Technical Information

Capacitive Leakage Currents

Information on the Design of Transformerless Inverters

SUNNY BOY/SUNNY MINI CENTRAL/SUNNY TRIPOWER

Contents

All PV modules have a certain parasitic capacitance according to fundamental physical relation. This capacitance is proportional to the surface area and inversely proportional to the thickness. It is also dependent on the material properties and the type of mounting. This capacitance is particularly high for PV modules made of flexible substrates and also for certain crystalline PV modules with integrated metallic lining on the back.

In combination with transformerless (TL) inverters, displacement currents of such a high magnitude can occur that the inverter's residual current monitoring will be triggered. However, this causes the inverter to disconnect itself from the power distribution grid for a short period of time. In such a case, SMA Solar Technology AG recommends the use of an inverter with a transformer.

The following pages illustrate the technical context that should be taken into consideration from the very beginning when planning a PV plant. This technical information is aimed at two target groups: first, at the manufacturers of the above mentioned PV modules with the request to pass on this information to their customers (especially laminate finishers), and second, directly at the electrically qualified persons and planners.

1 How is the Capacitance of the PV Array to Ground Calculated?

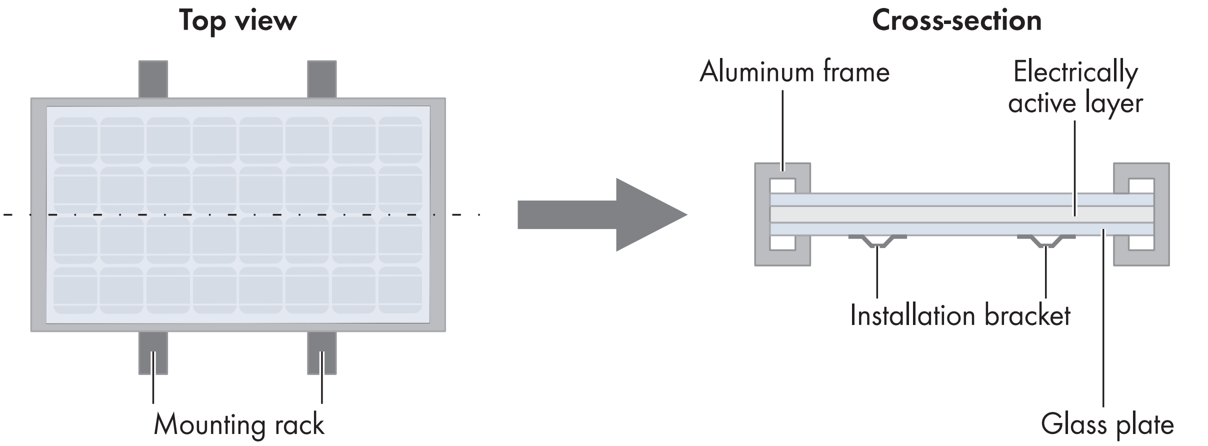
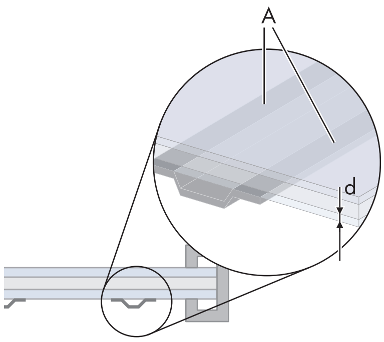


Figure 1: Plan view and cross-section of a PV module with a mounting frame.



A PV module generates an electrically chargeable surface area, which faces a grounded frame. Such a configuration, which stores charge under applied voltage, is known as a capacitor, the capacitance of which is most often designated with "C". Since this capacitance occurs 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:

$C = \varepsilon_0 \varepsilon_r \cdot A/d$

Meaning of the factors:

ε_0: permittivity, physical constant: $8.85 \cdot 10^{-12}$ As/Vm

ε_r: permittivity number, dependent on material: $\varepsilon_{rAir} = 1$; $\varepsilon_{rGlass} \approx 5 - 10$

A: effective surface area of the capacitor

d: distance between the capacitor plates

What should be used as the surface area A and distance d? This is not always easy to determine, because in addition to the data of the PV module, the type of mounting must also be taken into consideration. That is why there is generally no information concerning this in the datasheet. The following 3 examples will be used to demonstrate how an estimation can nevertheless be made (an $\varepsilon_r = 6$ is assumed for each glass used).

NOTICE!

In addition to the aforementioned factors based on the structure itself, weather-related factors can also play a role. For example, moisture or water on the surface of the module can significantly increase the effective surface area.

Example 1: Frameless glass-glass module with aluminum frame on an assembly stand (open air)

Basic conditions:

- The module has a surface area of 1 m^2.
- The module is 1 cm thick.
- The electrically active layer is exactly half-way between the front and rear glass.
- The module is mounted on the grounded metal support with only 10% of its surface area directly touching.
- There is a clearance of 1 m between the module and the ground.

The 10% surface area on the frame represents a capacitor with a 0.1 m^2 surface area and 0.005 m plate clearance. This results in a capacitance of approx. 1 nF. The remaining 90% of the surface area against the ground accounts for a 0.9 m^2 surface area and a clearance of 1 m. This amounts to just 0.05 nF and can be ignored. The overall capacitance of a module to ground therefore amounts to approx. 1 nF.

Example 2: In-roof glass-glass module with aluminum frame

Basic conditions:

- The module has a surface area of 1 m^2.
- The module is 2 cm thick.
- The electrically active layer is exactly half-way between the front and rear glass.
- The module is located directly on the grounded roof sheeting.

The total surface area is just 1 cm away from the roof sheeting. If it is grounded, the result will be a capacitor with a 1 m^2 surface area and 0.01 m plate clearance. The parasitic capacitance of a module to ground is therefore approx. 5 nF.

Example 3: Thin-film PV module on flexible substrate

Basic conditions:

- The module has a surface area of 1 m^2.
- The module is 2 mm thick.
- The electrically active layer is half-way between the front and rear foils.
- The module is laid as a laminate directly onto an aluminum roof.

Now, the total surface area is just 1 mm away from the roof sheeting. The result is a capacitor with a 1 m^2 surface area and a plate clearance of 0.001 m. The parasitic capacitance of a module to ground is therefore approx. 50 nF.

2 How Does a Capacitive Leakage Current Occur?

During operation, the PV module is connected to the alternating current grid via the inverter. Thus, depending on the device type, a portion of the alternating voltage amplitude arrives at the PV module. At this point, two cases must be distinguished (see illustration):

Transformerless Inverters

In almost all **1-phase** transformerless inverters, half the grid amplitude is operationally passed on to the PV module. The configuration oscillates at 115 V/50 Hz. This applies to Sunny Boy/Sunny Mini Central/ Sunny Tripower devices with "TL" in the product names.

In **3-phase** transformerless inverters, AC voltage pass-through to the PV module is largely suppressed. That applies for all Sunny Tripower devices.

Inverters with Transformers

In inverters with transformers, the voltage within the PV module fluctuates at a so-called "ripple" of just a few volts.

The fluctuating voltage constantly changes the state of charge of the parasitic PV capacitor. This is associated with a displacement current, which is proportional to the capacitance and the applied voltage amplitude.

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

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

Here, f = 50 Hz is the power frequency and V is the root-mean-square value of the alternating voltage at the PV array (approx. 2 V for inverters with a transformer and 115 V for transformerless inverters). This leakage current is a reactive current with its phase shifted by 90° to the line voltage. It is thus lossless in the first approximation.

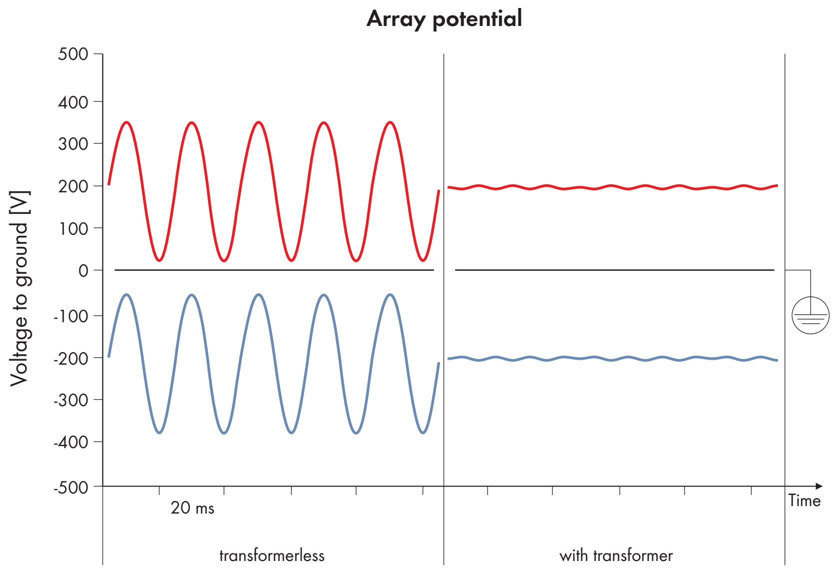


Figure 2: The potential of a string's lowest (blue) or highest (red) PV module depends on the inverter used and whether an array pole is grounded. Example for an MPP voltage of 400 V.

3 How Does the Leakage Current Affect the Detection of the Residual Current?

The capacitive leakage current as described in section 2 is a reactive current (lossless).

On the other hand, if a fault, such as defective insulation, causes a live line to come into contact with a grounded person (see figure 3), an additional current, known as a residual current, flows. The total of the two currents (leakage current and residual current) is known as the differential current.

Differential current = leakage current + residual current

Residual currents greater than 30 mA can be life-threatening to people.

In order to ensure personal safety, in addition to the insulation, electrical devices must be disconnected from the power distribution grid in the event of a residual current of 30 mA at the latest (German Standard DIN VDE 0126-1-1). With transformerless inverters, these measurements cannot be made directly during operation. They must therefore be implemented indirectly via an all-pole sensitive residual-current monitoring unit (RCMU). However, these systems can only measure the differential current (leakage current + residual current). The determination of the residual current is only possible to a certain limit and becomes more difficult with increasing leakage currents. Starting with approx. 50 mA, random fluctuations in the leakage current are so great that they can be interpreted as suddenly occurring residual currents of above 30 mA. In such a case, the inverter disconnects automatically from the power distribution grid as a preventative measure. Inverters with transformers can also measure the residual current directly during operation. Their measurement is not affected by leakage current. They do not switch off until much later, i.e. at a leakage current of 300 mA (fire prevention).

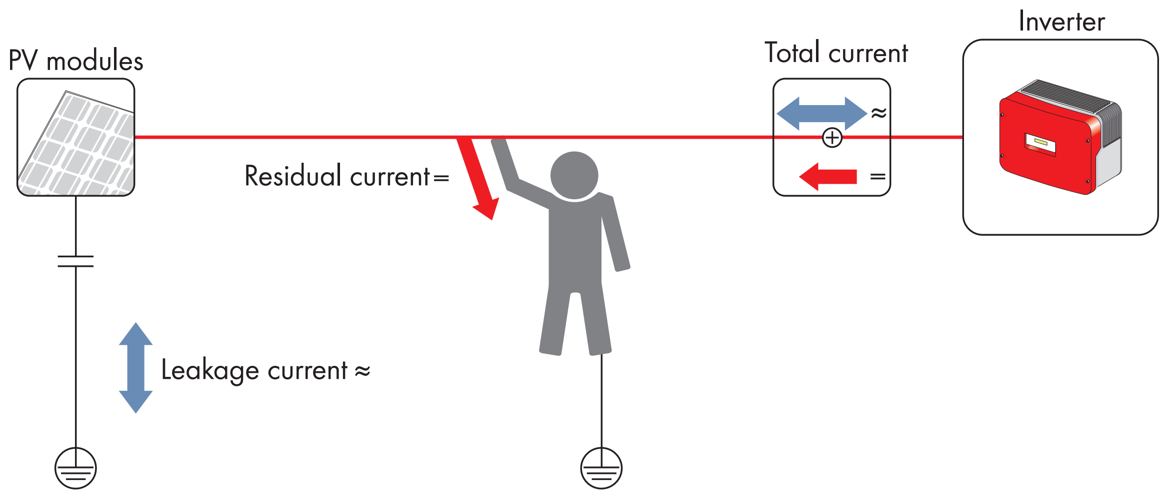


Figure 3: Occurrence of a residual current due to contact of a live line with a grounded person.

4 At What Point Does it Become Problematic?

Capacitance Limit

As previously described, leakage currents of above 50 mA should be avoided in order to ensure the functionality of the residual current monitoring. Since the leakage current is directly dependent on the capacitance of the PV module to ground, for each line voltage there is a respective specified capacitance limit, above which an operation susceptible to faults is to be expected.

The result for all 1-phase transformerless inverters is a capacitance limit of approx. 1400 nF, in accordance with the above mentioned formula:
$I = C \cdot 2\pi \cdot f \cdot V$ (with I = 50 mA, f = 50 Hz and V = 115 V).

The capacitance limit for Sunny Tripower is 2 560 nF.

For experts: Rule of thumb

Insert the following values into the above mentioned formula for the capacitance:

$\varepsilon_0 = 8.85 \cdot 10^{-12}$ As/Vm; $\varepsilon_{rGlass} = 6$

This results in $C = \varepsilon_0 \varepsilon_r \cdot A/d \rightarrow C\,[nF] \approx 50 \cdot A\,[m^2]/d\,[mm]$.

The following approximation formula applies: **$C\,[nF] \approx 50 \cdot A\,[m^2]/d\,[mm]$**

However, the above mentioned values are only achieved in very rare cases in practice. Comprehensive field testing revealed that the values calculated using the rule of thumb are peak values for most glass-glass modules, and are only reached in very heavy rain. The values are also higher for morning condensation, but drop to very low values during the times with the best yield (sunshine). The leakage current of 7 mA measured at this time is also caused by the inverter capacitance to a certain extent.

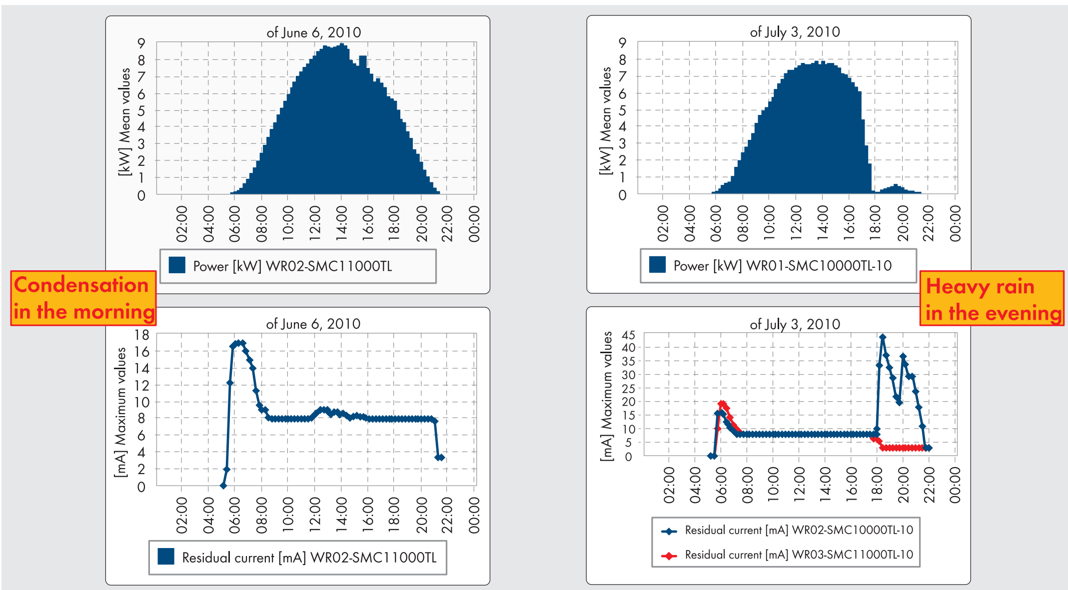


Figure 4: Properties of the capacitance limit of glass-glass modules in the event of condensation and heavy rain

5 Check List

Every PV plant should be reviewed based on the above mentioned requirements during the planning phase. In cases of uncertainty, it is strongly recommended that you involve the PV module manufacturer in the planning process. This particularly applies if a PV module type is to be operated with a transformerless inverter for the first time.

In addition, we recommend the following test phases:

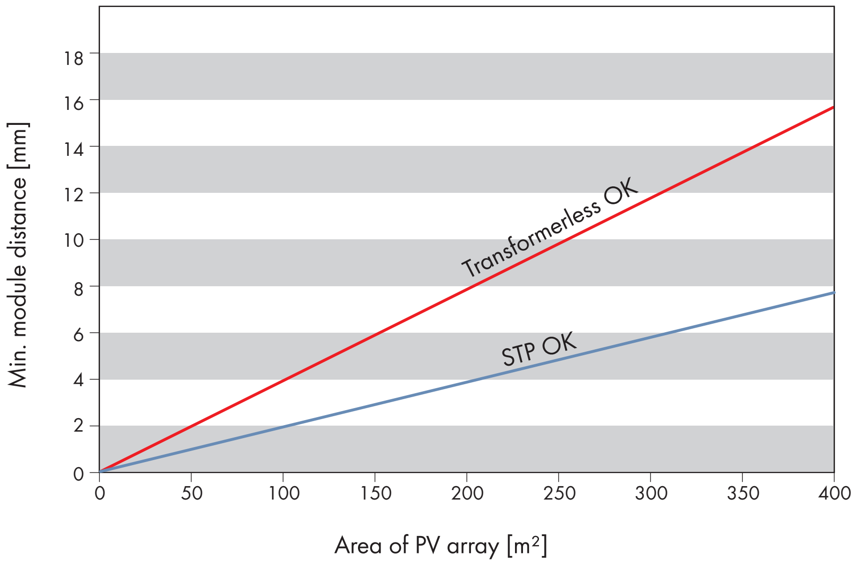
1. Does the PV module in question possess the previously described features (laminate, integrated metallic lining on the back)?

   If so, try to estimate the parasitic capacitance, taking into account the following points.

2. Determine the clearance from the PV module to the roof and the PV module surface area.

   Are you already in the lower, red area depicted in the graphic below?

   If so, SMA Solar Technology AG recommends the use of a Sunny Boy/Sunny Mini Central with transformer.



3. If you still wish to install an inverter without transformer, please consult the PV module manufacturer. Is something already known about parasitic capacitance?

4. The safest way to identify possible problems with the installation and operation of a PV plant is with the PV module manufacturer's approval of the plant design. SMA Solar Technology AG gladly supports the module manufacturers in this task.

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