ADVANCED FUNCTION INVERTER TEST LAB SPECIFICATION

Version 1.0

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ACKNOWLEDGEMENTS

ABSTRACT

Distributed Energy Resources (DERs) with advanced functions and standard communication interfaces enhance the efficiency of clean renewable energy technologies, such as PV with smart inverters and energy storage, while being supportive of the grid, thus allowing accommodation of more renewable generation.

The California Public Utilities Commission (CPUC) updated Electric Tariff Rule 21 to require advanced functions on all new grid-interconnected DER, especially smart inverters. The legal ruling on the CPUC Rulemaking (R.) 11-09-011 ("Order Instituting Rulemaking on the Commission's Own Motion to improve distribution level interconnection rules and regulations for certain classes of electric generators and electric storage resources.") confirmed the updates to Electric Tariff Rule 21 and established a procedure for compliance. PV inverters in the US are certified to Underwriters Laboratories (UL) Standard 1741[1] and the the UL 1741 Standards Technical Panel (STP) working group developed UL 1741 SA to support the advanced functions described in the ruling. The procedure for compliance laid out by the CPUC ruling mandates new grid-connected DER to meet UL 1741 SA certification protocol.

This document delivers a standard testing framework that allows equipment suppliers to speedily deliver well tested and CA Rule 21 compliant DER solutions to the marketplace. The framework described in this document covers an easily replicatable test lab setup, test procedures detailing the parameters for exercising the smart inverter functions, detailed test process for replicabilty and automation, and interpretation of the test results.

The concepts included herein are intended to be applied to address requirements put forth in other regions around the world.

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[1] Underwriters Laboratories Std. 1741 Ed. 2, "Inverters, Converters, Controllers and Interconnection System Equipment for use with Distributed Energy Resources," 2010.

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CHAPTER 1:
CA Rule 21 DER System Compliance Test Lab

1.1   Overview

A key requirement for ensuring compliance and interoperability of DER systems is a test and validation framework. SunSpec Alliance has established such a framework for the solar industry that includes verification of system conformance in complex grid conditions, validation with the SunSpec conformance test suite, and interoperability testing. Specifically, SunSpec Alliance started the test program in 2014 to initially provide automated testing of SunSpec compliant smart inverters and subsequently leveraged it to add more testing modes including energy storage tests for a more complete DER system testing.

This chapter describes the configuration and operation of the equipment of a DER system test laboratory. The lab setup described herein and related technology has already been deployed at national energy labs around the globe (including Sandia and NREL) as part of the Smart Inverter Facilities Research Network (SIRFN).

As part of the EPIC funded project, the lab setup described here has been replicated at the UCSD Smart Inverter Laboratory for testing smart inverters for CA Rule 21 and UL 1741 SA criteria. The specifications of the equipment used in the UCSD Smart Inverter Laboratory are also described in this chapter for ready reference and easy recreation of the test bed.

Figure 1: Block Diagram of a Typical DER System Test Bed
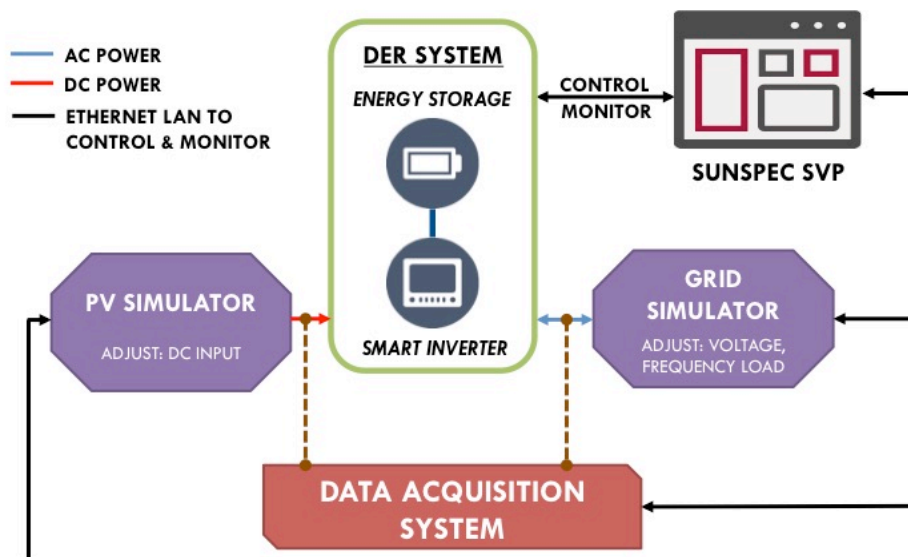
1.2   Major Lab Components

The major components in the DER test lab consist of a PV simulator, AC grid simulator, DER system under test, data acquisition system, test workstation, and a test automation & data archival system.

1.2.1 PV Simulator

A typical DER test lab setup will utilize a PV Simulator with DC power sources that are controllable and programmable to simulate the actual performance of a photovoltaic system. The output of the PV Simulator will be input directly to the inverter, which is a part of the DER System under test.

1.2.2 AC Grid Simulator

The AC output of the inverter, which is a part of the DER System under test, will be input to a 3-phase AC power supply, whose purpose is to simulate a 3-phase AC Grid.

1.2.3 DER System Under Test

A DER System could comprise of a smart inverter or a smart inverter with energy storage. In both cases, it is the inverter's input/output interfaces that would be attached to the other components within the test bed. The PV Simulator will provide DC input to the inverter, and the output of the inverter will be interfaced with the AC Grid Simulator.

1.2.4 Data Acquisition System

Measurements taken during each test include DC voltage and current from the PV Simulator, and voltages and currents from the 3 AC phases of the Grid Simulator. A Data Acquisition System (DAS) is used to receive the measurements, perform various calculations, and send data to the test workstation.

1.2.5 Test Workstation

The test workstation provides test monitoring and management capabilities, the execution environment for the test automation system, and export of test results to data archival system.

1.2.6 Test Automation System

The test automation system configures the PV and Grid Simulators, executes test logic based on the test procedures that have been automated, monitors the DAS and manages the test results. This document references the SunSpec System Validation Platform (SVP) as the test automation system for functional and conformance testing of DER systems.

1.2.7 Data Archival System

The data archival system archives the data collected during the tests and test results. The SunSpec SVP is capable of archiving test results for easy analysis of the test results and to simplify the evaluation of DER firmware revisions over time.

1.2   Electrical Configuration of Test Bed

Figure 2 depicts the electrical configuration of the components within the test bed. The diagram depicts the flow of DC power from the PV Simulator to the DER system under test, the flow of

AC power between the inverter and the AC Grid Simulator, and the measurement points for data acquisition.

Figure 2: Electrical Line Diagram for the DER System Test Bed
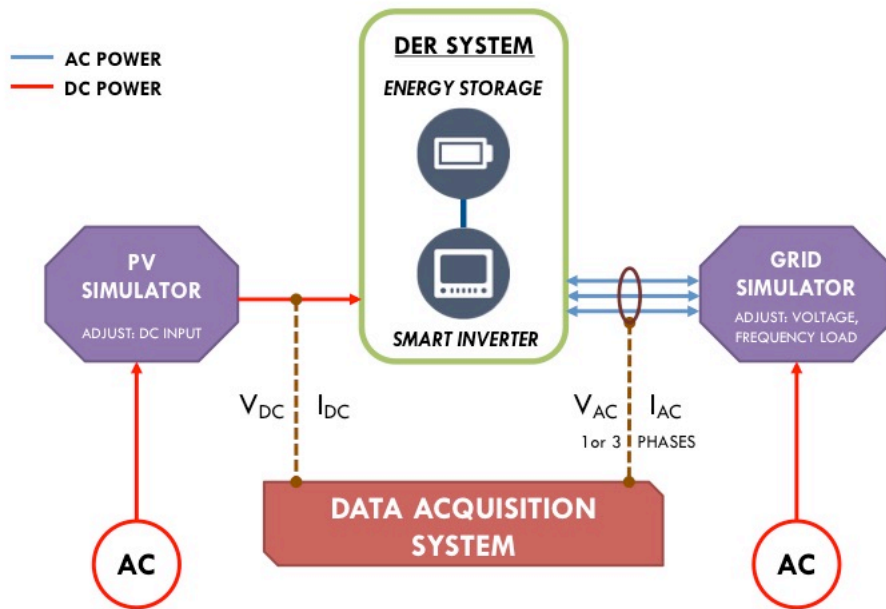
1.3 Test Bed Control & Data Flow

Most PV simulators in the market can be controlled and configured using IEEE 488.2 Standard Commands for Programmable Instruments (SCPI) over TCP/IP connected using a CAT5 Ethernet cable. Based on the test parameters provided, the test automation system can then configure simulated PV I-V curves, creating and running irradiance profiles, and turning on and off the power to the System Under Test.

Similarly, most AC grid simulators can be communicated with using SCPI commands. These commands are sent over IEEE 488 General Purpose Interface Bus (GPIB) to read and write nominal voltage and frequency, voltage and frequency sag/surge profiles, and energization settings.

Currently available smart inverters use Modbus over RS-485 serial interface or over TCP/IP using an Ethernet interface for communication. Most smart inverters in the market have implemented SunSpec Modbus interface and the the SunSpec Inverter Information Models that are derived from the IEC TR 61850-90-7 standard and inclusive of advanced inverter functions in CA Rule 21. This combination provides all the elements needed for a common interface for inverters that allows them to connect to any grid communication system. The test automation

system can read and manipulate the Modbus registers that control the advanced inverter function of the System Under Test.

Data is collected by the DAS and acquired by the test automation system through an Ethernet interface that is supported by most DAS. The DAS is configured for each test and the data collected during test is downloaded upon test completion. Data points collected during the test include measured data such as DC current, DC voltage, AC voltage, AC current, and calculate data such as AC frequency, AC power, AC apparent power, AC reactive power, AC power factor. UL 1741 SA defines the standard data set associated with each advanced grid function required by CA Rule 21. The data set definitions specify the data channels and sampling rates.

1.4 UC San Diego Smart Inverter Laboratory Setup

This section describes the configuration and general operation of the equipment at the UCSD Smart Inverter Laboratory, which the first such location where this specification has been applied.

1.4.1 PV Simulator

The test setup will utilize three (3) DC power sources of 10 kW capability each, for a total of 30 kW. These sources are controllable and programmable to simulate the actual performance of a 30 kW photovoltaic system. The Elgar PV Simulator specifications are outlined in Table 1.

Table 1: PV Simulator Specifications

Manufacturer	Elgar
Model	TerraSAS ETS600X17E-PVF
AC Power Supply	408 V (3-φ)
Max. Output	10 kW
Max. Output Voltage (DC)	600 V
Short Circuit Current (DC)	16.7 A
Interface	TerraSAS Software
Tracking Speed	200 Hz
Accuracy	Voltage: ± 0.02% of full scale Current: ± 0.05% of full scale
Sampling Resolution	200 kS/s

1.4.2 AC Grid Simulator

A California Instruments AC Grid Simulator is used in the lab for simulating a 3-phase AC grid. The California Instruments Simulator specifications are outlined in Table 2.

Table 2: AC Grid Simulator Specifications

Manufacturer	California Instruments
Model	MX30-3
Capacity	30 kW (10 kW per phase)

AC Power Supply	408 V (3-φ)
Output Voltage Ranges	Low: 0–150 V
	High: 0–300 V
Output Current Ranges	0–66.6 A (Low V)
	0–33.3 A (High V)

1.4.3 Data Acquisition System

A Yokogawa PX8000 Power Scope will be used to receive the measurements during tests and perform calculations. The Yokogowa DAS specifications are outlined in Table 3.

Table 3: Data Acquisition System Specifications

Manufacturer	Yokogawa
Model	PX8000
Options	
Voltage Input	1.5 – 1000 volts
Current Input	10 mA – 5 A
Interfaces	GPIB, USB, Ethernet

1.4.4 Test Workstation

The test workstation used in the lab is capable of running the SunSpec SVP, monitoring and managing the tests, interface with the data archival system, and handle multi-user access. The workstation has two Ethernet ports: one for the lab network and one for the external network. The test workstation specifications are outlined in Table 4.

Table 4: Test Workstation Specifications

Make & Model	Dell Precision T3620 Mini Tower
Processor	3.4 GHz Quad-core Intel i7-6400
RAM	16 GB
Storage	(2) 1 TB SATA 7200 rpm hard drives
Graphics	Dell HD 530 graphics card
I/O Devices	23" Dell HD monitor, wired keyboard and multifunction mouse
Interfaces	(2) 1-Gbit NIC (Ethernet), RS232, USB
Operating System	Microsoft Windows 7 Pro
Other	Microsoft Office 2016 Adobe Acrobat Pro

1.4.5 Test Automation System

The test automation system configures the PV and Grid Simulators, executes test logic based on the test procedures that have been automated, monitors the DAS and manages the test results.

This document references the SunSpec System Validation Platform (SVP) as the test automation system for functional and conformance testing of DER systems.

1.4.6 Data Archival System

The data archival system consists of an OSIsoft PI system residing on a separate server. While physically located in the same laboratory as the rest of the test bed equipment, the PI server is not part of the laboratory LAN and instead connected to the UCSD WAN so that remote access is available to authorized persons.

The test result sets are sent ("pushed") as a flat file to the OSIsoft PI system at the completion of each test. The SunSpec SVP may do a transformation of the result set depending on the format of the data set before sending to the data archive system. Data sent to the OSIsoft PI system includes user-entered data such as test number, test descriptive data, information on system under test, metered data from the DAS, and data from the PV simulators and AC Grid simulator.

Table 5 outlines the specifications for the server running OSIsoft PI.

Table 5: Data Archival System Server Specifications

Make & Model	Dell Precision T3620 Mini Tower
Processor	3.4 GHz Quad-core Intel i7-6400
RAM	32 GB
Storage	(2) 4-TB SATA 5400 rpm hard drives (2) additional HDD expansion slots
Graphics	Dell HD 530 graphics card
I/O Devices	23" Dell HD monitor, wired keyboard and multifunction mouse
Interface	2 x 1-Gbit NIC (Ethernet), wireless NIC, RS232, USB
Operating System	Microsoft Windows 10 with Hyper-V to support virtual machines
Other	Microsoft Office 2016, Adobe Acrobat Pro

Note: It is possible to configure SunSpec SVP to output CSV and Microsoft© Excel workbook files. As such, OSISoft and other librarian systems are not required.

1.4.7 Communication and Control Configuration

The test workstation will communicate with the laboratory devices via a dedicated LAN utilizing an 8-port Ethernet switch. The PV Simulators and the Grid Simulator are controlled from the test workstation via the SunSpec SVP using SCPI over Ethernet during the tests. Communication to the DER system under test will be via SunSpec Modbus using TCP/IP over Ethernet. The SunSpec SVP communicates with the DAS using TCP/IP over Ethernet. The test workstation will communicate with the data archival server hosting OSIsoft PI over the UCSD network. Authorized project participants will be able to securely access the lab network

remotely, via the UCSD VPN system, for the purposes of monitoring tests, analyzing test results, and other tasks.

Figure 3 shows the communications and control paths for the UCSD lab.

Figure 3: UCSD Smart Inverter Lab Communication & Control Paths