Ground Fault Protection
Improvements to Prevent Fires

Description of problem
and potential solutions

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Ground-Fault Protection Blindspot

Recent fires on large PV Systems have had similar origins

• April 5, 2008 – Bakersfield, California
• April 16, 2011 – Mount Holly, North Carolina
• May be others (several)
Common Elements in Fires

• Undetected fault in a grounded conductor that can continue indefinitely. Undetected fault becomes new “normal” and the ground fault fuse does not blow.

• Ungrounded conductor fault occurs some time after grounded conductor fault. This fault blows the ground fault fuse but instead of interrupting the fault, short circuit current persists in the array.
Typical Sequence of Events

Stage 1 - Faulted Grounded String Conductor

22 STRING SUBARRAY WITH 159-AMP MAX CIRCUIT CURRENT AND 558 VOLTS MAX SYSTEM VOLTAGE AT 800 W/m²

COMBINER BOX 8

CB1 22 STRING SUBARRAY

CB2 22 STRING SUBARRAY

CB3 22 STRING SUBARRAY

CB3 22 STRING SUBARRAY

CB2 22 STRING SUBARRAY

CB1 22 STRING SUBARRAY

INVERTER DC INPUT

300A FUSE

300A FUSE

300A FUSE

300A FUSE

300A FUSE

300A FUSE

300A FUSE

300A FUSE

5A FUSE

UNWANTED GROUND FAULT CURRENT 3.1 AMPS

FAULT CURRENT OF 3.1 AMPS NOT ENOUGH TO CLEAR FUSE

FAULTED CONDUCTOR

INSULATION DAMAGE IN STRING CONDUCTOR

String Conductor

Grounding Conductor

6.2 AMPS

3.1 AMPS

136 AMPS

6.2 AMPS

0 AMPS
Typical Sequence of Events

- 0-AMPS (Faulted Conductor)
- INSULATION DAMAGE IN STRING CONDUCTOR
- 6.2-AMPS
- 3.1 AMPS
- 133-AMPS
- 136 AMPS
- CB1 22 STRING SUBARRAY
- CB2 22 STRING SUBARRAY
- CB3 22 STRING SUBARRAY
- F15
- F1
- F2

UNWANTED GROUND FAULT CURRENT 3.1AMPS
Typical Sequence of Events

136 AMPS

CB1 22 STRING SUBARRAY

CB2 22 STRING SUBARRAY

CB3 22 STRING SUBARRAY

136 AMPS

136 AMPS

5A FUSE

3.1-AMPS

FAULT CURRENT OF 3.1 AMPS NOT ENOUGH TO CLEAR FUSE

FAULT CURRENT 3.1AMPS
Typical Sequence of Events

Stage 1 - Faulted Grounded Subarray Conductor

22 STRING SUBARRAY
WITH 165-AMP MAX CIRCUIT CURRENT
AND 558-VOLT MAX SYSTEM VOLTAGE
AT 800 W/m²

Combiner Box B

F1

F2

F15

136 AMPS

6.2-AMPS

Grounding Conductor

String Conductor

FAULTED CONDUCTOR
INSULATION DAMAGE IN SUBARRAY CONDUCTOR

136 AMPS

136 AMPS

CB1 22 STRING SUBARRAY

CB2 22 STRING SUBARRAY

CB3 22 STRING SUBARRAY

5A Fuse

2-AMPS

FAULT CURRENT OF 2-AMPS NOT ENOUGH TO CLEAR FUSE

300A Fuse

136 AMPS

136 AMPS

136 AMPS

INVERTER DC INPUT
Typical Sequence of Events

CB1 22 STRING SUBARRAY

CB2 22 STRING SUBARRAY

CB3 22 STRING SUBARRAY

136 AMPS

136 AMPS

136 AMPS

134-AMPS

2-AMPS

5A Fuse

136 AMPS

FAULT CURRENT OF 2 AMPS NOT ENOUGH TO CLEAR FUSE

FAULTED CONDUCTOR
INSULATION DAMAGE IN SUBARRAY CONDUCTOR

UNWANTED GROUND FAULT CURRENT 2 AMPS
Typical Sequence of Events

Stage 1 - Faulted Grounded String Conductor

Stage 2 - Faulted Ungrounded Subarray Conductor

22 STRING SUBARRAY
WITH 150-AMP MAX CIRCUIT CURRENT AND 558 VOLT MAX SYSTEM VOLTAGE AT 800 W/m²

Combiner Box 8

CB1 22 STRING SUBARRAY
136 AMPS

CB2 22 STRING SUBARRAY
136 AMPS

CB3 22 STRING SUBARRAY
136 AMPS

INVERTER DC INPUT

1082-AMPS

6.2-AMPS

String Conductor

Grounding Conductor

0-AMPS

F1

F2

F15

136 AMPS

FAULTED CONDUCTOR INSULATION DAMAGE IN SUBARRAY CONDUCTOR

136 AMPS

952-AMPS

ARRAY COMBINER FUSE
300A, 600/DC FUSE DESIGNED TO HOLD (NOT CLEAR) FOR 60 SECONDS AT 952-AMPS

5A FUSE

HIGH FAULT CURRENT CLEARS GFP FUSE ALLOWING ARRAY SHORT CIRCUIT CURRENT TO FLOW THROUGH THE TWO FAULTS

BURNING CONDUCTOR INSULATION ON 10AWG CONDUCTOR IGNITES AT HIGH CURRENT IGNITING MODULES AND OTHER NEARBY FUEL

Typical Sequence of Events
Typical Sequence of Events

- CB1 22 String Subarray
  - 136 Amps

- CB2 22 String Subarray
  - 136 Amps

- CB3 22 String Subarray
  - 136 Amps

- Faulted Conductor Insulation Damage in Subarray Conductor

- 952 Amps

- 1088 Amps

- Array Combiner Fuse
  - 300A, 600VDC fuse designed to hold (not clear) for 60 seconds at 952-Amps.
Typical Sequence of Events

- 136 AMPS
- 1082-AMPS String Conductor
- 2-AMPS
- 1088-AMPS
- 6.2-AMPS
- 952-AMPS
- 1088-AMPS
- BURNING CONDUCTOR INSULATION ON 10AWG CONDUCTOR IGNITES AT HIGH CURRENT IGNITING MODULES AND OTHER NEARBY FUEL
Typical Sequence of Events

Stage 1- Faulted Grounded Subarray Conductor
Stage 2- Faulted Ungrounded Subarray Conductor

22 STRING SUBARRAY
WITH 159A MAX CIRCUIT CURRENT AND 558VOLT MAX SYSTEM VOLTAGE
AT 800Watt

COMBINER BOX B

FAULTED CONDUCTOR INSULATION DAMAGE IN SUBARRAY CONDUCTOR
136 AMPS

CB1 22 STRING SUBARRAY
136 AMPS

CB2 22 STRING SUBARRAY
136 AMPS

CB3 22 STRING SUBARRAY

30A FUSE

INVERTER DC INPUT

6.2-AMPS

136 AMPS

0-AMPS

6.2-AMPS

ARCING CONDUCTOR
HIGH CURRENT CAUSES CONNECTION TO MOVE SLIGHTLY FROM GROUNDED POINT INITIATING AN ARC THAT CONTINUES UNTIL ARRAY COMBINDER FUSE CLEARS IN 60 SECONDS

ARRAY COMBINDER FUSE
300A 600V DC FUSE DESIGNED TO HOLD (NOT CLEAR) FOR 60 SECONDS AT 952-AMPS.

HIGH FAULT CURRENT CLEARS GFP FUSE ALLOWING ARRAY SHORT CIRCUIT CURRENT TO FLOW THROUGH THE TWO FAULTS

136 AMPS

136 AMPS

952AMPS

952AMPS

5A FUSE
ARRAY COMBINER FUSE
300A, 600VDC FUSE DESIGNED TO HOLD (NOT CLEAR) FOR 60 SECONDS AT 952-AMPS.

HIGH FAULT CURRENT CLEARS GFP FUSE ALLOWING ARRAY SHORT CIRCUIT CURRENT TO FLOW THROUGH THE TWO FAULTS

ARCING CONDUCTOR
HIGH CURRENT CAUSES CONNECTION TO MOVE SLIGHTLY FROM GROUNDING POINT INITIATING AN ARC THAT CONTINUES UNTIL ARRAY COMBINER FUSE CLEARS IN 60 SECONDS
Blindspot

- Established GFDI limits are larger for larger PV systems
- Evidence suggests faults on the grounded array conductor can exist without tripping the ground fault fuse
- Higher ground-fault trip threshold also yields a larger blind-spot
Solar ABCs Project

- White Paper
- Research
- Report with Recommendations
White Paper

• Describe Problem
• Identify tests to determine if a specific installation is safe
• Identify possible solution
Research

• Determine the conditions where the existing ground-fault protection is inadequate

• Develop a mitigation proposal
  – Implement through changes to NEC and UL Standards
  – Current proposal is a combination of a morning check and measurement of differential current.
What about Existing PV Systems with Blindspot?

• Several Important Steps Should Be Taken Soon

  1. proper installation techniques with close attention to wire management,

  2. annual preventative maintenance actions to identify and resolve progressive system damage,

  3. detailed data acquisition to monitor the operation of all PV systems at a level sufficient to determine if unscheduled maintenance is required, and,
What about Existing PV Systems with Blindspot?

4. additional ground fault and PV array isolation sensing devices

- Options likely to be recommended by research.
  - Retrofit large systems with more sensitive Residual Current Monitors (300mA or less)
  - Where possible, apply daily array insulation test before starting the inverter.
Design Recommendations for Future PV Systems

• Possible options based on future research:
  – Employ retrofit recommendations up front for grounded PV arrays.
  – UNGROUND the array
  – Employ segmenting contactors to reduce current during faults.
  – Arc Fault Detectors (2011 NEC)
  – Module level control to react to faults