SAND2015-3170PE

Exceptional service in the national interest

Sandia National Laboratories

energy.sandia.gov

Changing Grid Codes Around the World

SunSpec Alliance Members Meeting
San Francisco – 31 March, 2015

Jay Johnson

Photovoltaic and Distributed Systems Integration

U.S. DEPARTMENT OF ENERGY
NNSA National Nuclear Security Administration

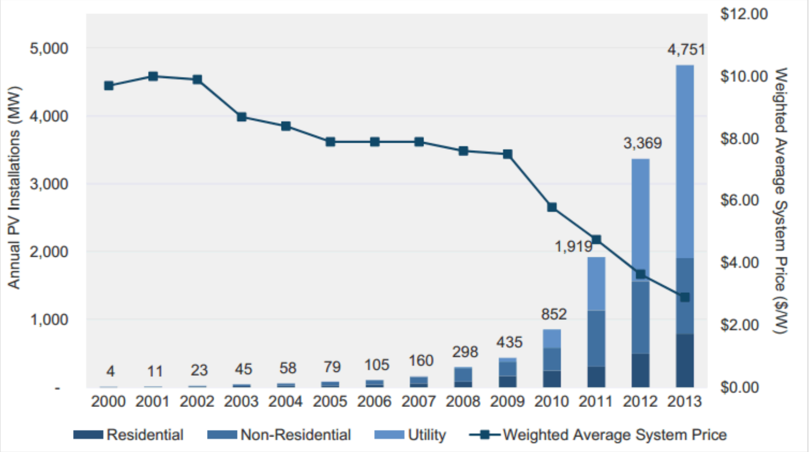
Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

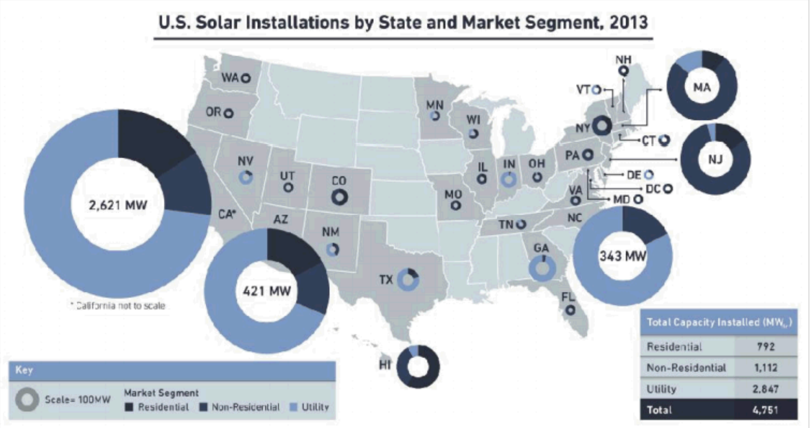
Outline

- The context
  - Total installed capacity of PV is growing fast in the US
  - Large growth expected in distribution systems
- The problem
  - Because the grid is slow to evolve, we will (already do!) encounter technical challenges
  - Unless mitigated, these challenges will make it increasingly difficult and costly to continue adding renewable energy to the grid
- Advanced inverters are a big part of the solution in the U.S.
  - Grid codes in the U.S. and around the world
    - European grid codes
    - National effort: IEEE 1547-2014
    - California's Electric Rule 21 new requirements
    - Hawaiian regulations (HECO regulations and Rule 14H)
  - Sandia projects
    - Sandia-SunSpec System Validation Platform development
    - California Solar Initiative Project
    - Smart Grid International Research Facility Network

PV capacity is growing fast in the US!

- 4.7 GW in 2013, 20 GW total
  - Installed capacity is projected to triple between 2013 and 2016!
  - Highest growth rate expected in distribution-connected PV
- High-Pen Areas
  - California
    - ~2 GW of distribution-connected PV
    - Aiming for 12 GW of DG (mostly PV) by 2020! [1-2]
  - Hawaii
    - Highest penetration at the balancing area-level (island grids)
    - Half of distribution circuits are at 100% of daytime minimum load



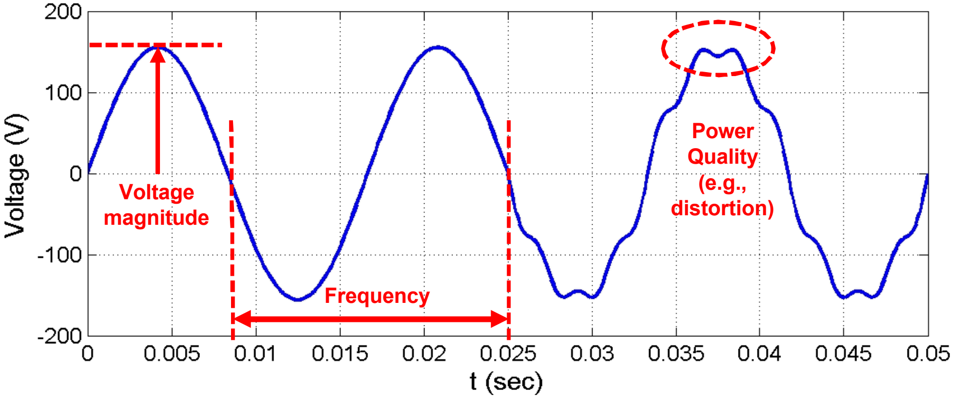


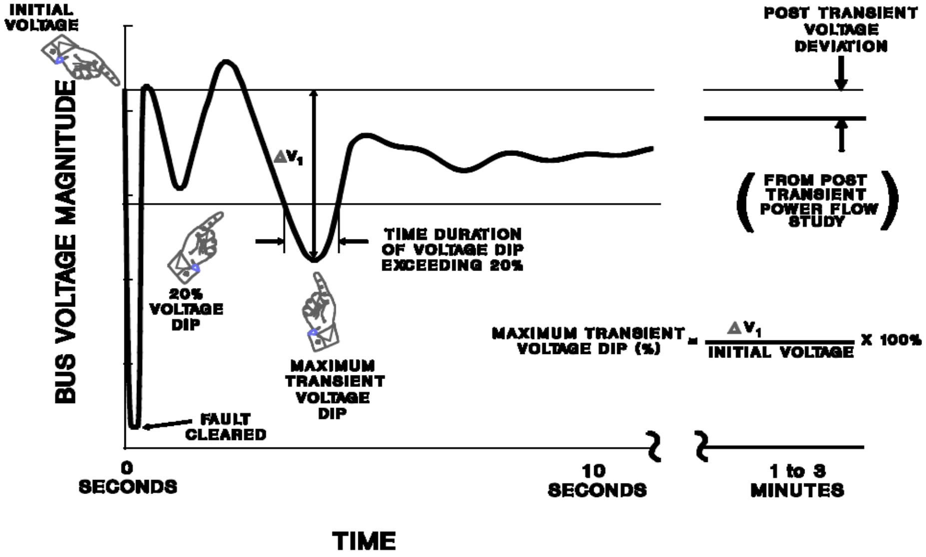
Total Capacity Installed (MW$_{dc}$)	
Residential	792
Non-Residential	1,112
Utility	2,847
Total	4,751

Source: SEIA/GTM Research, US Solar Market Insight 2013 Year in Review

Grid performance requirements

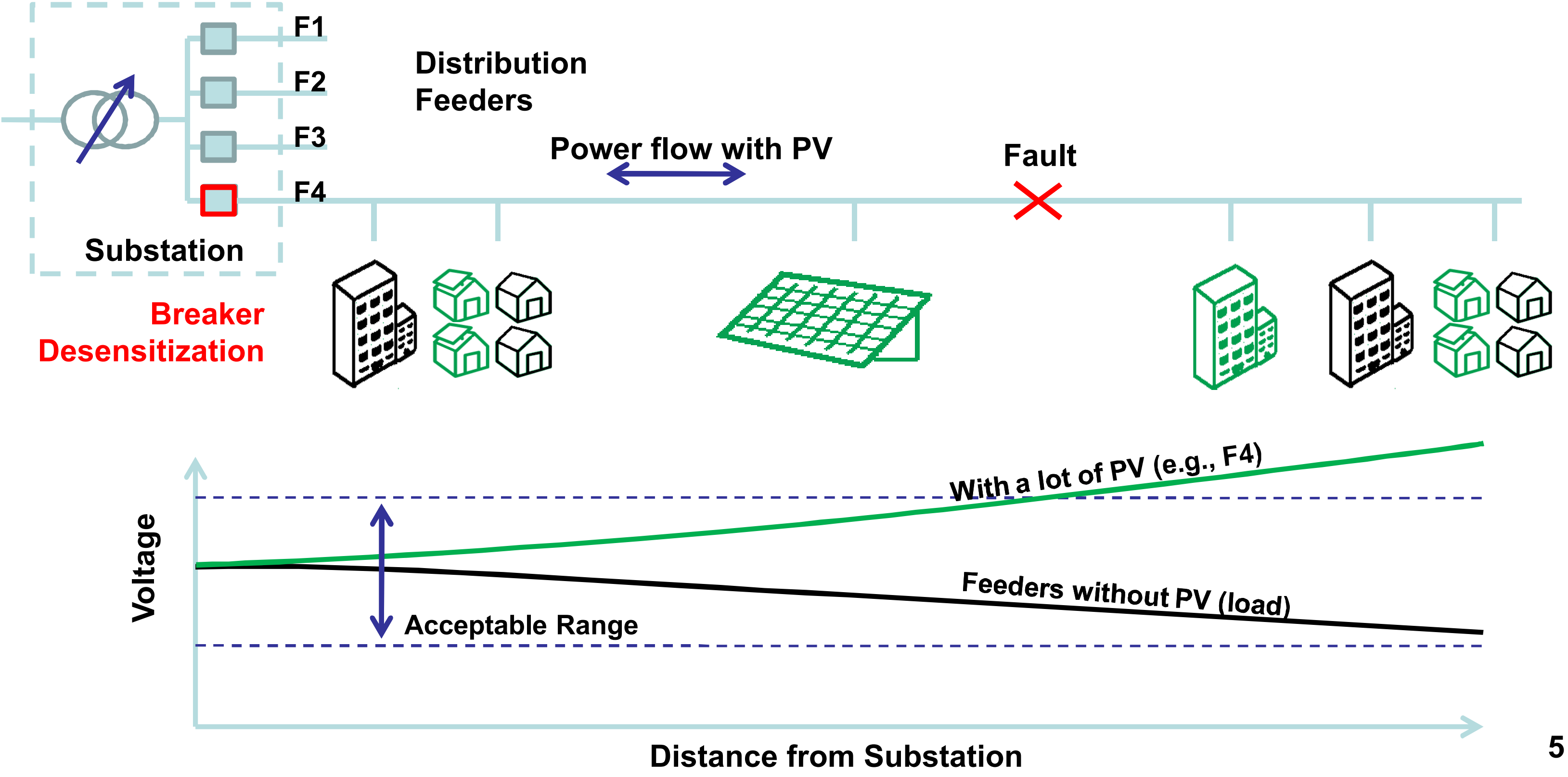
- Voltage & frequency control
- Protection
  - How to tell when/where there is a problem (e.g., fault)
  - Ensure safety, prevent damage to equipment, avoid cascading
- System stability
  - How voltage and frequency recover from a disturbance
- Continuity of service
  - Benchmark: 1-day cumulative outage per customer in a 10-year span (99.97% reliable)





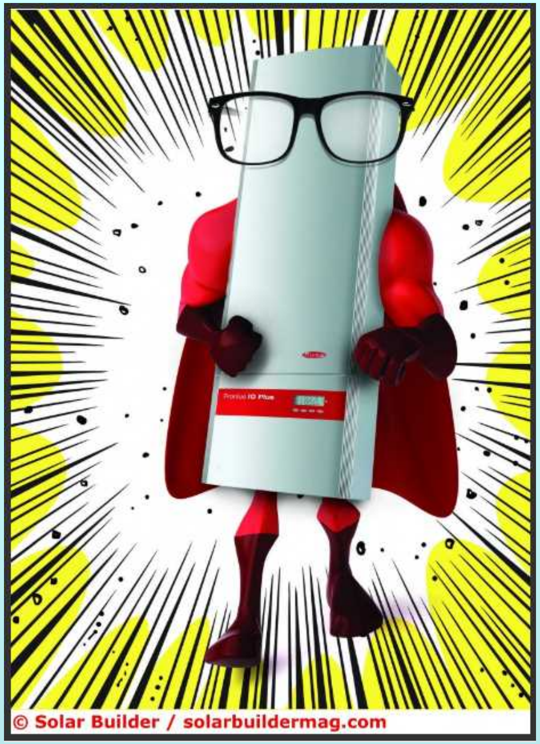
High-Pen PV and grid performance

- PV characteristics (variable, non-dispatchable, inverter-based, distributed) can affect grid performance
  - Local voltage control & protection issues tend to emerge first



Grid integration challenge

- It can become increasingly difficult and expensive to integrate high-pen PV [3-6]
- A big part of the solution: deployment of advanced inverters in future distribution-connected PV systems [7-8]
  - Mitigate high-pen impacts and enhance value of PV to owner and grid
- Definition [8-9]: Advanced inverters…
  - Actively support voltage and frequency by modulating the output
  - Have high tolerance to grid disturbances
  - Interact with the system via communications


© Solar Builder / solarbuildermag.com

…Faster than a tap changer

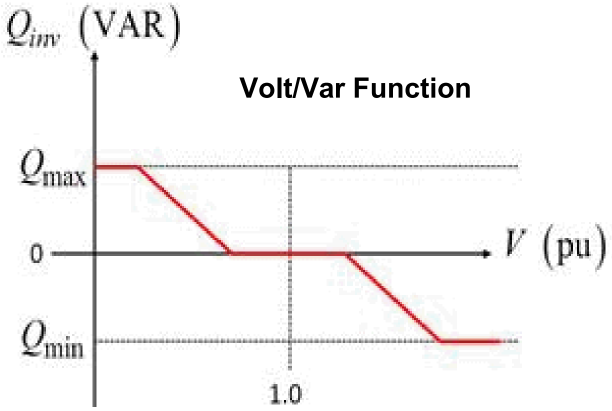
…More powerful than a rotating machine

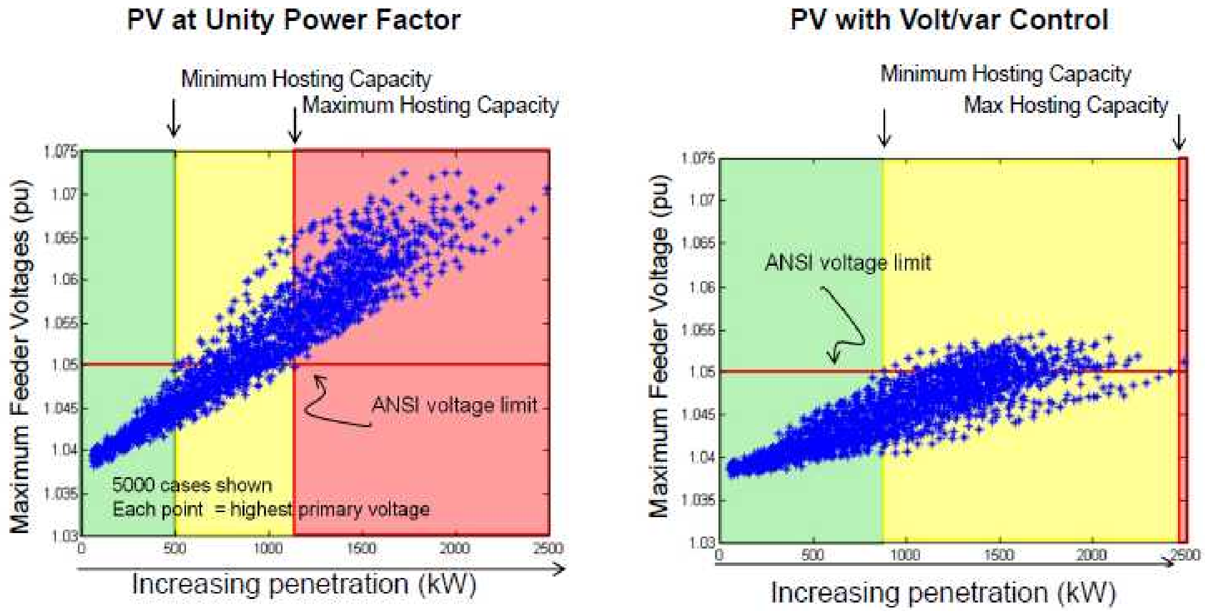
…Able to leap deep voltage sags in a single bound

Courtessy of B. Lydic, Fronius

Example Advanced Inverter Solution

- Advanced inverters allow for higher PV penetration
  - It has been shown that PV inverters with Volt/Var capability can double a distribution circuit's PV hosting capacity (see illustration below) [10]
  - Voltage and frequency ride-through (V/FRT) capability is required to maintain bulk system reliability with high penetration PV [11]





- Sandia collaborates with EPRI and NREL to analyze the benefits of advanced inverters

Illustration courtesy of B. Seal, EPRI [10]

Types of Codes and Standards

- **Definitions Documents**
  - Defines the capabilities of the DER (e.g., IEC TR 61850-90-7, IEEE Std. 1547)
- **Grid Codes/Interconnection Requirements**
  - Often at the national level (e.g., National Electrical Code, FERC requirements like Order No. 792, IEEE 1547 when ratified, CEI 0-21 in Italy, etc.)
  - Additional regulations at state or other jurisdictional level (CA Electric Rule 21)
- **Certification/Compliance/Conformance/Acceptance Tests**
  - Detailed experiments which produce a *pass* or *fail* outcome (IEEE 1547.1, UL 1741).
  - Can be safety-, quality-, or performance-based testing.
  - Certification completed by Nationally-Recognized Test Laboratories (NRTLs) in the U.S.
    - Typically completed for exemplary products. Fixes hardware and firmware for the product line.
  - In Europe, there is a “self-certification” process. No 3rd party certifies products, but there are heavy fines for non-compliance.
    - CE marking granted once manufacturer submits a Declaration of Conformity (DoC) for applicable requirement(s).
- **Performance Tests**
  - Produce quantitative metric of the quality of the product, e.g., CEC Inverter Performance Test Protocol (efficiency tests), PNNL Energy Storage Performance Protocol (PNNL-22010).
- **Internal Manufacturer/Vendor Testing**
  - Manufacture/vendor experiments completed as part of a quality assurance process.

IEEE 1547 does not have any legal ‘teeth’ unless it is adopted by a regulatory agency.

IEEE 1547

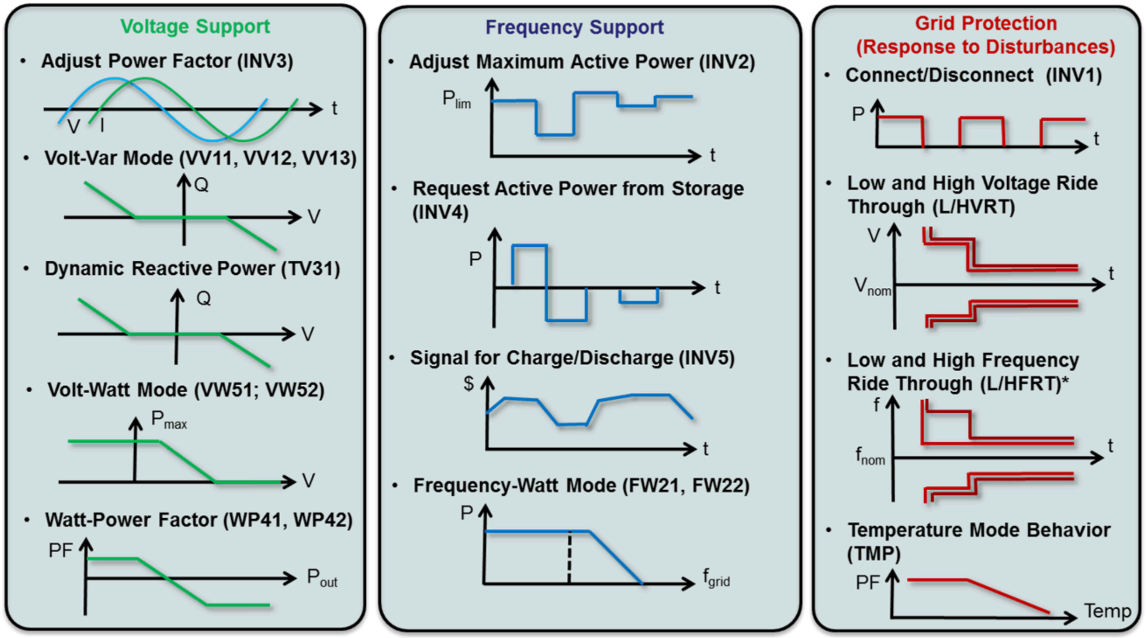
↓ Legal adoption by state public utility commission, individual utility, or other regulatory institution.

Grid Code

Nearly all U.S. states have adopted IEEE 1547-2003 for their interconnection rules. Many rural electricity cooperatives and municipal utility companies also use IEEE 1547.

Functional Definitions

- Describe how functions are implemented [8-9, 12]
  - Stand alone reports (e.g. IEC TR 61850-90-7) or grid codes/interconnection requirements
  - Advanced Grid-Support Functions include:
    - Autonomous: Inverter response to local voltage and frequency conditions
    - Commanded: Remote control (e.g., on/off) & configure autonomous behavior



Advanced functions as defined in IEC TC 61850-90-7 [7].

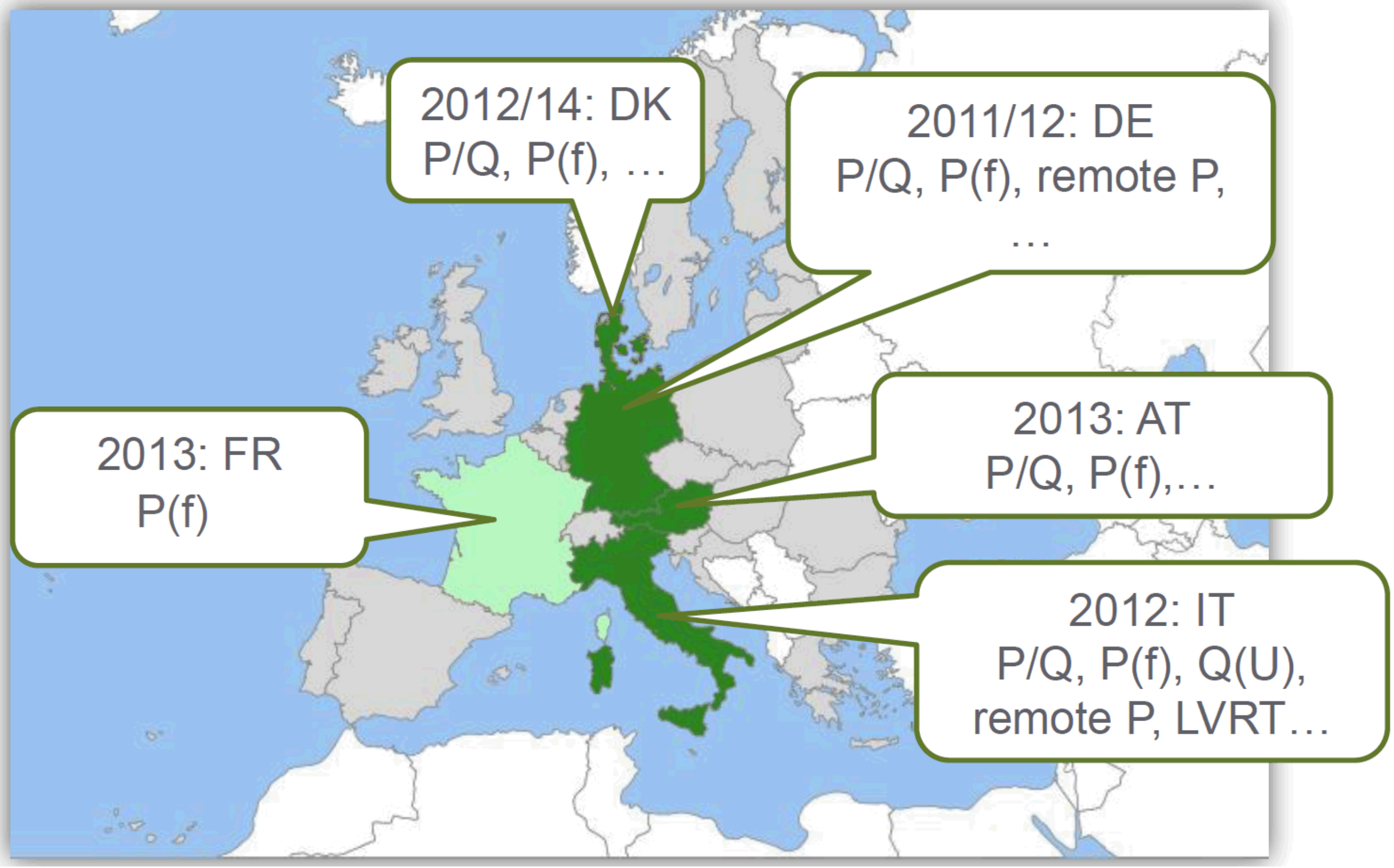
- ➢ In 2009, EPRI and Sandia initiated an effort to develop industry consensus on advanced inverter functions definitions, part of SEGIS effort
- ➢ Effort covered inverter-based DER (including PV and storage)
- ➢ The product became part of the EPRI "Common Functions for Smart Inverters" and eventually the IEC 61850-90-7 Technical Report.

Changing Grid Codes in Europe

- No EU-wide directive for DER interconnection
- Composed of national grid codes, standards, guidelines, laws
- Different legal and administrative levels
  - Fundamental differences between the countries
- Issues for manufacturers and project developers
  - Specific DER product settings for each country/market
  - Complex and time consuming certification schemes
  - Increased costs and reduced competiveness
- Critical issues for power system operation
  - Lack of coordination and compatibility
  - Risk of system reliability during critical events due to undefined behavior of DER

Source: Roland Bründlinger, "Grid Codes in Europe for Low and Medium Voltage," 6th International Conference on Integration of Renewable and Distributed Energy Resources, Kyoto, 18 November, 2014.

Requirements for advanced grid support DER connected to LV distribution grids



Key

P/Q – Real and reactive power.

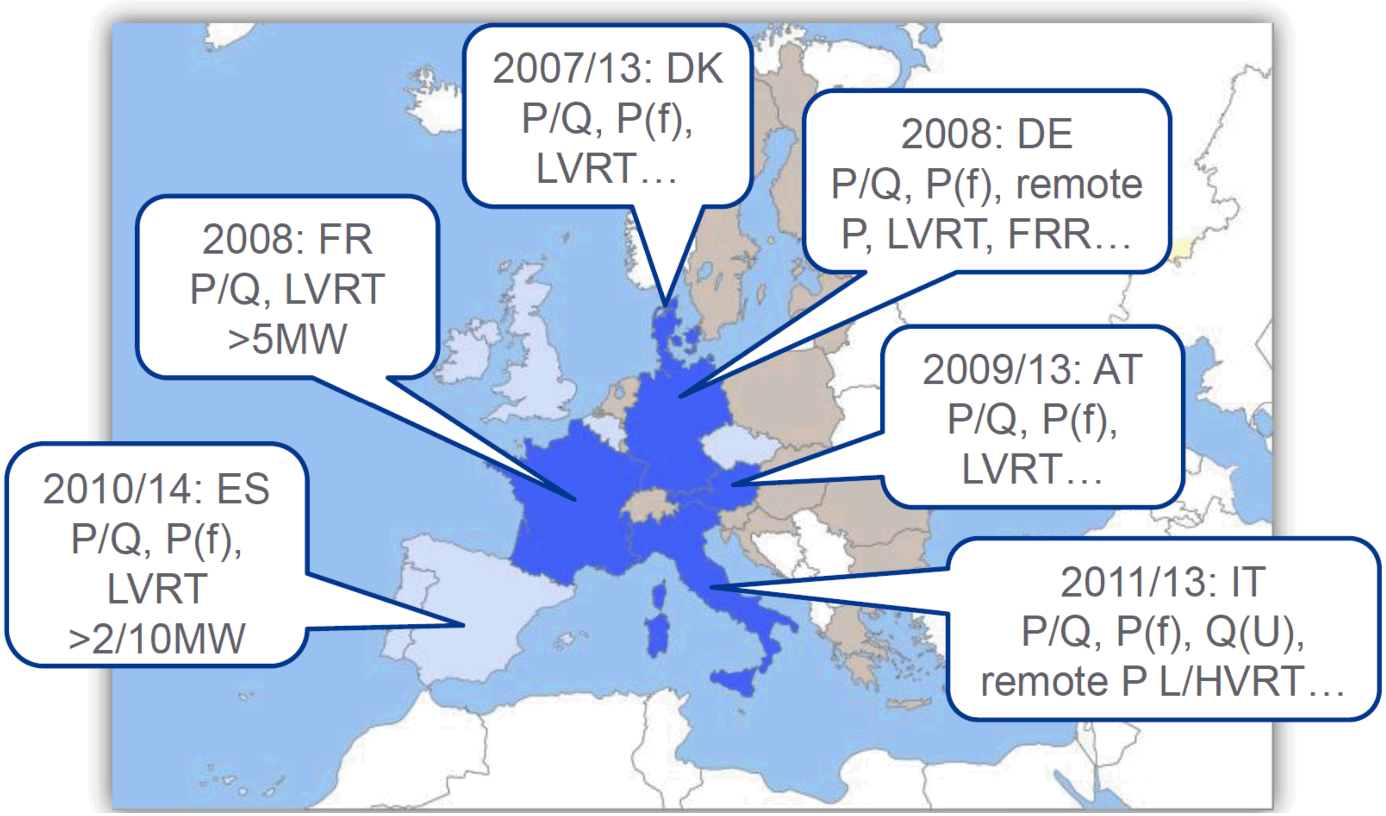
P(f) – Power as a function of grid frequency, i.e., freq-watt.

Remote P – commanded power level.

LVRT – Low Voltage Ride Through.

Source: Roland Bründlinger, "Grid Codes in Europe for Low and Medium Voltage," 6th International Conference on Integration of Renewable and Distributed Energy Resources, Kyoto, 18 November, 2014.

Requirements for advanced grid support DER connected to MV distribution grids



Key

P/Q – Real and reactive power.

P(f) – Power as a function of grid frequency, i.e., freq-watt.

Q(U) – reactive power as a function of grid voltage, i.e., volt-var.

Remote P – commanded power level.

LVRT – Low Voltage Ride Through.

Source: Roland Bründlinger, “Grid Codes in Europe for Low and Medium Voltage,” 6th International Conference on Integration of Renewable and Distributed Energy Resources, Kyoto, 18 November, 2014.

Selected European Country Requirements LV Connection

Country	Europe (≤16 A)	Germany	Italy	Austria	France	Spain	Europe (≤16 A)	Europe (>16 A)
Function	2007	2011	2012	2013	2013	11/14	2013	2014
P at low f	No	Yes (all)	Yes (all)	Yes	No	No	Yes	Yes
P(f)	No	Yes (all)	Yes (all)	Yes	Yes*	No	Yes	Yes
Q/cosφ	No	**>3.68kVA**	>3 kVA	**>3.68kVA**	No	No	Yes	Yes
Q(U)	No	No	>6 kVA	optional	No	No	Yes	Yes
Remote P	No	>100kW	>3 kVA	>100kW	No	No	No	Yes
Rem. trip	No	No	Yes	No	No	No	No	Yes
LVRT	No	No	>6 kVA	No	No	No	No	Yes
HVRT	No	N/A	No	No	No	No	No	Yes
Reference	EN 50438 2007	VDE AR N 4105: 2011	CEI 0-21:2012	TOR D4:2013	* ERDF-NOI-RES_13E Version 5 - 30/06/2013	RD 1699/2011 206007-1 IN:2013	EN 50438 2013	FprTS 50549-1:2014 DRAFT!

- EN 50438:2007 “Requirements for micro-generating plants to be connected in parallel with public low-voltage distribution networks” (Updated in 2013)
- VDE-AR-N 4105 “Technical requirements for the connection to and parallel operation with low-voltage distribution networks”
- CEI 0-21:2012 “Reference technical rules for the connection of active and passive users to the LV electrical Utilities”
- TOR D4:2013 “Technical and organizational rules for network operators and users, Part D: Special technical rules, Parallel operation of generation facilities with distribution networks”
- ERDF-NOI-RES_13E v5 “Protections des installations de production raccordées au réseau public de distribution” (Protections for production facilities connected to the public distribution network)
- Royal Decree 1699/2011, of November 18, by which the connection is regulated a network of facilities for production of electricity from small power.
- UNE 206007-1 IN “Requisitos de conexión a la red eléctrica. Parte1: Inversores para conexión a la red de distribución” (Requirements for connection to the mains. Part 1: Inverters for connection to the grid.)
- CLC/FprTS 50549-1:2014 “Requirements for the connection of a generating plant to a distribution system - Part 1: Connection to a LV distribution system and above 16A”

Source: Roland Bründlinger, “Grid Codes in Europe for Low and Medium Voltage,” 6th International Conference on Integration of Renewable and Distributed Energy Resources, Kyoto, 18 November, 2014.

Selected European Country Requirements MV Connection

Limited Interoperability Requirements in Europe

Country	Germany	Italy	Austria	France	Spain	Europe	ENTSO-E
Function	2008	2012	2013	2013	2010	2014	2013
P at low f	yes	yes	yes	>5MW	No	yes	Yes ABCD
P(f)	yes	yes	yes	No	>2/10MW	yes	Yes ABCD
Q/cosφ	yes	yes	yes	Yes	>2/10MW	yes	Yes BCD
Q(U)	optional	yes	optional	No	No	yes	yes BCD
Remote P	>100kW	yes	>100kW	No	>2/10MW	yes	yes BCD
Rem. trip	optional	yes	No	No	No	yes	yes ABCD
LVRT	Yes	yes	Yes	>5MW	>2MW	yes	yes BCD
HVRT	No	yes	No	No	No	yes	No
	BDEW MV Guideline (2008)	CEI 0-16:2012	TOR D4:2013	Arrêté du 23 avril 2008	P.O.12.3:2006 P.O.12.2: RD1565:2010 UNE 206007-2 IN:2014	FprTS 50549-2	Final Version RfG 2013

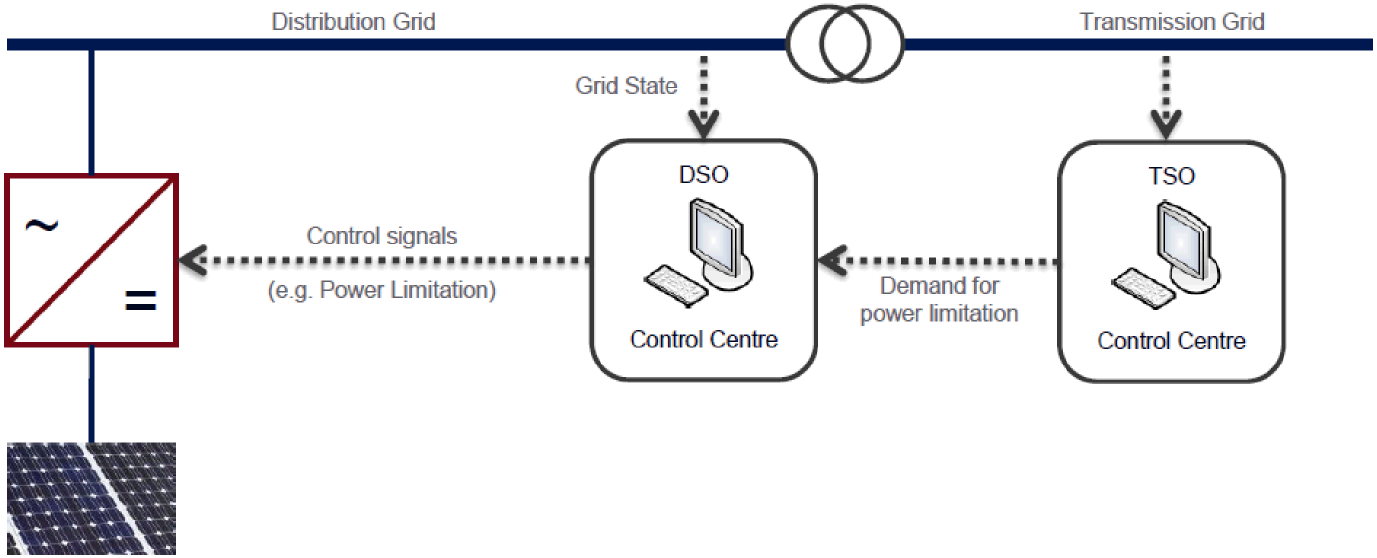
Code-makers, please consider finding, translating, comparing, and harmonizing with these national grid codes before making new requirements.

- BDEW MV Technical Guideline: “Generating plants connected to the medium-voltage network - Guideline for generating plants connection to and parallel operation with the medium-voltage network”
- CEI 0-16:2012 “Reference technical rules for the connection of active and passive consumers to the HV and MV electrical networks of distribution company ”
- TOR D4:2013 “Technical and organizational rules for network operators and users, Part D: Special technical rules, Parallel operation of generation facilities with distribution networks”
- Arrêté du 23 avril 2008 relatif aux prescriptions techniques de conception et de fonctionnement pour le raccordement à un réseau public de distribution d’électricité en basse tension ou en moyenne tension d’une installation de production d’énergie électrique.
- Procedimientos de operación (P.O.) 12.3:2006 “Requisitos de respuesta frente a huecos de tensión de las instalaciones eólicas” (Procedure for verification validation and certification of the requirements of the PO 12.3 on the response of wind farms and photovoltaic plants in the event of voltage dips)
- Procedimientos de operación (P.O.) 12.2:2005 “Instalaciones conectadas a la red de transporte: requisitos mínimos de diseño, equipamiento, funcionamiento y seguridad y puesta en servicio” (Installations connected to the transport network: minimum requirements for design, equipment, operation and safety and commissioning)
- Royal Decree 1565/2010, of 19 November, by which regulates and modifies certain aspects relating to the activity of production of electrical energy in special regime.
- UNE 206007-1 IN “Requisitos de conexión a la red eléctrica. Parte1: Inversores para conexión a la red de distribución” (Requirements for connection to the mains. Part 1: Inverters for connection to the grid.)
- CLC/FprTS 50549-2:2014 “Requirements for the connection of a generating plant to a distribution system - Part 2: Connection to a MV distribution system”
- European Network Code Requirements for Generators (RfG):2013 “ENTSO-E Network Code for Requirements for Grid Connection Applicable to all Generators”

Source: Roland Bründlinger, “Grid Codes in Europe for Low and Medium Voltage,” 6th International Conference on Integration of Renewable and Distributed Energy Resources, Kyoto, 18 November, 2014.

Limited European Interoperability Requirements

- Possibility for DSO to send setpoint values to generators
  - Reduce the active power output or change power factor.
  - Guarantee grid stability in case of emergency situations or congestion.
  - As early as 2015, Italy plans to require MV DG-shedding functionality (remote disconnect) through a simple but secure SMS-based system at TSO request*



---

*Luca Lo Schiavo, “Regulatory incentives for smart grids demonstration and deployment in Italy, within the European framework,” 6th International Conference on Integration of Renewable and Distributed Energy Resources, Kyoto, 18 November, 2014.

Roland Bründlinger, “Grid Codes in Europe for Low and Medium Voltage,” 6th International Conference on Integration of Renewable and Distributed Energy Resources, Kyoto, 18 November, 2014.

American Codes and Standards

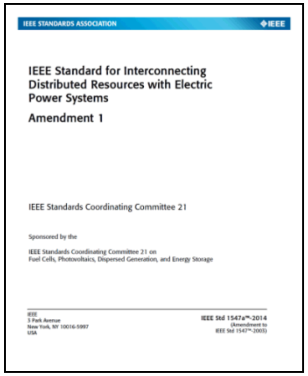
- IEEE Std. 1547 is the U.S.-wide Distributed Resource (DR) Standard

DER must not participate in V/f regulation ("get out of the way") when there are grid disturbances.

IEEE 1547-2003	IEEE 1547a-2014
Shall not regulate voltage [no volt/var allowed]	May participate in voltage regulation [no specification]
Shall not regulate frequency [no freq/watt allowed]	May participate in frequency regulation [no specification]
Restrictive voltage and frequency must-trip range [opposite of V/FRT]	More widely adjustable voltage and frequency must-trip range [No V/FRT requirement]

DER *may* assist with voltage and frequency regulation with Electric Power System Operator approval.

- The 1547 "full revision" is in process, but not expected for at least 2 years.
- Opens the door for jurisdictions to create interconnection requirements
  - Will likely lead to lack of harmonization and over-specification
  - CPUC, HECO, PJM, others starting to develop standards addressing advanced functions



IEEE STANDARDS ASSOCIATION IEEE

IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems

Amendment 1

IEEE Standards Coordinating Committee 21

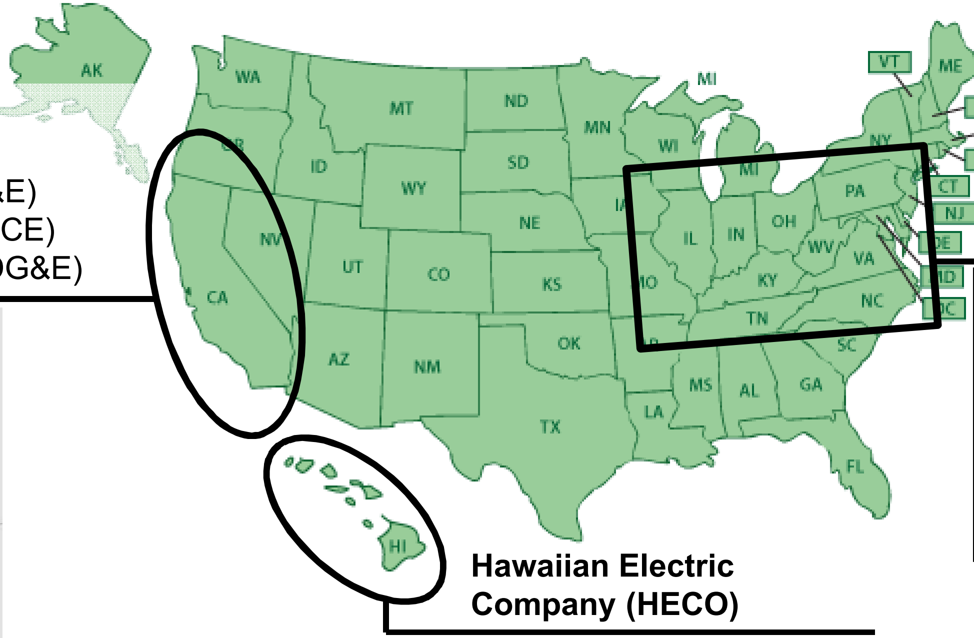
Sponsored by the

IEEE Standards Coordinating Committee 21 on Fuel Cells, Photovoltaics, Dispersed Generation, and Energy Storage

IEEE
3 Park Avenue
New York, NY 10016-5997
USA

IEEE Std 1547a™-2014
(Amendment to
IEEE Std 1547™-2003)

Smart Inverter Requirements in USA



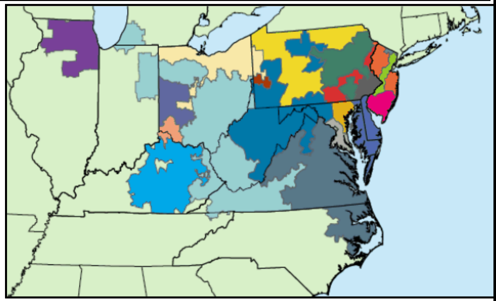
California Investor-Owned Utilities (IOUs):
Pacific Gas and Electric (PG&E)
Southern California Edison (SCE)
San Diego Gas & Electric (SDG&E)

- Serve ~68% of the load in CA
- Governed by California Public Utilities Commission (CPUC) and California Energy Commission (CEC) Electric Rule 21 statute which states the technical requirements for distributed-generation resources to interconnect to the California grid
- Likely to include MANY autonomous and communication-enabled advanced grid functions in the next 1-3 years

Hawaiian Electric Company (HECO)

- Serves 95% of the state's 1.4 million residents
- Many customers cannot connect their PV systems to the grid because the penetration levels are >100%*
- HECO investigating advanced functions in PV inverters, communications, and mandatory voltage and frequency ride-through requirements

PJM Interconnection LLC (regional transmission organization)



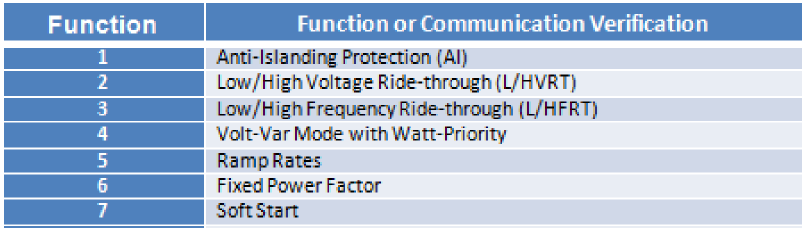
- World's largest competitive wholesale electricity market
- 830 companies
- 60 million customers
- 167 gigawatts of generating capacity
- Closely watching CA developments in Smart Inverters – expected to adopt many of the same interconnection requirements

All eyes on CA right now.

*http://www.kitv.com/news/heco-says-its-trying-to-connect-more-customers-to-the-grid/28161878

CA CPUC Rule 21 Status

- Jan, 2014: Smart Inverter Working Group (SIWG) consisting of ~200 experts from gov., utilities, PV manufacturers, etc. created “Recommendations for Updating the Technical Requirements for Inverters in Distributed Energy Resources”
  - **Phase 1: Autonomous functions**, ride-throughs, ramp rates, volt/var, etc.
  - **Phase 2: Include communication capabilities**, add data model, cybersecurity, etc.
  - **Phase 3: Add advanced inverter functionalities requiring communications**, status reporting, connect/disconnect, limit real power, etc.
- **Phase 1** was adopted by the CPUC in January 2015 – all 7 new functions are autonomous (not requiring communications)
- **Phase 2** recommendations from the SWIG were submitted to the CPUC on 28 Feb, 2015.
- **Phase 3** discussions have begun with the SIWG members.
  - Need to ID functions for inclusion.
  - Survey of functions for inclusion distributed to stakeholders.



Function	Function or Communication Verification
1	Anti-Islanding Protection (AI)
2	Low/High Voltage Ride-through (L/HVRT)
3	Low/High Frequency Ride-through (L/HFRT)
4	Volt-Var Mode with Watt-Priority
5	Ramp Rates
6	Fixed Power Factor
7	Soft Start

Phase 1 Functions

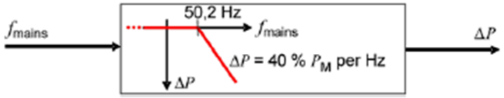
Development of Rule 21 Certification Procedures

- UL 1741 Supplement A (SA) – “Grid Support Utility Interface Inverters and Converters” has been drafted by multiple Standards Technical Panel (STP) Working Groups.
  - UL expects STP approval in the August timeframe.
- The draft will be submitted to the greater UL 1741 STP soon, with the following functions:
  - Appendix 1 – Anti-islanding Protection
  - Appendix 2 – Low and High Voltage/Frequency Ride-Through
  - Appendix 3 – Normal and Soft-Start Ramp
  - Appendix 4 – Fixed Power Factor and Volt/Var
  - Appendix 5 – Communications Interface (Optional)
  - Appendix 6 – Optional - Data Model (Optional)
  - Appendix 7 – Monitor Alarms (Optional)
  - Appendix 8 – Monitor DER Status and Output (Optional)
  - Appendix 9 – Frequency-Watt (Optional)
- CPUC Rule 21 states the **mandatory implementation** date is the later of:
  - eighteen months after publication of revised Electric Tariff Rule 21 (Jan 2015), or
  - **twelve months after the Underwriters Laboratories approval**.

Value of Interoperability

Without Communications

- German "50.2 Hz" problem: high frequency event will trip inverters and cause system destabilization.
- 200,000+ inverters retrofitted for more than €170M.
- VDE-AR-N 4105 (Freq-Watt Function) replaces a tight HFRT trip curve.



German Energy Blog

Energy in Germany – Legal Issues, Facts and Opinions

Blog | Authors (and Disclaimers) | Overview German Energy Law | Archives | Newsletter

BDEW: Sluggish Response to Retrofitting of Solar Power Plants to Prevent 50.2 Hertz Problem

Published on December 21, 2012 in Grid, Renewable and Solar. Closed

Tags: sysstabv, systemstabilitätsverordnung.

The operators of roughly 300,000 solar power plants only sluggishly fulfill their obligation to cooperate with grid operators in retrofitting those plants falling under the scope of the ordinance on technical security and system stability in the electricity networks (Systemstabilitätsverordnung– SysStabV), the Federal Association of the Energy and Water Industry (BDEW) warned.

Type and Wait to Search

Main Authors

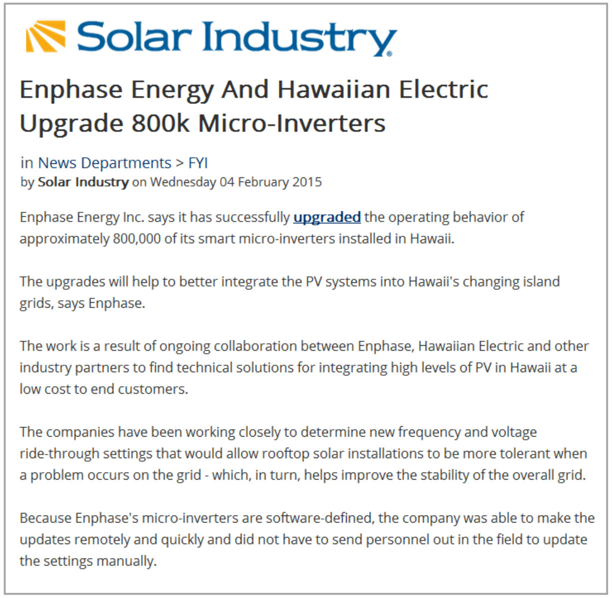
Dr. Matthias Lang
Rechtsanwalt

Annette Lang
Rechtsanwältin

http://www.germanenergyblog.de/?p=11786

With Communications

- HI Problem: PV and renewables are causing high F/V deviations.
- VRT, FRT settings adjusted in Hawaii
  – HECO memo to PV inverter manufacturers.
- Enphase updated 800,000 microinverters in 2 days.



Solar Industry

Enphase Energy And Hawaiian Electric Upgrade 800k Micro-Inverters

in News Departments > FYI
by **Solar Industry** on Wednesday 04 February 2015

Enphase Energy Inc. says it has successfully **upgraded** the operating behavior of approximately 800,000 of its smart micro-inverters installed in Hawaii.

The upgrades will help to better integrate the PV systems into Hawaii's changing island grids, says Enphase.

The work is a result of ongoing collaboration between Enphase, Hawaiian Electric and other industry partners to find technical solutions for integrating high levels of PV in Hawaii at a low cost to end customers.

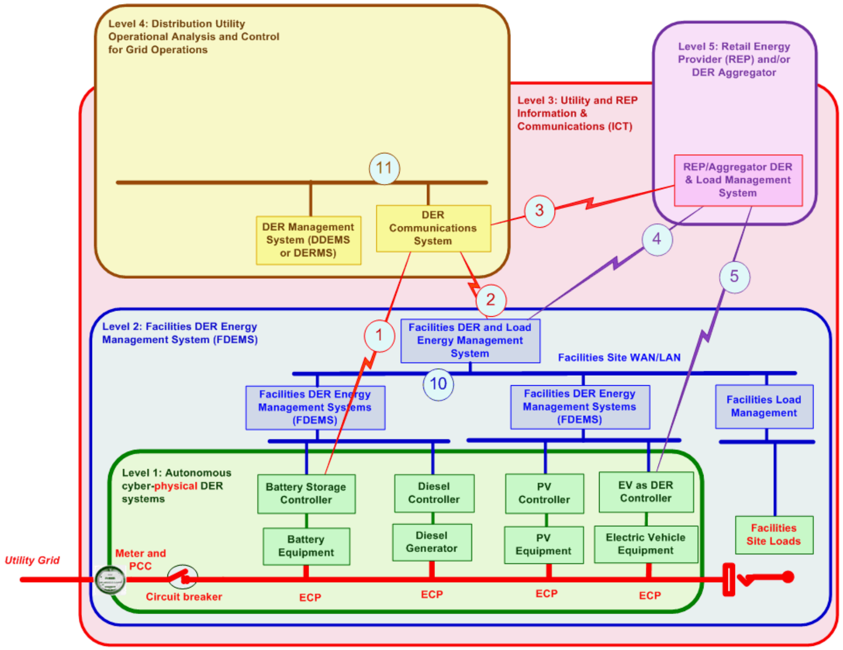
The companies have been working closely to determine new frequency and voltage ride-through settings that would allow rooftop solar installations to be more tolerant when a problem occurs on the grid - which, in turn, helps improve the stability of the overall grid.

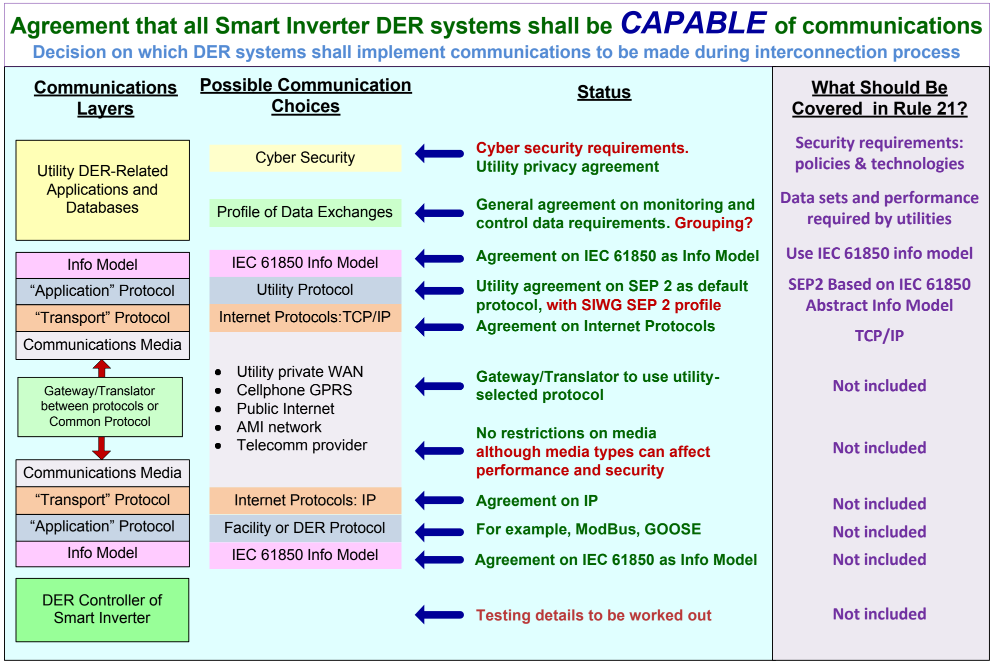
Because Enphase's micro-inverters are software-defined, the company was able to make the updates remotely and quickly and did not have to send personnel out in the field to update the settings manually.

http://www.solarindustrymag.com/e107_plugins/content/content.php?content.14999

Communication Requirements for Rule 21

- Wanted!: Interoperability certification procedure and certification agency (UL?)
  - Electrical certification is well understood but the process for certifying inverters to the communications requirements is uncharted ground.





Agreement that all Smart Inverter DER systems shall be *CAPABLE* of communications

Decision on which DER systems shall implement communications to be made during interconnection process

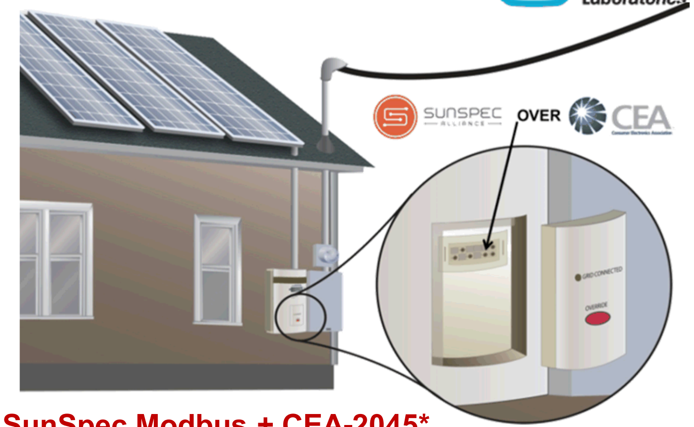
Communications Layers	Possible Communication Choices	Status	What Should Be Covered in Rule 21?
Utility DER-Related Applications and Databases	Cyber Security	Cyber security requirements. Utility privacy agreement	Security requirements: policies & technologies
	Profile of Data Exchanges	General agreement on monitoring and control data requirements. Grouping?	Data sets and performance required by utilities
Info Model	IEC 61850 Info Model	Agreement on IEC 61850 as Info Model	Use IEC 61850 info model
"Application" Protocol	Utility Protocol	Utility agreement on SEP 2 as default protocol, with SIWG SEP 2 profile	SEP2 Based on IEC 61850 Abstract Info Model
"Transport" Protocol	Internet Protocols:TCP/IP	Agreement on Internet Protocols	TCP/IP
Communications Media	• Utility private WAN • Cellphone GPRS • Public Internet • AMI network • Telecomm provider		
Gateway/Translator between protocols or Common Protocol		Gateway/Translator to use utility-selected protocol	Not included
Communications Media		No restrictions on media although media types can affect performance and security	Not included
"Transport" Protocol	Internet Protocols: IP	Agreement on IP	Not included
"Application" Protocol	Facility or DER Protocol	For example, ModBus, GOOSE	Not included
Info Model	IEC 61850 Info Model	Agreement on IEC 61850 as Info Model	Not included
DER Controller of Smart Inverter		Testing details to be worked out	Not included

More information in "Recommendations for Utility Communications with Distributed Energy Resources (DER) Systems with Smart Inverters, Smart Inverter Working Group (SIWG) Phase 2 Recommendations"

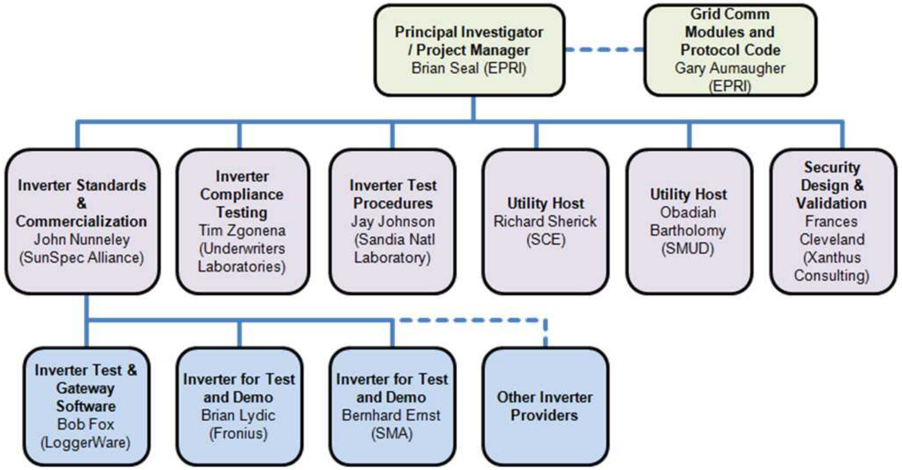
Research at Sandia National Laboratories

Grid integration pre-standardization research with EPRI and SunSpec

- California Solar Initiative (Grant 4) “Standard Communication Interface and Certification Test Program for Smart Inverters”
- Sandia led development of inverter test procedures and currently developing <u>cyber recommendations</u> with SunSpec, et al.



SunSpec Modbus + CEA-2045*



Principal Investigator / Project Manager
Brian Seal (EPRI)

Grid Comm Modules and Protocol Code
Gary Aumaugher (EPRI)

Inverter Standards & Commercialization
John Nunneley (SunSpec Alliance)

Inverter Compliance Testing
Tim Zgonena (Underwriters Laboratories)

Inverter Test Procedures
Jay Johnson (Sandia Natl Laboratory)

Utility Host
Richard Sherick (SCE)

Utility Host
Obadiah Bartholomy (SMUD)

Security Design & Validation
Frances Cleveland (Xanthus Consulting)

Inverter Test & Gateway Software
Bob Fox (LoggerWare)

Inverter for Test and Demo
Brian Lydic (Fronius)

Inverter for Test and Demo
Bernhard Ernst (SMA)

Other Inverter Providers

Function	Function or Communication Verification
1	Anti-Islanding Protection (AI)
2	Low/High Voltage Ride-through (L/HVRT)
3	Low/High Frequency Ride-through (L/HFRT)
4	Volt-Var Mode with Watt-Priority
5	Ramp Rates
6	Fixed Power Factor
7	Soft Start
8	Communication Interface
9	Transport Protocols
10	Data Model
11	Mapping to Application Protocols
12	Transport Cyber Security
13	User Cyber Security
14	Monitor Alarms
15	Monitor DER Status and Output
16	Limit Maximum Real Power
17	Connect/Disconnect
18	Provide DER Information at Interconnection/Startup
19	Initiate Periodic Tests of Software and Patches
20	Schedule Output Limits at PCC
21	Schedule DER Functions
22	Schedule Storage
23	Frequency-Watt Mode
24	Voltage-Watt Mode
25	Dynamic Current Support
26	Limit Maximum Real Power
27	Set Real Power
28	Smooth Frequency Deviations

Rule 21 Advanced Inverter/DER Functions

ANSI/CEA-2045 specifies a modular communications interface (MCI) to facilitate communications with residential devices for applications such as energy management.
ANSI = American National Standards Institute, CEA = Consumer Electronics Association

SIRFN Smart Grid Collaboration

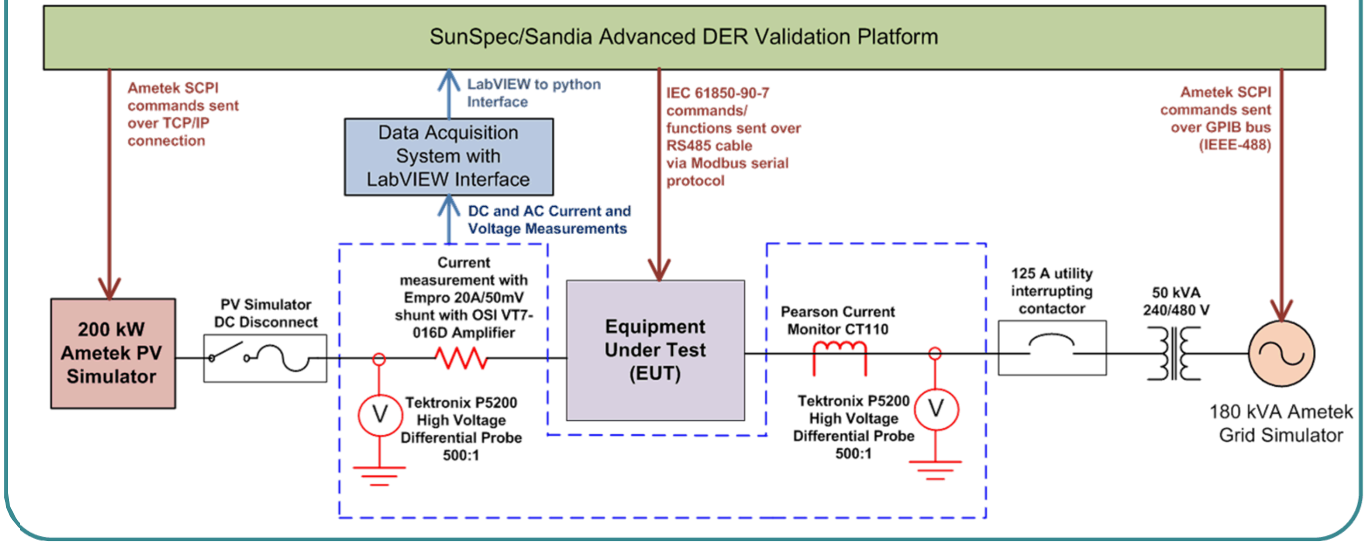
- IEA (International Energy Agency)
  - Clean Energy Ministerial (CEM)
    - International Smart Grid Action Network (ISGAN)
      - Smart Grid International Research Facility Network (SIRFN)
        - Smart Grid Distribution Automation
        - Advanced Laboratory Testing Methods
        - Power Systems Testing
        - Test Protocols for Advanced Inverter Functions

SIRFN - A coordinated network of smart grid research facilities from:

- **Primary goal**: Develop and demonstrate a consensus-based interoperability certification standard for IEC 61850-90-7 advanced Distributed Energy Resources (DERs).
  - Design and compare advanced interoperability test-beds.
  - Perform round-robin testing of advanced DER.
  - Compare test results, communications methods, and automation procedures.
  - Gradually improve draft test procedures for advanced DER with the goal of becoming an internationally-accepted standard.
- NEW! SIRFN is creating energy storage test procedures.

SNL, AIT, and TECNALIA Test-Bed Designs

Sandia National Laboratories



EUTs:

- SNL: 3 kW single-phase inverter
- AIT: 20 kW three-phase inverter
- Tecnalia: 5 kW single-phase inverter

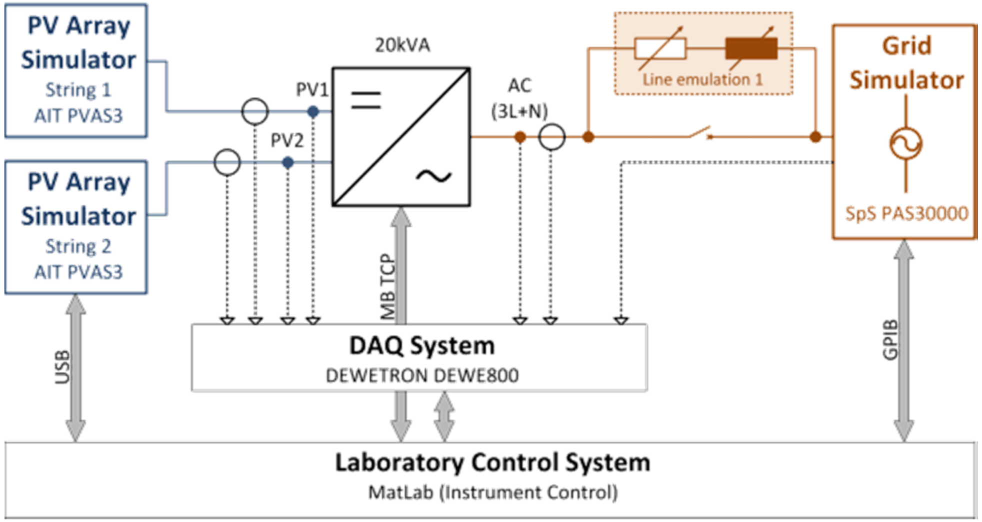
EUT Communications

- SNL: 61850-90-7 over serial
- AIT: 61850-90-7 over TCP
- Tecnalia: 61850-90-7 over serial

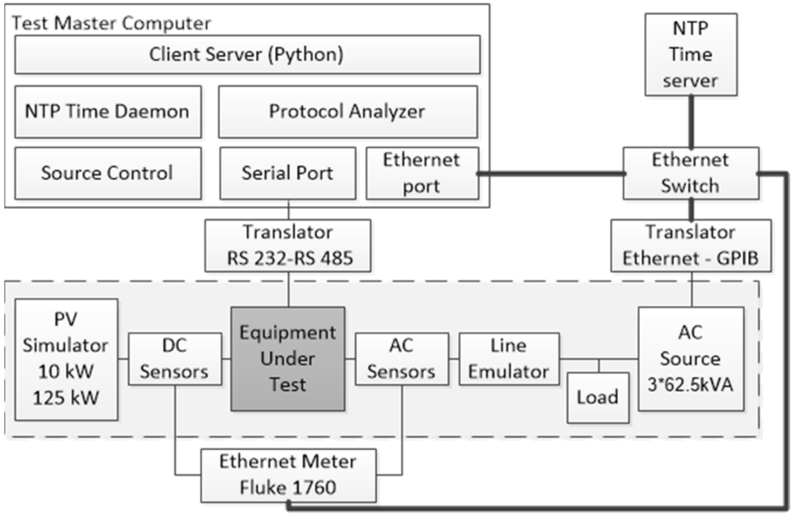
Control system

- SNL: SunSpec Test Tool (Python)
- AIT: Lab Control System (Matlab)
- Tecnalia: Master Computer (Python)

Austrian Institute of Technology

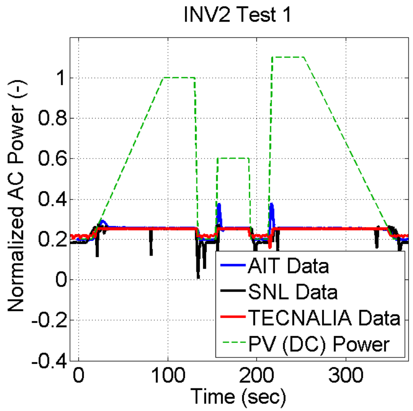


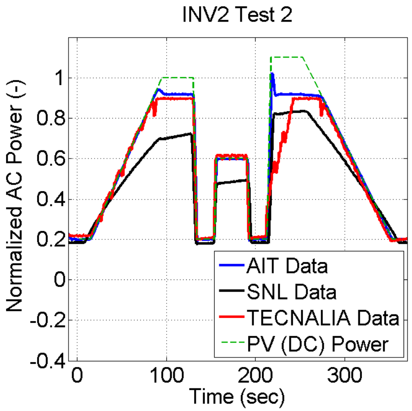
TECNALIA

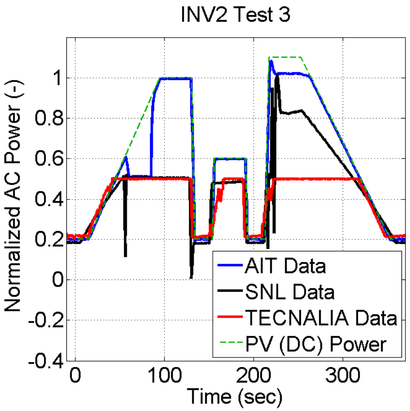


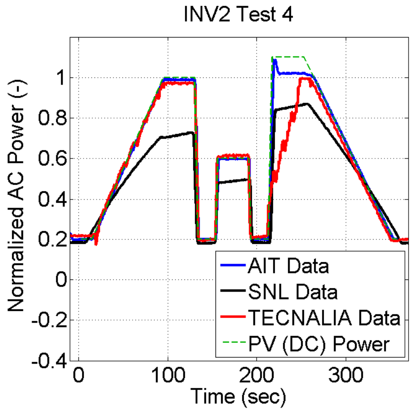
J. Johnson, R. Bründlinger, C. Urrego, R. Alonso, "Collaborative Development Of Automated Advanced Interoperability Certification Test Protocols For PV Smart Grid Integration," EU PVSEC, Amsterdam, Netherlands, 22-26 Sept, 2014.

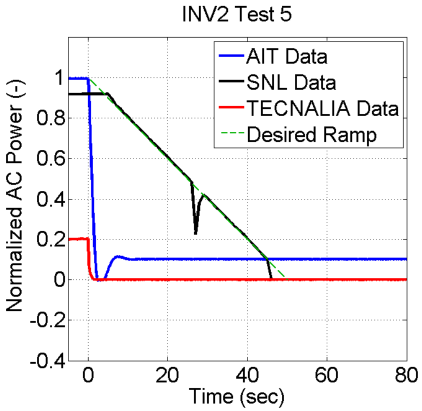
Real Power Curtailment (INV2) Results

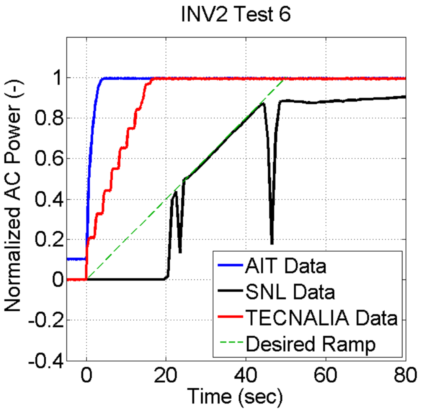

INV2 Test 1


INV2 Test 2


INV2 Test 3


INV2 Test 4


INV2 Test 5


INV2 Test 6

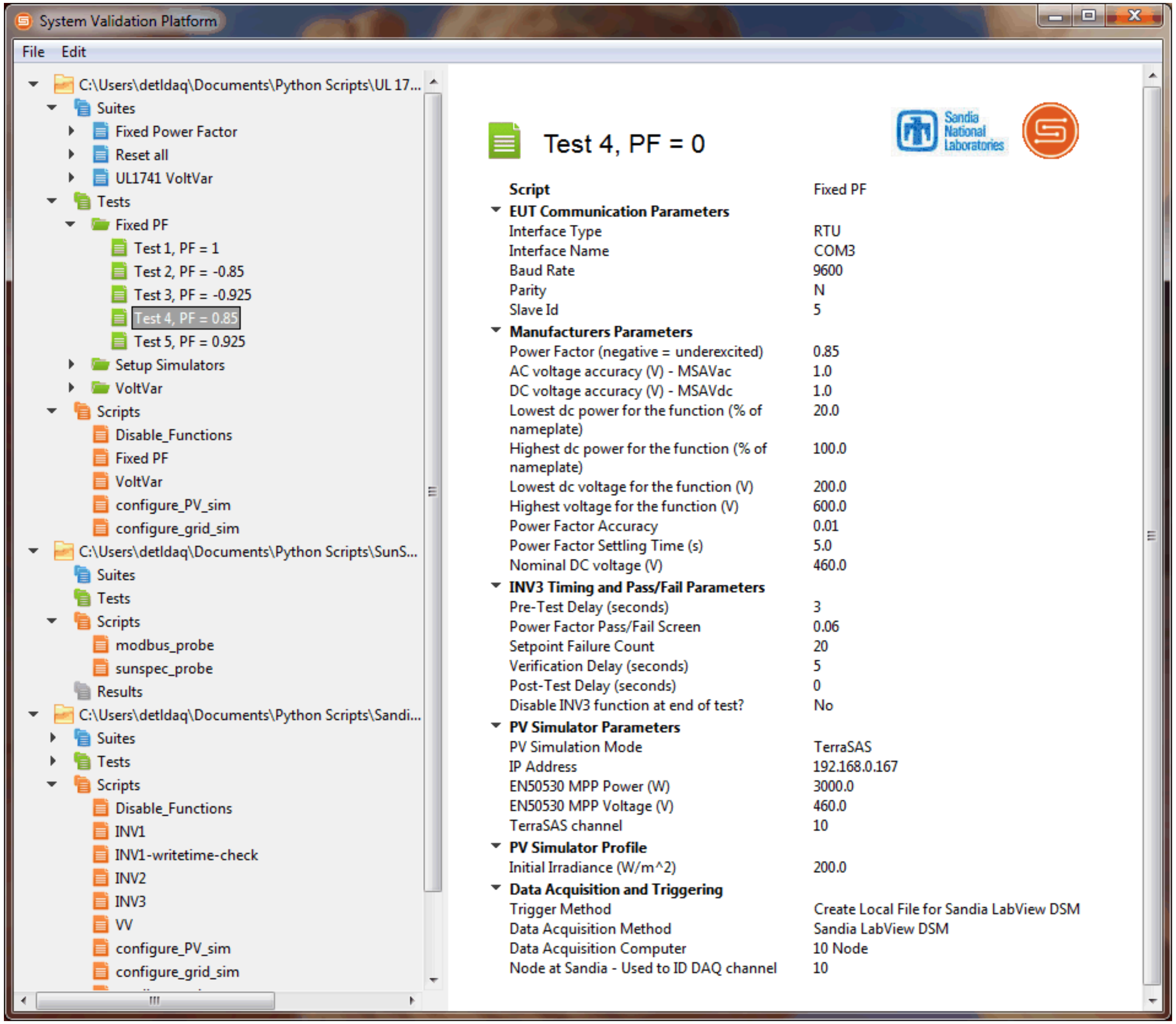
Test	WMax (% nameplate)	Ramp Rate (% nameplate watts/sec)	Time Window (sec)	Timeout Period (sec)	PV Power Profile
1	25	0	0	0	Fig. A2- 1
2	90	0	300	0 AIT:60	Fig. A2- 1
3	50	20	60	30 AIT:60	Fig. A2- 1
4	100	0	0	0	Fig. A2- 1
5	0 AIT:10	2	0	0	Const.
6	100	2	0	0	Const.

J. Johnson, R. Bründlinger, C. Urrego, R. Alonso, "Collaborative Development Of Automated Advanced Interoperability Certification Test Protocols For PV Smart Grid Integration," EU PVSEC, Amsterdam, Netherlands, 22-26 Sept, 2014.

SunSpec/Sandia System Validation Platform

Coming Soon!

- System Validation Platform (SVP) is an automated Certification Platform
    - Fully scriptable
    - Interacts with DAQs, PV and grid simulators and SunSpec-compliant DER.



- C:\Users\detldaq\Documents\Python Scripts\UL 17...
    - Suites
        - Fixed Power Factor
        - Reset all
        - UL1741 VoltVar
    - Tests
        - Fixed PF
            - Test 1, PF = 1
            - Test 2, PF = -0.85
            - Test 3, PF = -0.925
            - Test 4, PF = 0.85
            - Test 5, PF = 0.925
        - Setup Simulators
        - VoltVar
    - Scripts
        - Disable_Functions
        - Fixed PF
        - VoltVar
        - configure_PV_sim
        - configure_grid_sim
- C:\Users\detldaq\Documents\Python Scripts\SunS...
    - Suites
    - Tests
    - Scripts
        - modbus_probe
        - sunspec_probe
    - Results
- C:\Users\detldaq\Documents\Python Scripts\Sandi...
    - Suites
    - Tests
    - Scripts
        - Disable_Functions
        - INV1
        - INV1-writetime-check
        - INV2
        - INV3
        - VV
        - configure_PV_sim
        - configure_grid_sim

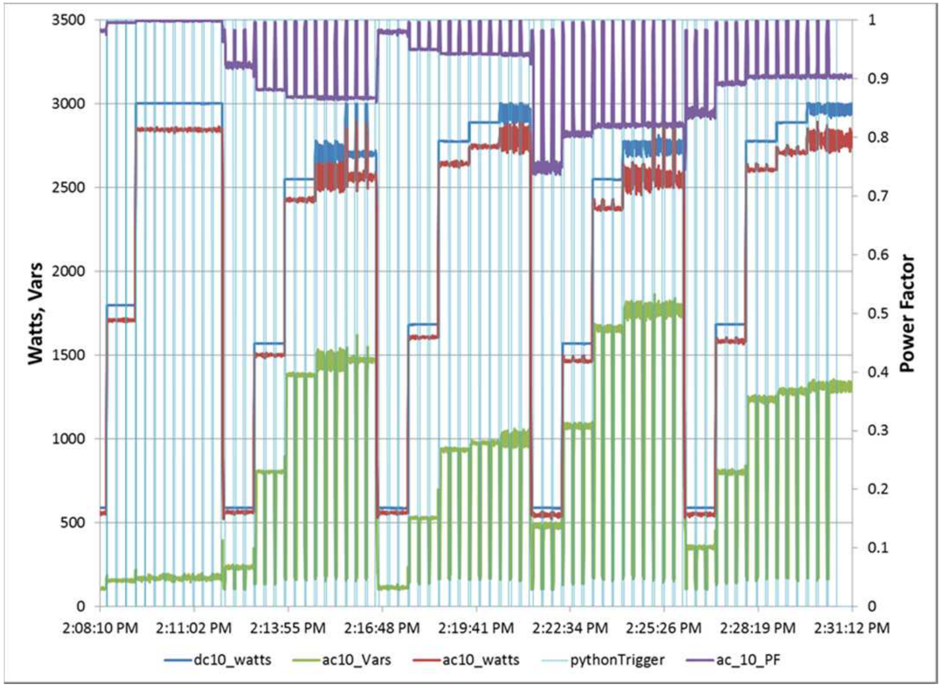
Test 4, PF = 0

Script	Fixed PF
EUT Communication Parameters	
Interface Type	RTU
Interface Name	COM3
Baud Rate	9600
Parity	N
Slave Id	5
Manufacturers Parameters	
Power Factor (negative = underexcited)	0.85
AC voltage accuracy (V) - MSAVac	1.0
DC voltage accuracy (V) - MSAVdc	1.0
Lowest dc power for the function (% of nameplate)	20.0
Highest dc power for the function (% of nameplate)	100.0
Lowest dc voltage for the function (V)	200.0
Highest voltage for the function (V)	600.0
Power Factor Accuracy	0.01
Power Factor Settling Time (s)	5.0
Nominal DC voltage (V)	460.0
INV3 Timing and Pass/Fail Parameters	
Pre-Test Delay (seconds)	3
Power Factor Pass/Fail Screen	0.06
Setpoint Failure Count	20
Verification Delay (seconds)	5
Post-Test Delay (seconds)	0
Disable INV3 function at end of test?	No
PV Simulator Parameters	
PV Simulation Mode	TerraSAS
IP Address	192.168.0.167
EN50530 MPP Power (W)	3000.0
EN50530 MPP Voltage (V)	460.0
TerraSAS channel	10
PV Simulator Profile	
Initial Irradiance (W/m^2)	200.0
Data Acquisition and Triggering	
Trigger Method	Create Local File for Sandia LabView DSM
Data Acquisition Method	Sandia LabView DSM
Data Acquisition Computer	10 Node
Node at Sandia - Used to ID DAQ channel	10

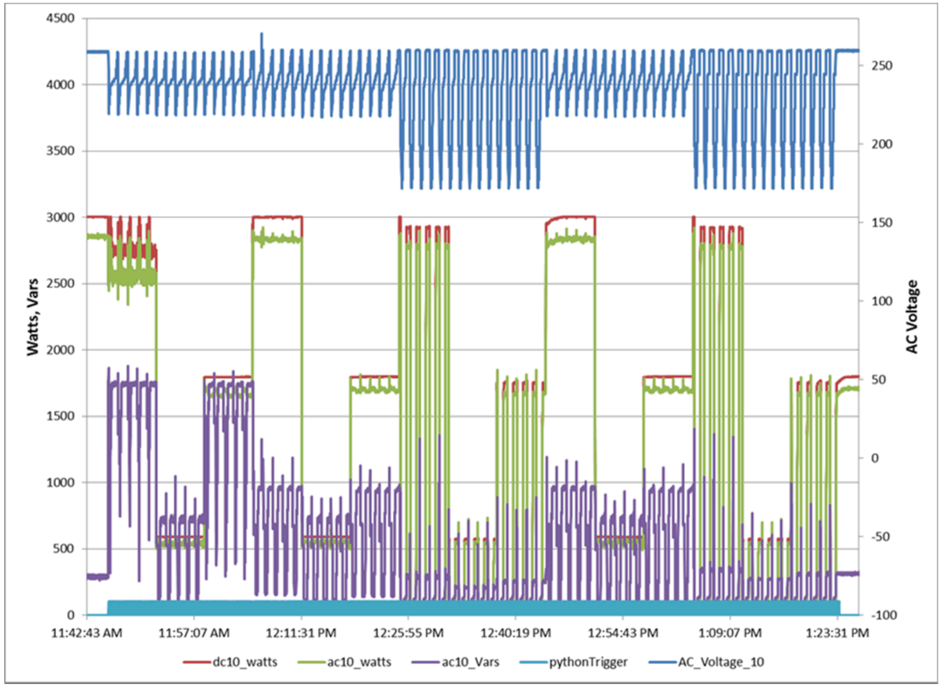
Power of Testing Automation

- UL 1741 SA permutations are large due to the number of settings in each advanced DER function:
    - 75 measurements for fixed power factor - takes about 25 minutes with the SVP
    - 375 measurements for volt/var - takes about 90 minutes with the SVP

Proposed UL 1741 SA fixed power factor tests.



Proposed UL 1741 SA volt-var tests.



Conclusions

- PV inverter advanced functions help support the electricity grid.
- Europe has many smart DER national grid codes, but **few interoperability requirements**.
- In the U.S., many **jurisdictions** are **considering smart DER requirements** (not just CA)
    - Newly allowed with the adoption of IEEE 1547a-2014
    - Regional differences could be an issue for manufacturers and certification laboratories
    - Autonomous functions will be rolled out first
    - **Communications methods are not finalized**, cybersecurity a big concern
- **Standardized test methods for verifying DER** functionality and **interoperability** are **critical**.
- **Sandia, SIRFN, and SunSpec** are **improving certification protocols and test capabilities** by:
    - Building test-beds for advanced inverter testing (electrical performance and interoperability).
    - Comparing advanced DER test results and improving draft certification protocols.
    - Recommending improvements to national and international codes and standards.

Questions?

Jay Johnson

Photovoltaic and Distributed Systems Integration

Sandia National Laboratories

P.O. Box 5800 MS1033

Albuquerque, NM 87185-1033

Phone: 505-284-9586

jjohns2@sandia.gov

References

[1] T. Hsu, Los Angeles Times, “Gov. Brown pushes 12-gigawatt clean-power goal,” July 26, 2011.

[2] J.F. Wiedman, et al., Interstate Renewable Energy Council, “12,000 MW of Renewable Distributed Generation by 2020,” July 2012.

[3] Eltawil, Mohamed A., and Zhengming Zhao. "Grid-connected photovoltaic power systems: Technical and potential problems—A review." *Renewable and Sustainable Energy Reviews*, pp. 112-129, 2010.

[4] Enslin, Johan HR. "Network impacts of high penetration of photovoltaic solar power systems." Power and Energy Society General Meeting, 2010 IEEE. IEEE, 2010.

[5] J. Bank, B. Mather, J. Keller, and M. Coddington, “High Penetration Photovoltaic Case Study Report,” NREL Technical Report TP-5500-54742, Jan 2013.

[6] R. Elliott, R. Byrne, A. Ellis, L. Grant, “Small Signal Stability of the Western North American Power System with High Penetration of Photovoltaic Generation”(in development).

[7] E. Malashenko, S. Appert, W. al-Mukdad, Advanced Inverter Technologies Report, CPUC Grid Planning and Reliability Energy Division, 18 Jan 2013.

[8] International Electrotechnical Commission Technical Report IEC 61850-90-7, “Communication networks and systems for power utility automation–Part 90-7: Object models for power converters in distributed energy resources (DER) systems,” Edition 1.0, Feb 2013.

[9] Electric Power Research Institute (EPRI), Common Functions of Smart Inverters, Dec 2011.

[10] J.W. Smith, W. Sunderman, R. Dugan, B. Seal, "Smart inverter volt/var control functions for high penetration of PV on distribution systems," Power Systems Conference and Exposition (PSCE), 2011 IEEE/PES , vol., no., pp.1,6, 20-23 March 2011.

[11] NERC Performance of Distributed Energy Resources During and After System Disturbance , Voltage and Frequency Ride-Through Requirements , IVGTF1-

[12] CEC/CPUC, Recommendations for Updating the Technical Requirements for Inverters in Distributed Energy Resources: Smart Inverter Working Group Recommendations, Jan 2014.

[13] J. Neely, S. Gonzalez, M. Ropp, D. Schutz, ”Accelerating Development of Advanced Inverters: Evaluation of Anti-Islanding Schemes with Grid Support Functions and Preliminary Laboratory Demonstration,” Sandia National Laboratories Technical Report SAND2013-10231; November 2013.

[14] M. Mills-Price, M. Scharf, et al., "Interconnection control of distributed generation with time-synchronized phasors," Power Systems Conference and Exposition (PSCE), 2011 IEEE/PES , pp.1,8, 20-23 March 2011.