Capacitive Discharge Currents

Information on the system layout for transformerless inverters

SUNNY BOY / SUNNY MINI CENTRAL

Volkswagen AG, Wolfsburg, 2.4 MWp
(Source: Suntimes Solar GmbH, Lübbecke)

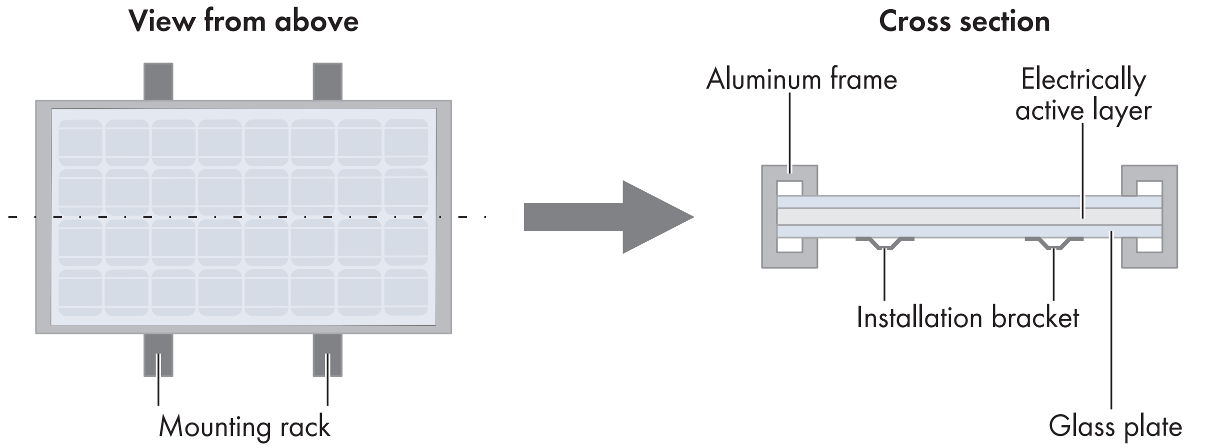
Contents

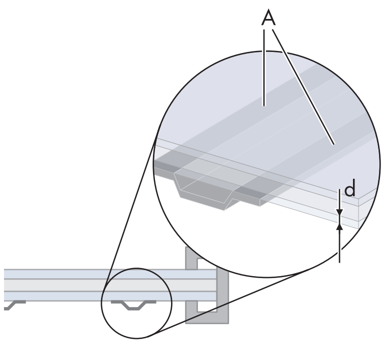
All PV modules have a certain parasitic capacitance according to a fundamental physical relation. This is proportional to the surface area and inversely proportional to the thickness. It is also dependent on the material properties and the type of mounting. This capacitance is particularly high for PV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

In combination with transformerless (TL) inverters, discharge currents of such a high magnitude can occur that the inverter's residual current monitoring will be triggered. This leads to the inverter disconnecting itself from the grid for a short period of time. In such a case, SMA 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 system. This technical information is aimed at two audiences: first, at the manufacturers of the above-mentioned modules with the request to pass on this information to their customers (especially laminate finishers), and second, directly at the installers and planners.

1 How to calculate the capacitance of the PV generator to ground?





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 four 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 is then the surface area A and distance d? This is not always easy to determine, because in addition to the module data, the type of mounting must also be taken into consideration. That is why there is generally no information concerning this in the data sheet. The following three examples should demonstrate how an estimation can nevertheless be made (for illustrative purposes, an $\varepsilon_r = 6$ for glass is 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 frames 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 distance 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 separation. 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 1 m separation. This amounts to just 0.05 nF and can be ignored. Therefore, the overall capacitance of a module to ground amounts to approx. 1 nF.

Example 2: In-roof glass-glass module with aluminum frames
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 separation. The parasitic capacitance of a module to ground is therefore approx. 5 nF.

Example 3: Thin-film 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 roofing. The result is a capacitor with a 1 m^2 surface area and 0.001 m plate separation. The parasitic capacitance of a module to ground is therefore approx. 50 nF.

2 How does a capacitive discharge 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):

1. Transformerless inverter

   In almost all transformerless models, half the grid amplitude is operationally passed on to the module. The set up oscillates with 115 V / 50 Hz. This applies to Sunny Boy / Sunny Mini Central devices with "TL" in the product names.

2. Inverter with transformer

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

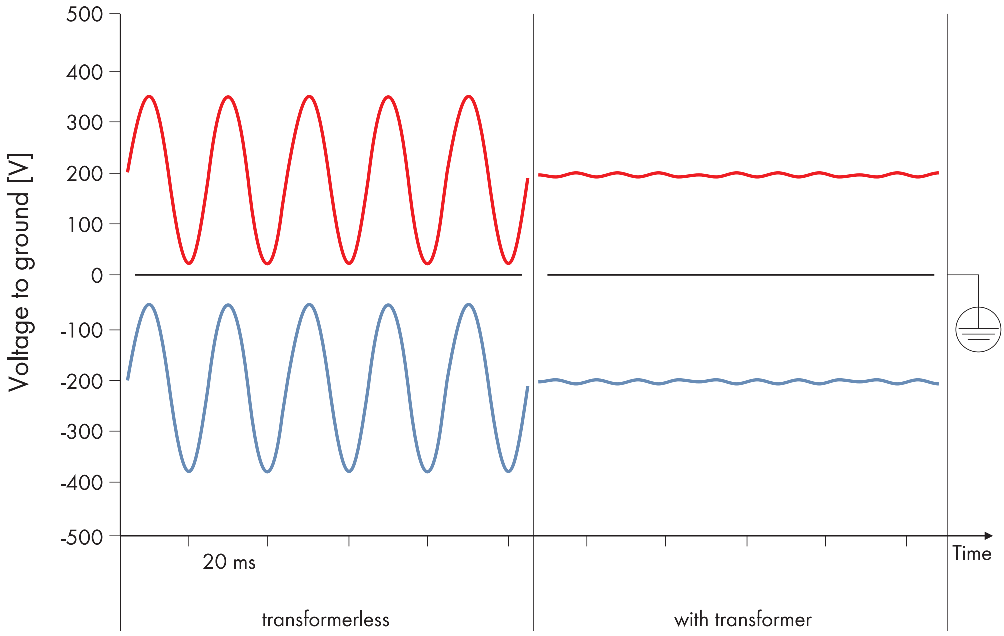
The fluctuating voltage constantly changes the charge state of the parasitic PV capacitor. This is associated with a displacement current, which is proportional to the capacitance and the applied voltage amplitude.

For experts: the displacement current (effective value) can be physically derived by:

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

Here, f = 50 Hz is the grid frequency and U is the effective value of the alternating voltage at the PV generator (for 230 V European grid approx. 2 V for inverters with a transformer and 115 V for transformerless inverters) This discharge current is a reactive current with its phase shifted by 90° to the grid voltage. It is thus lossless in the first approximation.

Generator voltage



3 How does the discharge current affect recognition of the residual current?

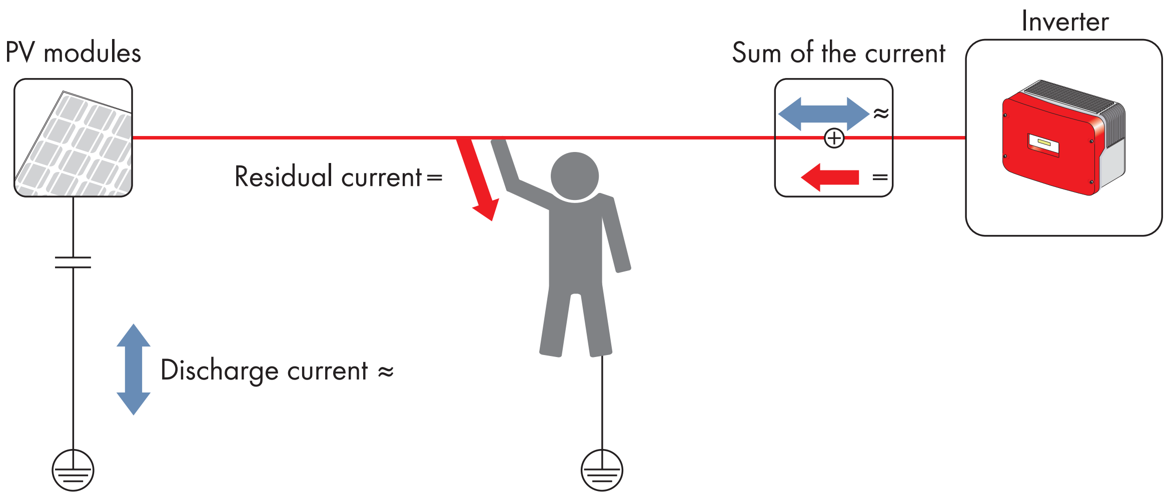
The capacitive discharge current as described in chapter 2 is a reactive current (lossless).

On the other hand, if there is a fault, such as defective insulation, where a live cable comes into contact with a grounded person (see photo), an additional current flows, known as a residual current. The sum of the two currents (discharge current and residual current) is known as the differential current.

Differential current = discharge current + residual current

Residual currents larger 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 grid in the event of a residual current of 30 mA at the latest (DIN VDE 0126-1-1). The inverter is equipped with a universal current-sensitive residual current monitoring unit (RCMU). However, this can only measure the differential current (discharge current + residual current). The determination of the residual current is only possible to a certain limit and becomes more difficult with increasing discharge currents. Starting with approx. 50 mA, random fluctuations in the discharge current are so large that they can be interpreted as suddenly-occurring residual currents of above 30 mA. In such a case, the inverter disconnects automatically from the grid as a preventative measure.



4 At what point does it become problematic?

Capacitance limit

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

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

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

$\varepsilon_{rGlass} = 6$

Then as a result $C = \varepsilon_0 \varepsilon_r \cdot A / d \rightarrow C\,[nF] \approx 50 \cdot A\,[m^2] / d\,[mm]$.

The following approximation formula applies:

$$\mathbf{C\,[nF] \approx 50 \cdot A\,[m^2] / d\,[mm]}$$

5 Check List

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

In addition, we recommend the following test sequence:

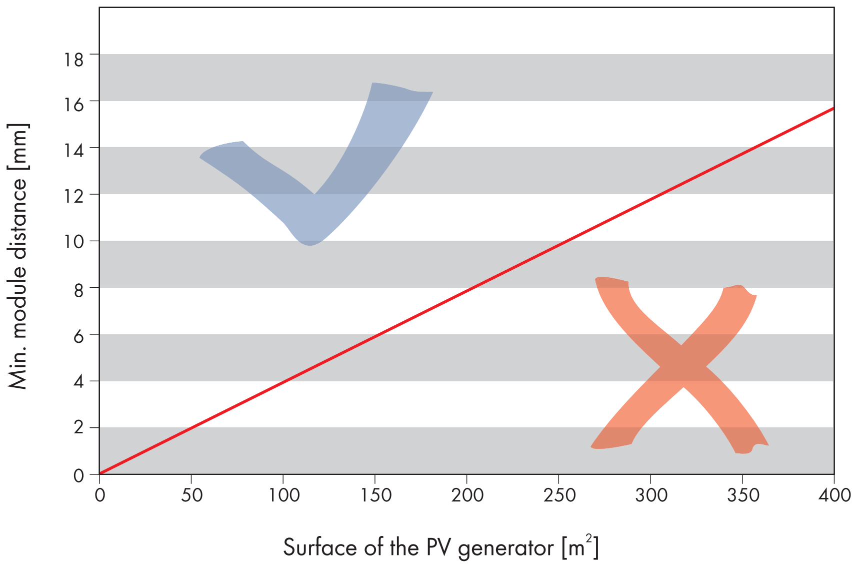
1. Does the module in question possess the previously-described features (laminate, integrated metal rear)?

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

2. Determine the distance from the module to the roof and the module surface area.

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

   If yes, SMA recommends the use of a Sunny Boy / Sunny Mini Central with transformer.



3. If you still wish to install a single-phase TL device, please discuss this with the 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 system is with the manufacturer's approval of the system design. SMA gladly supports the module manufacturers in this task.

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