This paper first appeared in the eleventh print edition of *Photovoltaics International* journal, published in February 2011.

New challenges for photovoltaic grid-connected inverters

Dr. Vicente Salas, Universidad Carlos III de Madrid, Madrid, Spain

ABSTRACT

As PV power generation adoption becomes more widely adopted globally, the grid-connected inverter market looks set to take its rightful role as a critically important element of solar installations. The grid-connected inverter market will deliver power quality and the stability of the electricity networks in order to ensure a stable and reliable grid operation. In order to keep up with these developments, network operators will release new grid codes to monitor the increased uptake, to which manufacturers must adhere. An additional obstacle for the inverter manufacturers is the wide range of requirements and norms that vary from country to country and, in many cases, even from utility to utility. This article presents a review of the new challenges facing grid-connected PV inverters in the light of these new developments.

One of the most formidable problems that must be tackled by grid-connected inverter manufacturers is that they must comply with different technical regulations for grid-connected PV systems in almost every country. For example, each European country has different requirements for grid interfaces. Germany has the VDE 0126-1 "Automatic Disconnection Device Between the Generator and the public low voltage grid" stipulation; Italy requires compliance to the Enel standard DK 5940 "Criteria for plant connections to the grid"... the list goes on. Each of these country- and region-specific standards will have different limits for voltage and frequency variation under which the inverter must disconnect from the grid. Beside the inevitable repercussions for parameters such as different schemes for fault-ride-throughs, it will also result in higher product cost.

From a technical point of view, up to now, the more common inverter designs have aimed to feature the following parameters: temperature range of -25°C to 50°C; lifetime evaluation of around 20 years; efficiency greater than 94% over a wide range; electromagnetic compatibility; low cost; reliability; tolerance of all grid faults; power factor close to 1; and maximum power point tracking (MPPT).

Nowadays, the objective of any inverter is the conversion of DC voltage at the PV generator to a sinusoidal AC current waveform at the output of the switch converter in order to connect and synchronize the generator to the utility network. But this objective has altered of late. New requirements are being asked of PV inverters at different levels: evolution of key characteristics such as efficiency, cost and reliability; compatibility with new materials (SiC, GaN); adoption of disruptive technologies like microinverters; effective MPPT capabilities; as well as compliance with new demands such as anti-islanding methods.

Concerning new materials requirements, for example silicon MOSFETs, SiC technology has undergone significant carbide challenge improvements that now allow fabrication of MOSFETs capable of outperforming their Si insulated-gate bipolar transistor (IGBT) 'cousins', particularly at high power and high temperatures. This illustrates one way in which PV inverter efficiencies can be improved.

Inverters and standards

The MPPT efficiency, or the ratio of the energy obtained by the inverter from a PV array to the energy obtained with ideal MPP tracking over a defined period of time, is another possible cause of energy losses in an inverter. The official method of testing MPPT efficiency is currently by application of the EN 50530 standard. This standard provides a procedure for the measurement of the

Figure 1. A PV grid-connected inverter installed in a Spanish PV plant.

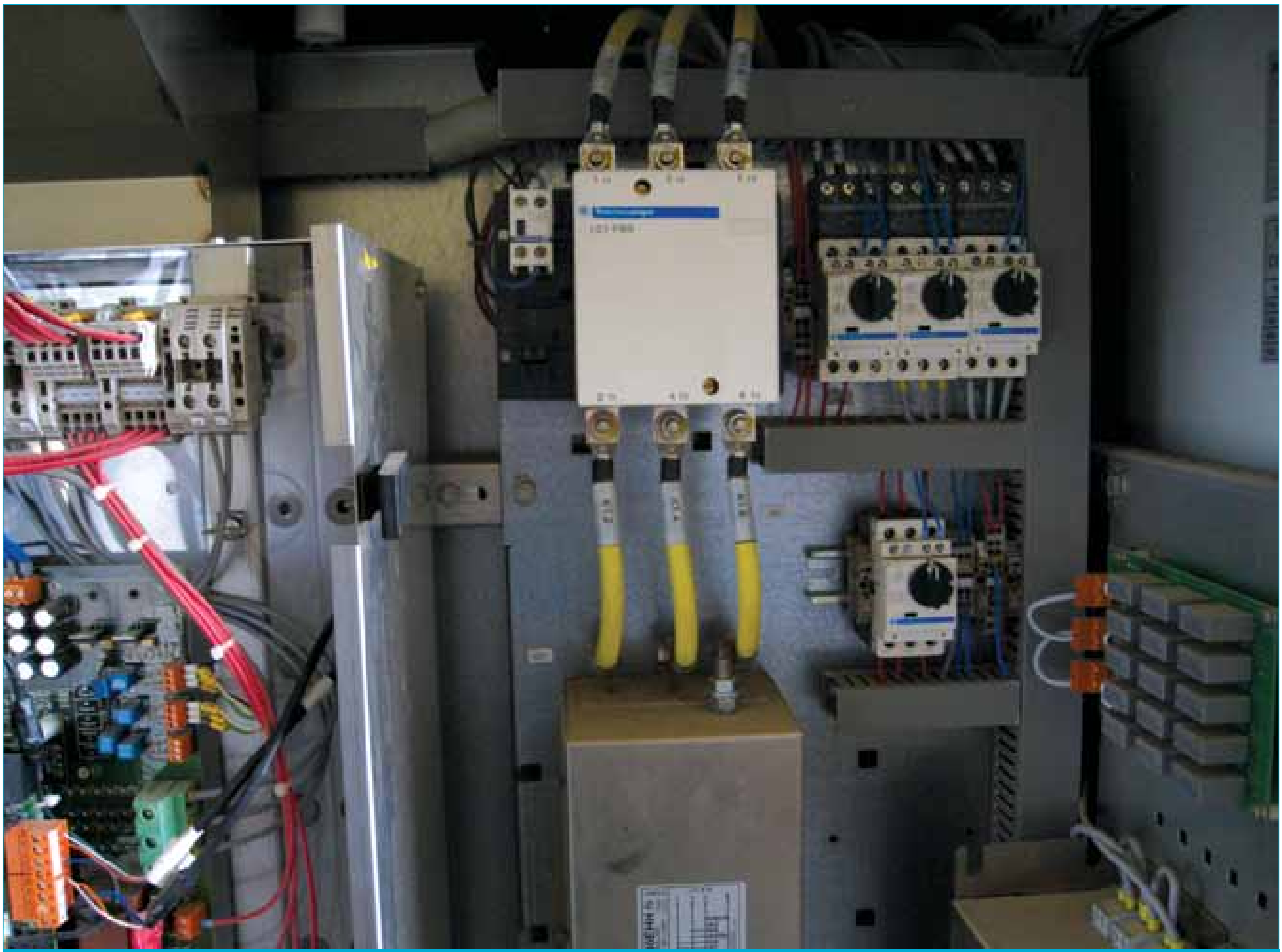

Figure 2. Electronic components of a grid-connected PV inverter.

MPPT of inverters that are used in grid-connected photovoltaic systems, and stipulates that the inverter energize a low-voltage grid of stable AC voltage and constant frequency.

"Static and dynamic conditions must also be considered in testing for this standard."

Static and dynamic conditions must also be considered in testing for this standard. The MPPT efficiency versus the overall inverter efficiency is estimated, which takes into account the static power conversion efficiency of the inverter.

However, any catalogue or handbook of PV inverters rarely provides an MPPT efficiency for an inverter; even when that figure is given, it is assumed by most to represent the rated power. On the odd occasion that this value is reached by the inverter in question, the fact that there is such a discrepancy between what is assumed to be the rated power and the reported MPPT efficiency is rarely mentioned. It is clear that there is a need for change in this sector, both from the point of view of improvement of MPPT efficiency and in the testing and display of the results.

Another factor that has been standardized is the islanding, as per the IEC 62116 standard. Islanding occurs when a portion of an electric power grid, containing both load and generation, is isolated from the remainder of the electric power grid. This is a situation with which electric power providers (utilities) must regularly contend, and can be extremely dangerous to those working on the power grid as it can lead to power flowing in the opposite direction.

EN 62116, a European standard that will be published later this year, will most likely not change very much compared to its predecessor, the IEC standard published in 2008. However, this standard will not specify setting parameters (voltage and frequency trip magnitude and trip time) nor pass/fail criteria as the region or country's specific national standards and/or grid codes must be applied in each case. Thus, standardization of inverters is not possible as it is in contradiction with the philosophy of a true international standard.

Another important issue is the increasing usage of non-linear electrical loads, such as electronic rectifiers or converters [1]. These loads can strain the grid by introducing current harmonics, creating a voltage drop over the grid impedance, with respective spectra, that leads to a non-sinusoidal grid voltage. PV inverters that feed the grid decentrally and can support the grid with reactive power are generally capable of supplying the grid with a sinusoidal active current as well as specific non-sinusoidal reactive currents, depending on the quick response of the current control. A compensating current can be determined with the measured grid voltage and the complex and frequency-dependent grid impedance, which eliminates the voltage harmonics. In order to achieve this, the grid voltage signal needs to be analysed by a group of digital filters tuned to different harmonics. The compensating current can then be determined from the filter results and the knowledge of the grid impedance angle or adequate control algorithms and adjusted accordingly.

A new PV inverter concept that is emerging onto the market is the range of smart inverter technologies for high penetration of PV, which are presenting a true challenge for inverters, as discussed within Task 14 of the IEA PVPS.

PV inverters play a key role as the interface between primary generation and the electricity grid itself. Their range of responsibilities includes the integration of protection and grid monitoring, system monitoring and control, and various other multifunctional characteristics [2].

Figure 3. The back-side of a PV module.

The future of inverters in high-penetration PV scenarios is uncertain. The next generation of inverters should be capable of acting as an interface between PV generation and the grid, providing reactive power during normal operation, operating during grid faults and contributing to short-circuit current and controllability of active and reactive power injection.

"PV inverters play a key role as the interface between primary generation and the electricity grid itself."

In addition, PV inverters will need to offer dynamic grid support (fault-ride-through), adapting their behaviour to the specific requirements of the system operation and PV support fault management in the grid. The PV inverter should be a hub and centre for data acquisition, system monitoring, communication and control. It should have standardized communication interfaces and control protocols for easy interconnection. Full integration into the EMS of the grid operator will also be necessary, as well as a feature that allows for the optimized direct utilization of PV electricity travelling towards grid parity.

"The inverter needs to be integrated into the grid management to allow for temporary short-term power curtailment during critical situations, as and when required by the grid operator"

From the point of view of integrated grid protection, a definite set of conditions should be provided that govern when a generator should remain connected and be adapted to the requirements of the system in question. Excellent communication and control is required for integration into the system's control. Smart inverters should be capable of coordinating the voltage control, the reactive power balancing, the active power limitation for frequency control and the power on demand from storage.

In addition, the smart inverter should have multifunctional characteristics such as voltage regulation, filtering/compensation of harmonics as well as backup supply functionality.

The PV inverter needs to act as an interface between local storage and the grid. In this way, it needs the capacity to integrate into grid management, to provide power on demand, peak shaving/shifting, and to be able to increase the security of supply and provision of ancillary services to the grid and the hosting capacity of the grid.

Furthermore, as a vital part of the grid management, the inverter needs to be integrated into the grid management to allow for temporary short-term power curtailment during critical situations, as and when required by the grid operator (operated by remote control).

The growth and extent of the penetration of inverters into the PV sector will require the active integration of installations into grid operation. At that point, PV inverters will become key elements towards enabling electricity grids to become more accessible to PV. The range of new requirements necessary in order to make this a reality will demand several big steps in inverter technology innovation. Some of the features that will help the sector excel in this regard include: the provision of system services; contribution to grid support; and integration into grid management with the aim of helping to significantly increase the proportion of PV-generated energy in the electricity grids.

The microinverter

A further noteworthy concept that will undoubtedly be essential to the future of PV inverters is the introduction to market of microinverters, essentially small inverters tuned to the output of a single typical panel. The concept behind microinverters was first introduced in the 1970s, with the launch of real-world products following in the 1990s. The main disadvantage of the microinverter concept is cost related: because each panel has to duplicate much of the complexity of a string inverter, the distributed and flat costs are much greater.

Microinverters are particularly well suited to use in small photovoltaic systems of 1kWp or less. In some larger photovoltaic systems that use string inverters, shading of individual modules and the subsequently lower energy harvest of the entire system can be avoided by equipping and operating those modules with individual module inverters.

The key feature of a 'true' microinverter is not its diminutive size nor its power rating, but its ability to provide one-to-one control over a single panel and its mountability either on the panel or near it. Both small string inverters and larger inverters control multiple panels and are generally mounted remotely, often indoors.

Microinverters produce grid-matching power directly at the back of the panel. Arrays of panels are connected to each other in parallel, and then to the grid feed. This has the major advantage that a single failing panel or inverter will not take the entire string offline. Combined with the lower power and heat loads, as well as improved mean time between failures (MTBF), it is suggested that overall array reliability of a microinverter-based system will be significantly greater than a string-inverter based one.

More and more microinverter brands are becoming active on the market, with product names such as Accurate Solar, Azuray, Direct Grid, Enecsys, EnPhase Energy, GreenRay Solar, Larankelo, OKE, Petra Solar and SolarBridge becoming commonplace. A new standard is due to be introduced to the industry in the near future in the form of the IEC 62109-4 standard: Safety of Power Converters for Use In Photovoltaic Power Systems – Part 4 – Particular Requirements for PV Modules with Integrated Electronic Devices.

Conclusion

Finally, it is vital that the revised standards include guidelines relating to evaluation of start-up and shut-down losses; power factors; performance outside normal operating conditions; DC current injection; MPPT performance under real conditions; overall performance measure (energy rating); active power control; reactive power control; limits for harmonics and flicker and low-voltage ride through (LVRT) capability. Topics related to electromagnetic compatibility (EMC) should also be taken into account. It is to be hoped that any future developments relating to international standardization will incorporate these topics in order to render it a worthwhile task.

Reference

[1] Burger, B., Reichert, S. & Siedle, C. 2010, "Improvement of power quality by PV inverters", Fraunhofer ISE [available online at http://www.ise.fraunhofer.de/].

[2] Bründlinger, R. 2010, "Inverter Technology enabling high penetration PV", *Proc. 25th EU PVSEC*, Valencia, Spain.

About the Author

Vicente Salas received his Ph.D. in electronics, electricity and automation from the Universidad Carlos III de Madrid in 2005. He is currently Associate Professor of the Power Electronics Systems Groups at the University Carlos III of Madrid. Dr. Salas's research has included the design and development of PV grid-connected inverters, hybrid PV systems and new methods of MPPT as applied to PV standalone and grid-connected systems. He has participated in numerous projects since 1999 and has published more than 50 papers in journals (reviews), conference proceedings and books in the field of photovoltaic energy. In addition, since 2005 he has participated in technical reviews of several major conferences and journals.

Enquiries

Photovoltaic Laboratory, Electronic Technology Department
Universidad Carlos III de Madrid
Avda. de la Universidad, 30
28911 Leganés
Madrid
Spain

Tel: +34 91 624 8867
Fax: +34 91 624 9430
Email: vicente.salas@uc3m.es
www.uc3m.es/inverters