

# Differentiating Series and Parallel Photovoltaic Arc-Faults

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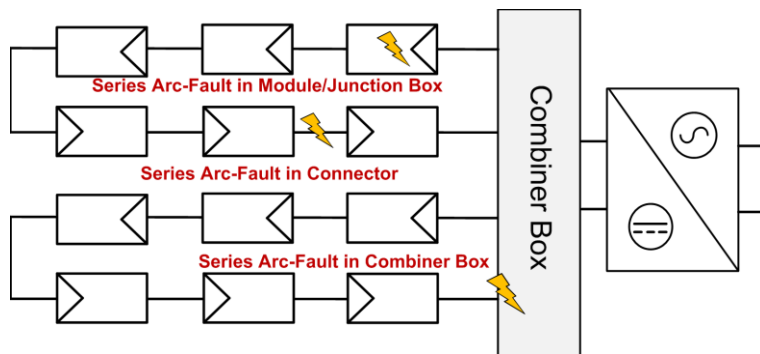
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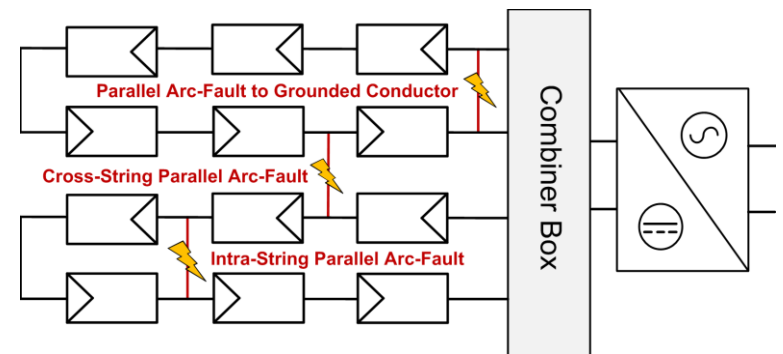


# Arc-Fault Types

- Types of arc-faults
  - Series Arc-Fault – Arc from discontinuity in electrical conductor
  - Parallel Arc-Fault – Electrical discharge between conductors with different potentials
- 2011 *NEC* requires **series** arc-fault protection in PV installations on or penetrating a building above 80 V
- 2014 *NEC* may require **parallel** arc-fault protection in PV installations



**Series Arc-Faults**

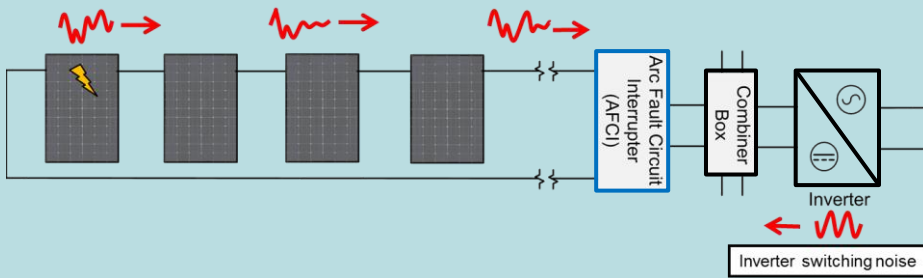


**Parallel Arc-Faults**

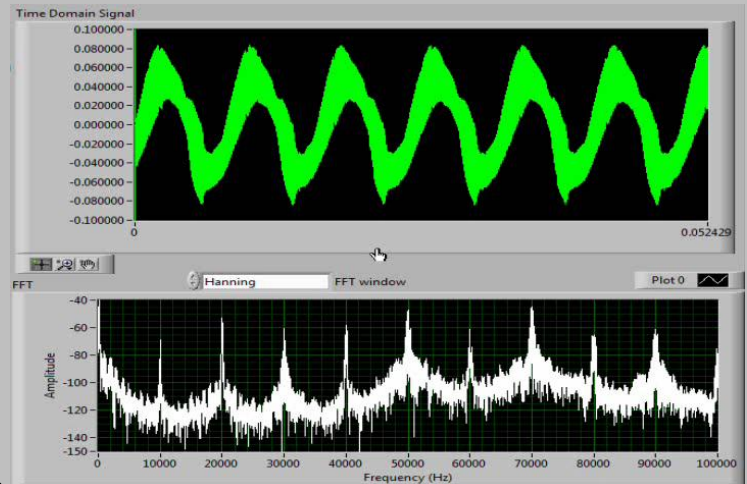
# Arc-Fault Detection Principle

The AC noise on the DC conductors is often used to identify when series arcing occurs in PV systems.

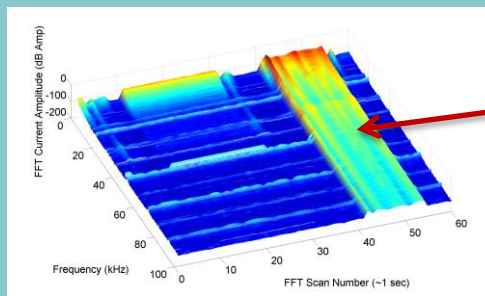
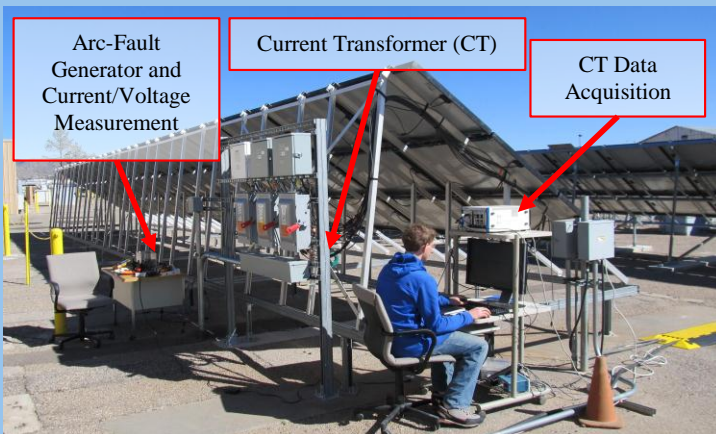
Series arcing noise propagating through the array



Arcing noise propagating through the array



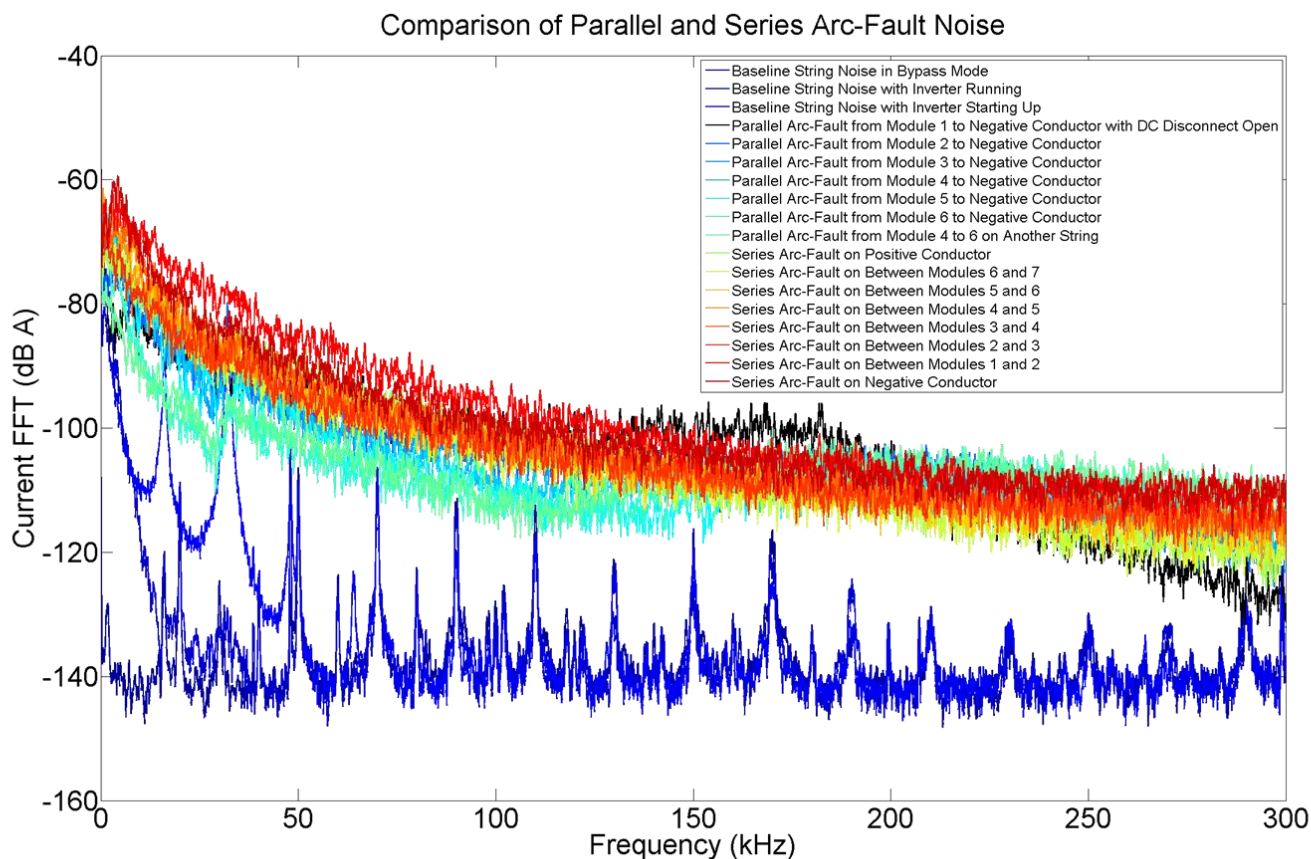
Test setup



Time period of arcing in the PV system.

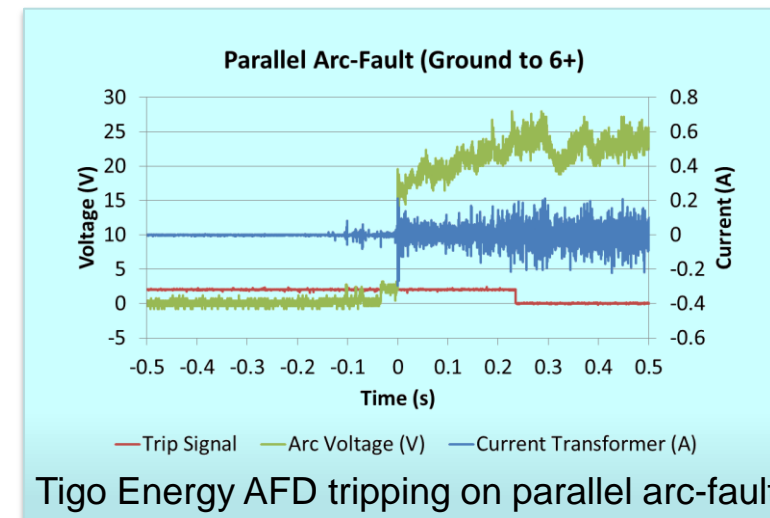
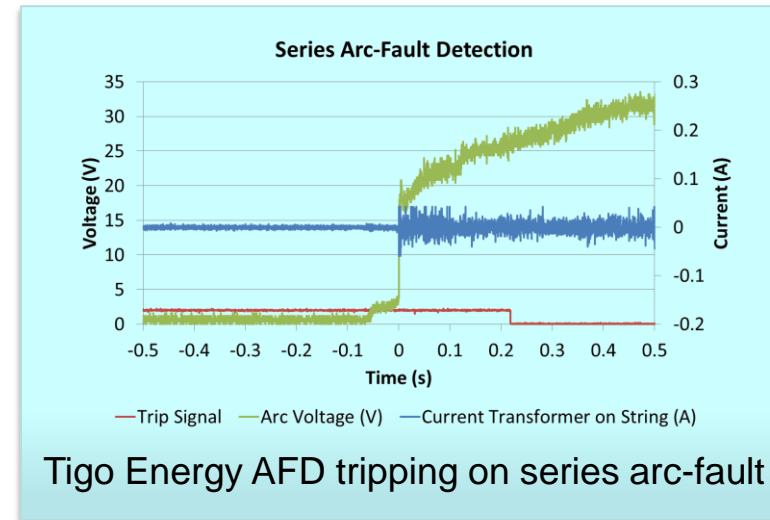
# Problem!

- Series Arc-Fault Detectors (AFDs) open the string or array to de-energize the arc.
- If a series AFD opens the string or array during a parallel arc-fault, the arc-fault will continue to burn!
- To the AFD the parallel arc-fault noise is similar to series arc-fault noise!



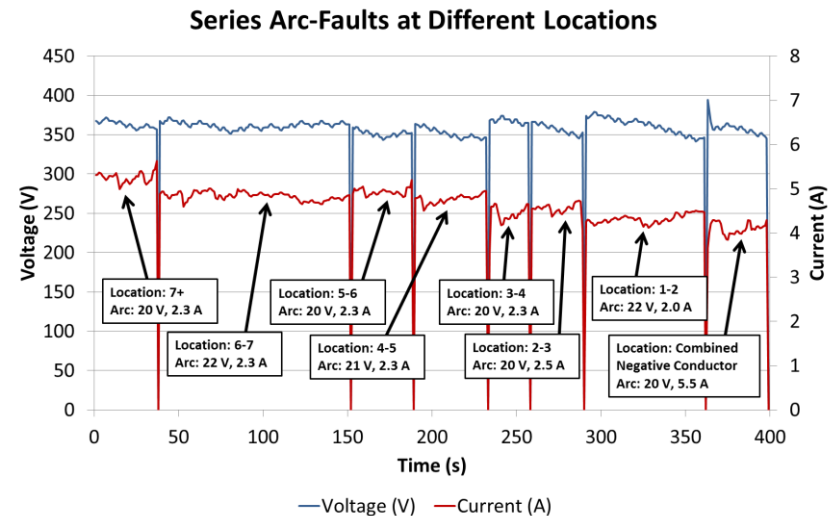
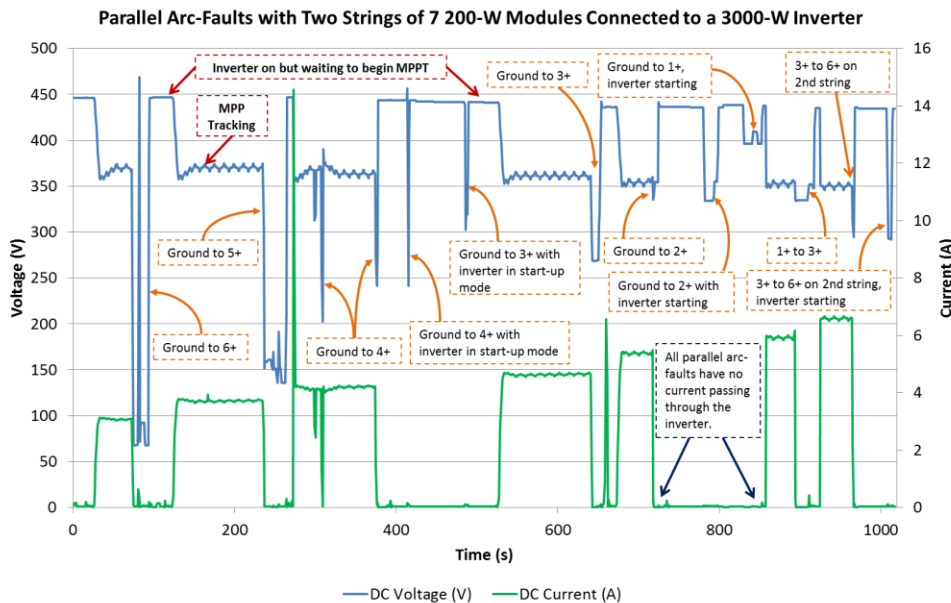
# How do we know the type of arc-fault?

- Need additional sensors or diagnostic tools to determine the type of arc-fault.
- Three methods proposed to differentiate parallel and series arc-faults:
  1. Use a combination of arc-fault high frequency noise along with changes in current or voltage.
  2. Force the PV array to  $V_{oc}$  and recheck arc-fault noise.
  3. Permanently connect parallel strings to establish noise path to the AFD.



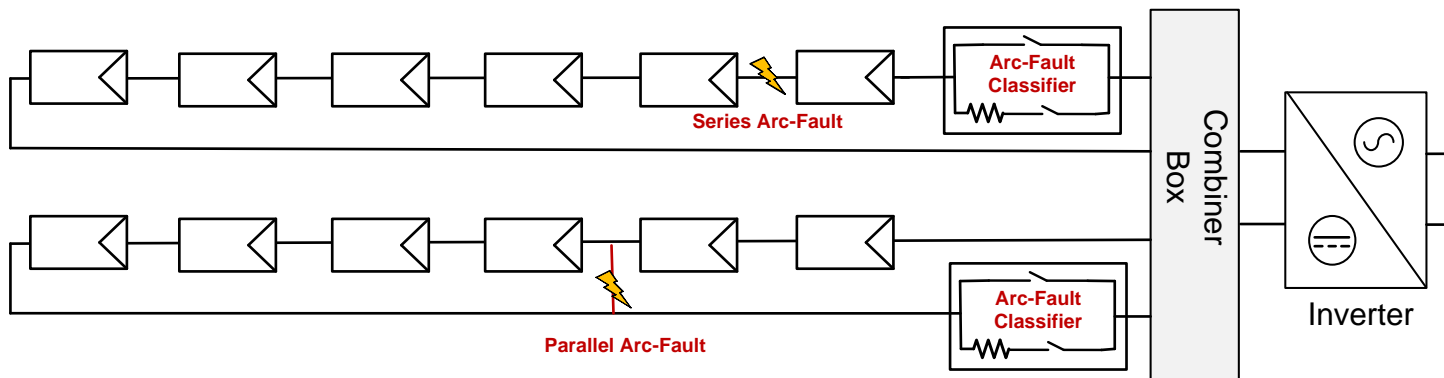
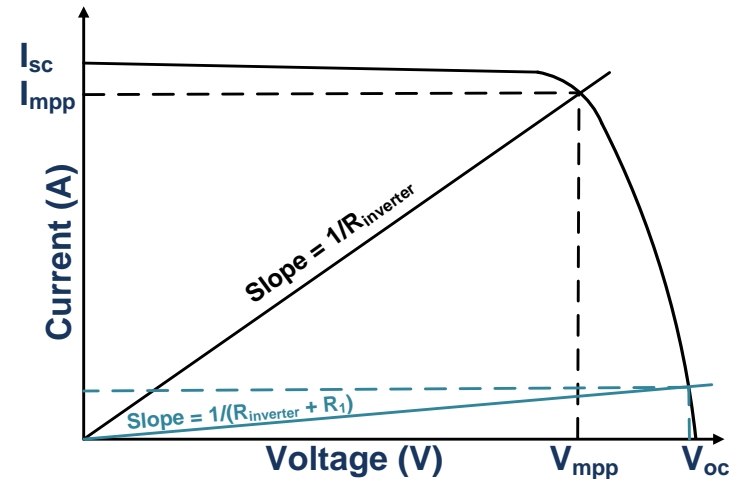
# 1. Monitor string or array current/voltage

- Series and parallel arc-faults influence the current and voltage on the array differently
- Parallel arc-fault = no current to inverter, drop in voltage
- Series arc-fault = little change in current and voltage



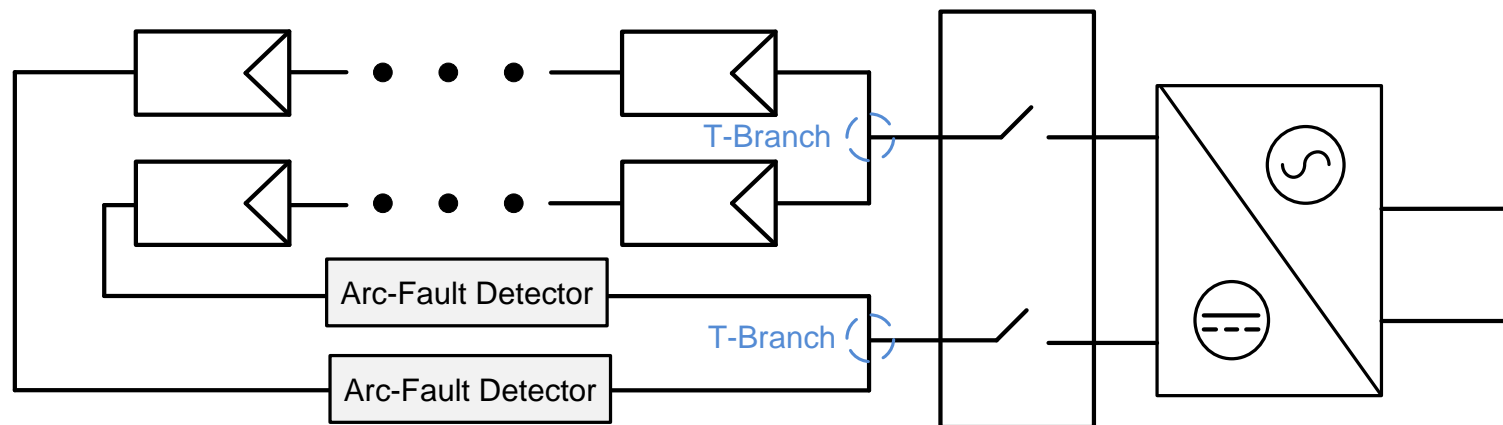
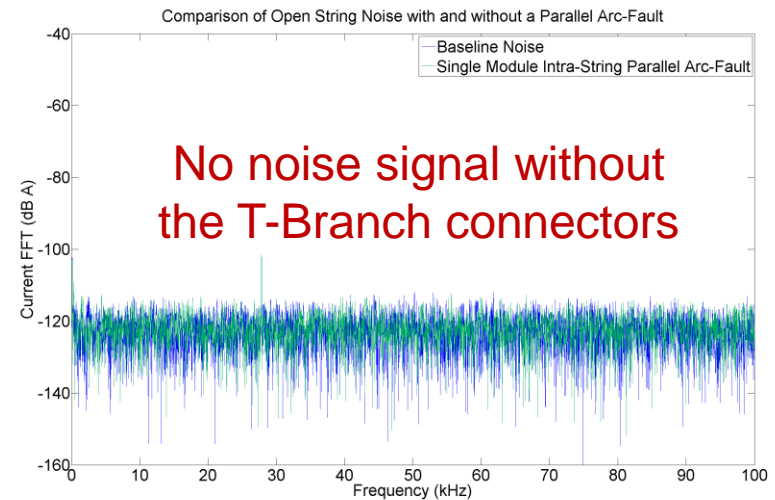
# 2. Increase string impedance

- Step 1: Increase the impedance of the string by:
  - Adjusting the MPPT point down toward  $V_{oc}$
  - Physically inserting a resistance into the string
- Step 2: Recheck for arc-fault noise
  - If there's noise, it's from a parallel arc-fault
- Concept tested with load bank at Sandia
  - Hard to establish an arc-fault with high load bank resistance
  - Parallel arc-fault noise easily identifiable with high resistance



# 3. Create noise loop with integrated AFD

- When arc-fault noise is detected:
  1. Open the DC disconnect – this de-energizes series arc-faults
  2. Recheck for arc-fault noise
  3. If noise still exists – de-energize the parallel arc-fault





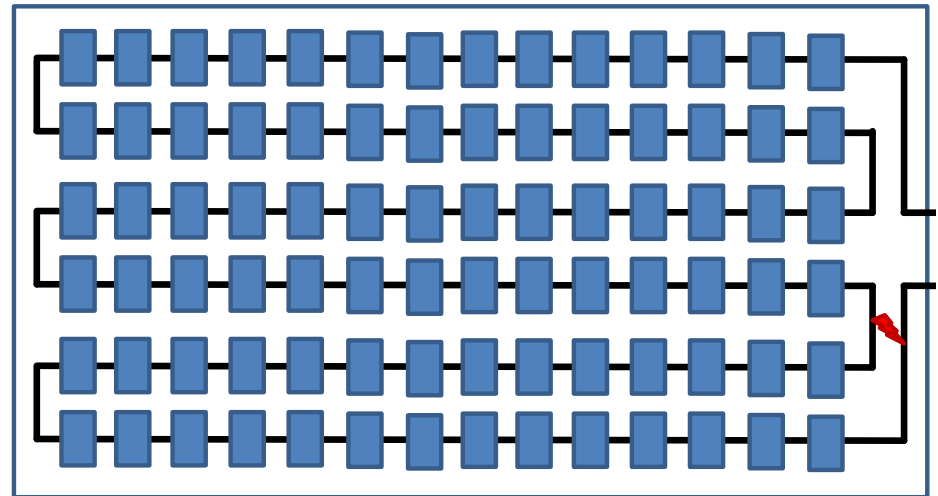
# How to de-energize parallel arc-faults?

- Possible options:

1. Open the connections between each module
2. Short the string(s)
3. Short each module

Situation where opening the connections between modules will not extinguish the arc-fault.

Testing at Sandia shows that this parallel arc-fault is extinguished by shorting the array.



High Power PV Module

Shorting the array has its own problems:

- Energy is dumped from the inverter's DC smoothing capacitor
- The PV system cannot be worked on until shaded or dusk

# Conclusions

- Parallel and series arc-faults must be de-energized to protect PV systems from fires
- NEC currently includes series arc-fault protection BUT not parallel arc-fault protection
- There are multiple methods for distinguishing parallel and series arc-faults but not possible with current detection algorithms
- Once the arc-fault type is determined specific actions are required to de-energize the arc-fault:
  - Open PV circuit for series arc-faults
  - Either open or short for parallel arc-faults...?