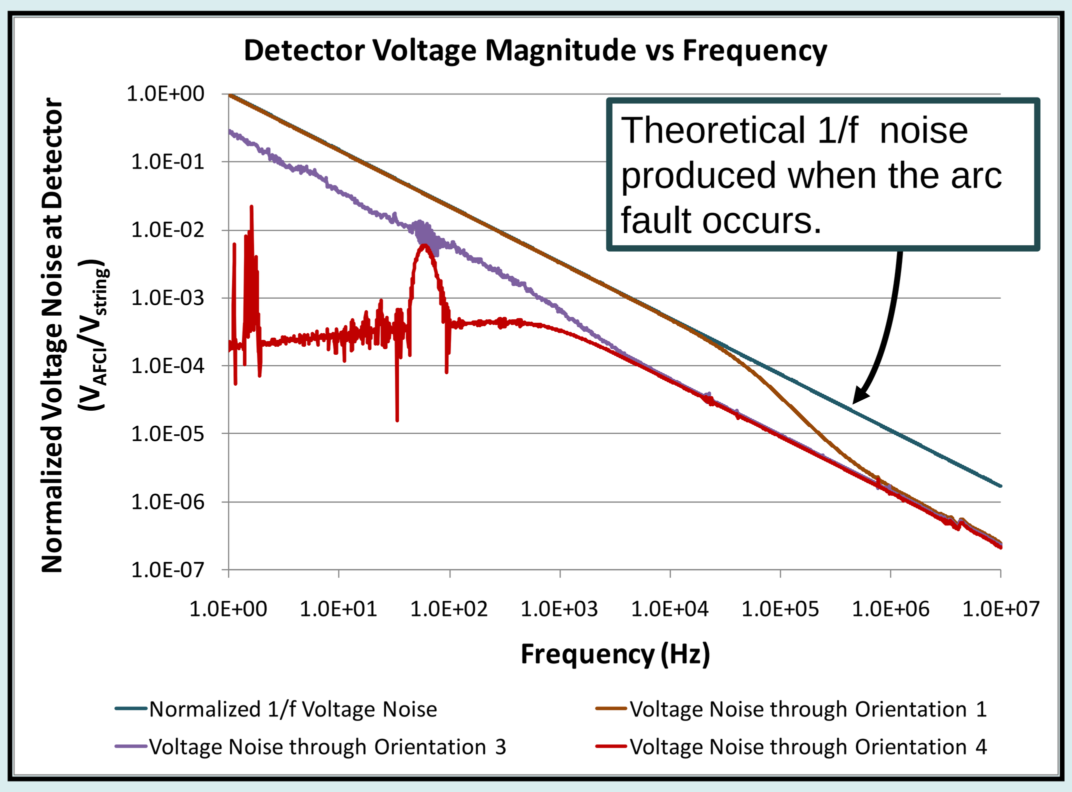
4. The modified arcing signal reaches the arc fault detector within the arc fault circuit interrupter. Detection of either the current or voltage content can be performed by the AFCI. Depending on the cell technology, system topology, meteorological conditions, and health of the modules, the signal reaching 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.



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

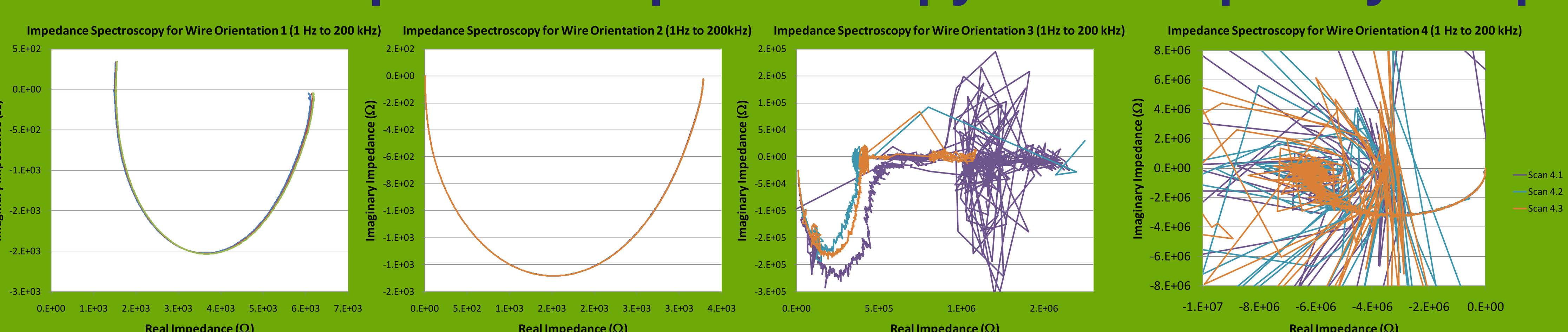


The AC frequency content of the arc reaching the detector is affected by the intermittent module for orientations 1, 3, and 4 of the damaged junction box wire.

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.

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



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

Conclusions

- 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.

National Nuclear Security Administration

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.
This work was funded by the US Department of Energy Solar Energy Technologies Program.

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