Sandia DER Interoperability Test Protocols: Relationship to Grid Codes and Standards

Jay Johnson, Sigifredo Gonzalez, and Abraham Ellis
Photovoltaic and Distributed Systems Integration
Sandia National Laboratories
Albuquerque, United States
jjohns2@sandia.gov, sgonza@sandia.gov, aellis@sandia.gov

***Abstract*—Sandia National Laboratories (Sandia) has created a set of test protocols for the International Electrotechnical Commission (IEC) TR 61850-90-7 advanced distributed energy resources (DER) functions. The test protocols are documented in a Sandia publication, "Test Protocols for Advanced Inverter Interoperability Functions," intended to accelerate the adoption of advanced functions becoming available in new DER equipment. The initial test protocol focus has been on testing functional interoperability of solar photovoltaic inverters and energy storage systems and can be expanded to other DER. The first draft of the test protocols was released publicly in November 2013 and circulated to international stakeholders to inform emerging IEC, Underwriters Laboratories, and equivalent national certification standards. Currently, several laboratories including Sandia, the National Renewable Energy Laboratory, Austrian Institute of Technology, and Ricerca sul Sistema Energetico in Italy, are performing DER testing using the Sandia Test Protocols to help refine test procedures as they become precursors to future harmonized, consensus certification standards. This paper identifies gaps in existing normative references that address definitions and certification procedures for interoperability and advanced functionality. It also discusses associated national grid codes in the U.S., Spain, Austria, Italy, and the United Kingdom.**

Keywords—distributed generation, photovoltaic, inverter, distributed energy resources, standards, harmonization, smart grid, interoperability, communications.

I. Introduction

Historically, solar photovoltaic (PV) inverters were designed to export the maximum available active power to the grid. However, with an increase in distributed energy resources (DER), particularly those utilizing variable renewable energy, it has become apparent that distributed generators should play a more significant role supporting power grid performance and reliability. Industry consensus is that DER devices must become more controllable and dispatchable in order for the grid to support significant amounts of renewable energy. As renewable energy sources expand, DER must do more than just autonomously generate power; they must have additional communications-enabled controllability and grid-stabilizing functionality.

In 2009, the Electric Power Research Institute, Sandia National Laboratories with support from the U.S. Department of Energy, and the Solar Electric Power Association initiated a large industry collaborative effort to develop standard definitions for a set of DER grid support functions such as volt-var and frequency-watt. The initial effort concentrated on grid-tied PV inverters and energy storage systems, but the concepts have applicability to all DER. The final product of this collaborative effort was the International Electrotechnical Commission (IEC) Technical Report (TR) 61850-90-7 ("definitions document") [1] that has become a basis for the expansion of related international grid codes and certification standards. At the time IEC TR 61850-90-7 was published, most grid codes did not require DER to have advanced functionality, and such functionality was not widely available. More recently, the PV industry has rapidly begun to adopt requirements for advanced DER functions, partly at the request of utilities.

In 2011, while the IEC definitions document was being prepared, Sandia began the development of set of test protocols to verify DER were properly executing advanced interoperability functions. The goal of the Sandia Test Protocols (STPs) [2-3] was to establish a means to test DER functionality and interoperability in a comparable, reliable, and repeatable manner. While the STPs do not establish pass/fail criteria, which are the responsibility of standard development organizations that follow a formal stakeholder engagement process, the protocols were designed to be a precursor to national and international certification standards by standardizing procedures and settings to test each function listed in IEC TR 61850-90-7.

Ideally, the STPs will become a basis for certification test procedures for DER advanced grid support functions as such functions are refined and validated over time. To this end, the STPs are being exercised by several laboratories around the world under a research activity organized by the International Smart Grid Action Network Smart Grid International Research Facilities Network (SIRFN). Specifically, Sandia, the National Renewable Energy Laboratory, the Austrian Institute of Technology, and Ricerca sul Sistema Energetico (RSE) are testing DER devices with the STPs and making recommendations for improving test procedure and test parameters. Additionally, many industry-led organizations are involved in updating the STPs, including the U.S. National Institute of Standards and Technology, the Smart Grid Interoperability Panel, and SunSpec Alliance.

From the point of view of this group of stakeholders, broad adoption of standards based on the STPs has multiple benefits, including:

- providing manufacturers and product developers with standard procedures, test points, and measurements for advanced inverter functions so that certification is consistent across different jurisdictions;
- assuring products are interoperable with respect to advanced DER functionality;
- creating internationally-accepted and harmonized measurements of inverter performance in response to commands/requests;
- reducing redundancy in certification/compliance tests;
- providing a reliable means to compare the performance and functionality of the advanced inverter functions as implemented by different manufacturers; and
- creating a foundation of accepted test procedures that can be expanded, refined, and extended over time to accommodate new innovations or advanced functions as they develop.

This report documents country-specific codes and standards which govern the definition and certification of interoperability and advanced DER functions for the U.S., Spain, Austria, Italy, and the United Kingdom (U.K.). For each country and IEC function, the following elements are identified:

1. *Grid code*, which requires grid-interconnected DER to have certain advanced functionality.
2. *Advanced function definitions standard (Adv. Fcn Std.)*, which defines the advanced function.
3. *Advanced function certification standard (Adv. Fcn Cert. Std.)*, which defines a test procedure/protocol to verify equipment functionality and certifies the DER for field deployment.
4. *Interoperability definition standard (IOP Std.)*, which defines the utility-to-DER or energy management system-to-DER communications.
5. *Interoperability certification standard (IOP Cert. Std.)*, which defines a test procedure/protocol to verify the communications to/from DER.

International experts were surveyed to provide examples of these codes and standards in their countries. This survey thereby identifies gaps in current standards that the STPs, with country specific pass/fail criteria, could address—especially with respect to testing procedures referenced in 3 and 5 above.

II. Test Protocols for Interoperability and Advanced Functions

Regulatory and policy entities have set ambitious renewable energy and distributed generation deployment goals. There is broad consensus that enhanced DER grid support capabilities will be necessary for the power grid to support the large amounts of DER expected in the near future, especially from variable renewable generation. The DER grid support functions defined by IEC 61850-90-7 are shown in Table I. These functions can be loosely classified into frequency, voltage, and grid protection, as shown in Fig. 1.

TABLE I. Functions Defined IEC TR 61850-90-7.

Command/Function		General Category
INV1	Connect/Disconnect	Immediate Control Functions
INV2	Adjust Max Generation Level	
INV3	Adjust Power Factor	
INV4	Request Active Power	
INV5	PV/Storage Functions	
VV11	Volt-Var mode 11	Volt-var management modes
VV12	Volt-Var mode 12	
VV13	Volt-Var mode 13	
VV14	Volt-Var mode 14	
FW21	Set maximum power output based on grid frequency	Frequency-Watt management modes
FW22	Set maximum power output based on grid frequency	
TV31	Dynamic reactive power support	
L/HVRT	Connect/disconnect settings for Low/High Voltage Ride-through (VRT)	"must disconnect" and "must remain connected" regions for freq. and voltage conditions
L/HFRT*	Connect/disconnect settings for Low/High Frequency Ride-through (FRT)	
WP41	Power factor settings	Watt-triggered behavior modes
WP42	Power factor settings	
VW51	Set power output to smooth voltage	Voltage-Watt management modes
VW52	Set power output to smooth voltage	
TMP	Temperature mode behavior	
PS	Signal mode behavior	
DS91	Modify DER Inverter Settings	Parameter setting and reporting
DS92	Event/History Logging	
DS93	Status Reporting	
DS94	Time Synchronization	

* Low/High Frequency Ride Through is not included in IEC TR 61850-90-7 but is being considered by some jurisdictions, like California [4].

The Sandia Test Protocols address each of the IEC functions, but they are also informed by emerging requirements under the California DER interconnection standard, the California Public Utility Commission (CPUC)/California Energy Commission Electric Rule 21 [4]. The STPs are divided into two documents: a main document that outlines the scope and objective of the test protocols [2] and a set of appendices that contain procedures for each of the functions defined in IEC TR 61850-90-7 [1]. Each appendix is a self-contained, stand-alone document to facilitate revisions as needed. The parameters found in the test matrices take into account international methods and practices, although some customization will be needed to adapt to specific grid code requirements. Ultimately, the testing procedures are positioned to help accelerate the adoption of advanced DER functionality.

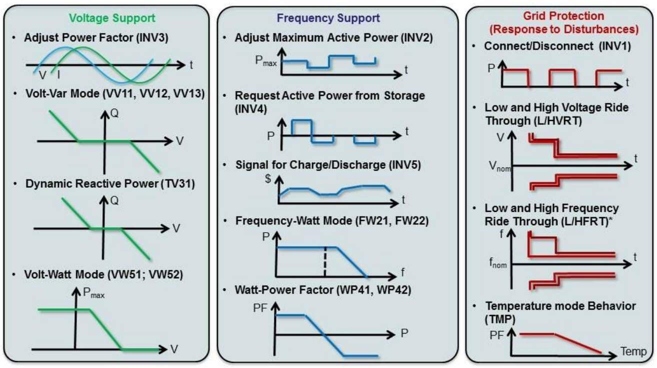

Fig. 1. Graphic representation of three types of functions defined in the IEC TR 61850-90-7.

Additionally, the Sandia Test Protocols were designed such that:

- The inverter/DER tests focus on an electrical characterization of the advanced functions, independent of the implemented communication protocols.
- The protocols test and verify each function individually, recognizing that not all the IEC TR 61850-90-7 functions will be required by all jurisdictions.
- The test matrices which define the test scenarios were designed to make the test sequence for each of the functions reasonably quick and simple, while still exploring the full functionality of the Equipment Under Test (EUT).
- The testing protocols employ suggested profiles for the PV simulator (or other DER supply) and grid simulator to investigate the response of the EUT under step changes and representative irradiance (or DC power) ramp rates.

III. GRID CODES AND STANDARDS

As part of the effort to support emerging internationally-recognized, consensus-based certification testing standards, the STPs incorporate requirements applicable in different regions around the world. This document describes where the protocols fit into international equipment certification processes. The following sections discuss and compare three different layers of codes and standards and their international status: grid codes, interoperability and advanced function definitions standards, and the associated certification test standards.

A. Grid codes requiring advanced functions

Globally, grid codes define the minimum required DER functionality in order to connect safely and reliably to the electricity grid. For instance, some countries have specific requirements for low and high voltage ride-through for DER, defining how long after a voltage sag or swell DER must remain connected to the grid. Table II shows a list of the grid codes applicable in the United States, Spain, Austria, Italy, and the United Kingdom.

In the U.S., IEEE Std. 1547 [5] defines the functionality requirements for interconnection of distributed resources to the electricity grid. This currently does not address the advanced grid functions contained in IEC 61850-90-7, but the approved ‘permissive’ IEEE 1547a [6] allows for the possibility that distributed resources regulate voltage and frequency in coordination with the utility or electric power system (EPS). This provided the legal framework for CPUC to consider a major revision to Electric Rule 21, which defines interconnection requirements for DER in California. The Smart Inverter Working Group (SIWG), a collaboration of more than 100 individuals representing PV inverter manufacturers, utilities, national laboratories, and other industry groups, has identified a set of advanced inverter and interoperability functions to be included in Rule 21. The recommendation includes autonomous grid functions (e.g., freq-watt, volt-var) and functions requiring communication to the DER (e.g., INV1, INV2). Current SIWG recommendations suggest implementation of all autonomous functions by October 2015 and implementation of all advanced functions by January 2016.

Advanced grid functions are already included in some grid codes outside the United States. In Austria, the latest edition of the “Technical and organizational rules for operators and users of electricity grids” part D4 (TOR D4) [7] introduces a number of advanced grid functions which correspond to INV2, INV3, FW21, and FVT and VRT. In Italy, there are interconnection requirements for the high voltage (HV) and the medium voltage (MV) systems in CEI 0-16 [8] and the low voltage (LV) interconnections in CEI 0-21 [9]. The U.K. also has DER interconnection requirements as part of Distribution Code v21 1/2014 [10], and interconnection requirements for smaller DER (<16 A per phase) are described in Engineering Recommendation G83/1-1 [11]. The German grid codes requiring advanced functionality are discussed in [12] and other international grid codes are categorized in a Generator to Grid Database on the website of the European Distributed Energy Resources Laboratories (DERlab) e.V. [13].

B. Interoperability and Advanced Function Definitions Standards

In order to provide grid support, several countries established definition standards for communications and advanced functions before the IEC publication was released. For instance, national advanced functionality standards are already in place in Spain [15-18] and the U.K. [10, 19-24], as shown in Table II. Germany established a frequency-watt function standard in 2008 [14] which fixed the active power droop as a function of grid frequency. The definition of frequency-watt function in IEC 61850-90-7 has adjustable setpoints that can be set to different values depending on the needs of the jurisdiction in which the DER is installed. Therefore, products that were designed for the German market with fixed FW21 curves can be considered a specific case of the FW21 function defined by IEC TR 61850-90-7. In the U.S., there are no interoperability or advanced DER definitions yet, but the new Rule 21 and subsequent update to Underwriters Laboratories (UL) Standard 1741 [25] will include them.

C. *Interoperability and Advanced Function Certification Standards*

In order to verify the functionality of devices with advanced functions, certification standards are necessary. However, based on the survey of SIRFN members in the U.S., Spain, Austria, Italy and the U.K., there are only limited certification standards or procedures in place to validate the interoperability or advanced inverter functions. Only in a few countries such as Italy (CEI 0-21 [9], CEI 0-16 [8]) and Germany (BDEW [14]), certification schemes with associated test plans are defined as part of the grid code. In most other European countries, self-certification programs are currently being used.

With the new CPUC and international grid requirements, there is a strong need to establish certification standards for DER interoperability and advanced functions. The STPs can be used as a starting place for international and national certification standards. In the U.S., Sandia and the UL 1741 Standards Technical Panel are collaborating to adapt the STPs into a new DER inverter certification standard which certifies DER inverters with advanced functions. A similar approach can be used to update other certification standards in other countries and jurisdictions.

IV. Conclusion

In order to stabilize electricity grids around the world, new requirements for advanced inverter functions and associated communications are being added to many grid codes. As these functions become requirements for interconnection, there is a need to certify the devices according to a harmonized procedure. As indicated in Table II, there is a clear gap in the certifications standards for these functions. Rapid implementation of harmonized certification test procedures can accelerate the adoption of advanced functions in new smart grid equipment. The Sandia Test Protocols have the potential to become the basis for the certification tests for the functions defined in IEC TR 61850-90-7.

Acknowledgment

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000. This work was funded by the U.S. Department of Energy Research and Development Program. The authors would also like to thank Maurizio Verga from RSE, Andrew Roscoe from the University of Strathclyde, Roland Bründlinger from the Austrian Institute of Technology, Angel Diaz Gallo from Tecnalia, and Diana Craciun from DERlab for providing information about European codes and standards. The authors also acknowledge SRA International, Inc. in the preparation of document.

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Table II. CODES AND STANDARDS FOR UNITED STATES, SPAIN, AUSTRIA, ITALY, AND U.K.

Grid Function	**United States**					**Spain**				
	Grid Code	*Adv. Fcn Std.*	*Adv. Fcn Cert. Std.*	*IOP Std.*	*IOP Cert. Std.*	*Grid Code*	*Adv. Fcn Std.*	*Adv. Fcn Cert. Std.*	*IOP Std.*	*IOP Cert. Std.*
Connect/Disconnect (INV1)	CPUC Rule 21 (CA) [4]	IEC TR 61850-90-7 [1]		[1]			UNE 206007-1:2013 IN [15] UNE 206006: 2011 IN [16] EN50438: A9-ES [17] RD 1699:2011 [18], [1]		[15], [16], [17], [18], [1]	
Adjust Maximum Generation Level (INV2)		[1]		[1]			[15], [16], [17], [18], [1]		[15], [16], [17], [18], [1]	
Adjust Power Factor (INV3)	CPUC Rule 21 (CA) [4]	[1]		[1]			[15], [16], [17], [18], [1]		[15], [16], [17], [18], [1]	
Request Active Power from Storage (INV4)		[1]		[1]			[1]		[1]	
Signal for Charge/Discharge Action (INV5)		[1]		[1]			[1]		[1]	
Volt/Var Mode (VV)	CPUC Rule 21 (CA) [4]	[1]		[1]			[1]		[1]	
Frequency/Watt Mode (FW)	CPUC Rule 21 (CA) [4]	[1]		[1]			[15], [16], [17], [18], [1]		[15], [16], [17], [18], [1]	
Dynamic Reactive Current Support (TV)		[1]		[1]			[15], [16], [17], [18], [1]		[15], [16], [17], [18], [1]	
Low/High Voltage Ride Through (VRT)	IEEE 1547a [6]	[1]		[1]			[15], [16], [17], [18], [1]		[15], [16], [17], [18], [1]	
Low/High Frequency Ride Through (FRT)	IEEE 1547a [6]						[15], [16], [17], [18]		[15], [16], [17], [18]	
Watt-Power Factor Settings (WP)		[1]		[1]			[15], [16], [17], [18], [1]		[15], [16], [17], [18], [1]	
Set Output to Smooth Voltage Variations (VW)		[1]		[1]			[15], [16], [17], [18], [1]		[15], [16], [17], [18], [1]	
Temperature Mode Behavior (TMP)		[1]		[1]			[1]		[1]	
Utility Signal Mode (PS)		[1]		[1]			[1]		[1]	
Event History/Logging (DS)		[1]		[1]			[1]		[1]	
Status Reporting (DS)		[1]		[1]			[1]		[1]	

Grid Function	Austria					UK					Italy				
	Grid Code	*Adv. Fcn Std*	*Adv. Fcn Cert. Std.*	*IOP Std.*	*IOP Cert. Std.*	*Grid Code*	*Adv. Fcn Std.*	*Adv. Fcn Cert. Std.*	*IOP Std.*	*IOP Cert. Std.*	*Grid Code*	*Adv. Fcn Std.*	*Adv. Fcn Cert. Std.*	*IOP Std.*	*IOP Cert. Std.*
Connect/Disconnect (INV1)		[1]		[1]		UK Distribution Code v21 1/ 2014 Small: G83/1-1	Distribution Code DPC6.3, [1]		[1]		HV&MV CEI 0-16 [8] LV CEI 0-21 [9]	[1]		[1]	
Adjust Maximum Generation Level (INV2)	TOR D4 [7]	[1]		[1]			ETR 130 (2006) , [1]		[1]		HV&MV CEI 0-16 [8] LV CEI 0-21 [9]	[1]		[1]	
Adjust Power Factor (INV3)	TOR D4 [7]	[1]		[1]		ER G83-2 v5 Section 5.6	ER G75 Dec 2002 Section 4.8, [1]		[1]		HV&MV CEI 0-16 [8] LV CEI 0-21 [9]	[1]		[1]	
Request Active Power from Storage (INV4)		[1]		[1]			ETR 124 (2004) , [1]		[1]			[1]		[1]	
Signal for Charge/Discharge Action (INV5)		[1]		[1]			[1]		[1]			[1]		[1]	
Volt/Var Mode (VV)	TOR D4 [7] (not mandatory)	[1]		[1]			ETR 126 (2004) , [1]		[1]		HV&MV CEI 0-16 [8] LV CEI 0-21 [9]	[1]		[1]	
Frequency/Watt Mode (FW)	TOR D4 [7]	[1]		[1]		UK Distribution Code DOC 6.5	[1]		[1]		CEI 0-16 [8] (overfrequency, underfrequency in future)	[1]		[1]	
Dynamic Reactive Current Support (TV)	TOR D4 [7] (MV only)	[1]		[1]			[1]		[1]			[1]		[1]	
Low/High Voltage Ride Through (VRT)	TOR D4 [7] (MV only LVRT only)	[1]		[1]		EN 50160:2007 & 2010	BS 7671, [1]		[1]		HV&MV CEI 0-16 [8] LV CEI 0-21 [9]	[1]		[1]	
Low/High Frequency Ride Through (FRT)	TOR D4 [7]					Distribution Code DPC4.2.2.2 Distribution Code DPC7.4.1.3	ER G59/2 9.3.2				HV&MV CEI 0-16 [8] LV CEI 0-21 [9]				
Watt-Power Factor Settings (WP)	TOR D4 [7]	[1]		[1]			ER G75 Dec 2002, [1]		[1]		HV&MV: CEI 0-16 [8] LV: CEI 0-21 [9]	[1]		[1]	
Set Output to Smooth Voltage Variations (VW)		[1]		[1]		EN 50160:2007 & 2010	BS 7671, [1]		[1]			[1]		[1]	
Temperature Mode Behavior (TMP)		[1]		[1]			[1]		[1]			[1]		[1]	
Utility Signal Mode (PS)	TOR D4 [7] (on DSO request)	[1]		[1]			[1]		[1]		HV&MV CEI 0-16 [8] LV CEI 0-21 [9]	[1]		[1]	
Event History/Logging (DS)		[1]		[1]			Distribution Code DPC7.4.2, [1]		[1]			[1]		[1]	
Status Reporting (DS)		[1]		[1]			[1]		[1]			[1]		[1]	