Advanced testing for smart inverters

Certification | As inverter technology advances in step with the development of the smart grid, so too are testing and certification regimes. Tim Zgonena of UL looks at how standards are evolving to ensure inverters are keeping up with the demands of a rapidly modernising power network

With the advent of today's modernising grid, it becomes imperative that standards, codes and deployment guidelines improve and advance in parallel with the integration of photovoltaic (PV) energy storage systems and the increased levels of distributed generation. In the United States alone, there are several hundred thousand miles of high-voltage transmission lines carrying electricity between the three major power grids: the Eastern Interconnection, the Western Interconnection and the Texas Interconnected system, and additionally there are several million miles of local distribution power lines. To date, the US Department of Energy (DOE) has invested more than US$100 million dollars in an effort to advance the US power grid's resiliency [1]. Though overall improvements were necessary due to aspects such as ageing infrastructure and population growth, many advancements are also the result of PV technology, energy storage systems and increased distributed generation being integrated into the grid.

Naturally, these changes made advanced inverter technology both important and necessary to help ensure continued grid reliability. As always, with many changes come a range of considerations that need to be addressed to effectively understand, align and harmonise protocols, standards and certifications because codes and standards vary internationally and by state or local jurisdiction.

Traditionally, testing and certification regimes tackled inverters from the safety perspective. Most traditional UL equipment safety standards evaluate functionality, electrical hazards, fire hazards, mechanical hazards and verification of electrical ratings. All of these hazards are evaluated and tested under both normal and foreseeable abnormal conditions. Standards, such as UL 1741, offer a means to determine that inverters and other renewable energy power conversion electronics:


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Inverter testing is becoming increasingly rigorous

- Are constructed per common industry requirements;
- Can be installed in accordance with US codes;
- Can be operated per industry-specific required ratings;
- Perform safely under rated normal worst-case conditions;
- Perform safely under foreseeable abnormal operating conditions and failure modes.

At the advent of PV generation, when the percentage of energy generated via PV was still quite low, the grid interconnection requirements were based on a "get out of the way" approach, meaning the PV inverters and other distributed generation equipment would go offline if the grid voltage or frequency transitioned outside the ranges of normal operation. However, as the grid faces ever increasing penetration of PV generation, that approach is reaching the limits of its usefulness.

The original utility interconnection requirements of IEEE 1547 Edition 1 state that DG devices must cease output current if grid instability conditions occur; however, utilities with high percentages of distributed generation are moving to new enhanced functionality to reinforce grid stability and the new technology required to accommodate this change must be able to operate safely in this new environment. A new methodology, designed to support the unique attributes of a grid that includes PV and works to minimise fluctuations to enhance grid stability was required.

Updating UL 1741 for an international audience

In 2014, an updated UL Standard, UL 62109, represented a significant step forward in harmonising PV power conversion equipment safety requirements with an international perspective. As a result, this standard is now the US harmonised version of the international PV power conversion standard IEC 62109, which was originally based on UL 1741. Utilities and authorities having jurisdiction (AHJs) require distributed generation that is reliable, safe, compatible with the requirements of the National Electrical Code (NEC) and has been tested and constructed to withstand the rigours of daily, full power operation under harsh electrical and environmental conditions.

While the UL 1741 and UL 62109 standards address many similar concerns, there are also key differences. UL 1741 was written to cover all forms of distributed energy (DE)/distributed generation (DG) source types, whereas UL 62109 was written specifically for PV applications (including specific requirements for battery-based energy storage) while also anticipating and addressing the connection of other (non-PV) energy sources. Unlike UL1741, IEC 62109-2 addresses the specific requirements for PV inverters but specifically excludes grid interconnection requirements. The UL 62109-2 draft standard being developed will reference UL 1741 for grid interconnection requirements as many US electric utility commissions require a UL 1741 certifi-

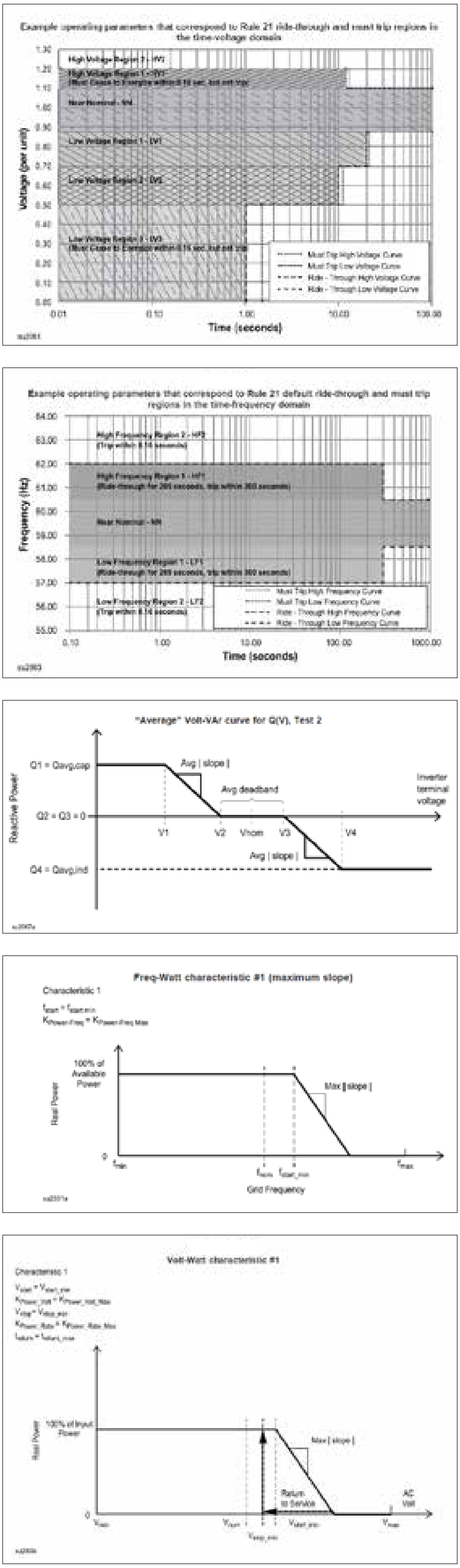

Figure 1. Some of the standard test protocols specified in UL 1741 SA. From top: voltage ride through; frequency ride through; volt/Var; frequency watt; volt watt

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cation for grid interactive PV inverters. National differences in the US/UL versions of IEC 62109 allow products to be brought into the U.S. market with little redesign and retesting required, while still allowing compliance with U.S. NFPA 70 National Electric Code (NEC) requirements. Many of the challenges of increased growth in PV generation have been addressed by the development, expansion and use of the UL 1741 and UL 62109 standards.

Necessary updates to UL 1741

'Grid support interactive' inverters, often referred to as 'advanced' or 'smart' inverters, are the future of smart grids and improved energy distribution, and the advanced inverter movement is now in full force. Worldwide solar power rose by a staggering 76GW in 2016, with the US and China leading the charge by almost doubling the solar added in 2015 [2]. In recognition of this growth and the growing need to address the changing landscape in the US market, UL published its long anticipated update to UL 1741, *Standard for Inverters, Converters, Controllers and Interconnection System Equipment for Use With Distributed Energy Resources,* in the autumn of 2016. Supplement SA for grid support utility interactive inverters and converters was published as a 60-page addition to the UL 1741 2nd Edition base standard to address safety concerns and performance needs of inverters that perform critical stabilising functions during abnormal grid events in lieu of tripping off line to get out of the way. To help strengthen smart grids and support their broader use, the UL 1741 Supplement SA specifies test methods that evaluate an inverter's ability to take action in accordance with specific utility defined performance criteria to help the utility grid stay within normal operating conditions, (hence the term "smart").

The intended next stage for grid support/advanced inverter functionality will allow electric utilities to intelligently control DG equipment to maximise grid reliability and flexibility. This feature is the foundation of the smart grid and the future of energy distribution with increasing amounts of DG. Both California and Hawaii (which runs on its own independent grid run by Hawaiian Electric Company, HECO) mandated advanced inverter functionality and the need to comply with these new requirements, raising the bar for grid interconnection in the US by establishing the need for new grid support inverter testing and certification requirements.

The new UL 1741 Supplement SA addresses this need and is the result of 19 months of work from a diverse panel with representatives from the inverter industry; electric utilities in California, Hawaii and Arizona; Sandia National Laboratories; National Renewable Energy Laboratory (NREL); Electrical Power Research Institute (EPRI); and other labs. Supplement SA is built on UL 1741 and specifies the test methods required to evaluate compliance with an electric utility 'source requirement document' (SRD) for limits and parameter settings.

Due to the high amount of PV and wind generation installed in California and Hawaii, these states first took action and expanded their grid interconnection requirements to improve power generation, efficiency and environmental impact. California's Electric Tariff Rule 21 (Rule 21) and Hawaiian Electric HECO 14H are SRDs that were written to define the specific grid interconnection requirements for these utilities and both can be evaluated using the requirements and tests in the UL 1741 Supplement SA even though it was not written exclusively for either market. For example, Arizona and other markets in the United States are making progress with green energy and grid modernisation and, as progress continues, further SRDs may be added. In addition to the technical requirement changes in California Rule 21 and Hawaiian Electric 14H, both also include a deadline for all inverters to be certified "listed" as a UL 1741 Supplement SA "Grid Support Interactive Inverter" for all new installations as of 7 September 2017.

Currently, UL 1741 SA contains both required and optional tests. Required tests are listed and described below, using the language from the standard:

- **Low/High Voltage Ride Through.** Testing determines how the inverter responds to low and high grid voltage excursions that are deemed abnormal. Ride through response behaviours include Momentary Cessation, Permissive Operation, or Mandatory Operation.
- **Low/High Frequency Ride Through.** Testing determines how the inverter responds to low and high frequency grid excursions that are deemed abnormal. Ride through response behaviours include Momentary Cessation, Permissive Operation, or Mandatory Operation and Trip.
- **Ramp Rate (Normal & Soft-Start).** Testing confirms the inverter's ability to ramp smoothly from one power level to

another over time, in accordance with specified characteristics.

- **Specified Power Factor.** This test verifies an inverter's ability to provide reactive power to the grid by operating at a specified non-unity power factor which is used to assist in maintaining stable grid voltage.
- **Volt/VAr Mode.** Testing verifies an inverter's ability to absorb or supply reactive power in response to fluctuations in grid voltage within the specified parameters for the test.
- **Anti-Islanding.** This test verifies an inverter's ability to trip off-line within two seconds of an unintentional islanded condition. This test is run with the inverter's worst case combination of grid support functions and settings.

There are also two optional tests included in the UL 1741 Supplement SA that may be required by some SRDs:

- **Frequency Watt.** This test verifies an active power response to a change in grid frequency. As grid frequency increases, the desired response of the inverter is to decrease active power output. Likewise, as frequency decreases it is desired for the inverter to increase active power output.
- **Volt Watt.** This test verifies an active power response to a change in grid voltage As grid voltage increases the desired response of a grid support inverter is to reduce its power output so as to not contribute to further increase in the grid voltage. Likewise, as voltage decreases it is desired for the inverter to increase power output.

When combined with one or more SRD, UL 1741 Supplement SA becomes an evaluation and certification programme that is capable of meeting the needs of various electric utilities. Essentially, the UL1741 Supplement SA becomes a multi-purpose tool into which a utility's SRD is inserted, and that combination is used to validate if an inverter meets that utility's specific performance criteria. This structure means it may be possible to reduce test time by combining the criteria of multiple SRDs into one test sequence. However, there will be a large volume of test data even if only one SRD is used and, after testing, the data must be carefully reviewed and mined for specific results before being further calculated to validate compliance with various manufacturer ratings and declarations.

It is important to note that, while UL 1741 Supplement SA marks a significant update within the industry, the standard does not serve as a blanket for utility interconnected products. Three key standards (detailed below), including the original UL 1741, are merged to evaluate a utility interconnected product with grid support functionality.

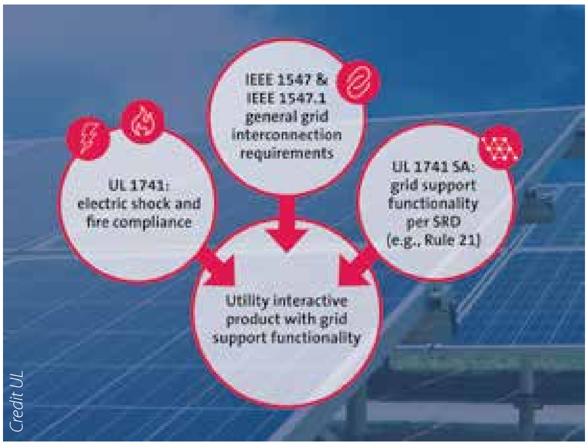

Figure 2. The standards used to evaluate a utility-interconnected product with grid support capabilities

Moving forward

While considerable effort has been made to address changes in the industry, additional work is in process to help further this cause. Presently, UL 1741 Supplement SA covers all certification needs for grid support interactive inverters of early adopters such as California Rule 21 and Hawaii 14H, but changes are already planned in response to upcoming industry updates. First, IEEE 1547 2nd Edition is expected to be published sometime in early 2018. Then, in mid to late 2019, IEEE 1547.1 2nd Edition should be published, as well. At that time, another revision is planned for UL 1741 to replace the UL 1741 Supplement SA requirements with references to the newly revised 2nd editions of IEEE 1547 and IEEE 1547.1. However, this also leaves a gap of approximately 15-18 months between the anticipated publication dates of the new IEEE 1547 and IEEE 1547.1 standards.

Currently, there is interest from utilities to use the IEEE 1547 2nd Edition as soon as possible. To help fill the gap, work has begun to develop an SRD based on the parameters in the soon-to-be published IEEE 1547. This will allow for the use of the existing UL 1741 Supplement SA standard and test protocols to provide a certification that addresses a majority of the IEEE 1547 2nd Edition requirements.

Just as standards and testing requirements are changing in response to new technologies for the smart grids of tomorrow, new technologies continue to evolve to address the growing demands for green energy and safer solutions. This means that many exciting, innovative products will be working their way through product development and into the market. However, these products will be required to meet safety and in some cases performance requirements before being accepted in most major global markets, including the US and Canada. With this area still experiencing intense growth, it is likely that some of these new products will not fit neatly into existing codes, standards, and certifications, but UL can work with manufacturers and the larger PV industry to understand changing needs and develop an evaluation programme that works for all parties involved.

With every major industry change comes the need for evaluation of the current safety standards and, if necessary, updates to these standards to accommodate the changes. This process will always be continuous and evolving and UL will continue to work with the industry and interested stakeholders to help ensure that all aspects of safety and performance are being considered in tandem with innovation. Though it remains impossible to know for sure where the global PV industry will go from here and which regions will continue to push global growth, it is fair to say that PV technology has proven to be a viable green energy solution with potential to integrate into smart grids as long as advanced smart-inverter technology performs, is safe, available and ready to meet the needs of tomorrow. ■

Author

Tim Zgonena has worked for UL since 1990 as principal engineer for distributed energy resources equipment and systems. His responsibilities include the development, maintenance and application of UL's certification requirements and delivery of UL conformity assessment services for utility grid interconnection systems equipment, inverters and converters, PV BOS equipment, engine generators, wind turbines and wind turbine system components. He serves on several distributed generation IEEE, IEC and AWEA technical committees and is a member of NFPA 70, NEC Code Making Panel 4.

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