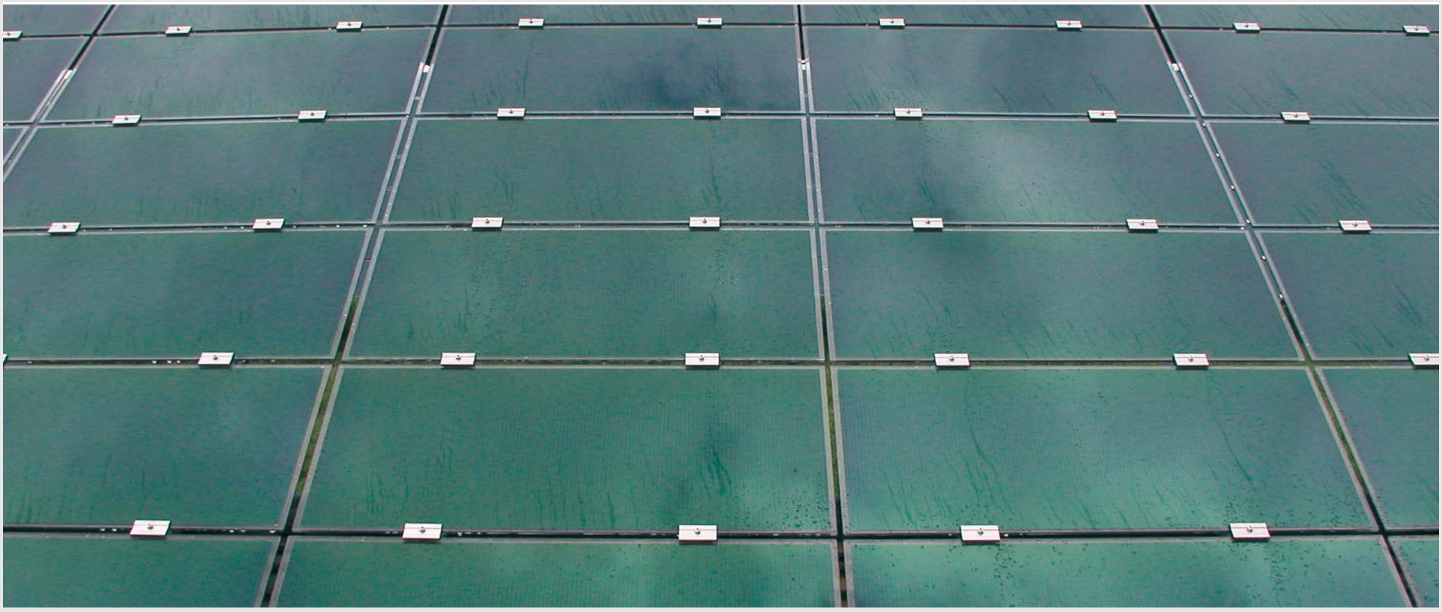
Module Technology

SMA inverters provide the optimum solution for every module



Contents

Alongside PV modules of crystallized silicium, new cell technologies and advancements of conventional PV modules are continually surging onto the market. At the same time, innovative technologies such as thin-film modules and back-side contacted cells provide trend-setting advantages such as low production costs, short energy return times or exceptionally high efficiencies.

It is to be noted however that certain technologies should only be used under certain conditions. For this reason, when employing PV modules the manufacturers' installation recommendations must be observed.

Due to the versatile range of different topologies, SMA inverters in combination with the optional supplementary equipment are so flexibly deployable that an optimum device is available for every module technology. This technical information describes the current state of experiences in the use of various cell and module technologies. This information will be supplemented by concrete experiences for the selection of the appropriate inverter.

1 Potential Induced Degradation (PID)

Many electrically qualified persons and plant operators have recently heard or read about an inexplicable power loss. This phenomenon occurs most commonly in the PV module that is closest to the negative pole. The potential (voltage against ground) of the PV cells here is between – 200 V and – 350 V depending on the length of the string and the on the device type of the inverter used. The frame of the PV modules have, however, a potential of 0 V, since it must be grounded for safety reasons.

This electrical voltage between the PV cells and the frame can cause electrons to come loose from the materials used in the PV module and discharge through the grounded frame (figure 1). This causes a polarization that can adversely alter the characteristic curve of the PV cells (figure 2). It has become apparent that such polarizations are generally reversible. They can therefore be distinguished from irreversible effects such as corrosion and normal deterioration.

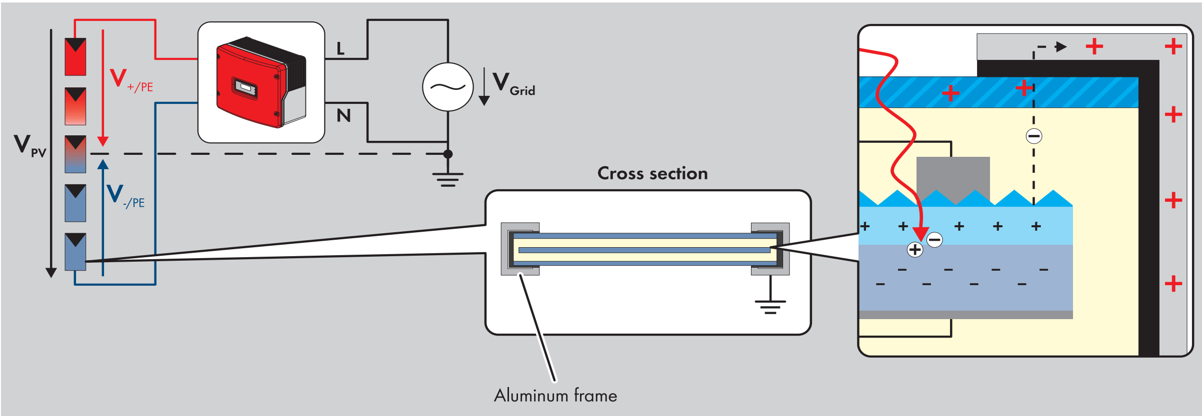


Figure 1: Build-up of electrical charges due to a leakage current between the PV cell and module frame

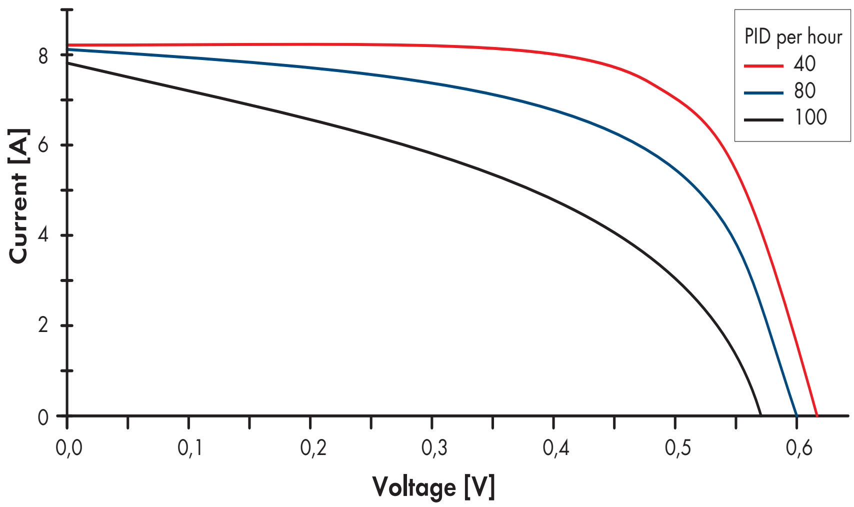


Figure 2: A PV module's characteristic curve before and during the degradation process. A flattening of the curve is characteristic, with the open-circuit voltage and the short-circuit current remaining nearly unchanged, but the maximum power point (MPP) will be reduced by up to 70%.*

In the past, polarization was known to occur in only a few cell types, which the manufacturers attributed to a certain treatment of the PV module. Of late, though, other cell types are also showing this fault scenario. Two distinct cases are to be differentiated here:

- For years the SunPower company have been advising that their modules with A-300 cells (n type) polarize when operated under positive electrical potential. A grounding of the positive array pole is recommended as a corrective measure.
- Many of the newly occurring cases also affect manufactures of p type cells. However, the polarization here is caused by negative potential and can be obviated by grounding the negative array pole.

If the array can not be grounded because of the inverter used, or if the PV modules are already polarized, then only a neutralization of the polarization will help. For this, SMA Solar Technology AG has developed the PVO-Box, which applies a reverse voltage to the effected pole overnight. You will find further information on this subject in the technical information "Potential Induced Degradation" (see www.SMA.de/en).

2 TCO Corrosion

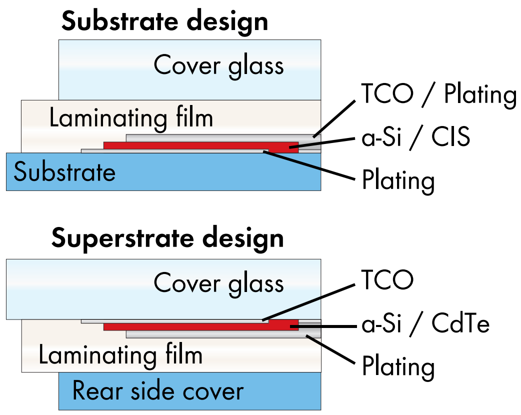
Even after a comparatively short operating time, damage to the so-called TCO layer (TCO: Transparent Conductive Oxide) of some of the thin-film PV modules was observed in the past. The damage of this electrically conductive layer on the inside of the cover glass cannot be repaired and results in substantial power losses.

Causes

The Florida Solar Energy Center (FSEC) has been studying the causes of TCO corrosion since 2000. This study shows that modules with cells made of a-Si and CdTe which are manufactured with superstrate technology are affected in particular. In this production process the individual layers of the module are structured starting with the cover glass.

TCO corrosion occurs primarily on the edge of the PV module as a result of the reaction of moisture with sodium that is contained in the cover glass.

As a result of the corrosion, the TCO becomes milky and loses its conducting properties. The efficiency of the PV module then decreases continuously.



a-Si amorphous silicon
CIS Copper-Indium-Diselenid
CdTe Cadmium telluride

* according to J. Berghold et al.: "Potential Induced Degradation of Solar Cells and Panels"; 25th EU PVSEC / 5th World Conf. on PV Energy Conversion, September 6 - 10, 2010, Valencia, Spain

Counter Measures

- Corrosion depends directly on leakage currents and this in turn on the potential of the PV array against ground. In contrast to the PV voltage between plus and minus, the voltage against ground is rarely considered during the design. It differs greatly depending on the inverter topology (see section 5 "Potential against Ground", page 6). The leakage currents can be somewhat reduced through a maximization of the distance between PV modules and grounded structures (e.g. module frames). However, the selection of a specific inverter topology alone does not solve the problem.
- By using galvanically isolating inverters and the negative grounding of the PV array with the grounding set (order number: ESHV-N-NR), an electric field is generated in which the positively charged sodium ions are repelled from the TCO layer. This clearly prevents corrosion. This measure should be preferred.
- Additionally, module manufactures are developing measures in order to prevent this effect. For example, the penetration of moisture is prevented through improved sealing of the module edges thus removing the basis of the corrosion process.

3 Leading Leakage Currents

A PV module generates an electrically chargeable surface area which is next to a grounded frame. Such an arrangement behaves as an electrical capacitor, whose capacitance is greater the larger the surface area and the smaller the distance from the grounded anti-pole (frame). Since this capacitance occurs here as an undesirable side effect, it is referred to as "parasitic capacitance". The capacitance is calculated using the following formula and is dependent on 4 factors:

$$\mathbf{C = \varepsilon_0 \varepsilon_r \times A \div d}$$

Meaning of the factors:

Factor	Meaning
ε_0	Dielectric constant or permittivity, physical constant: 8.85×10^{-12} As/Vm
ε_r	Relative permittivity, dependent on material: $\varepsilon_{rAir} = 1$; $\varepsilon_{rGlass} \approx 5–10$
A	Effective surface area of the capacitor
d	Distance between the capacitor plates

Additionally, during operation the PV modules are connected via the inverter to the power distribution grid. During this connection, depending on the device type of the inverter used, a part of the alternating voltage amplitude is passed on to the PV modules. For many transformerless inverters this amounts to half of the alternating voltage (115 V / 50 Hz). The fluctuating voltage constantly changes the state of charge of the parasitic PV capacitor and causes a displacement current that is proportional to the capacitance and to the voltage amplitude.

For experts: the displacement current (root-mean-square value) can be derived as follows:

$$I = \frac{\Delta Q}{\Delta t} = C \times \frac{\Delta U}{\Delta t} = C \times 2\pi \times f \times V$$

Here, f = 50 Hz the power frequency and V the root-mean-square value of the alternating voltage on the PV array (approx. 115 V for transformerless inverters). This leakage current is a reactive current with its phase shifted by 90° to the line voltage. It is therefore approximately loss-free.

The leakage current described above is a reactive current, which on its own is not dangerous. However, it superimposes a possible residual current that could for example occur through touching a live line on a damaged insulation and can seriously hinder its detection. Above a leakage current of 50 mA it is almost impossible to detect a life threatening residual current of 30 mA. The inverter then disconnects itself automatically from the power distribution grid for safety reasons. In many 1-phase transformerless inverters, this 50 mA will be reached by a parasitic capacitance of 1 400 nF. You will find further information on this subject in the Technical Information "Leading Leakage Currents" (see www.SMA.de/en).

4 Insulation Resistance R_{iso}

The most cells in a PV plant lay permanently on a non-zero potential. Since large leakage currents are to be avoided for personnel and fire protection reasons, the PV modules must be well insulated. To put it another way: the insulation resistance R_{iso} must not exceed a certain value. Transformerless inverters can not continuously measure the R_{iso} in operation because of the direct connection to the grounded power distribution grid. The insulation of the PV array is therefore continuously monitored before the grid connection via the measurement of the insulation resistance and during feed-in operation via the control of the leakage current.

The following regulations exist for the R_{iso}:

- For PV modules the R_{iso} must be at least 40 M Ω × m². This means that a PV module with a module surface area of 1 m² must have an insulation resistance of at least 40 M Ω , a PV module with a surface area of 2 m² in contrast only a minimum of 20 M Ω .
- For PV plants without galvanic isolation (transformerless), the R_{iso} must be at least 2 000 k Ω per kW input power of the inverter. Adherence to this limiting value must be monitored by the inverter.

Until the end of 2010 the limiting values were even more stringent, resulting in the two regulations often being in conflict with each other in large PV plants. This does not occur as often today, but as before is still possible. The following is an example:

Standard conflict

A 17 kW PV plant made up of PV modules with an efficiency of 8.5% requires a module surface area of 200 m². These must have an insulation resistance of at least 40 M Ω / 200 m² = 200 k Ω according to the standard. This allows no safety margin to the existing standard and can therefore lead to problems during the feeding in of the inverter into the power distribution grid. PV modules with an even lower efficiency (e.g. a-Si) or ever larger PV arrays are therefore more likely to be affected by the problem.

You will find further information on this subject in the Technical Information "Insulation resistance" (see www.SMA.de/en).

5 Potential against Ground

In order to find the most suitable inverter for each of the described requirements of the PV modules, it must be known which array potential appears during feed-in operation on the plus and minus poles. This is shown in the following diagram:

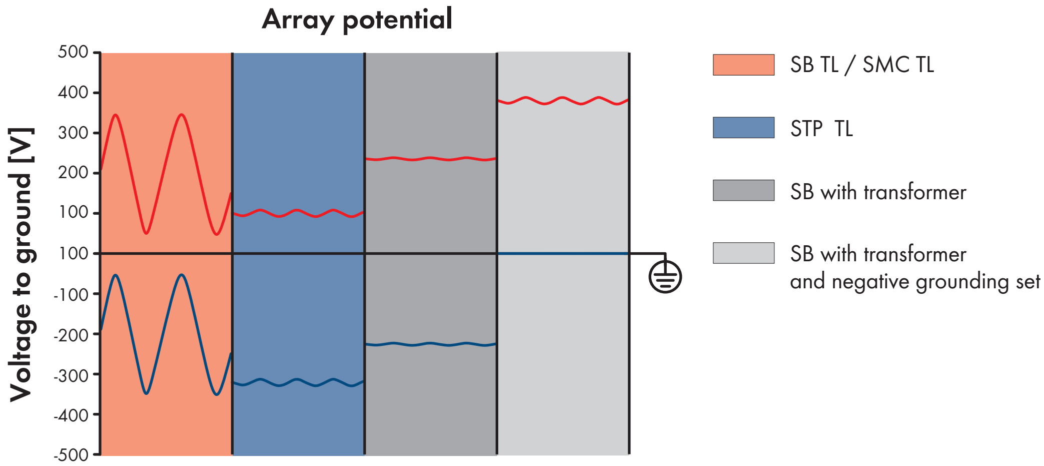


Figure 3: The potential of the lowest (blue) or highest (red) PV module in a string (see also figure 1) depends on the inverter used and whether an array pole is grounded. Example for MPP voltage of 400 V.
SB = Sunny Boy, SMC = Sunny Mini Central, STP = Sunny Tripower, TL = Transformerless

The array potential varies depending on the topology of the inverter. In addition there is the possibility of hard grounding (inverter with transformer) and soft grounding through potential shifting (transformerless inverter). Altogether, SMA inverters offer the following possibilities:

- Grounding set classic; this type of grounding is only possible with SMA inverters with transformer. The ground connection to the plus or minus pole is made via an internal thermal fuse and therefore offers additional safety (fire protection). The fuse is monitored in order that the insulation monitoring is not compromised. The grounding set is available for both positive and negative grounding.
- The SMA inverter SB xxxxHF has a so-called grounding plug that can be plugged into the inverter in two different positions. Therefore either a positive or negative grounding can be realized with one and the same plug.
- The function of the grounding set is integrated into UL certified inverters for the USA and Canada, since these must be equipped with a GFDI (Ground Fault Detection Interrupter).
- TL Grounding Solution: in transformerless inverters, the potential of the PV array is coupled to the power distribution grid. A hard grounding is not possible here, but the potential of the neutral point of the 3-phase system can be shifted so far that even the minus pole on the PV array always remains within the positive range. This, a simple grounding improvement measure, is known as "TL Grounding Solution" and is currently limited to PV plants with Sunny Tripower, which feeds into the medium-voltage grid via an individual transformer.

In addition, the possibility exists of reversing the potential overnight in order to neutralize any accumulated charge carriers. For this, the PVO-Box is used, which is used for the regeneration of reversible PV modules (see section 1: "Potential Induced Degradation").

6 Check List

In order to simplify selection of the right inverter for every module type, we have compiled the currently most important recommendations here:

1. Check whether the PV module manufacturer issues recommendations on the grounding of the array or on the topology of the inverter to be used.
2. Should the manufacturer of the PV modules not offer any specifications for the use of its products, then selection of the inverter should be made based on the characteristics of the PV module listed in the following table.

If these recommendations do not correspond with those of the module manufacturer, follow the recommendations of the module manufacturer.

Cell technology / Module design	Inverters without transformers		Inverters with transformers		
	SB xxxxTL SMC xxxxTL	STP xxxxTL	Series devices SB xxxx SMC xxxx		
			without grounding set	with negative grounding set	with positive grounding set
c-Si*	●	●	●	○	○
Thin film**	–	–	–	●	–
Monocrystalline Si (A-300)*	–	–	–	–	●
Flexible or with metal-plated rear side***	–	○	●	●	●
Legend: ● recommended; ○ recommended to a limited extent; – not recommended					

* see section 1 "Potential Induced Degradation (PID)", page 2

** see section 2 "TCO Corrosion", page 3 and section 4 "Insulation Resistance R_{iso}", page 5

*** see section 3 "Leading Leakage Currents", page 4

Example: The company SunPower recommends grounding the positive terminal for PV arrays of modules with the A-300 cell type.

The right choice: Sunny Boy with transformer and a positive grounding set (see section 1 "Potential Induced Degradation (PID)", page 2).

Example: Thin-film PV modules with cells of CdTe or amorphous silicon often use a TCO coated glass plate as a substrate for the cell design.

The right choice: Sunny Boy with transformer and a negative grounding set (see section 2 "TCO Corrosion", page 3).

Example: in flexible thin-film PV cells, a stainless steel foil is often used as a carrier substrate.

The right choice: Sunny Boy with transformer (see section 3 "Leading Leakage Currents", page 4).