Ground Fault Detection "Blind Spot" Study: Field Test Results

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Solar ABCs GFDI Webinar

May 2, 2013

Solar America Board for Codes and Standards

Field Test Program Overview

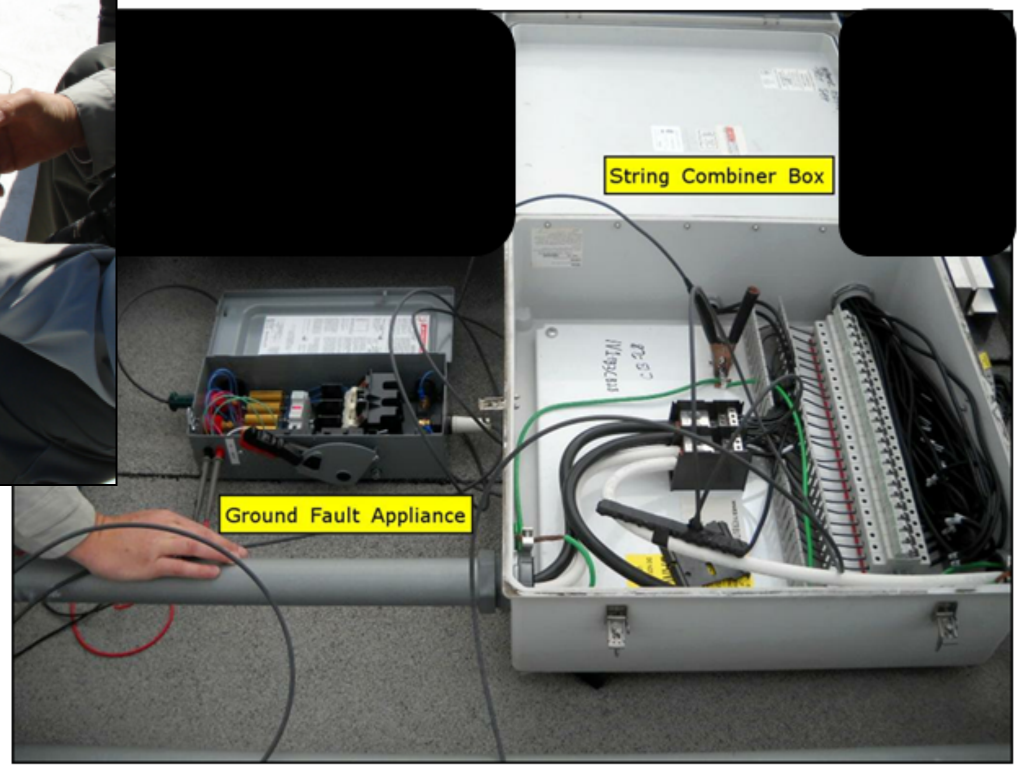
- Sites selection criteria (in order of decreasing importance):
  - Variety of inverter types
  - Rooftop and ground mount
  - c-Si and thin film
  - Geographic/climate variety

- Tests conducted:
  - Megger conductors and array to check for existing faults
  - Use differential current device to measure background DC leakage current
  - Measure the impedance of a typical array's Equipment Grounding Conductor
  - Use oscilloscope to characterize AC component in ground connection
  - Introduce controlled ground faults to characterize fault current and detection capabilities

- Tests performed at the following sites:
  - Sandia National Laboratories ,Albuquerque, NM (March 2012)
  - Fontana, CA (May 2012)
  - Union City, CA and Fresno, CA (June 2012)
  - Solar ABCs gratefully acknowledge the support of Duke Energy, Southern California Edison, and SunPower Corp. with the field testing program

Ground-fault test equipment

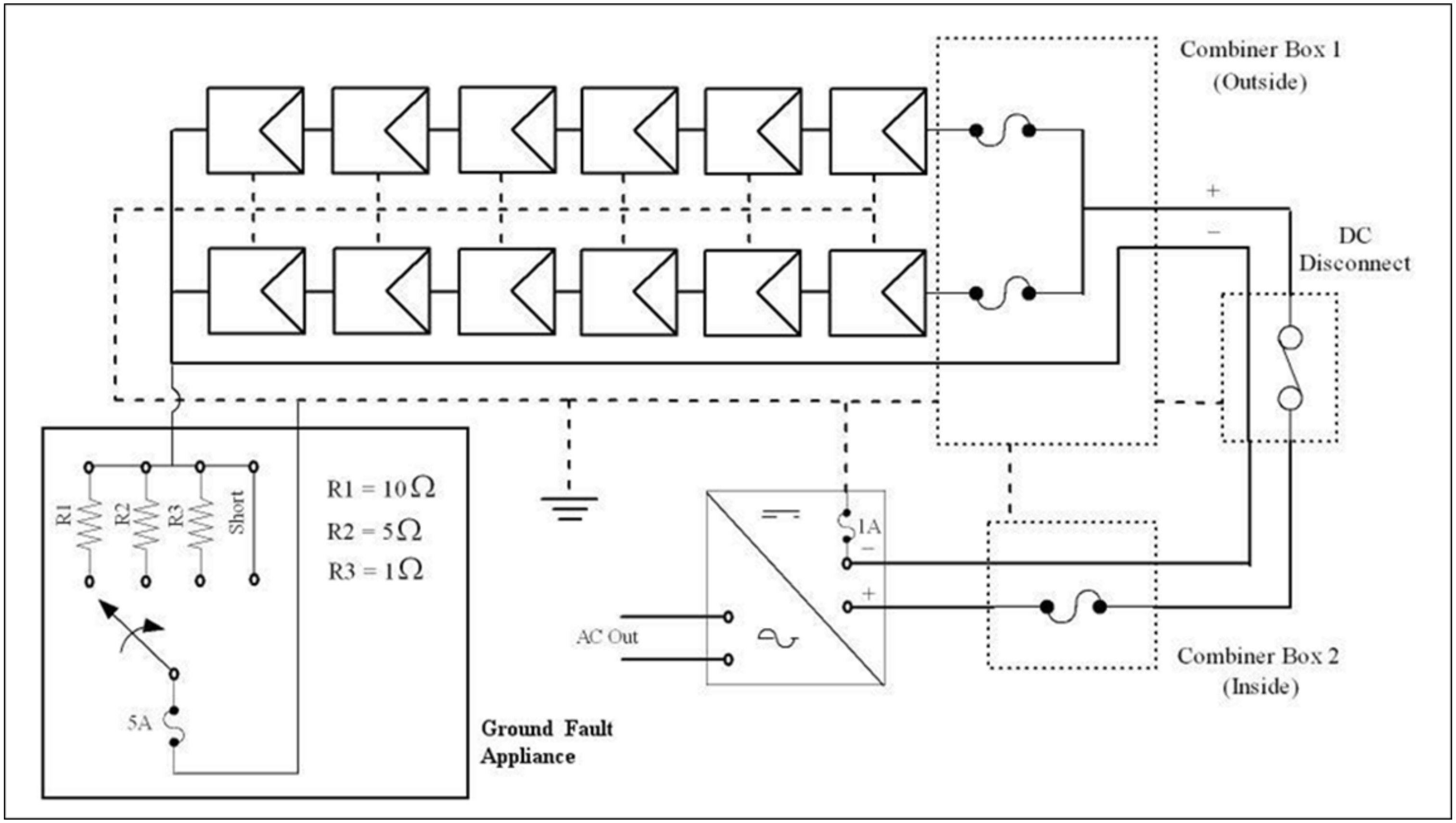
Ground-Fault Tester
10, 5, 1 and 0 Ω settings



Megger testing of cables
with and without modules
in circuit. 50 and 500 V settings.

Field schematic for introducing ground faults

Simulates blind-spot fault



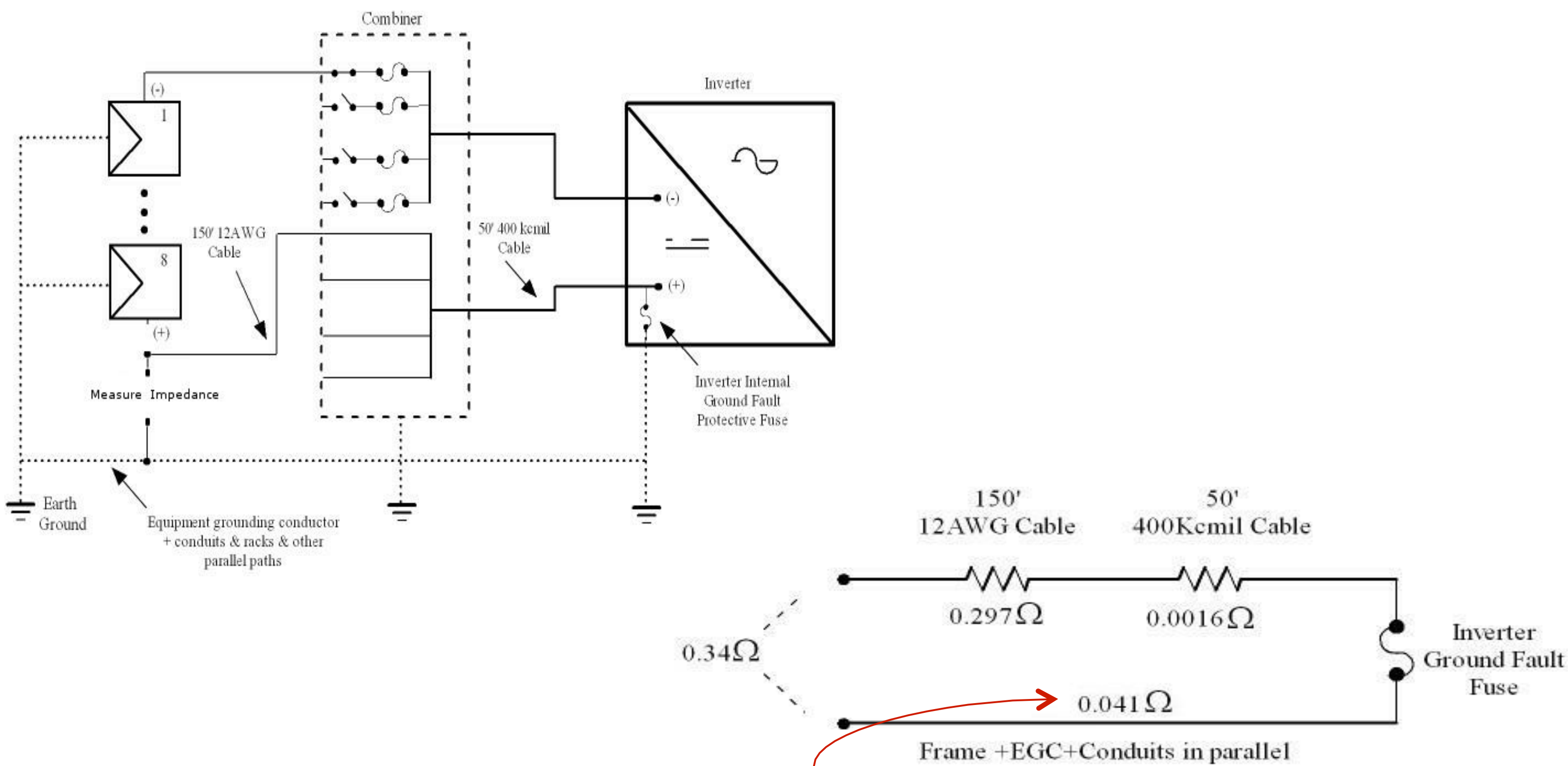
Representative fault currents

Fault Resistance	Rooftop c-Si	Rooftop thin-film	Rooftop c-Si	Ground Mount c-Si	Rooftop c-Si
10 Ω	5.3 mA	9 mA	97 mA	144 mA	340 mA
5 Ω	11 mA	36 mA	159 mA	277 mA	690 mA
1 Ω	52 mA	152 mA	660 mA	1.0 A	3.0 A
0 Ω (short)	542 mA	1.1 A	3.9 A	3.1 A	>5 A TRIP*

- Currents measured with handheld meter at location of fault (shunt measurement)
- Dry conditions for most tests
- Inverter operating throughout testing
- * One short-circuit test resulted in 5A GFA fast-acting fuse blowing. This prevented the inverter GFI fuse from blowing.

Measure Impedance of Equipment Grounding Conductor

- This example: one string in a grounded array (note: example shows positive grounded array)
- Measure impedance from positive end of string, through home run wiring to inverter, with return via EGC



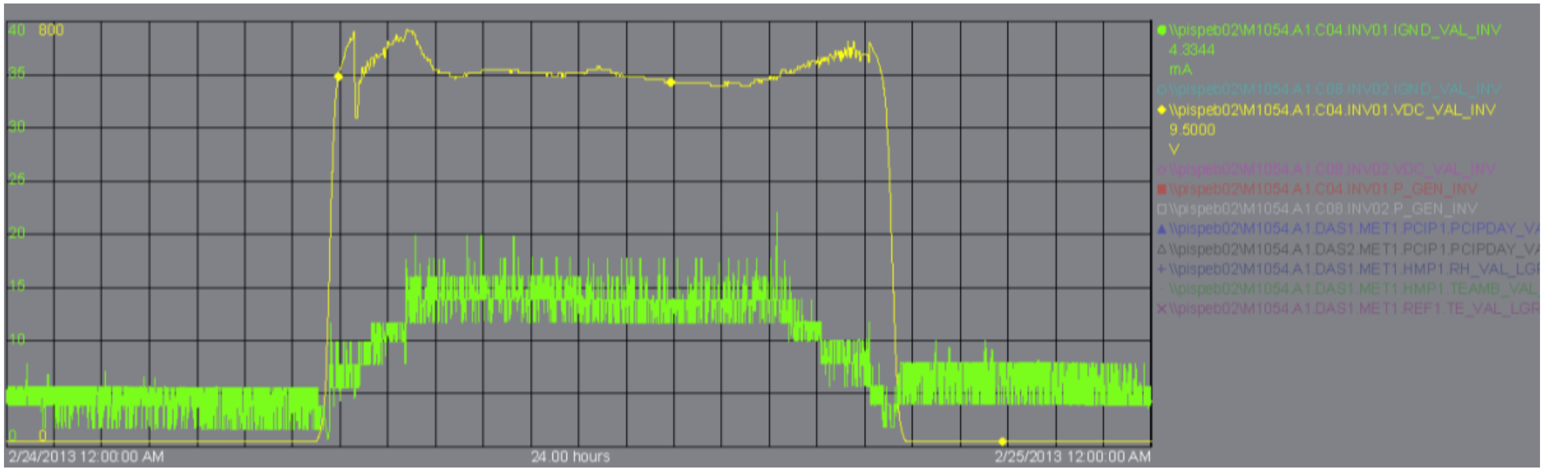
<u>Result</u>: EGC impedance = 0.041 ohm

General Results

- Twelve inverters from eight different manufacturers were tested
- **In every case**, inverters operated normally in the presence of some or all of the introduced ground faults
- Background DC leakage currents measured in large arrays found to be generally very low (~5-10 mA range or less, measured at inverter)
  - Some evidence that leakage currents can be higher in other systems
- AC component in ground circuit not well characterized due to measurement noise
- Low ground system resistances on healthy systems (< 1 Ω)
- Introduced ground fault currents measured from mA to 3+ Amps depending on system and fault impedance
- Residual current detector monitoring shows excellent capabilities for detecting grounded conductor faults in 10's of mA range
- RCD's set to trip at 60 mA not causing nuisance trips (and have detected and enabled correction of two high impedance faults that could have led to fires)

Additional Data Provided by SunPower Corporation

- SunPower provided recorded RCD data from two sites



Ground Current for Typical Clear Day: Approx. 15 mA

- Observations:
  - Ground current ramps to 7-10 mA as PV system voltage comes up in the morning
  - Ground current then increases to 15 mA as system current rises with increasing irradiance
  - Infrequent , short duration ground current spikes recorded – source unknown
  - SunPower programmed their RCDs to record fault current as a 10 second moving average
    - this method prevents false trips from short duration lightning transients

Additional Data Provided by Duke Energy

- Data Source:
  - Duke Energy elected to install RCDs on all of Duke's roof-mounted PV systems in NC following the Mt. Holly fire
  - 45 PV array segments instrumented with RCDs
  - Across this data set, typical ground current found to be in the 20 to 50 mA range
  - Most systems have been operating with RCDs set to trip at 60 mA

- Duke Data Used to Study Effects of Lightning on Ground Currents:
  - Some elevated residual current readings (above trip setting) were recorded at night
  - Elevated RCD currents positively correlated with periods of storm activity
  - Since lightning and it's impacts are short in duration, effects can be filtered out and false trips avoided by extending measurement duration (such as used by SunPower with a 10-second moving average)