Hot Spots

Hot spots are areas of elevated temperature affecting only part of the solar panel. They are the result of a localized decrease in efficiency, which results in lower power output and an acceleration of the materials degradation in the affected area (Fig. 1). 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 in crystalline silicon solar panels represent an additional stress for the materials used in module construction. This can be temporary or permanent, depending on the type and cause of the hot spot. The selection of materials with higher thermal stability can help reduce the risk of performance and safety issues associated with hot spots.

Module Design and Mitigating Strategies

The causes of hot spots and susceptibility of solar panels have been investigated in the past and test standards have been developed to address this issue (Ref. 2).

In a crystalline silicon solar panel, the silicon cells are typically connected in series, so that each 6-inch cell produces a current of about 8 amps (A), and each voltage at about 0.6 volts (V) is added through the string to build up the power (Power = Voltage*Current). This leads to panels with a direct electrical output of about 8A and typically 30 to 35V.

- If a cell cannot generate the peak current produced around it, it will act as a power dissipation device (like a resistor). This is called reverse bias.
- A resistor dissipates power by heating up, so a cell in reverse bias will exhibit a hot spot.
- Cells may not be able to produce the current because of shadows (either cast or from soiling), or because of cell damage or inherent cell lower performance (poor cell matching).
- Bypass diodes segregate cells in groups of 20 cells. This is supposed to limit the reverse voltage across the cells to less than 10V.
The 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. This condition is the result of wide bins in the cell sorting process. In general, this should only mildly affect the temperature of the underperforming cells.

- Cell damage can occur during the production process because the silicon cell will be subjected to many stresses in lamination and handling. The cell is about 180μm thick and is very brittle. The cell will be transported, soldered, handled as part of a string and then laminated. Each stage subjects the cells to mechanical and/or thermal stresses. Thereafter, module transport and installation can generate further stresses on the cells which can cause them to break. In particular, it was highlighted by the Institute for Solar Energy Research Hamelin, Germany (ISFH) that transportation of the panels parallel to the ground will generate particular damage to the cells (Ref. 3).

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

- Situations where an engineering, procurement and construction (EPC) company may want to accept shading conditions in the winter (as it may only represent 10 percent of the annual production in specific areas) to increase electricity production in the summer. This means that the panel will suffer systematic shading of the bottom row of cells every morning and evening for several months. This is where it is particularly important to install panels with the strings of cells parallel to the ground (landscape orientation) to allow the bypass diodes to work and enable the generation of 10 percent electricity, even in winter.

- For solar installations on roofs, the topography of the roof can sometimes present a challenge. Again, the installation designers may decide that it is acceptable for a cell to be completely shaded, thereby putting a lot of stress on the panel. This condition may not be sufficient for the bypass diode to operate, resulting in an increase in temperature which will accelerate the panel degradation. Similarly, tree or tall vegetation growth around a solar installation should be controlled to avoid partial shading conditions.

- Panels can be soiled due to dust, dirt and other contaminants during their lifetime. It can be useful to design the parks to mitigate these sources of soiling. The operations and maintenance (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. For example, a solar park that is cleaned in the south of Italy will usually gain 2 percent for only a few days and stabilize thereafter for many months. In this case, the cost of cleaning may not be worth the effort. A solar park in dusty desert conditions, however, can lose up to 30 percent power output if not cleaned regularly. Today the Middle East has developed dry cleaning methods to de-dust the solar panels, due to the scarcity of water in the region.
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 (Fig. 4).

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.

Figure 4. 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.
Mitigating the Impact of Hot Spots

While hot spots may not be directly caused by poor material selection and may be more directly related to processing problems (from cell manufacturing to panel installation and maintenance), certain materials have been found to be more sensitive to hot spot conditions. While the hot spot condition can be temporary (such as for partial shading or soiling), it is important to select materials which can withstand the temporary occurrence of hot spots.

There are two variables which are of interest in the backsheet to mitigate the likelihood of permanent damage.

1. The softening of the backsheet inner layer may compromise the adhesion of the insulation layer, thereby affecting the electrical insulation of the panel.

2. The smaller the thermal coefficient of expansion, the fewer stresses there are at the edges of the hot spots. Large expansion coefficients may increase the likelihood of backsheet delamination.

The backsheet is the electrically insulating component on the back of the solar panel. It is usually made of several layers with a core of polyester (PET). The polyester middle layer or core layer provides the main electrical insulation function. The other layers fulfill protection and/or adhesive functions. DuPont™ Tedlar® polyvinyl fluoride (PVF) film, used in a tri-layer backsheet composed of Tedlar®/PET/Tedlar® (referenced as TPT in figures 7 and 8) is well recognized to provide the best combination of electrical insulation and durability against moisture, UV and temperature degradation. DuPont™ Tedlar® PVF film is also used in a corresponding single-sided structure (Tedlar®/PET/Tie layer, known as TPE). The tie layer, which is in contact with the ethylene vinyl acetate (EVA) encapsulant, is also called the inner layer.

In situations of high hot spot intensity caused by shunts or electrical arcs, no material can be expected to withstand the very high temperatures reached. Some cells may be more prone to edge shunts. Arcs can occur within the panel when the soldering bus wires are placed too close to one another inside the panel and the water saturation of the EVA reaches equilibrium with the ambient moisture levels. These situations can only be remedied at the cell selection and the panel design level and should be addressed by the panel manufacturer.
Dependence of Hot Spot Conditions on Installation Type

Cells and panels can operate at elevated temperatures for reasons other than a malfunction in the panel. Rooftop systems can create an environment where the temperature of the panel can be more than 40 °C above the ambient air temperature (Fig. 9).

The occurrence of a hot spot on a rooftop system can further accelerate the degradation and affect the electrical safety protection. An additional challenge is that the effect of a hot spot on the backsheet will not be apparent in most cases (e.g. on pitched rooftops). System owners may have a serious electrical safety protection issue without knowing. In any case, higher operating temperatures due to poor air ventilation of the panels require the use of materials that have higher thermal stability.

DuPont™ Tedlar® PVF film-based backsheets used in a TPT construction demonstrate the best thermal characteristics to mitigate the impact of diffuse hot spots for three reasons:

1. The highest melting temperature of the inner layer provides stable mechanical properties of the electrical insulation at higher temperatures.
2. The lowest thermal expansion coefficient reduces the stresses at the edges of the hot spot and the damage to the electrical insulation.
3. Ensures the highest combined UV, humidity and thermal resistance.

Figure 9. Levels of temperature intensity for various types of solar installations

Conclusions

Hot spot conditions are never desirable in a solar park and are usually associated with power loss (Ref. 5). Any power loss means lower return on investment 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.

If the panel materials have been selected carefully, mild hot spot situations resulting from partial shading or soiling should not lead to instantaneous damage of the panel. This will give the O&M team the time they need to detect these by infrared (IR) thermal inspection, for example, and to remedy the situation before significant damage can occur.

References:

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