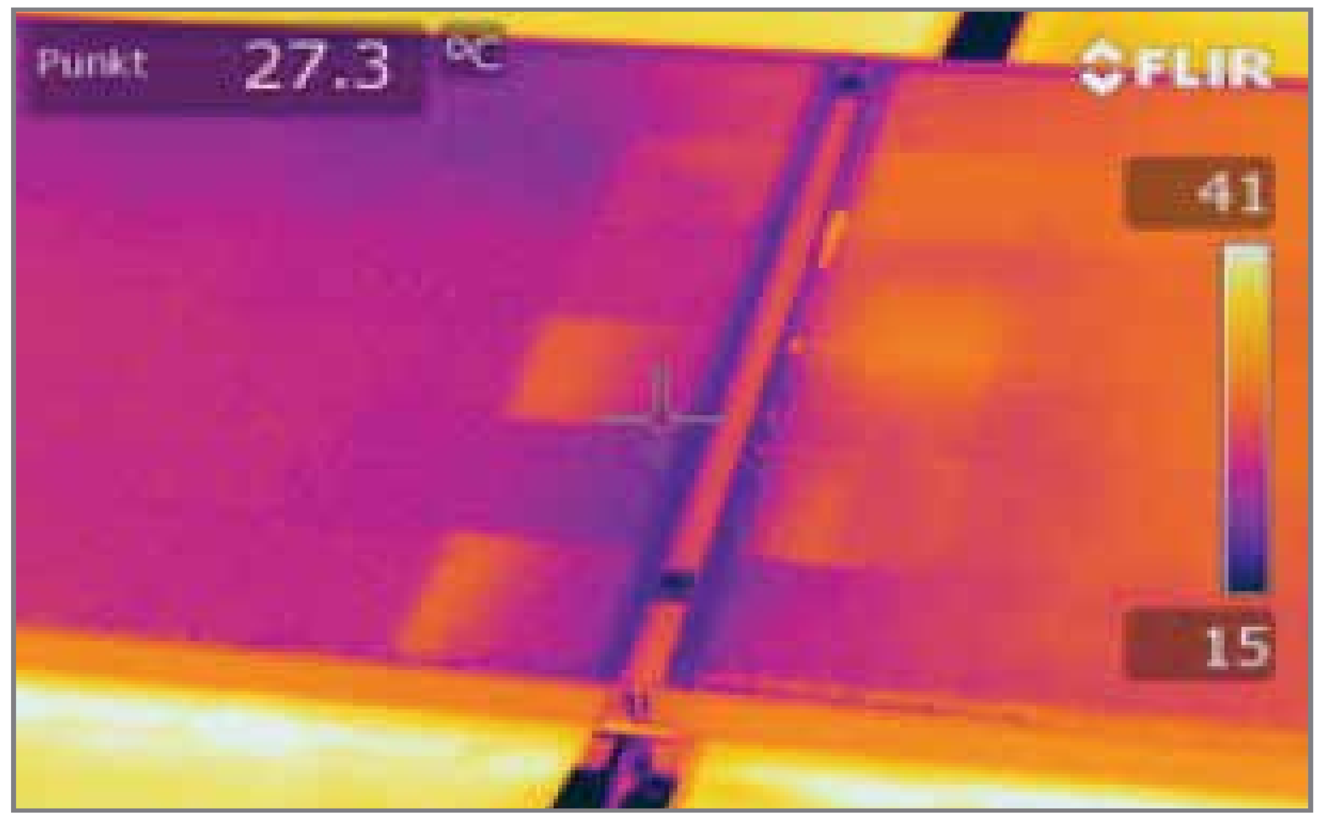
Mitigating Strategies for Hot Spots in Crystalline Silicon Solar Panels

Hot Spots

Hot spots are areas of elevated temperature affecting only part of the solar panel. They are a result of a localized decrease in efficiency, which results in lower power output and an acceleration of the materials degradation in the affected area.

Solar panels generate significant power and hot spots can occur when some of that power is dissipated in a localized area. Hot spots are rarely stable and will usually intensify until total failure of the panel performance in terms of electricity production and/or safety.



Hot spots are evident in this infrared photo showing elevated temperature where the cells are damaged along the frame.

Main Causes of Hot Spots

There are multiple causes of hot spots, and they can be functional or operational. The functional reasons can be divided into two areas:

- **Cell mismatch** occurs when cells of varying current production are connected in series.
- **Cell damage** can occur during the production process because the silicon cell will be subjected to many stresses during lamination, handling and transportation.

The operational reasons for hot spots are related to the solar park design and operation, and can include:

Winter Shading

An EPC company may want to accept shading conditions in winter to increase electricity production in summer. Panels will suffer systematic shading of the bottom row of cells every morning and evening during winter.

Installing panels in landscape orientation will enable the bypass diodes to work and enable the generation of 10 percent electricity, even in winter.

Rooftop Conditions

Rooftops can present challenges. When cells are completely shaded (by design of the system), this may not be sufficient to trigger the bypass diode, resulting in increased temperature which will degrade the panel. Partial shading due to trees or tall vegetation should be controlled.

Soiling

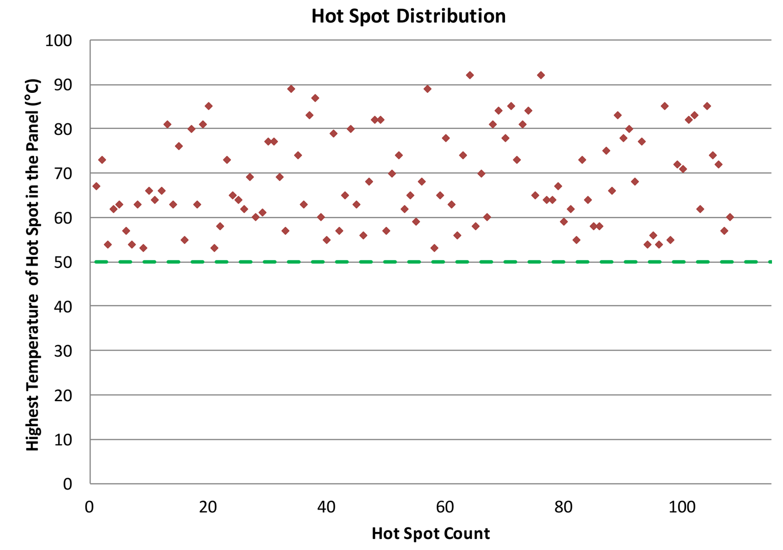
Panels can be soiled due to dust, dirt and other contaminants during their lifetime. The O&M company should also identify situations requiring cleaning, which means regular visits to the park. The frequency of cleaning will be heavily dependent on the climate conditions and ground surrounding the park.

The Temperature Challenge

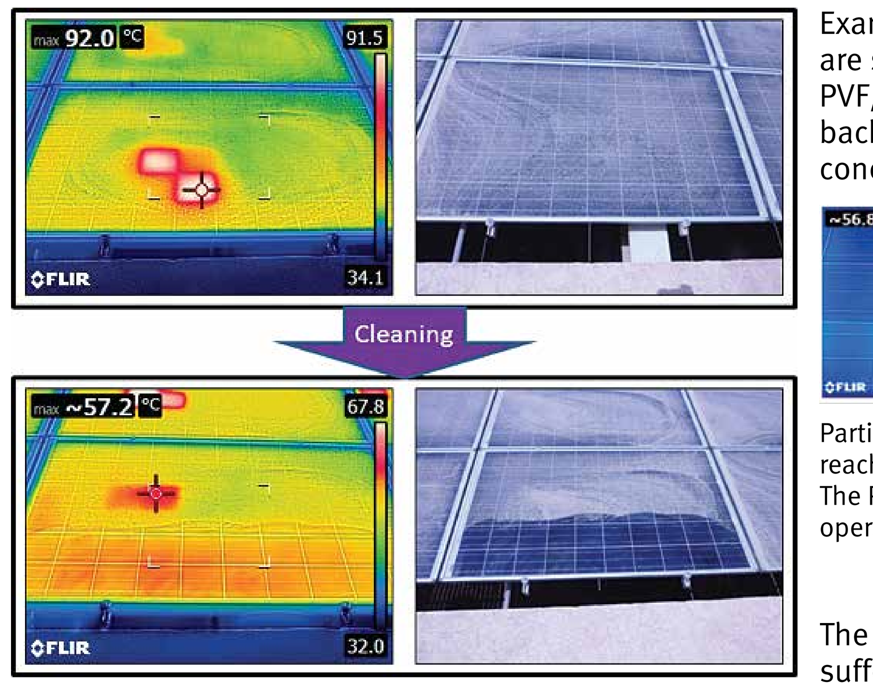
Relevance of hot spots following a sand storm

A survey of the impact of sand buildup on hot spots following a sand storm on 2,000 panels showed that 1.7% of the panels had hot spots of 10°C to 20°C above normal operating temperature and 2.2% of the panels featured hot spots of more than 20°C above the normal operating temperature.

The hot spot situation can be remedied by cleaning the panel.



Distribution of hot spots following a sand storm. Operating state prior to cleaning. A total of 2,040 panels surveyed.



Cleaning the panel in this case allowed a return to normal operating conditions.

Soiling can have dramatic consequences on the safe operation of the park as well as its operability.

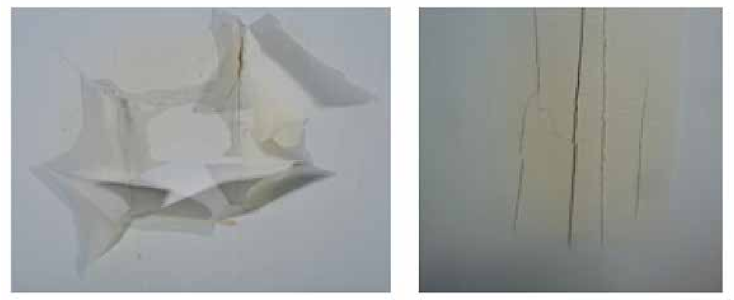
High temperatures can accelerate the degradation of backsheets

Hot spots can occur as a result of the park operation, in particular when operating in hot, dry areas prone to sanding and dusting. Hot spots are caused by underperforming cells. The cell will dissipate the current produced by the string and behave like a resistor, converting current into heat. The higher resulting temperature of the cell (heat) will accelerate aging mechanisms of the neighboring materials, in particular of the encapsulant and the backsheet.

Examples of damanged backsheets due to hot spots are shown below. A tri-layer backsheet composed of PVF/polyester/PVF presents an advantage over other backsheet constructions, in particular in partial shading conditions.

Partial shading of the cell by sand created a hot spot condition reaching 100°C (50°C above normal operating temperatures). The PVF-based backsheet suffered no damage and normal operation resumed upon cleaning.

The polyester-based backsheet shown below has suffered from delamination of the outer coating and deep cracks through the entire depth of the backsheet. The electrical insulation of this backsheet was compromised. The polyvinyl difluoride (PVDF)-based backsheet shown below also suffered deep cracks, compromising the electrical insulation of the panel. In addition, the backsheet suffered from yellowing and surface cracking.

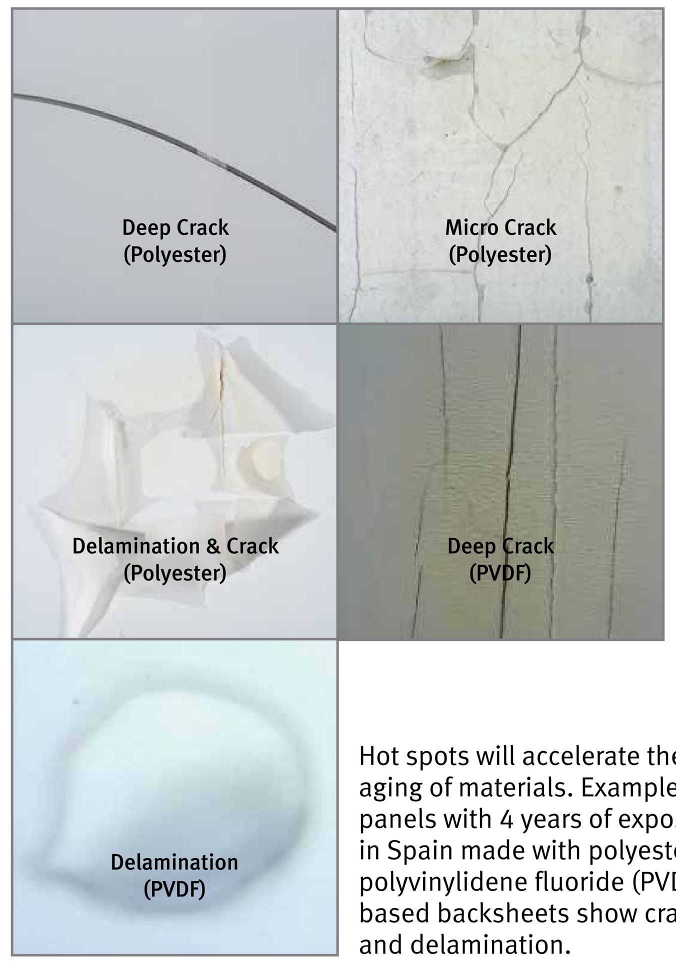


Polyester-based backsheet PVDF-based backsheet
Examples of backsheet damage in hot spot conditions.

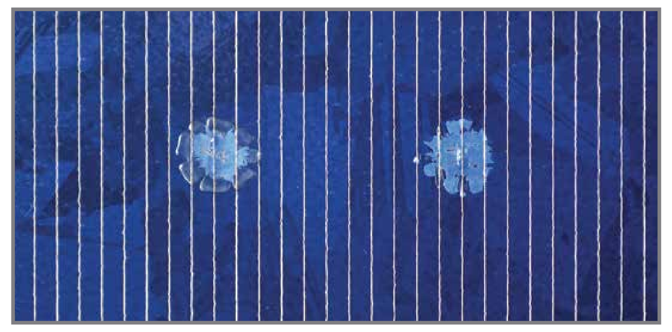
Impact of Hot Spots on the Electrical Protection of the Panel

The consequences of hot spots can range from dramatic fires to accelerated aging of the materials and, in most cases, we will see the more diffuse temperature increase leading to an accelerated aging of the backsheet/encapsulation material set.

A hot spot resulting from, or leading to, a short circuit between the front and the back of the cell will result in very localized high intensity heating. This type of hot spot can result in melting of the backsheet and can lead to fires.



Hot spots will accelerate the aging of materials. Examples of panels with 4 years of exposure in Spain made with polyester and polyvinylidene fluoride (PVDF)-based backsheets show cracking and delamination.

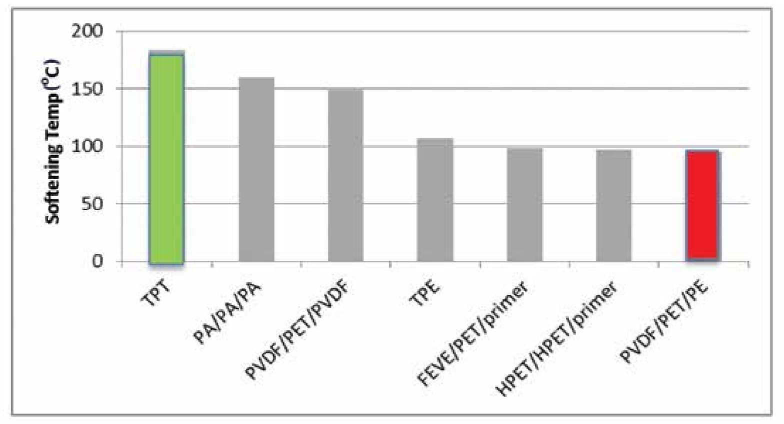


Hot spots lead to bubbling

Bubbling leads to cracking

High intensity hot spots in PVDF-based backsheets

Temperature Resistance of the Adhesion Layer of the Backsheet

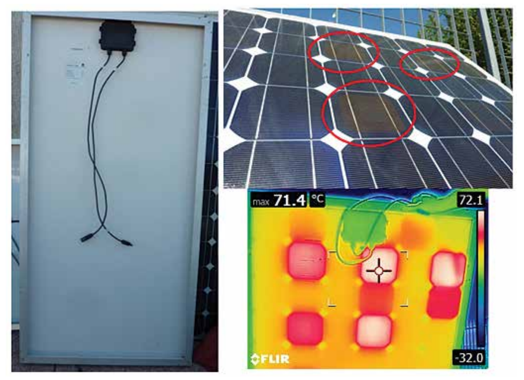


JIS K7196 Heat Deformation Test—weighted stylus impinges on sample being heated, thermal transitions noted.
TPT: Tedlar® PVF/PET/Tedlar® PVF; TPE: Tedlar® PVF/PET/primer

In addition to the acceleration of the aging mechanisms, the temperature resistance of the inner layer (the layer in the backsheet which ensures durable adhesion to the encapsulant) is a factor of prime importance in retaining the adhesion of the insulation layer to the EVA at the back of the panels.

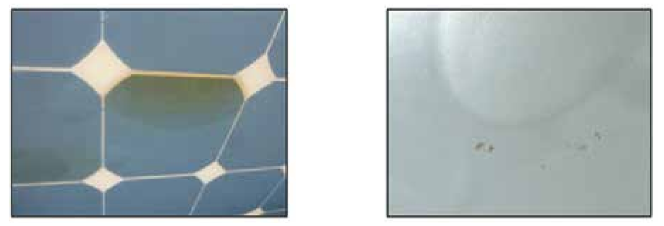
- Tedlar®/PET/Tedlar® or TPT backsheet has Tedlar® PVF as an adhesion layer. This material exhibits the highest temperature resistance of all the backsheets studied here while providing optimum UV and moisture resistance.
- Polyvinyl difluoride (PVDF) backsheets exhibit varying degrees of temperature resistance according to the formulation and manufacturer of the PVDF. Therefore, this material exhibits variable properties that can impact its suitability for the field.

Our field experience has shown that a Tedlar® inner layer can retain good adhesion to the EVA at high operating temperatures, as well as in hot spot conditions created by partial shading or underperforming cells.



Tedlar® TPT backsheet does not show any sign of degradation under hot spot stress.

We have also observed delamination of polyester-based backsheets, as well as PVDF-based backsheets, consistent with a lower temperature resistance of the adhesion layer to the EVA.



Polyester-based backsheet PVDF-based backsheet

Backsheets with low inner layer softening temperatures can be expected to delaminate in addition to the accelerated aging shown before.

Bypass Diodes to Mitigate Hot Spots

Bypass diodes are designed to cut out an underperforming string of cells to guarantee power production from the rest of the panel. An operating bypass of a string containing an underperforming cell will also prevent overheating of the cell acting as a resistor. Our experience of hot spots in the field shows us numerous examples where bypass diodes are indeed not functioning as in the field.

In this example, we dismantled the junction box to examine the interior. We found visually undamaged bypass diodes; however, the diodes were unable to prevent the hot spot that damaged the backsheet. In this case, the bypass was not triggered, showing either that the diode did not function as expected or that the diode had not reached the designed reverse bias for operation. In all cases, the non-operation of the bypass should be considered as a failure.

However, we have also encountered situations where although the bypass was triggered, it resulted in overheating of the diode and subsequent melting of the junction box. This shifts the safety risk from the backsheet to the junction box with increased risk of fire damage coming from burning of thermoplastic materials.

Delamination of PVDF-based backsheet on 134°C hot spot.

Example of bypass diode overheating and subsequent junction box melting.

Conclusions

- Hot spot conditions are never desirable in a solar park and are usually associated with power loss and a higher levelized cost of electricity (LCOE) for the system owner.
- While some hot spots can be remedied, others are the sign of irreversible damage to the panel.
- Hot spots stress the panel materials and can eventually degrade them to the extent that not only the power of the panel is substandard, but more importantly, the safety of the panel and potentially the installation is compromised.
- It is important to identify hot spot situations and remedy the ones that can be prevented by removing partial shading situations or implementing a cleaning cycle.
- It is important to select materials that have the highest thermal stability. As a result, mild hot spot situations caused by partial shading or soiling should not lead to instantaneous damage of the panel.