Fire Safety Issues (Arc-fault Issues)

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Solar ABCs Stakeholder Meeting

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Acknowledgements

2011 NEC Changes for PV

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Introduction

- What is an “Arc-fault”
- What is done for other (ac) systems
- The emerging codes and standards for PV
- Overview of technical challenges
- Technical developments underway
- Summary

Arc Fault Detection and Standards in Non-PV Applications

- AC Arc Fault Detection for Dwelling Electrical Systems (60Hz, 80-600V)
  - Def: A DEVICE intended to provide protection from the effects of arc faults by recognizing characteristics unique to arcing and by functioning to de-energize the circuit when an arc fault is detected.
  - Required beginning in 1999 via *NEC* Article 210.12 (Arc-fault Circuit Interrupter Protection), 550.25 (Mobile Homes)
  - Devices listed for safety through UL Standard 1699
- Aircraft (400Hz)
  - Hardware and diagnostics are commercially available and in use
  - Technologies tested include: Frequency Signatures, Time Domain Reflectometry, Frequency Domain Reflectometry, Multi-carrier Reflectrometry, Standing Wave Reflectometry, Noise Domain Reflectometry, Spread Spectrum TDR…
- Automotive (Low Voltage dc)

National Electrical Code DC Arc-fault Changes

The new 2011 NEC

New arc-fault requirements for dc PV circuits

- **Article 690.11** (New)
  - **Written to detect and interrupt "series" arc-faults in modules, connections, wiring, and other components**
  - **Requires inverters, charge controllers or other devices in the arcing circuit to be disconnected and disabled**
  - **Requires manual resets and reconnects once an arc is detected and fixed**

NEC ARC FAULT DETECTION REQUIREMENT 690.11 (NEW)

690.11 Arc-Fault Circuit Protection (direct current): Photovoltaic systems with dc source circuits, dc output circuits, or both, on or penetrating a building operating at a PV system maximum system voltage of 80 volts or greater, shall be protected by a listed (dc) arc-fault circuit interrupter, PV type, or other system components listed to provide equivalent protection. The PV arc-fault protection means shall comply with the following requirements:

(1) The system shall detect and interrupt arcing faults resulting from a failure in the intended continuity of a conductor, connection, module, or other system component in the dc PV source and output circuits.
(2) The system shall disable or disconnect one of the following:
  a. Inverters or charge controllers connected to the fault circuit when the fault is detected.
  b. System components within the arcing circuit.
(3) The system shall require that the disabled or disconnected equipment be manually restarted.
(4) The system shall have an enunciator that provides a visual indication that the circuit interrupter has operated. This indication shall not reset automatically.

Underwriters Lab PV DC AFCI Standard

SUBJECT 1699B

DRAFT

OUTLINE OF INVESTIGATION FOR PHOTOVOLTAIC (PV) DC ARC-FAULT CIRCUIT-INTERRUPTERS

version May 12, 2010

PURPOSE & STATUS

- **Requirements for Arc Fault Circuit Interrupter Devices**
  - ➢Written for new 2011 *NEC* compliance
  - ➢Uses ac arc-fault circuit interrupter standard for mechanical/device safety tests
- **Draft under development via UL/industry/user committee**
- **Effective date TBD (Next Meeting Nov 30, Dec 1, 2010)**

AC AFCI breaker

Technology Challenges for AF Detectors

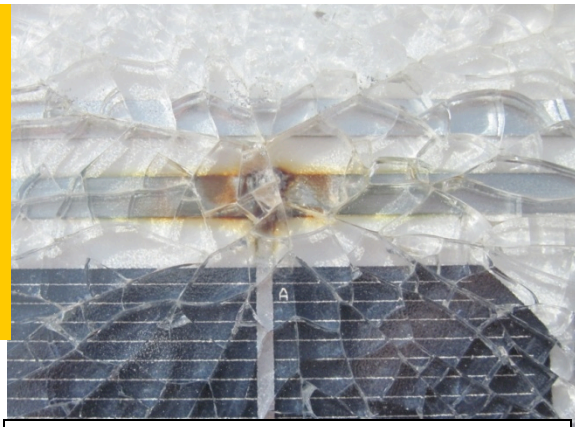
- Unequal sizing and distributions of parallel PV strings
  - Loop inductance and stray capacitance of wiring and PV modules
  - System communications signals (conducted and radiated), noise
  - PV string combiners (smart and future)
- Detection Spatiality
  - At the inverter, between inverter to array, within array, in module, etc.
  - PV string combiners with isolation and MPPT functionalities (dc-dc)
  - PV string combiners with communications and switching functions
- Arc-fault frequency signatures and characteristics response affected by materials and PV module technology
  - Thin film, crystalline, multi-junction, slivers, etc
  - Conductors, terminal compositions, insulation types, humidity
- Inverter topology interaction with PV array and BOS
  - Input capacitance, EMI filters, switching noise, spurious noise
  - Anti-islanding and MPPT perturbations
  - Backfeeding and Transformerless (non-isolated) inverter topologies

Sandia Arc-fault Modeling

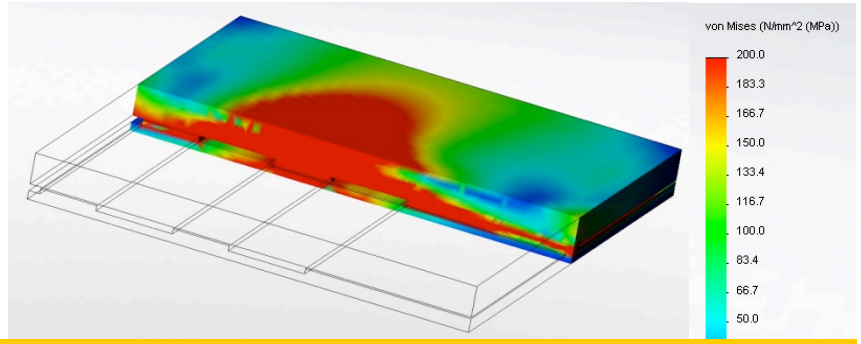
- **Sandia has developed a physics-based simulation model of a general solar module with full geometric and material details. Model based on one module, but is adaptable to other designs and types of modules.**

- **Model has been validated by confirming arc faults were the cause of a number of module failures: glass breakage, busbar deformation and EVA/ backsheet burning.**

Picture of failed module glass breakage shows radial pattern centered at arc burn



Module glass breakage modeling



Close up view of glass and busbar junction stress after 2 seconds of arcing on the ~½ mm^2 connection. Patterned and tempered glass likely shatters at about 100 MPa of tensile stress.

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Solar America Board for Codes and Standards

Detection and Mitigation?

- System Level
  - Detect (now at inverter)
  - Determine arc location
  - Interrupt circuit (faulted circuit or entire array) (AC PV Modules?)
  - Mitigate (likely manual)
- Module Level
  - Detect, locate, isolate
  - Prevent by design (i.e. materials, circuit designs, dc-dc converters)
  - Eliminate by design (integrated mechanisms and techniques)

Summary [Challenges & Opportunities]

Arc-faults Cause Fires

- Arc-faults Have Been Observed/Reported in:
  - PV modules
  - J-boxes
  - Conductors
  - Connectors
- Studies are underway and products may emerge this year

Codes and Standards for PV are Emerging

- National Electrical Code
  - Article 690.11 (PV)
  - Article 210.12 (ac) (fyi)
- UL1699B in Progress
  - PV Standards Development
  - Collaborative and Independent Testing
  - Modeling and Arc Analysis
- International Collaboration