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 2\textsuperscript{nd} fault on ungrounded conductor
High fault current through GFDI
Sustained fault, arcing and fire
Protection by-passed

I = 100s of Amps

RECOMBINER

COMBINER BOX

GROUND CIRCUIT

INVERTER (OFF)

GFDI BLOWN

AC
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

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

<table>
<thead>
<tr>
<th>Fault Resistance</th>
<th>Rooftop c-Si</th>
<th>Rooftop thin-film</th>
<th>Rooftop c-Si</th>
<th>Ground Mount c-Si</th>
<th>Rooftop c-Si</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 Ω</td>
<td>5.3 mA</td>
<td>9 mA</td>
<td>97 mA</td>
<td>144 mA</td>
<td>340 mA</td>
</tr>
<tr>
<td>5 Ω</td>
<td>11 mA</td>
<td>36 mA</td>
<td>159 mA</td>
<td>277 mA</td>
<td>690 mA</td>
</tr>
<tr>
<td>1 Ω</td>
<td>52 mA</td>
<td>152 mA</td>
<td>660 mA</td>
<td>1.0 A</td>
<td>3.0 A</td>
</tr>
<tr>
<td>0 Ω (short)</td>
<td>542 mA</td>
<td>1.1 A</td>
<td>3.9 A</td>
<td>3.1 A</td>
<td>&gt;5 A TRIP*</td>
</tr>
</tbody>
</table>

- 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

<table>
<thead>
<tr>
<th>Ground Fault Resistance Value</th>
<th>Fault Current at the Array (Digital meter)</th>
<th>Residual Current at the Inverter (Bender Device)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 Ω</td>
<td>97 mA</td>
<td>98 mA</td>
</tr>
<tr>
<td>5 Ω</td>
<td>159 mA</td>
<td>167 mA</td>
</tr>
<tr>
<td>1 Ω</td>
<td>660 mA</td>
<td>&gt;600 mA</td>
</tr>
<tr>
<td>0 Ω (short)</td>
<td>3.88 A</td>
<td>&gt;600 mA</td>
</tr>
</tbody>
</table>

- 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