Module Safety Issues

2012 PV Module Reliability Workshop

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How can Modules be Dangerous?

- Shock hazard
  - ❑ Touch hazard
- Mechanical
  - ❑ Parts can fall on somebody
  - ❑ Ice or snow can be dumped on someone
  - ❑ Dangerous particles (glass) can come off when modules are broken
- Fire
  - ❑ Can the module start a fire?
  - ❑ Can the module spread a fire?

Module Safety Testing

IEC 61730 and UL 1703

They have similar requirements

Both have a Design Criteria Section and a Testing Section

Both cover the following topics quite well:

- Shock hazards – Although corrosion of ground terminals can impair the protection afforded by grounding the frames
- Spread of flame - Although as next talk indicates changes are coming
- Mechanical safety – Although paying attention to local building codes is also very important

Neither covers the potential of the module itself to start fires.

Effort is underway to modify 61730 (edition 2) to improve how it addresses the potential for modules to cause fires.

Propose to adopt IEC 61730 edition 2 in US to replace UL 1703.

Corroded Ground Terminals

PV Grounding Problems

Corrosion in a harsh environment

This system is installed on an off-shore island of Taiwan for only 5 years

Pictures provided by Tim Zgonena of UL

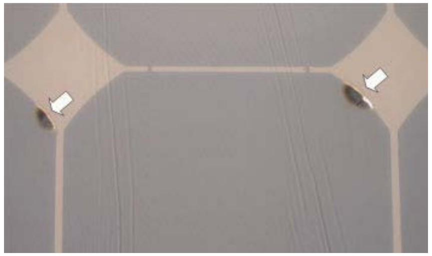
Wind Damage

Hans Urban's presentation at TUV Sponsored Module Workshop, 2006

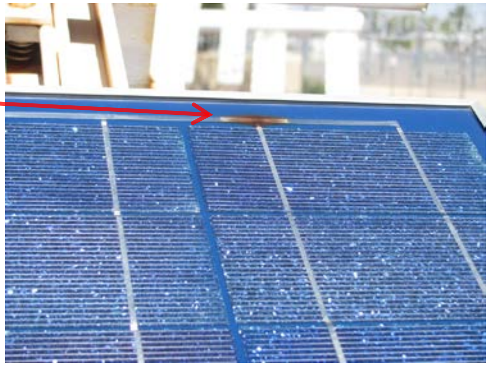
PV Module Fire Hazards

What can cause a module to locally overheat and potentially cause a fire?

1. Hotspots



2. High Series Resistance

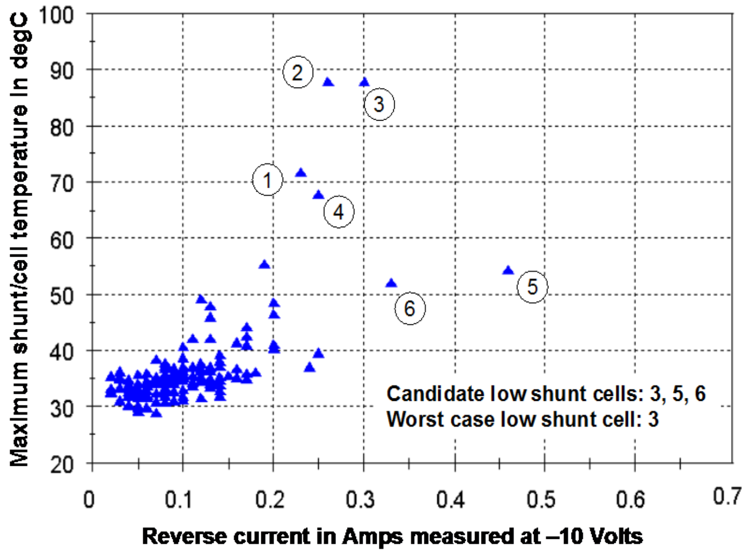


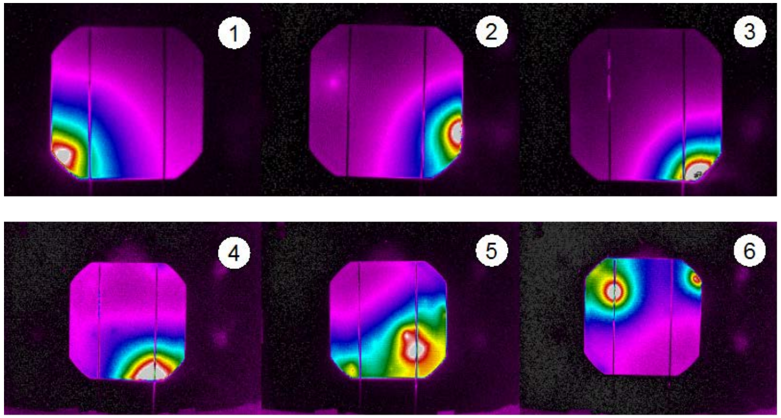
3. Arcing

Hot Spots

- When a cell (or cells) are forced into reverse bias because it (they) can not carry the peak power current being produced by the other cells.
- Can be caused by poor matching, cracks, localized soiling (bird droppings) or shadowing.
- Cells are suppose to be protected by the by-pass diodes that limit the reverse voltage across a cell to less than ~ 10 volts (20 cells per diode).
- Problems occur when the by-pass diodes fail or are never installed correctly or when the cells have low shunt resistances due to localized defects and therefore overheat at 10 volts reverse bias.

Hot Spots





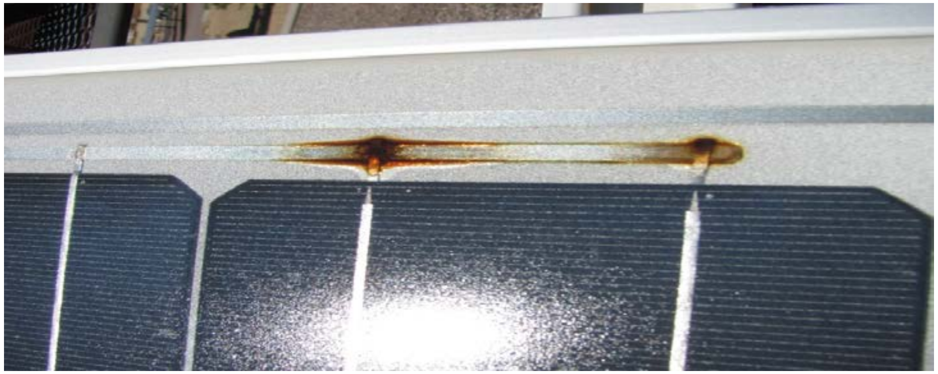
- Cells 2 and 3 have highest localized temperature although not the lowest shunt resistance.
- Cell 5 has the highest leakage current so lowest shunt resistance.
- For some cells 1 diode per 20 cells is not adequate.
- Either need fewer cells per diode or have to screen out cells with low shunt resistances or those with localized hot spots.
- This issue becomes more important with the use of larger cells when there is more power to cause overheating

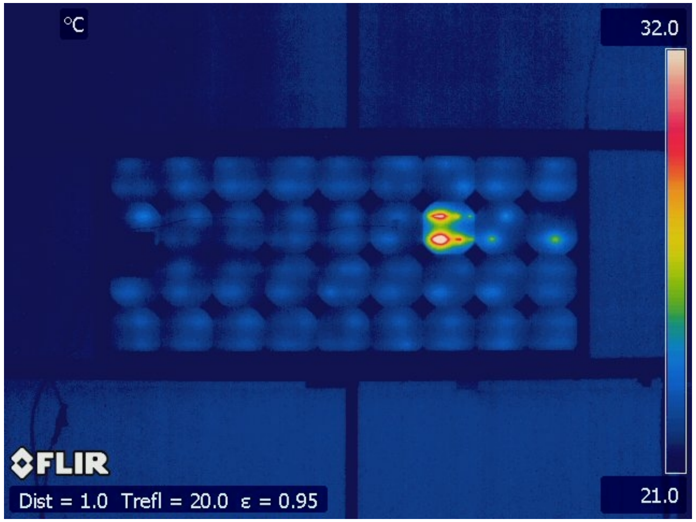
Hot Spots – Are they likely to cause a fire?

- The temperatures shown on the previous page topped out at around 90 C.
- On the other hand I have personally seen a hot spot melt silicon – but at much higher voltages such as might happen if the by-pass diode failed.
- When the hot spot melted silicon it was a localized event:
  - It did result in melting of the encapsulant and back sheet.
  - The melting silicon quickly shunted the cell so badly that it no longer produced a voltage or a hot spot.
  - The short duration of the localized heating did not result in a fire.
- I have never observed a "Hot Spot" causing a module to catch fire.
- See also "Analysis of Hot Spots in Crystalline Silicon Modules and their Impact on Roof Structures" by Cunningham, et. al. from 2011 NREL PVMRW showing that neither hot spots nor resistive heating causes fires.

High Series Resistance

- Failure of solder bonds within the module can lead to overheating at the solder bond that is failing and at the bonds that are left to carry the additional current.
- Such high resistance bonds do result in significant output power loss.
- However the temperatures reached at these poor solder bonds are typically not high enough to cause fires.
- The danger occurs when the resistive heating results in total failure of the bond – that is an open circuit which can lead to an arc.





Arcing in a PV Module

Two types of arcing

1. Series arc – caused by an open circuit in a high voltage dc array
2. Parallel arc – caused by close proximity between two different dc polarities.
   - ❖ In modules parallel arcs can occur due to ground faults.
   - ❖ Unlike an ac circuit, ground faults in a dc PV system usually do not trip the fuse or circuit breaker.

No material selection or module design is going to prevent a module from catching fire once an arc is sustained.

Series Arcs

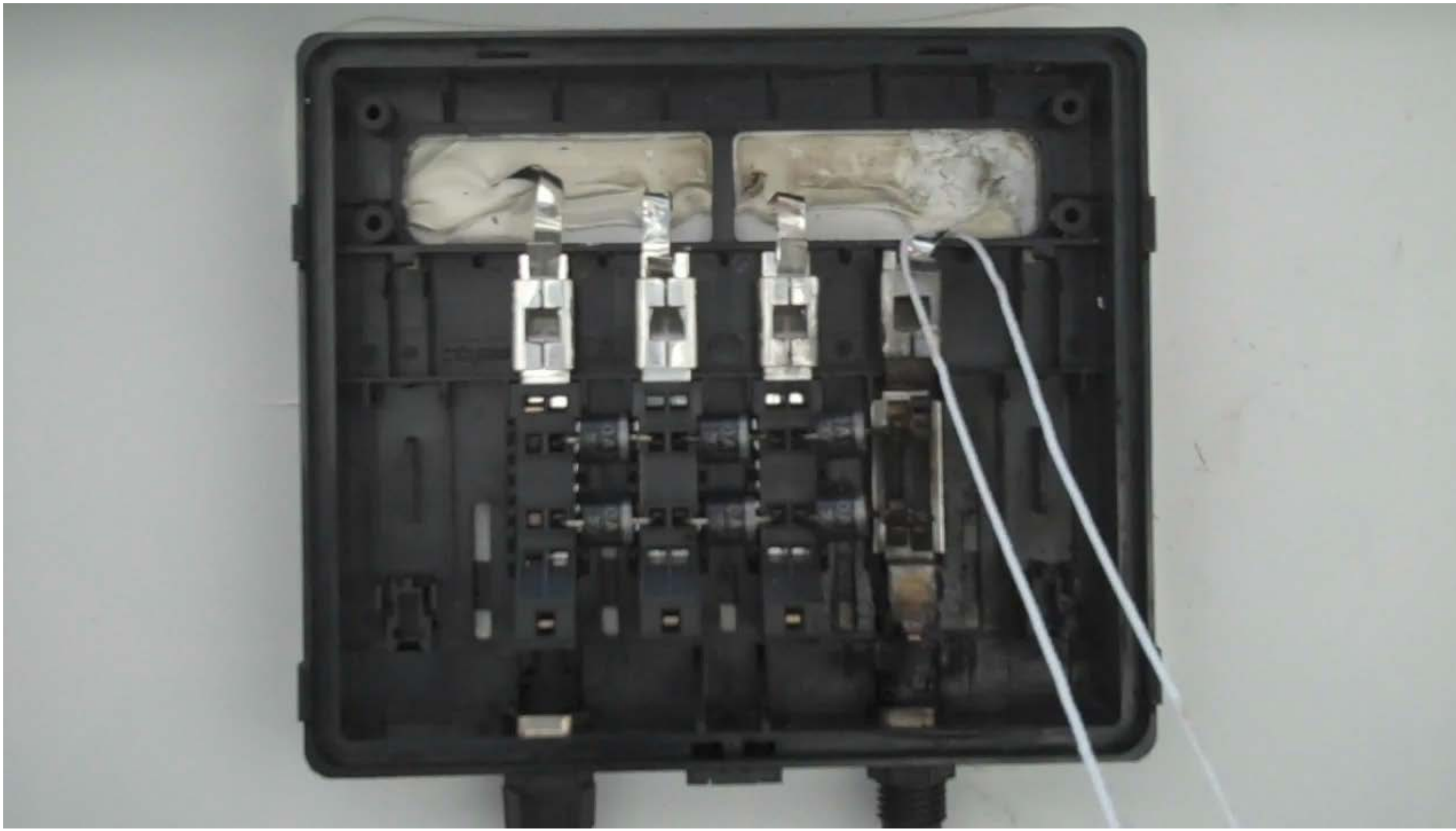
- In modules a series arc can occur whenever the current path is disrupted.
- This is much worse for dc than ac as there is no zero cross-over every cycle to extinguish the arc.
- Once such a dc arc starts it will continue to arc until the current stops flowing by
  - Control system shuts it off
  - The sun goes down or
  - One of the connection points falls away.

Today UL 1703 says “Strain relief shall be provided so that stress on a lead intended for field connection, or otherwise likely to be handled in the field, including a flexible cord, is not transmitted to the connection inside the module or panel.

This has often been met by potting the output wires or running them through a compression fitting.

Either can hold the wire in place while it arcs.

Demonstration of Series Arc



Parallel Arcs

- In modules parallel arcs can occur due to ground faults.
- In US NEC calls for grounding one side of ac lines as well as the equipment itself.
- Because one side of the circuit and the equipment are both grounded, any ground faults to the active circuit usually trip the fuse or circuit breaker.
- Unlike an ac circuit, ground faults in a dc PV system usually do not trip the fuse or circuit breaker.
- In most cases it is not a good idea to ground one of the dc polarities.
  - Makes it more difficult to detect ground faults.
  - Makes it easier for ground loops to occur.
- Flow of current through components not designed to carry such currents means the potential for disruption of the current is high.
- Disruption of the current flow can result in arcing.

So how do we stop arcs from occurring in modules? {1}

Stopping open circuits from occurring

- Design modules so that multiple failures are required in order for an open circuit to occur within the module. *For example use two or more tabbing ribbons per cell with multiple solder bonds on each ribbon.*
- Protect module circuits with by-pass diodes and make sure the by-pass diodes are operational in the module before shipping.
    - ❖ This is even true for thin film modules that don't need by-pass diodes to protect cells from reverse bias {Hot Spot} damage. In thin film modules broken glass can result in arcing across the thin film cells. This will be prevented by the by-pass diode.

So how do we stop arcs from occurring in modules?{2}

Stopping open circuits from occurring (2)

- All output leads (the most likely place to get an open circuit) should have redundant electrical connections.
  - Instead of a single solder bond use both a mechanical clip and a solder bond.
  - Instead of one weld use 2 independent welds.
  - Instead of one spring clip use a clip plus a second independent electrical connection (solder, screw, weld)
- Process Control
  - Train personnel performing any manual soldering.
  - Inspect and periodically test all solder bonds for quality – not just the ones on the cells.
  - Perform periodic accelerated stress testing (TC beyond 200) to validate all electrical bonds using IR to identify degradation before power loss occurs.

A redundant output connection is being discussed for the draft of IEC 61730-1 ed 2.

Examples of Arcs in Module

So how do we stop arcs from occurring in modules? {3}

Stopping ground faults from occurring

Many ground faults are installation related. Efforts to minimize their occurrence should include:

- Better installer training
- Improved installation documentation
- Publication of installer safety design rules

Module mounting systems should be designed to minimize the potential to contact active circuit area. This specifically means:

- Do not attach mounting brackets or clips, etc to a polymer backsheet behind electrically active area.
- Module mounting like frames should attach outside the active area, meeting the creepage and clearance distance requirements for the rated systems voltage.

So how do we stop arcs from occurring in modules? {4}

Stopping ground faults from occurring (cont)

- **Module manufacturers must pay particular attention to adhesion between encapsulant and glass.**
  - **Electrical leakage from active circuit to the ground plane along a delamination between encapsulant and glass is one of the failure modes observed in the field.**
  - **Such leakage is a shock hazard if the mounting system is not grounded and a ground fault hazard if it is.**
  - **The solution to this problem is a robust process with good process control.**
    - **Cleanliness of the glass**
    - **Use of a diffusion barrier on the inside of the glass to keep Na ions from diffusing to the surface and weakening the bond to the encapsulant material.**
    - **Control of the lamination cycle**
    - **Periodic accelerated stress testing of product, particularly damp heat**
    - **Continuous monitoring of the encapsulant cross-link density**

SUMMARY

Making modules inherently safer with minimum additional cost is the preferred approach for PV.

- ❑ **Safety starts with module design to ensure redundancy within the electrical circuitry to minimize open circuits and proper mounting instructions to prevent installation related ground faults.**
- ❑ **Module manufacturers must control the raw materials and processes to ensure that that every module is built like those qualified through the safety tests. This is the reason behind the QA task force effort to develop a "Guideline for PV Module Manufacturing QA".**
- ❑ **Periodic accelerated stress testing of production products is critical to validate the safety of the product.**

SUMMARY {2}

Combining safer PV modules with better systems designs is the ultimate goal.

This should be especially true for PV arrays on buildings.

❑ Use of lower voltage dc circuits

- AC modules
- DC-DC converters

❑ Use of arc detectors and interrupters to detect arcs and open the circuits to extinguish the arcs.

Thank you for your attention!

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