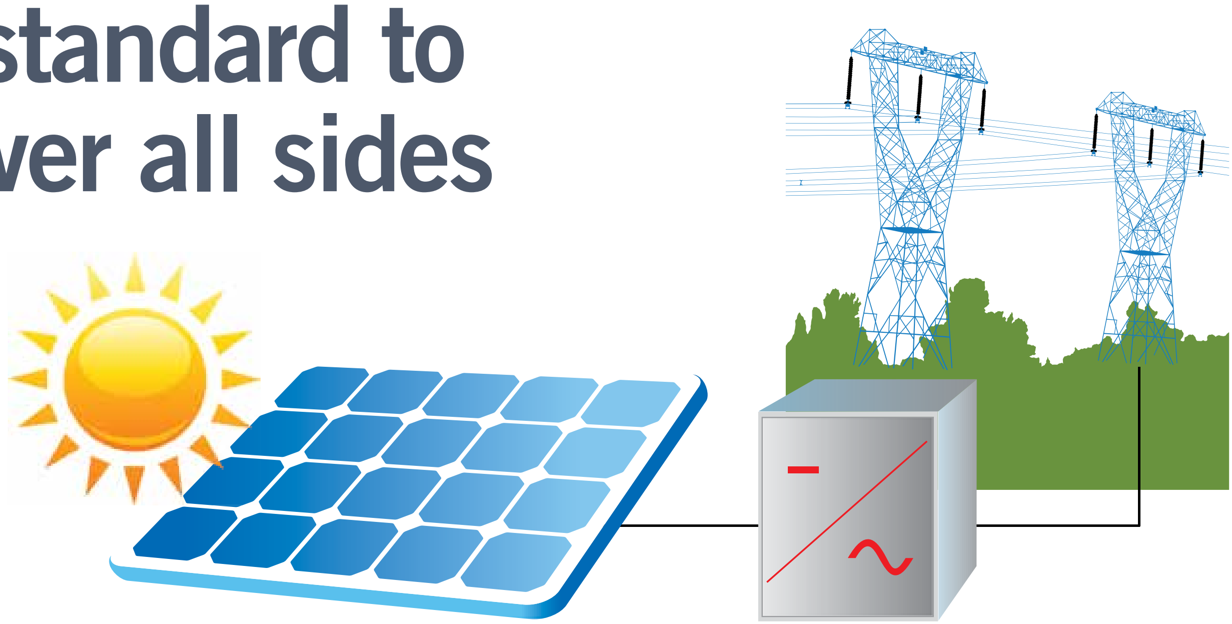
A standard to cover all sides



Words: Peter Mock

While manufacturer Spitzenberger & Spies have discussed the DC aspect of the solar inverter in previous PES articles, they return to PES today to discuss the impact of an inverter's DC and AC aspects…

In common solar installations the main focus of the owner is set to the maximum efficiency of the solar energy conversion. The main focus of the public utility companies is set to safety, monitoring and power quality aspects. The typical interconnection of a local solar installation with the public grid is:

The central element for the energy conversion is the solar inverter with a DC side and an AC side. For the DC side as well as for the AC side, several international electrical standards are specified to cover safety, functionality, efficiency and power quality of the solar installation (see table 1).

For the development and performance verification process of a modern inverter it is essential to reproduce the typical field installation and its parameters like different cell types, changing irradiation, partial shading and many more. Around the central component to be tested, the solar inverter, the DC input side needs to be simulated as well as the AC output side (see Fig. 1). For each component inside such a laboratory environment, several requirements exist in the covered standards as well as per physical limitations.

Table 1: DC and AC side standards and specifications

DC side	AC side
EN50530 – Efficiency of solar inverters	**IEC/EN62116 –** Islanding prevention for grid-connected solar inverters
IEC/EN61683 – PV systems – Power conditioners – measuring efficiency	**IEEE1547a –** Immunity against voltage dips and frequency deviations
IEC/EN61727 – Utility connected PV systems	**IEC/EN61000-3-2, IEC/EN61000-3-12 –** Emission limits for harmonic currents
CEI021	**IEC/EN61000-3-3, IEC/EN61000-3-11 –** Emission limits for voltage fluctuations and flicker
UL1741	**IEC/EN61000-4-11 –** Immunity against voltage dips and voltage variations
Sandia	**IEC/EN61000-4-13 –** Immunity against harmonics, interharmonics and signalling
	IEC/EN61000-4-14 – Immunity against voltage variations
	IEC/EN61000-4-27 – Immunity against voltage unbalance
	IEC/EN61000-4-28 – Immunity against frequency variations

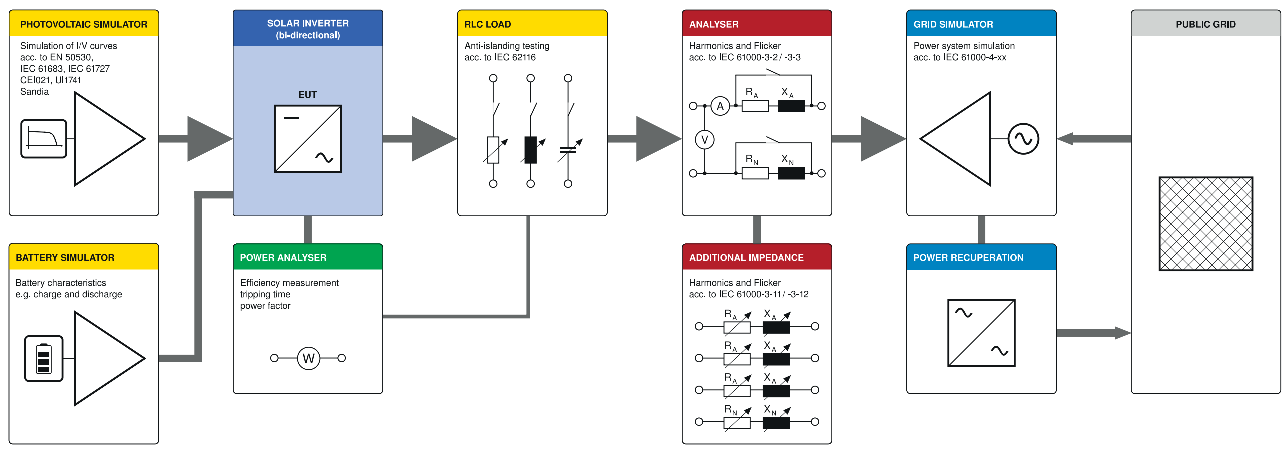


Fig. 1: Typical laboratory setup of a field installation environment

To simulate the DC side of the solar inverter, a high speed PV simulator is necessary which is able to reproduce the dynamic generation of the solar irradiation. The technical design must be linear technology to be fully compliant to the requirements of the EN50530 (see Infobox "Necessity for high speed PV Simulators").

The DC side of the inverter was already discussed in previous PES articles from Spitzenberger & Spies. Also the possibility to simulate a battery storage system has been part of a former PES article.

For the AC side of the solar inverter a lot of standards are in the scope of the inverter's manufacturer. Due to the installation place, which is the PCC (Point of Common Coupling) the inverter needs to be compliant to the European Union CE-marking standards and other national or international standards.

These standards are divided into emission (IEC/EN61000-3-series) and immunity standards (IEC/EN6100-4-series). An IEC working group has discussed and published a technical report (IEC/EN61000-3-15 TR) which specifies the set of standards out of the whole series necessary to be compliant to.

The emission standards define on the one hand limits of maximum allowed harmonic current components of loads up to 16A (IEC/EN6100-3-2) respectively 75A (IEC/EN61000-3-12) fundamental current per phase. If we take the 75A maximum current as the base for a three-phase inverter the maximum power capability of the inverter to be tested is 50kVA per inverter.

On the other hand, the emission standards are specifying limits for voltage fluctuations and flicker for the grid-connected inverters. Each disconnection and reconnection because of islanding preventing functions of the inverter (according to IEC/EN62116) causes changes of the supply voltage at the PCC.

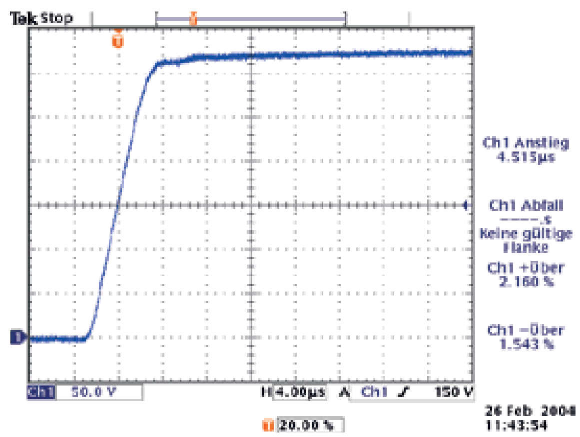


Fig. 3: Rise time of the PAS amplifier

The new IEEE1547a Amendment from May 2014 specifies test procedures for these voltage fluctuations, as well as for frequency deviations. The immunity against changing of the grid frequency is also subject of the IEC/EN 61000-4-28, where test setup and compliance levels are specified.

For all emission and immunity test the most important part of a test system setup is a reference voltage source. The quality of this reference voltage source is necessary at all the emission measurements to minimize disturbances on the supply voltage caused by the supply source. These limits for maximum allowed harmonic voltages under each possible load condition are pushing all switched-mode sources into the area of pre-compliance or more worse into non-compliance.

Only advanced high-speed linear power sources in 4-quadrant technology are able to fulfill all the requirements according to the emission and immunity standards.

One very heavy requirement is the rise time specification in the IEC/EN61000-4-11, which specifies a maximum voltage rise time below 5µs. Practical measurements in domestic supply networks with short-circuit failures demonstrate and show the necessity of this very fast rise time specification, which is absolutely a reality value.

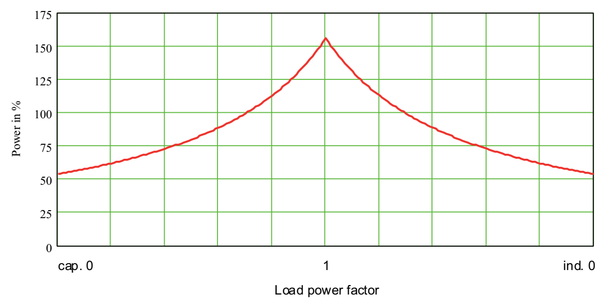


Fig. 3a

PAS performance characteristic

Due to the many devices with a pulse-shaped input current, it is also absolutely necessary for the power source to have an inrush-current capability of up to 500A (specified in the IEC/EN61000-4-11).

Using a PAS power amplifier as the power source leads to an extremely high load ability of the source. 150% of rating is available in the case of a real load. Amplifier stability is absolutely assured when operating with either inductive or capacitive loads.

In addition to the perfect power source a fully compliant harmonic analyzer and flicker meter is necessary. The measurements of flicker shall be carried out over a reference impedance network according to IEC60725. The ARS solution from Spitzenberger & Spies includes harmonic analyzer, flicker meter and reference impedance network into one device.

For the future energy mix of utility companies including all the many solar installations the power quality and its standards is one of the most important technical challenges. It is much more difficult to control, monitor and supervise the huge number of “small local power plants” and to establish and guarantee a clean, stabile and power sufficient public supply network as it was in former times, when only a small number of nationwide power stations were on the grid.

One of the best ways to establish this future public grid quality is to cover all the emission and immunity standards with each local solar installation. In summary, this will improve the quality of the public grid.

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Introducing the need for high speed PV Simulators

The fast response time of PV simulator is required to realistically simulate the I/V characteristic when the inverter produces a ripple on DC voltage and DC current of the PV simulator. Real solar cells have a I/V characteristic like shown in Fig. 1:

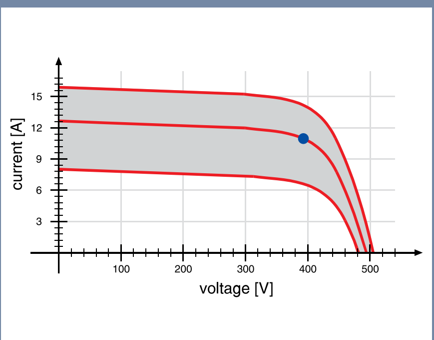

Fig. 1: Current/voltage characteristic of real solar cells

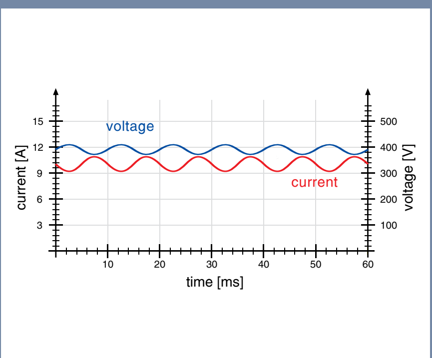

Fig. 2: Phase shift between current and voltage at ripple 50Hz

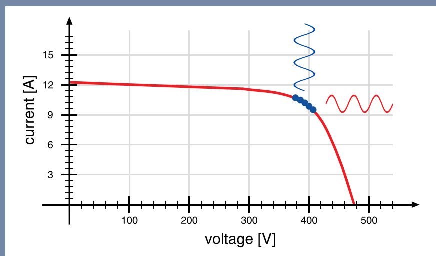

Fig. 3: Operating points (blue) when using PVS

So when the voltage goes up the current goes down and vice versa. The PV simulator has to simulate this characteristic as realistically as possible. To achieve the maximum accuracy to reach the I/V characteristic the PV simulator measures voltage and current and controls its output accordingly. When there is an abrupt load change it takes typically 100µs with the PV simulator PVS from Spitzenberger & Spies until the output is adjusted according to the I/V characteristic. Switch mode PV Simulators need much longer time (maybe 2ms or more).

For example: single phase inverters have a typical ripple with twice the grid frequency. With 50Hz mains frequency this is a 100Hz ripple. With real solar generators as well as with the linear type PV simulator PVS from Spitzenberger & Spies the voltage and current characteristic look like the following diagram in Fig. 3:. The operating points are lying all on the desired I/V characteristic. It is very important that the PV simulator is fast enough, to follow and to make as less additional phase shift as possible.

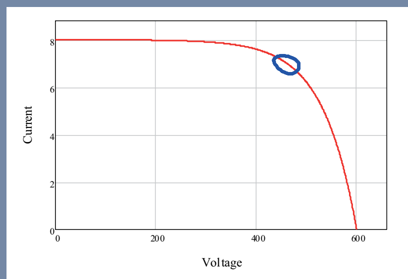

Fig. 4: Operating points (blue) when using switch-mode simulator

The voltage and current ripple are inverse (current goes up => voltage goes down), so phase angle is 180 degrees. If you take a rise time of 100µs (from 10% to 90%) and assume that the simulator acts like a first order filter, then the time constant T and phase shift is calculated as:

$$T = \frac{t_{rise}}{ln(9)} = 45\mu s; \ \varphi = -\operatorname{atan}(2 * \pi * f)$$

For the PVSt (T=45µs) the calculation of the phase shift at 100Hz is -1.6 degrees.

For a switch mode amplifier with a rise time of e.g. 2ms the phase shift would be about 30 degrees which is too much for efficient MPP tracking measurement. When the PV simulator is too slow for the ripple produced by the inverter, the operating points are not on the I/V characteristic. The behaviour is different to the beha¬viour of real solar cells. Accurate MPP tracking efficiency measurements like described in IEC/EN 50530 wouldn’t be possible in such a case.