Ground Fault Protection Improvement Study

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Why improve ground fault protection?

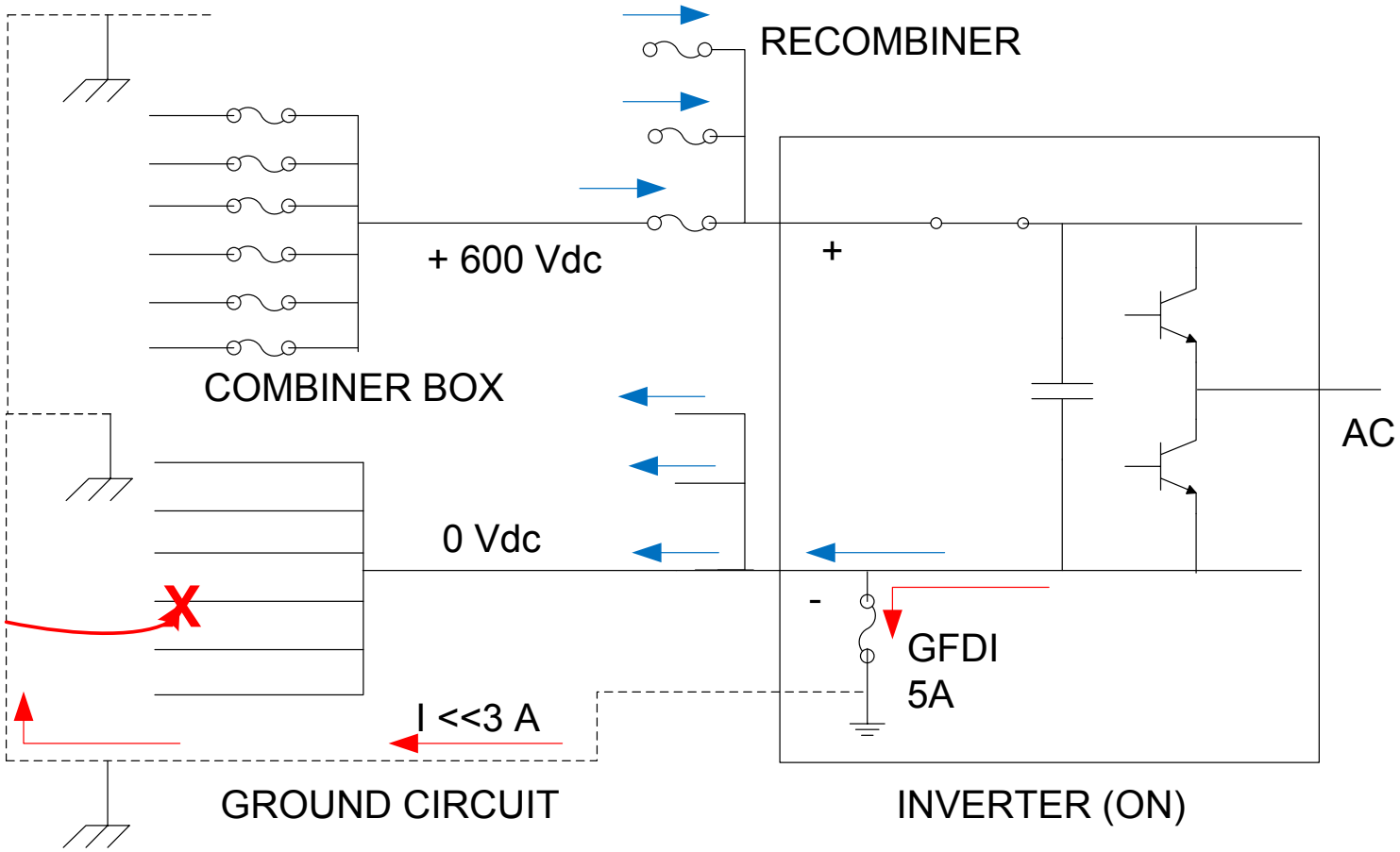
- Notable rooftop fires (e.g Bakersfield, Mt. Holly, NC) resulted from undetected ground faults
- Analysis of faults reveal a "blind spot" problem in grounded PV arrays – faults on the grounded conductors
- Existing ground fault protection (fuse in inverter) generally oversized
  - Designed for *ungrounded* conductor faults
  - Conservative assumptions of leakage current to avoid nuisance trips
- Ground faults not causing these problems in Europe and elsewhere where ungrounded or floating systems are the norm
- The problem is not going away, and will be more prevalent with aging systems

Solar ABCs study objectives

- Characterize DC and AC leakage currents in existing, large PV arrays (≥100kW)
- Characterize the performance of their ground-fault detection devices.
- Determine the conditions where existing ground-fault protection is inadequate.
- Investigate alternatives for improved detection/protection
  - Minimizing allowable ground fault current
  - Minimizing nuisance tripping
- Develop a consensus-based set of recommendations for:
  - Retrofitting existing systems
  - Functional requirements for new systems

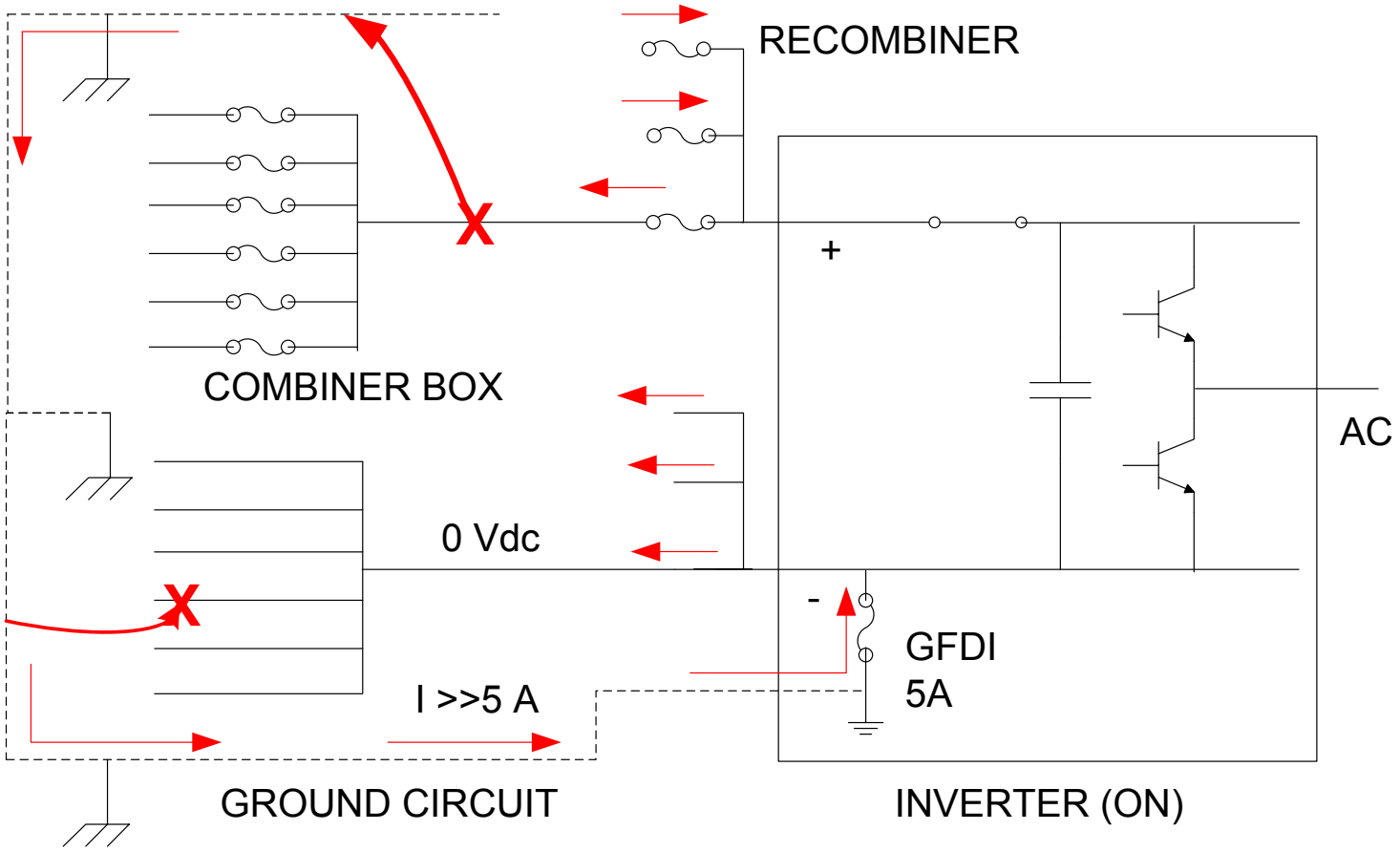
Grounded conductor "blind spot" fault

Below GFDI rating, goes undetected indefinitely



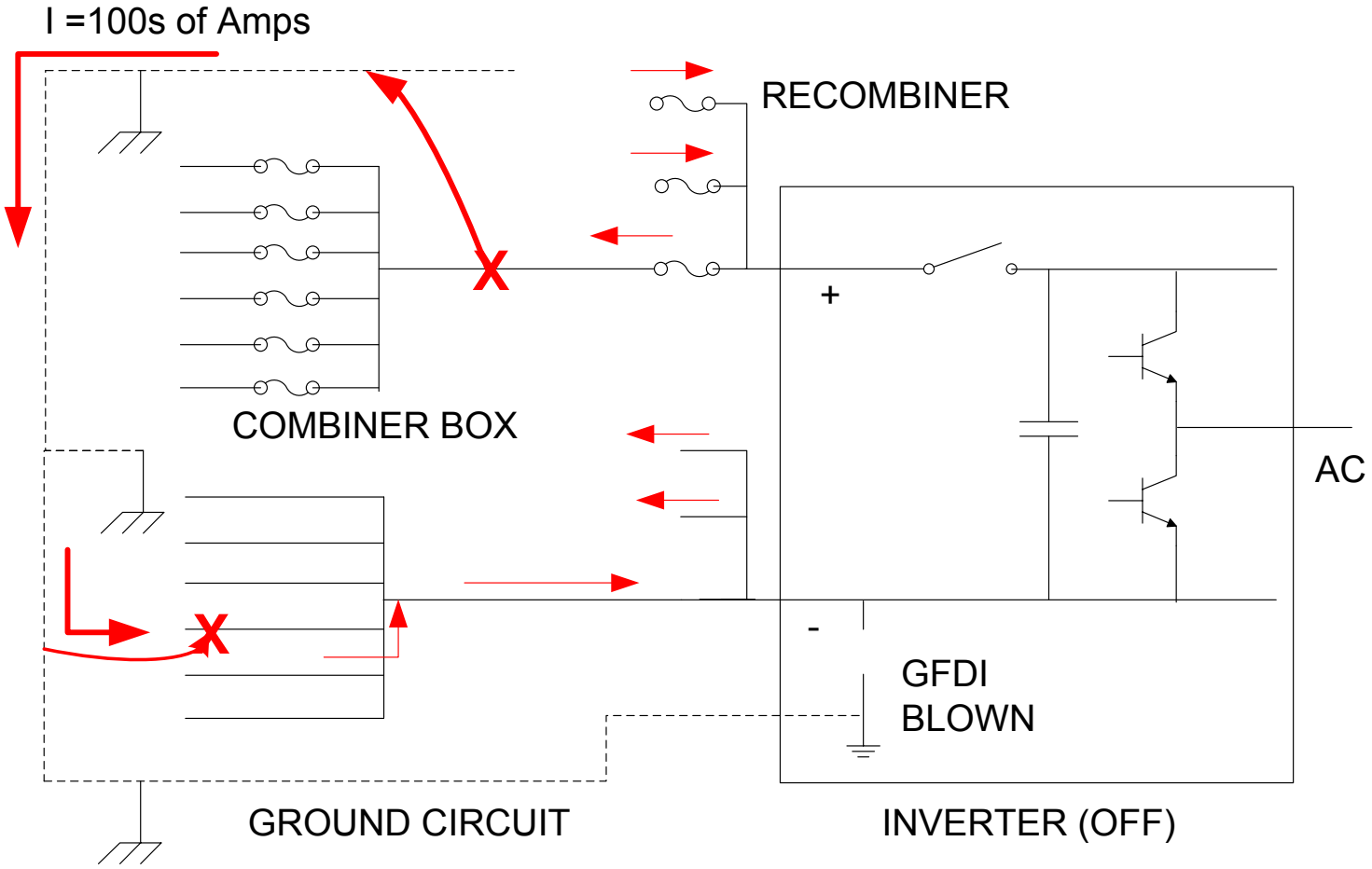
Eventual 2nd fault on ungrounded conductor

High fault current through GFDI



Sustained fault, arcing and fire

Protection by-passed

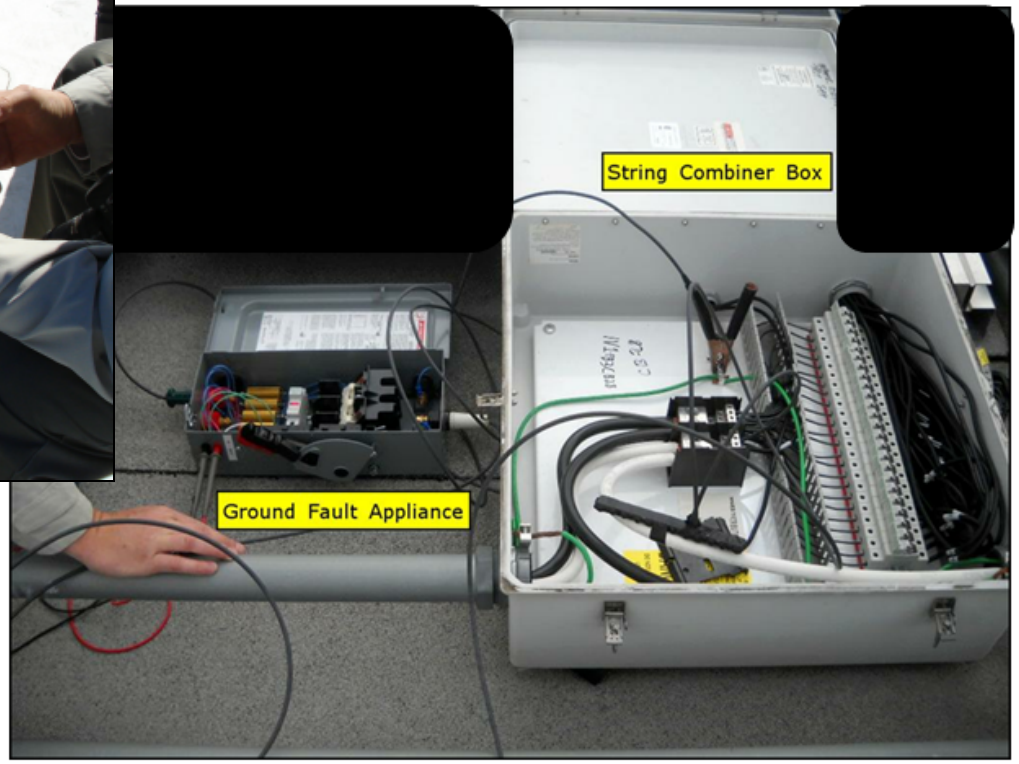


Field Testing

- Sites selected for:
  - Variety of inverter types
  - Rooftop and ground mount
  - c-Si and thin film
  - Geographic/climate variety
- Tests performed in northern CA, southern CA, North Carolina, and NM (Sandia)
- 10 systems so far, plus several at PVUSA
- Tests conducted:
  - Megger conductors and array to check for existing faults
  - Use differential current device to measure background DC leakage current
  - Use oscilloscope to characterize AC component in ground connection
  - Introduce controlled ground faults to characterize fault current and detection capabilities

Ground-fault test equipment

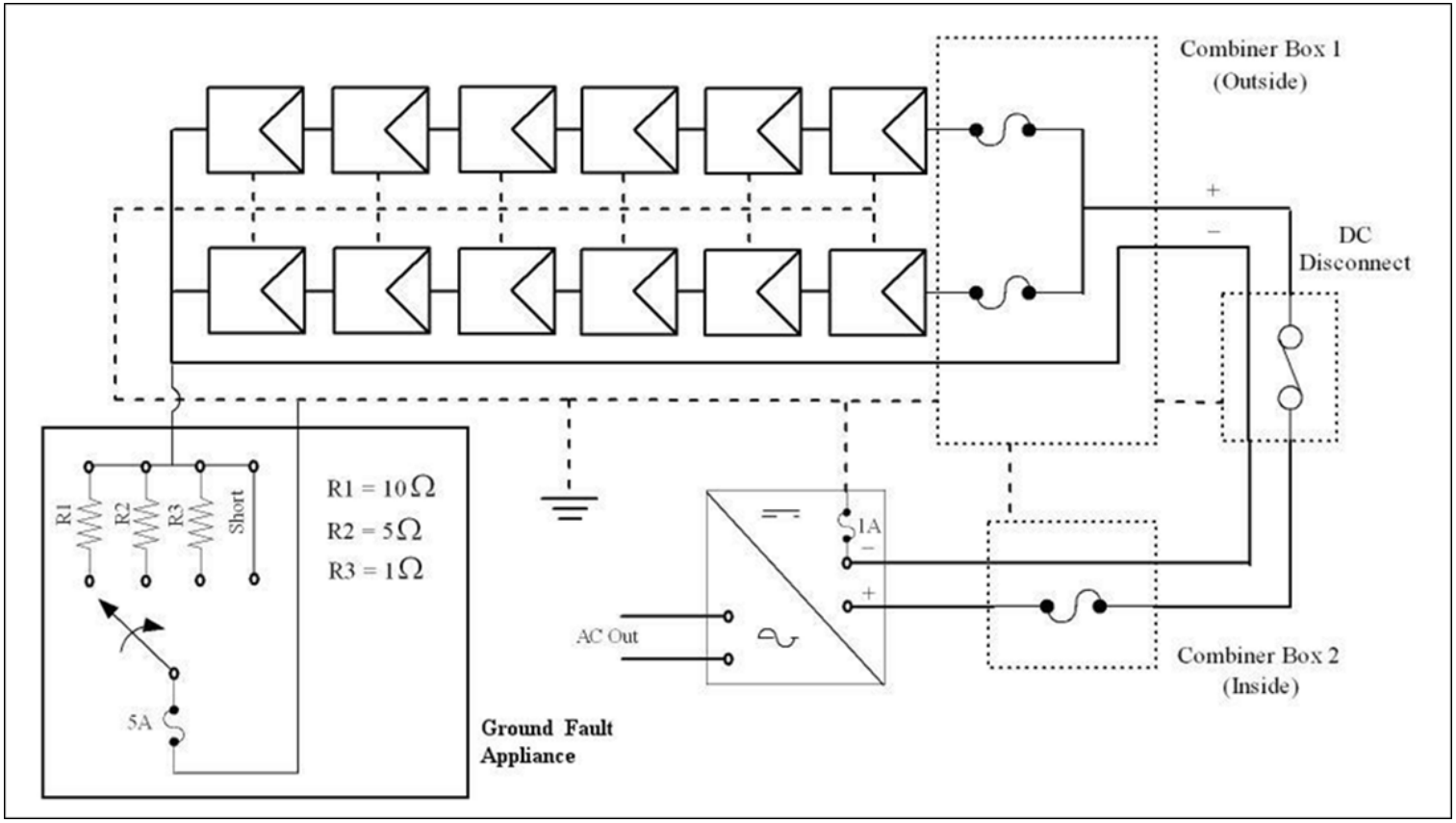
Ground-Fault Tester
10, 5, 1 and 0 Ω settings



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

Field schematic for introducing ground faults

Simulates blind-spot fault



Representative fault currents

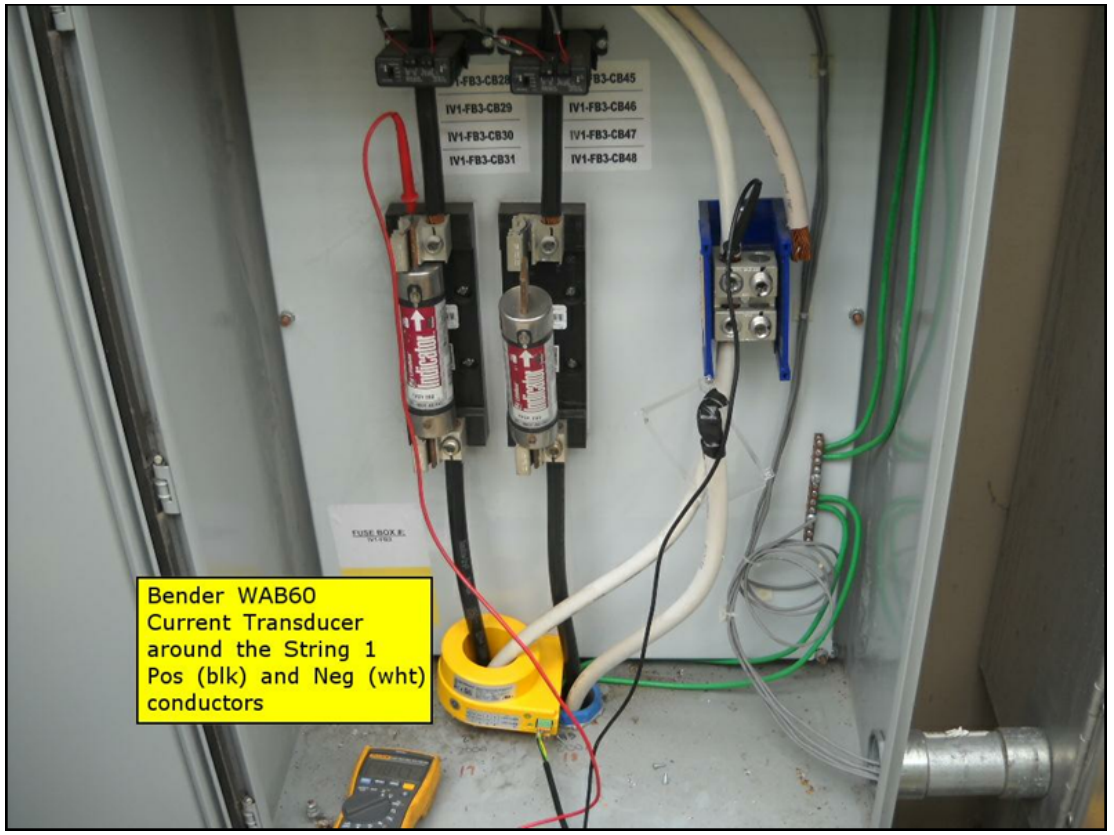
Fault Resistance	Rooftop c-Si	Rooftop thin-film	Rooftop c-Si	Ground Mount c-Si	Rooftop c-Si
10 Ω	5.3 mA	9 mA	97 mA	144 mA	340 mA
5 Ω	11 mA	36 mA	159 mA	277 mA	690 mA
1 Ω	52 mA	152 mA	660 mA	1.0 A	3.0 A
0 Ω (short)	542 mA	1.1 A	3.9 A	3.1 A	>5 A TRIP*

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

Residual current measurements

Measured at inverter on individual feeder circuits

- Current transformer around positive and negative cable
- CT capability good to 5 mA
- Measured value should be zero if no parallel fault path exists



Residual Current Measurements

Good agreement with measured fault current

Ground Fault Resistance Value	Fault Current at the Array (Digital meter)	Residual Current at the Inverter (Bender Device)
10 Ω	97 mA	98 mA
5 Ω	159 mA	167 mA
1 Ω	660 mA	>600 mA
0 Ω (short)	3.88 A	>600 mA

- Typical results – rooftop system with framed modules
- Differences not considered significant – some measurement variation
- Inverter operating during tests
- Dry conditions

Conclusions so far

- Background DC leakage currents measured in large arrays generally very low (~5-10 mA range or less, measured at inverter)
  - Known to be higher in some systems
- AC component in ground circuit not well characterized due to measurement noise
- Low ground system resistances on healthy systems (< 1 Ω)
- Test ground fault currents measured from mA to 3+ Amps depending on system and fault impedance
- In most cases, fault current in equipment ground conductor (EGC) considerably less than in grounded conductor.
  - One exception: 3A fault current in EGC, 2A in grounded conductor
- Residual current monitoring (RCM) shows excellent capabilities for detecting grounded conductor faults in 10s of mA range
- RCM settings in 40-50 mA range not (yet) causing nuisance trips
- Inverter ground fault fuse ratings can be reduced

Next Steps

- Repeat some tests with wetted arrays to better characterize background leakage current
- Install long term ground current monitoring on sample system(s) to look for changes or variations due to environment, electrical conditions, etc.
- Finalize test reports
- Draft recommendation report for retrofit and new systems
- Meanwhile, the NEC 2014 tentative changes include:
  - Enhanced ground fault protection functionality for grounded systems, possibly daily check of ground impedance
  - More floating systems
  - More arc-fault detection