Technical Information

Leading Leakage Currents

Information on the design of transformerless inverters of type **Sunny Boy, Sunny Tripower, Sunny Highpower**

The way PV modules are designed means that they always exhibit capacitance towards their environment. This capacitance is not required for the function of the PV array, but comes about essentially from the mechanical structure of the modules and their installation, and is therefore also known as "parasitic" capacitance. In particular, this capacitance increases with the conductive surfaces present in the the PV array. Consequently, a large, powerful PV field exhibits a correspondingly large parasitic capacitance which will increase even further if the surfaces are damp (e.g. from rain, condensation).

This phenomenon does not affect the insulation of the PV modules in any way, so personal safety is of course guaranteed at all times. However, the operating behavior of the inverters may be influenced by parasitic capacitance. If transformerless inverters are used, so-called displacement currents can occur which are capable of tripping the residual current monitoring of the inverter or even that of the feed-in line. In the former case, this causes the inverter to temporarily disconnect from the utility grid, after which it will automatically revert to feed-in operation. In the latter case, feed-in will be interrupted until the residual-current device (RCD) of the feed-in line has been manually reactivated.

Feed-in interruptions of this kind can be largely prevented by careful and professional system planning. In the following, we will therefore be explaining the crucial technical aspects to be taken into account in the planning phase, as well as during installation and commissioning of a PV system. This technical information is intended for two distinct groups: firstly, for manufacturers of the PV modules, with a request to pass it on to their customers, and secondly, for PV system planners and installers.

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

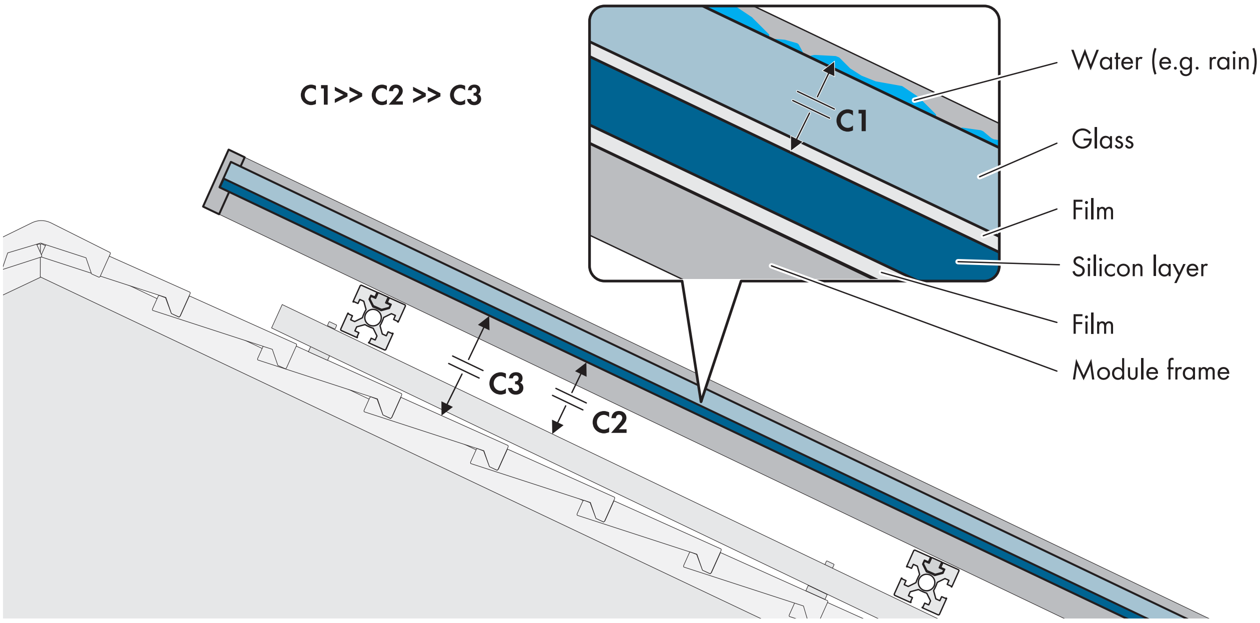

Figure 1: Illustration of a roof assembly of a PV module and schematic illustration of "parasitic capacitance"

C1	Parasitic capacitance due to film of water on the glass
C2	Parasitic capacitance due to grounded support frame
C3	Parasitic capacitance due to roof surface area

A PV module forms an electrically conductive surface which stands opposite a grounded support frame. This type of arrangement, which stores charge when voltage is applied, is referred to as a capacitor and its capacitance as "C". Since this capacitance occurs as an undesirable side-effect, it is referred to as "parasitic capacitance" C_{PE}, which is made up of the sum of all individual capacitances:

$\mathbf{C_{PE} = C1 + C2 + C3}$

The capacitance is calculated using the following formula and it depends on four factors:

$\mathbf{C = \varepsilon_0 \varepsilon_r \cdot A/d}$

Meaning of the factors:

ε_0: vacuum permittivity, physical constant (8.85 • 10-12 As/Vm)

ε_r: Permittivity number, dependent on material (ε_{rAir} = 1; ε_{rGlass} ≈ 5 – 10)

A: electrically effective surface area of the capacitor

d: distance between the capacitor plates

What values are to be assumed for 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. For this reason, there is generally no value specified in the datasheet. The following two examples will be used to demonstrate how an estimation can nevertheless be made (ε_r = 6 is assumed for the glass used).

For the value of the parasitic capacitance in Figure 1, the following relation is valid in rainy and wet conditions:

C1 >> C2 >> C3

This reveals that in rainy and wet conditions, the overall capacitance C_{PE} is dominated by C1, so for the purposes of further consideration, C2 and C3 can be neglected. In dry conditions, on the other hand, C1 is so small that the other parasitic capacitances must be taken into consideration. However, the overall capacitance C_{PE} remains so small that any effect on the operating behaviour of the PV system is negligible. The size of C1 during rainy and wet conditions is therefore relevant to further consideration.

Examples for Estimation of the Parasitic Capacitance C_{PE} with Different Module Types Assuming a Continuous Film of Water on the Glass Surface

Example 1: Standard module with crystalline silicon cells (monocrystalline, polycrystalline)

- Typical efficiency: 15% to 20%
- Thickness of glass: 3 mm to 4 mm
- Per m^2 module surface, the module has a capacitance of 12 nF to 17 nF
- Per kW of installed DC power, the PV system has a capacitance of 60 nF to 110 nF
- For a 5 kW PV system, this means that the C_{PE} value is 330 nF to 550 nF

Example 2: Thin-film module, e.g. CdTe

- Typical efficiency: 10% to 15%
- Thickness of glass: 3.2 mm
- Per m^2 module surface, the module has a capacitance of 16 nF
- Per kW of installed DC power, the PV system has a capacitance of 100 nF to 160 nF
- For a 5 kW PV system, this means that the C_{PE} value is 500 nF to 800 nF

2 How Does a Capacitive Leakage Current Occur?

During operation the PV modules are connected to the AC grid via the inverter. Thus, depending on the device type, a portion of the alternating voltage amplitude arrives at the PV module. As a result, the complete PV array oscillates with an alternating voltage in relation to its environment. At this point, two cases must be distinguished:

In almost all **single-phase** transformerless inverters, for operational reasons, half of the grid amplitude is passed on to the PV module. In many European utility grids with 230 V/50 Hz, this arrangement oscillates, for instance, at 115 V/50 Hz.

In **three-phase** transformerless inverters, for systemic reasons, the oscillations are of a much smaller amplitude and, as a result, they generate smaller leakage currents. The pass-through of AC voltage to the PV module is largely suppressed.

This fluctuating voltage constantly changes the state of charge of the parasitic capacitor described in the previous section. This is associated with a displacement current, which is proportional to the capacitance and the applied voltage amplitude. The electric circuit of this displacement current is connected to the house connection initially via the ground connection of the PV modules and that of the grounding busbar. Therefore, this current is also referred to as (capacitive) leakage current.

For experts: The physical description of the displacement current I (RMS value) is as follows:

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

Here, f = 50 Hz is the power frequency and V is the RMS value of the alternating voltage at the PV array (115 V with 1-phase transformerless inverters). This leakage current is a reactive current with its phase rotated by 90° to the line voltage. In the first approximation, it is without loss.

---

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

The capacitive leakage current described in Section 2 is a reactive current (without loss).

However, if a fault such as a defective insulation causes a live line to come into contact with a grounded person (see Figure 3), an additional current flows to ground. This unwanted current causes losses and is referred to as residual current. The total of both currents (leakage current and residual current) is the differential current.

Differential current = leakage current + residual current

AC residual currents greater than 30 mA can be life-threatening.

To guarantee additional personal safety beyond the inverter's protection class, transformerless inverters must therefore be disconnected from the utility grid at the latest when a residual current jump of 30 mA occurs (IEC 62109-2). For this purpose, during feed-in operation, the differential current (leakage current + residual current) is measured using an all-pole sensitive residual-current monitoring unit (RCMU). The residual current is calculated from this measured value. At high leakage currents, it is not always possible to accurately calculate the residual current. The resulting calculation errors can lead to an undesired shutdown of the inverter.

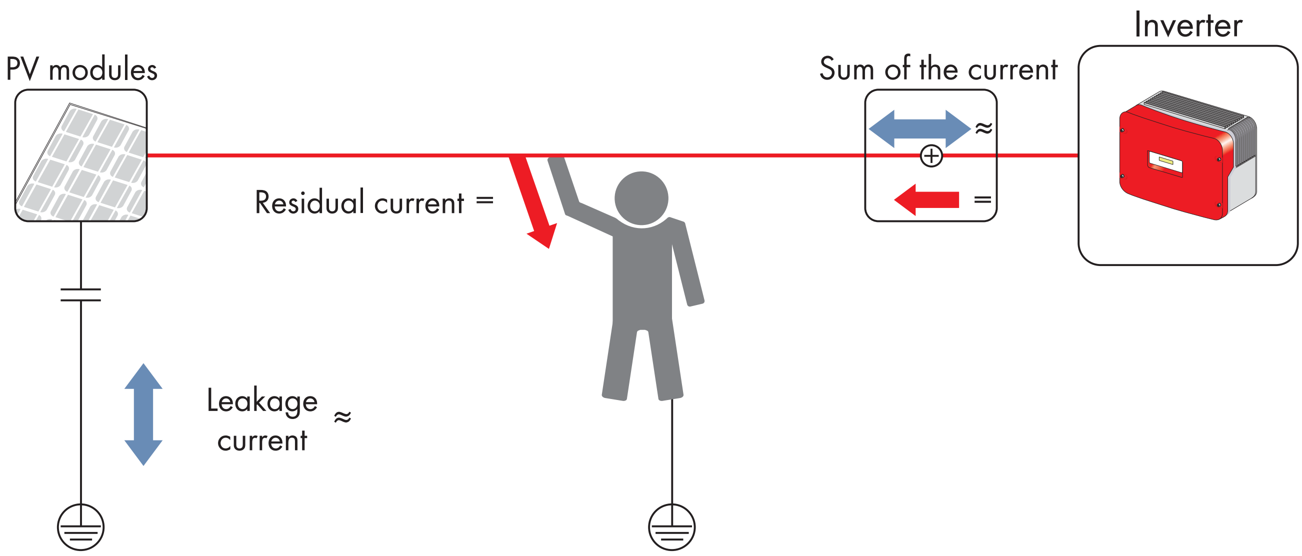

Figure 2: Formation of residual current through contact between a grounded person and a live line

4 At What Point Does it Become Problematic?

Capacitance Limit

As described above, high leakage currents should be avoided in order to prevent false tripping of the residual current monitoring system of the PV array.normally. Since the leakage current is directly dependent on the capacitance of the PV module to ground, for each AC voltage to ground a capacitance limit can be specified, above which operation will be susceptible to disturbances. You can find the capacitance limit of the inverter in the inverter manual.

Comprehensive field testing revealed that the values calculated using the capacitance limit are peak values for most glass-glass modules, and are only reached in very heavy rain. The values are also higher if there is morning condensation, but drop to very low values during times of highest yield (when the sun is shining). In the following figure, the reaction of the leakage current of a PV array to such events can be seen.

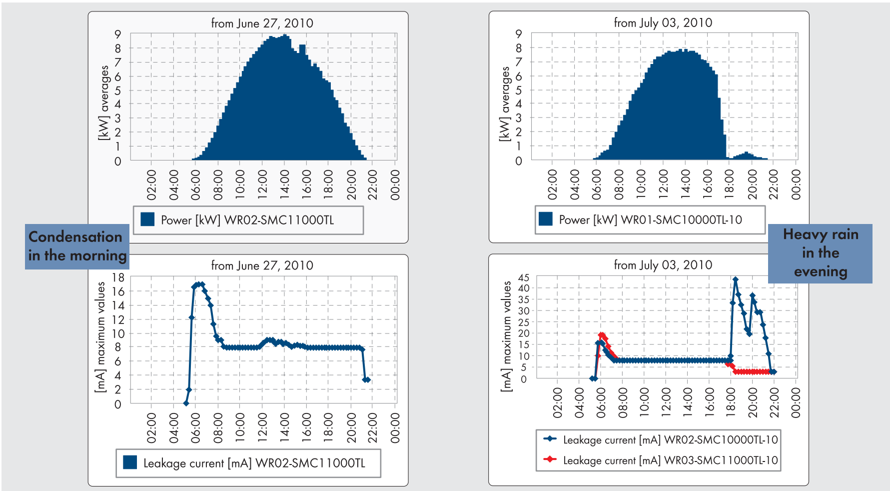

Figure 3: Pattern of leakage current as a reaction to the change in parasitic array capacitance of glass-glass modules in the event of condensation and heavy rainfall

5 Checklist

During the planning phase, every PV system should be reviewed based on the requirements specified in the above sections. In addition, we recommend the following test steps:

Test Step 1

The PV module under review exhibits a high design-related capacitance to ground C_{PE} (laminate, integrated metal rear panel), or it is necessary to reliably prevent feed-in interruptions due to rain/condensation. Determine the critical capacitance to ground as follows:

1. Calculate the total module surface of the modules connected to one inverter.
2. Determine the smallest distance of the PV cells to a conductive surface.

   This conductive surface may only be conductive at certain times (e.g. under conditions of rain or condensation). Therefore, in the event of rainfall the thickness of the cover glass, and in the event of condensation the thickness of the rear-panel insulation, is critical for the distance.
3. Enter the values for the module area and distance in the calculation formula (see Section 1 "How is the PV Capacitance to Ground of the PV Array Calculated?", page 2) to determine the capacitance.

Test Step 2

When the capacitance to ground is in the critical range (see inverter manual), measures for preventing feed-in interruptions should be considered:

- Use of an external residual-current device with higher rated residual current
- Use of an inverter with a higher capacitance limit (data according to information in the manual)
- Segmentation of one PV array into smaller substrings and use of additional inverters

Test Step 3

Consult the PV module manufacturer. Is there any known data on parasitic capacitance?

In cases of doubt, we strongly recommend involving the PV module manufacturer in the planning process. This applies particularly in cases where the operator does not have any first-hand experience of combining a PV module type with a transformerless inverter.

Contact

www.SMA-Solar.com