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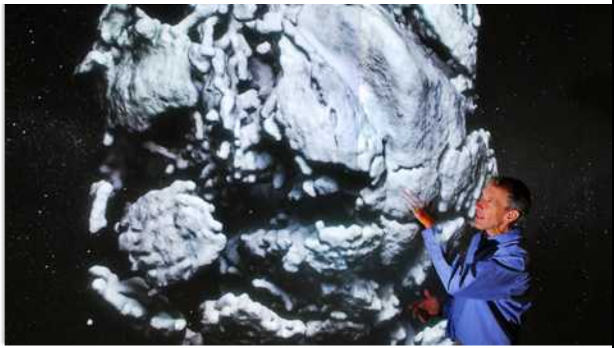

Interoperability and Advanced Inverter Functionality Testing Update

Smart Grid International Research Facility Network (SIRFN) Workshop
Bangalore, India - 4 Mar, 2014

Jay Johnson

Photovoltaic and Distributed Systems Integration, Sandia National Laboratories

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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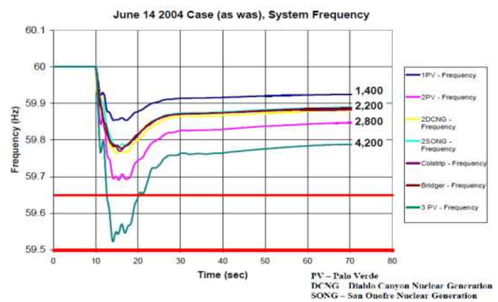
Outline

- Background information
- Advanced Inverter functions
- Advanced functionality and interoperability test beds
- Results for INV1, INV2, INV3, and VV11
- Automating the test protocols using the SunSpec Alliance pysunspec core (python) based on SunSpec advanced inverter Modbus specifications
- California Rule 21 update – potential rollout of advanced functions in the U.S.
  - California Solar Initiative project with EPRI, SunSpec, utilities, and inverter manufactures
- Expanding the test protocols to energy storage systems
- Gaps in codes and standards where the Sandia Test Protocols can help
- Conclusions/future work

Background



High PV penetrations are leading to grid voltage and frequency stability concerns.

Command	Function
INV1	Connect/Disconnect
INV2	Adjust Max Generation Level
INV3	Adjust Power Factor
INV4	Request Active Power
INV5	PV/Storage Functions
VV11	Volt-Var mode
VV12	Volt-Var mode
VV13	Volt-Var mode
VV14	Volt-Var mode
FW21	Set maximum power output
FW22	Set maximum power output
TV31	Dynamic reactive power support
L/H VRT	Connect/disconnect settings
WP41	Power factor settings
WP42	Power factor settings
VW51	Set output to smooth voltage
VW52	Set output to smooth voltage
TMP	Temperature mode behavior
PS	Signal mode behavior
DS91	Modify DER Inverter Settings
DS92	Event/History Logging
DS93	Status Reporting
DS94	Time Synchronization

Based on EPRI and SNL research, advanced interoperability DER functions are standardized in IEC 61850-90-7.


California Energy Commission
&
California Public Utilities Commission

Recommendations for Updating the Technical Requirements for Inverters in Distributed Energy Resources

Smart Inverter Working Group Recommendations

January 2014

California Public Utilities Commission (CPUC) considers updating Rule 21 to require inverters to have advanced grid functions.

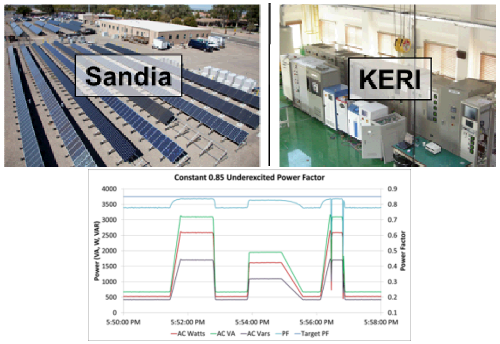

SANDIA REPORT
SAND2013-9880
Unlimited Release
Printed November 2013

Test Protocols for Advanced Inverter Interoperability Functions – Main Document

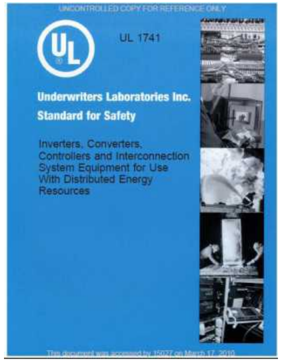
Jay Johnson, Sigifredo Gonzalez, Mark E. Ralph, Abraham Ellis, and Robert Broderick

Sandia National Laboratories

In Nov 2013, Sandia releases the Advance Interoperability Test Protocols matching the IEC functions.



Sandia and other laboratories begin exercising the test protocols to refine the procedures, parameter selection, and number of tests.



Based on recommendations from Sandia and other industry experts, UL 1741 is updated to cover inverters required by CPUC Rule 21.

Current Electricity Grid

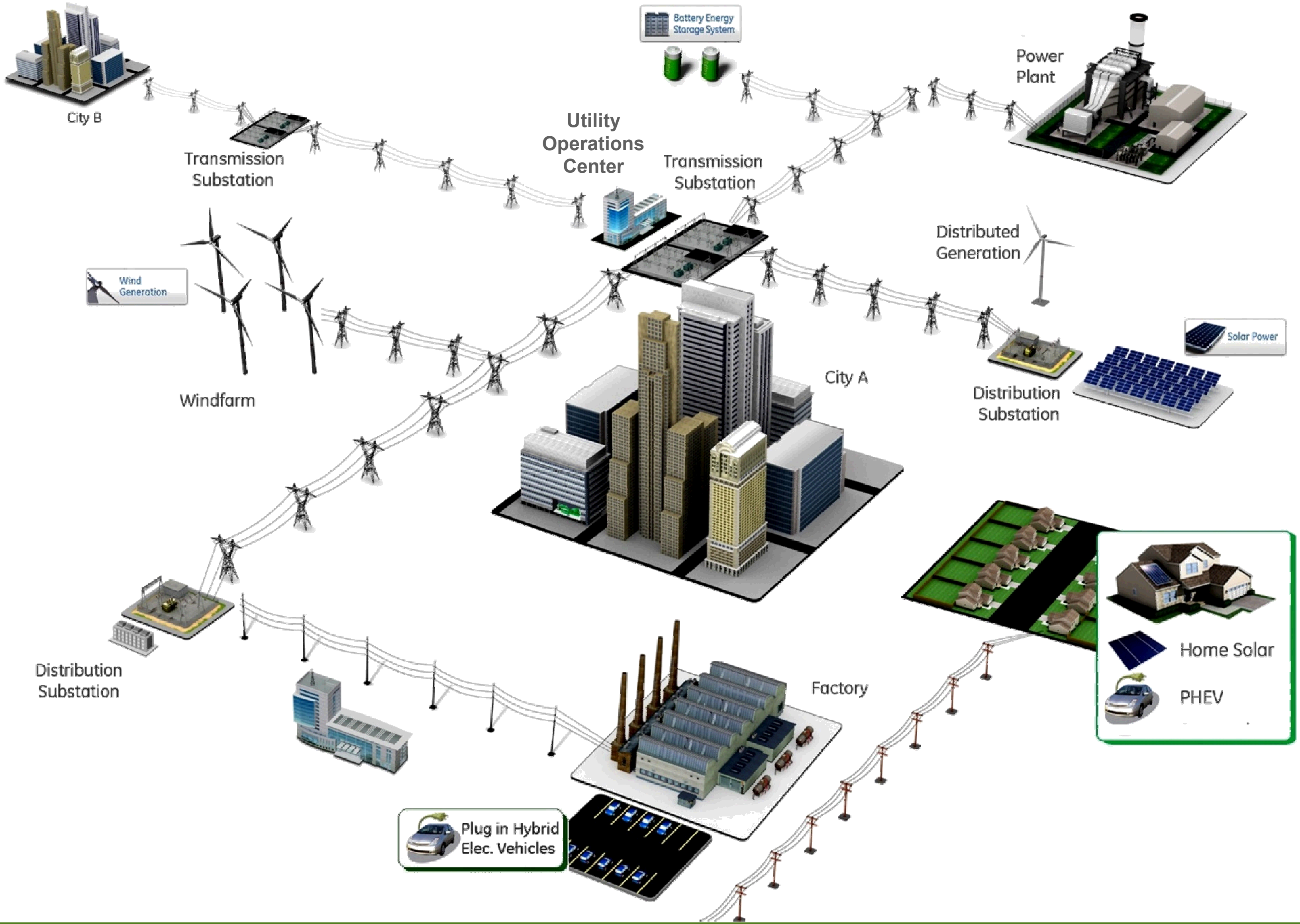


Image: Forbes India

Current Electricity Grid Communications

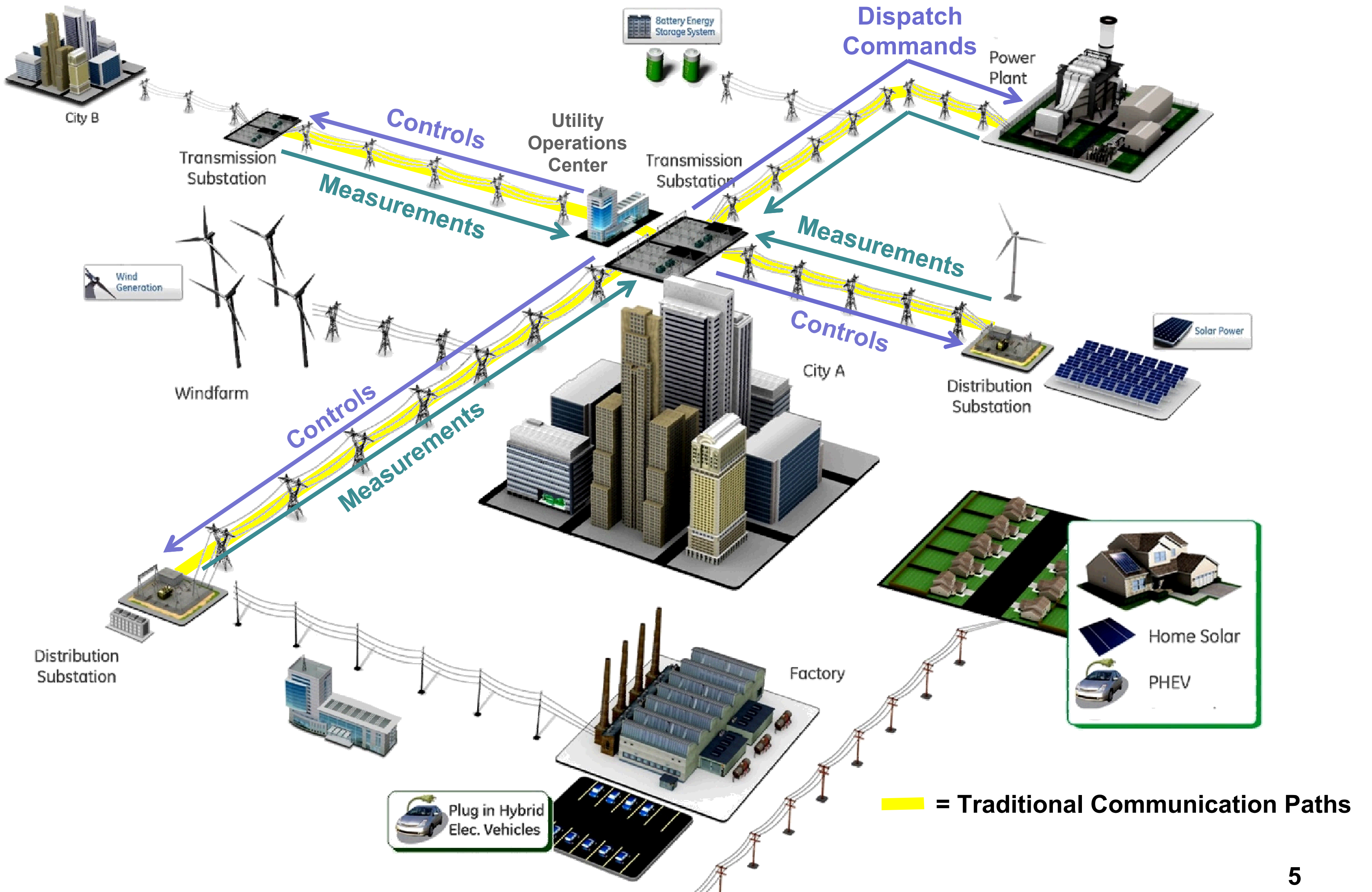


Image: Forbes India

Smart Electricity Grid

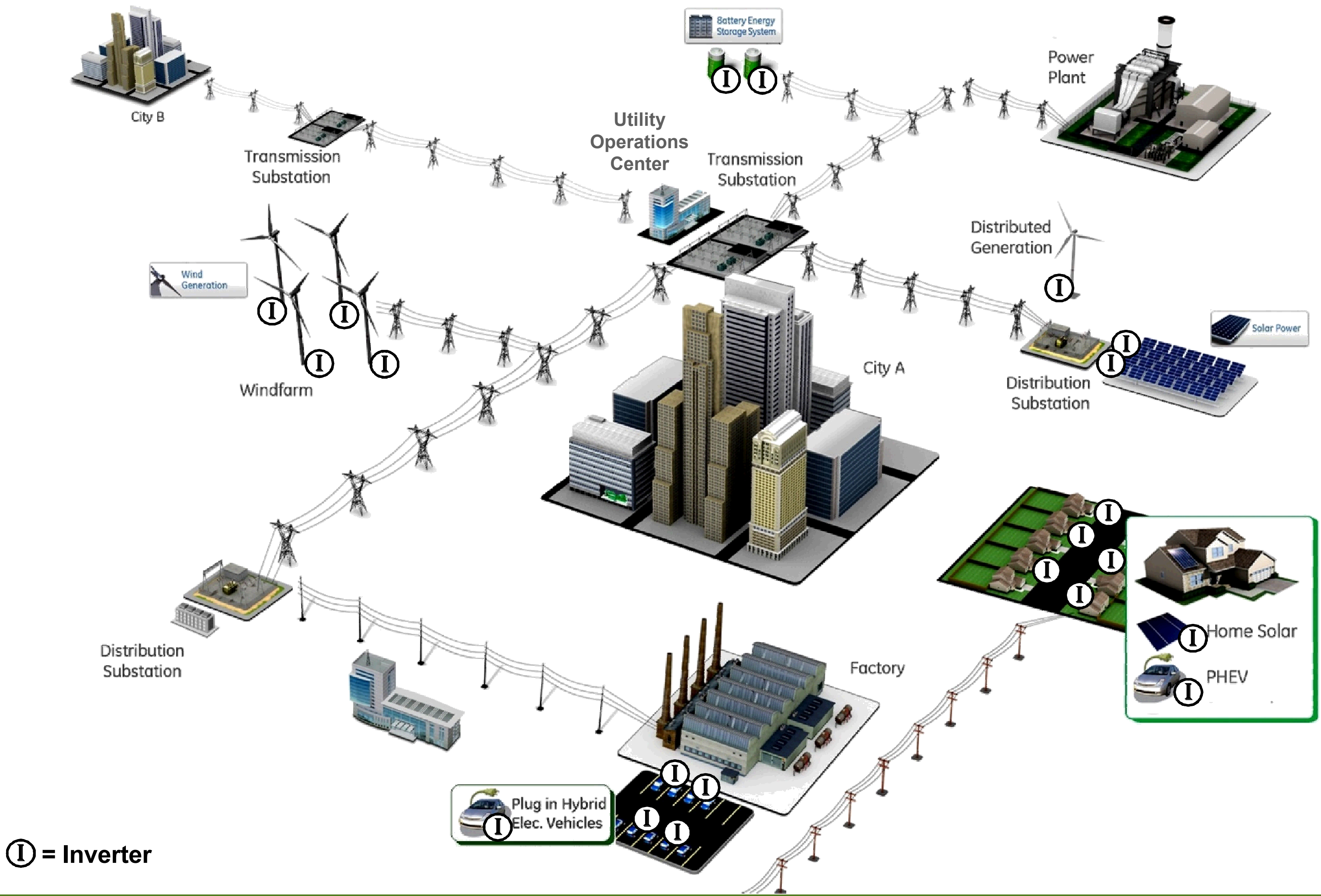


Image: Forbes India

Smart Electricity Grid Communications

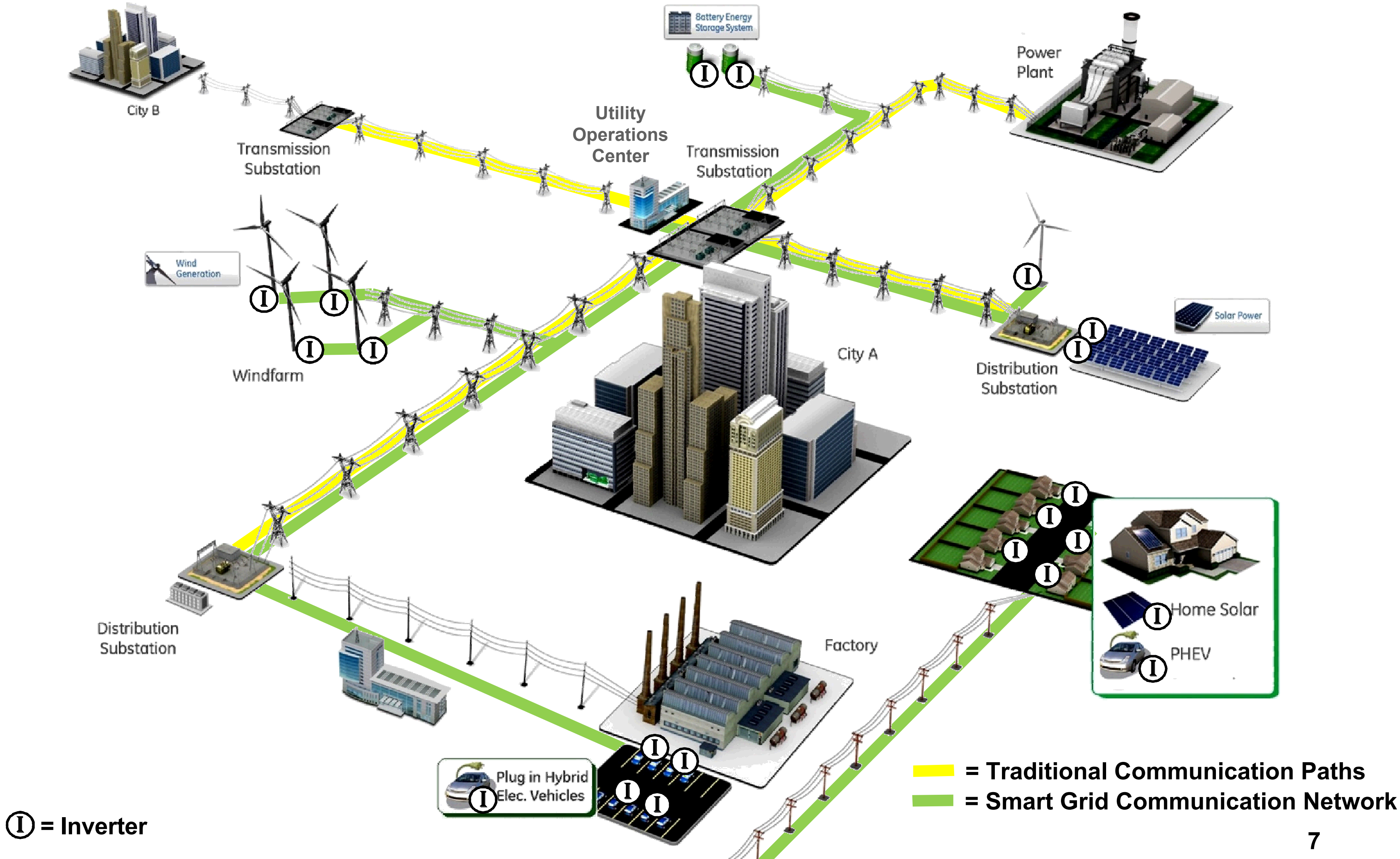


Image: Forbes India

Smart Electricity Grid Communications

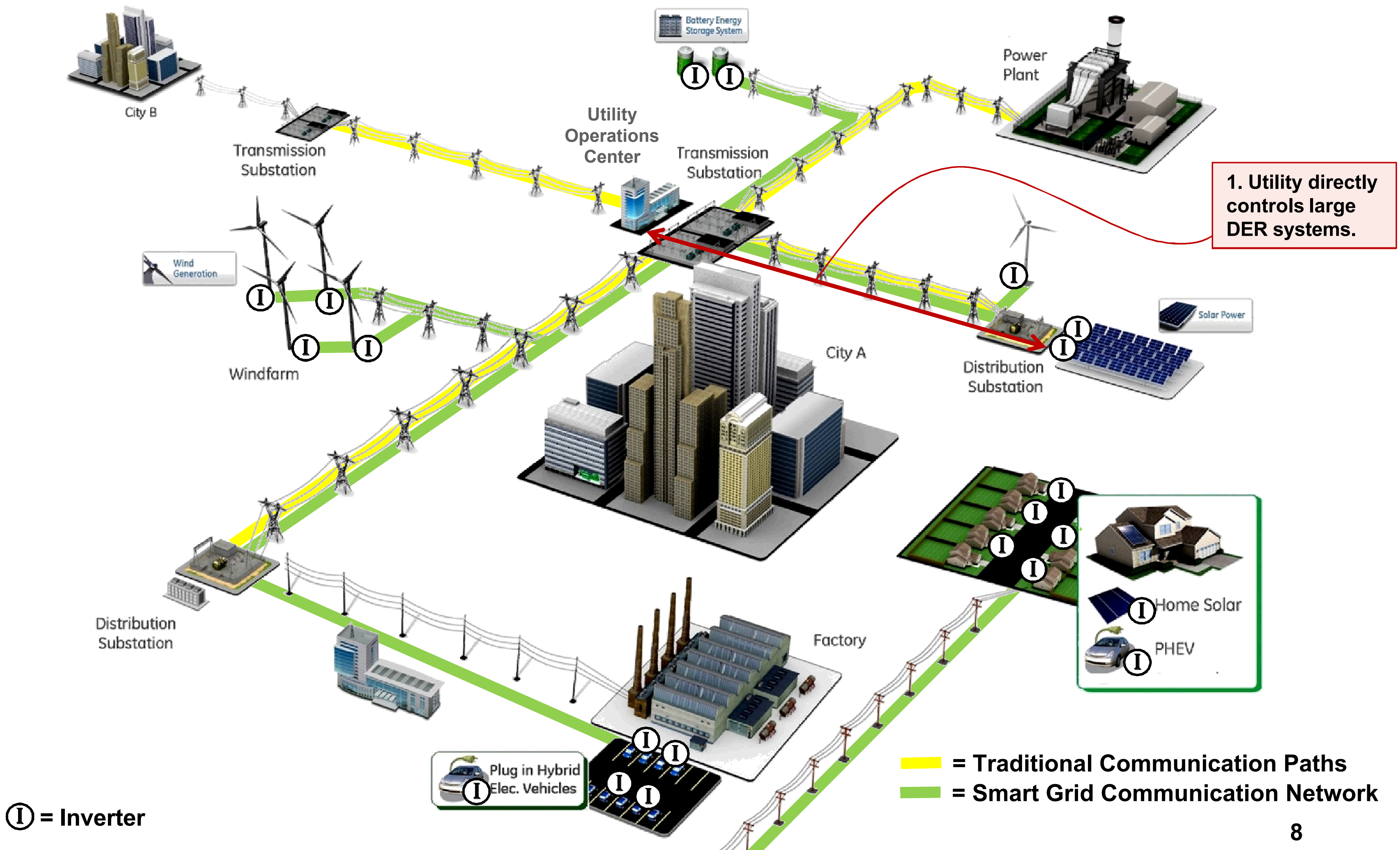


Image: Forbes India

Smart Electricity Grid Communications

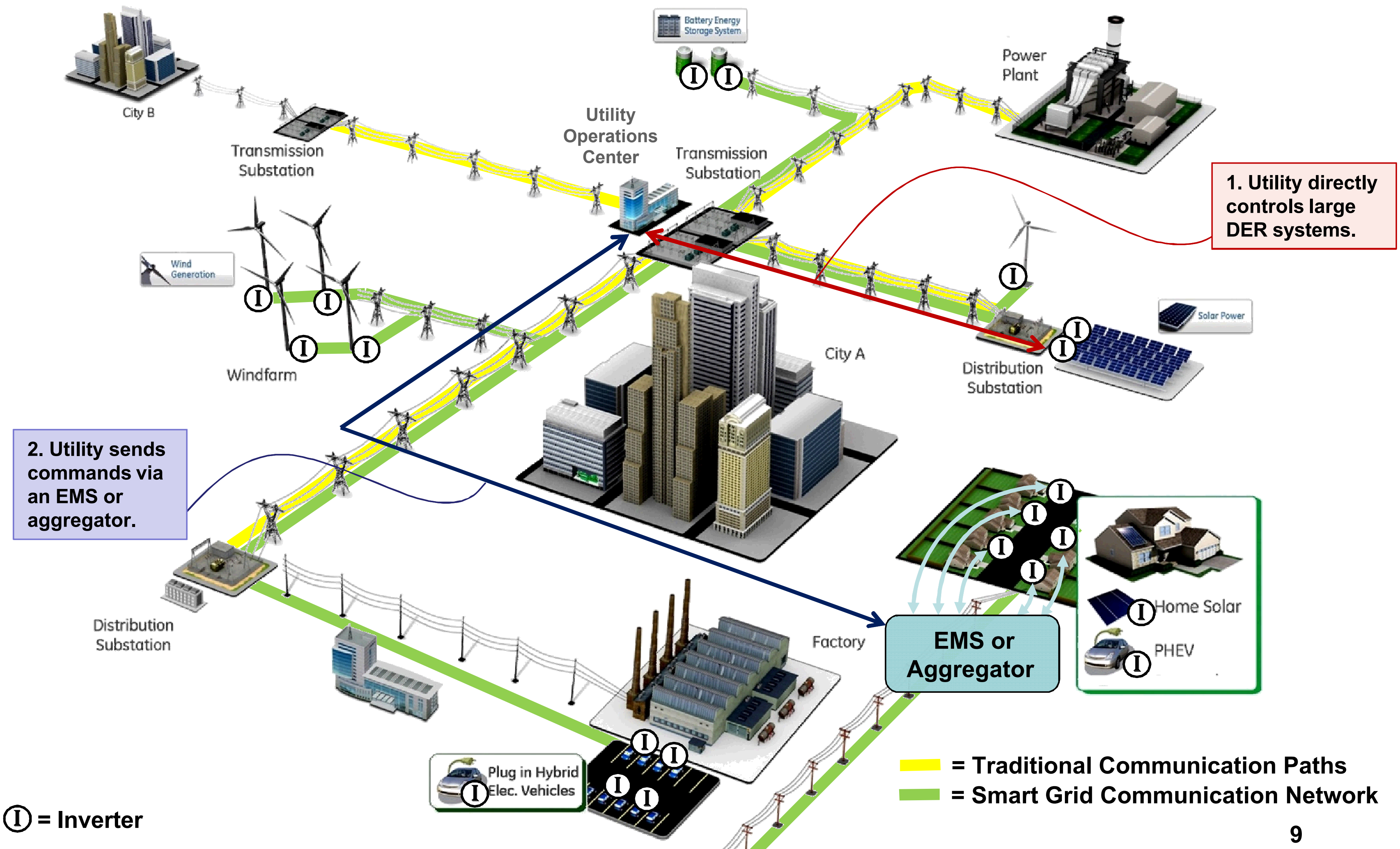
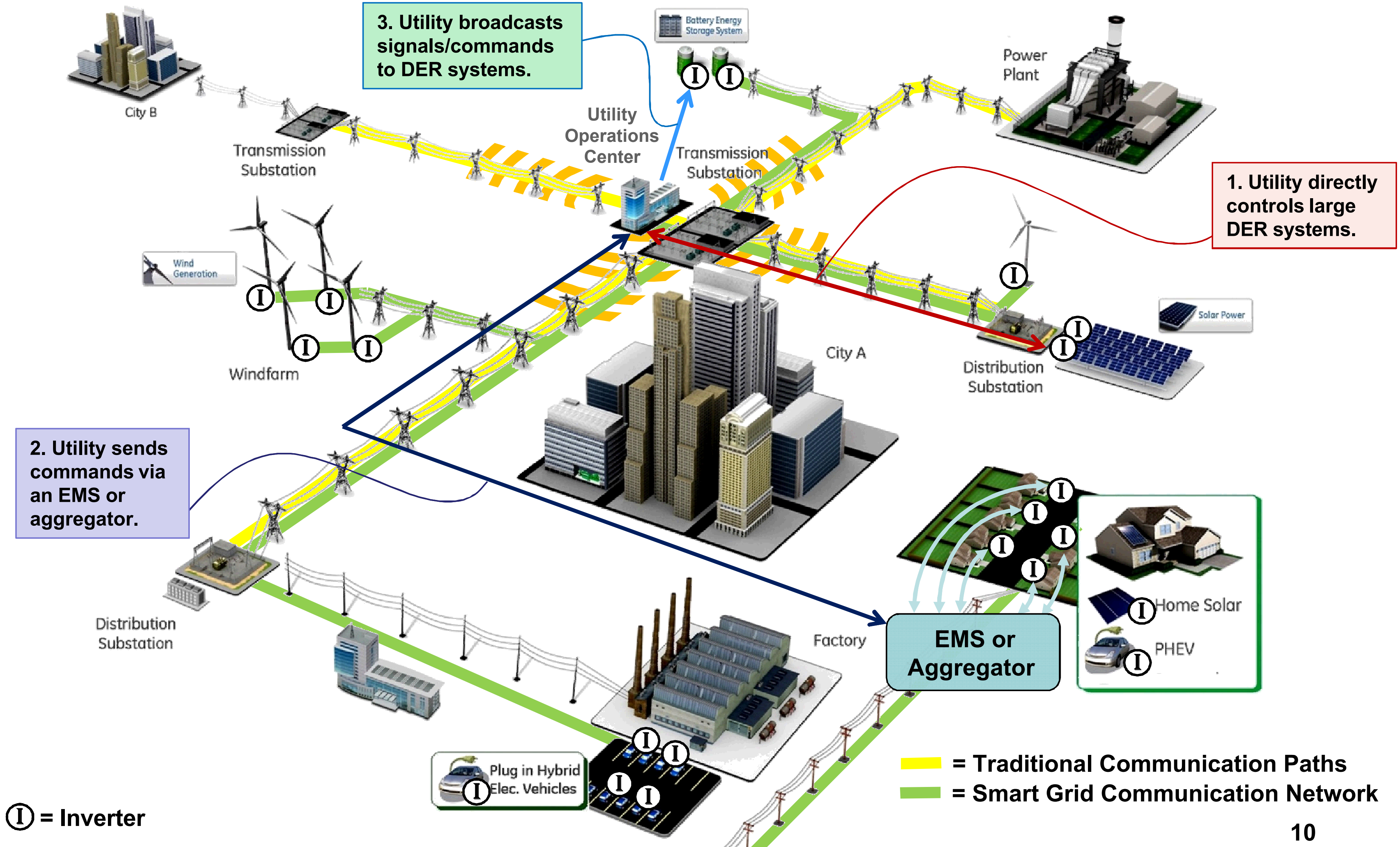


Image: Forbes India

Smart Electricity Grid Communications

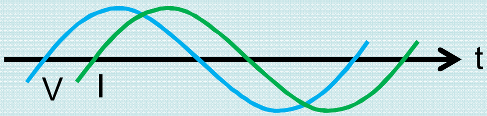


Types of Advanced Inverter Functions

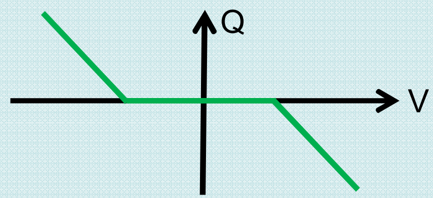
Advanced functions defined in IEC Technical Report 61850-90-7:

Voltage Support

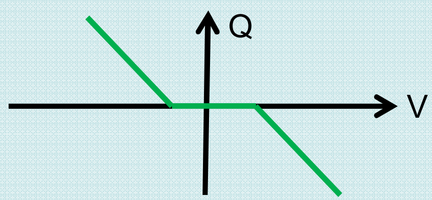
- **Adjust Power Factor (INV3)**



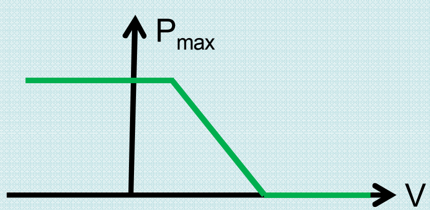
- **Volt-Var Mode (VV11, VV12, VV13)**



- **Dynamic Reactive Power (TV31)**

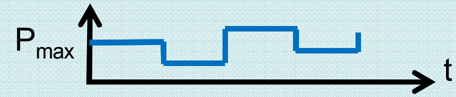


- **Volt-Watt Mode (VW51; VW52)**

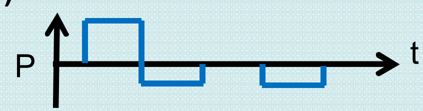


Frequency Support

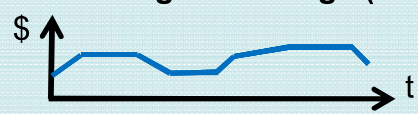
- **Adjust Maximum Active Power (INV2)**



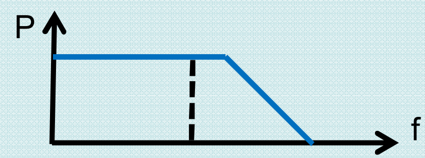
- **Request Active Power from Storage (INV4)**



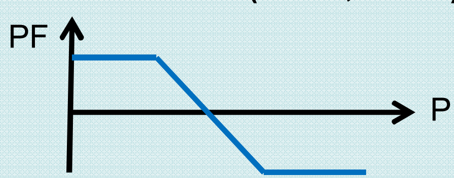
- **Signal for Charge/Discharge (INV5)**



- **Frequency-Watt Mode (FW21, FW22)**

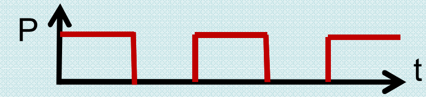


- **Watt-Power Factor (WP41, WP42)**

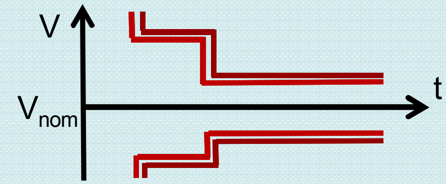


Grid Protection (Response to Disturbances)

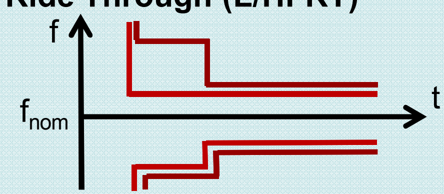
- **Connect/Disconnect (INV1)**



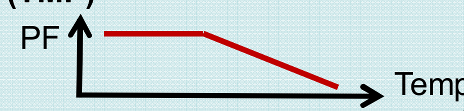
- **Low and High Voltage Ride Through (L/HVRT)**



- **Low and High Frequency Ride Through (L/HFRT)***

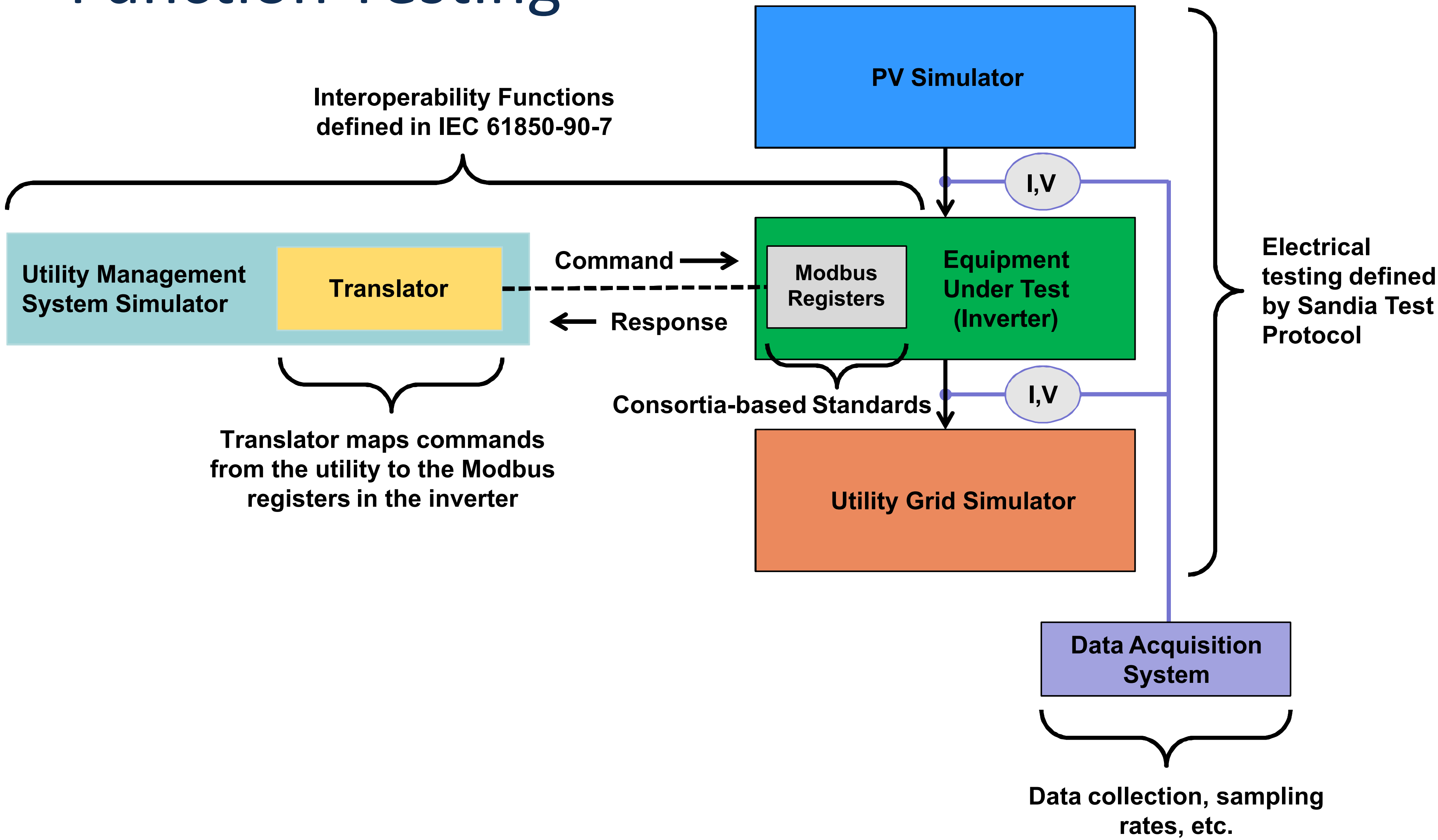


- **Temperature Mode Behavior (TMP)**



*FRT not included in IEC 61850-90-7, but is included in Rule 21 SIWG recommendations and Sandia Test Protocols.

DER Interoperability and Advanced Function Testing



Sandia Test Protocol

- General guidelines for harmonized equipment testing across different laboratories.
- Precursor to equipment certification procedures.
- Two distinct phases for most functions:
  - Communication
    - Send the signal from the Utility Management System Simulator
    - Verify the communications reached the EUT
  - Electrical behavior characterization
    - Measurement of the DC and AC characteristics to verify the inverter updated its operation
- Communication phase of the test protocol sequence may be skipped for some inverters if there is no translator.

Example Test Protocol Sequence (Volt/Var VV11)

Step	Task	Function	Notes

Communication (Command inverter to change behavior. Listen for response.)

Electrical Behavior Characterization (Electrically test the inverter to ensure the new functionality is enabled.)

Analysis (Verify inverter behavior.)

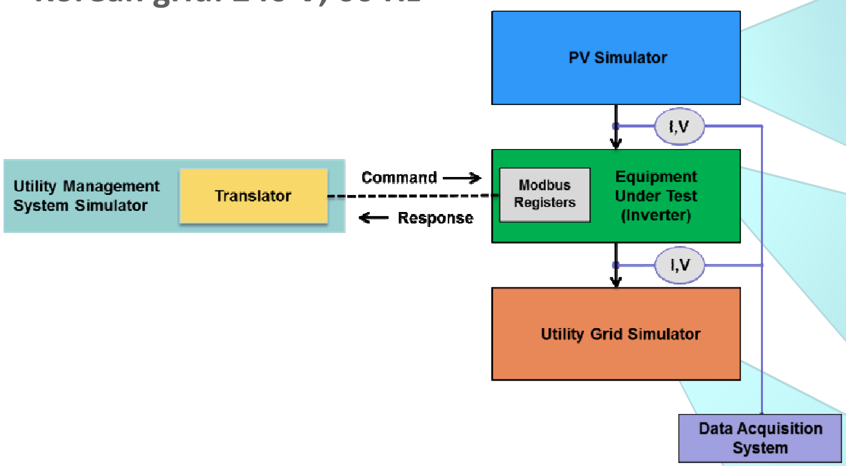
Inverter Interoperability Test beds at Sandia and KERI

Sandia National Laboratories

Both Sandia and KERI have designed interoperability testbeds. Differences in hardware and grid voltage and frequency demonstrate the capabilities of the testing protocols.

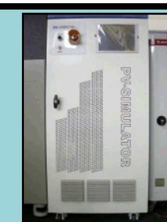
US grid: 120/240 V, 60 Hz

Korean grid: 240 V, 60 Hz



PV Simulator
Power: 200 kW
Voltage: 0-1000 V_{dc}/output
Current: 10 A/output

PV Simulator
Power: 10 kW
Voltage: 0-500 V_{dc}
Current: 50 A



Inverter: European Partner
Power: 3 kW
Communications: Modbus, RS485
- Available worldwide
- Inexpensive
- SunSpec compliant

Inverter: Korean Partner
Power: 3 kW
Communications: SEP 2.0

Grid Simulator
Power: 180 kVA
Voltage: 480 V 3ϕ
Current: 700 A/Phase

Grid Simulator
Power: 10 kVA
Voltage: 380 $V_{L\text{-}L}$
3ϕ, 4-wire

- **AIT is exercising the test protocols on a 5 kW Fronius inverter. They have also worked with a 680 kW Schneider Electric using an IEC 61850-90-7 gateway.**
- **RSE has a 5 kW Fronius inverter.**

Sandia and AIT collaboration

- Sandia and AIT submitted an abstract regarding advanced inverter testing to EU PVSEC (Amsterdam, 22-26 Sept.)
- The paper:
  - Discusses experience exercising the Sandia Test Protocols and modifications to the test procedures/test matrices (parameters) based on the experiments.
  - Compares the different laboratory test beds (hardware and software).
  - Methods for automating the test protocols
    - Sandia is using python and SunSpec controllers
    - AIT is using Matlab controllers
  - Comparison of results for four (or more) functions
    - Currently INV1, INV2, INV3, VV11

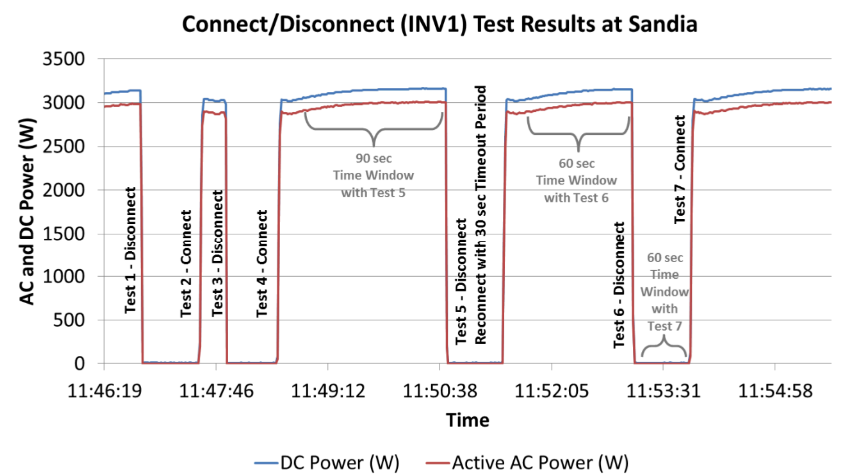
INV1 – Connect/Disconnect

INV1 Test Protocol Sequence.

	Step	Task	Function	Notes
Communication	1	Request Status to EUT.	**DS93** (Status Reporting) & Direct Measurement (**DM**) of inverter output	Log time sent.
	2	UMS receives response to the DS93.command.		Log time received.
	3	Inverter output is measured and logged		Direct Measurement sensors record inverter output
	4	UMS issues a Disconnect /Connect Command to EUT.	**INV1** – Connect/ Disconnect	Log time sent. Command may include the following parameters: time window (optional) timeout period (optional) ramp rate (optional)
	4	EUT responds to the command.	**DS92** – change in status is noted	Expected response message from EUT: Successful (DS92 status change logged and DM monitored output) Rejected (includes reason)
Electrical Behavior	5	Verify command was successfully executed (DS92 and DM).	**DM** – EUT output is recorded & logged	Monitor electrical output of EUT to determine if EUT connects/ disconnects and at what time. Measure voltage, current, power factor Record time
	6	Repeat test with varying parameters (see Table A1-3). Each test should be repeated at least once as needed.	[illegible]	
Analysis	7	Characterize EUT's response.	**DS92; DM**	Determine how command was executed.

INV1 Test Matrix.

Test Number	EUT Initial Operating State	Connect/Disconnect Command	Time Window (seconds)	Timeout Period (seconds)
Test 1	>50% rated power, unity power factor	Disconnect 1	Default (e.g., 0)	Default (e.g., 0)
Test 2	Inverter off	Connect 1	Default (e.g., 0)	Default (e.g., 0)
Test 3	>50% rated power, unity power factor	Disconnect 2	0	Default (e.g., 0)
Test 4	Inverter off	Connect 2	0	Default (e.g., 0)
Test 5	>50% rated power, unity power factor	Disconnect 3	90 seconds	30
Test 6	>50% rated power, unity power factor	Disconnect 4	60 seconds	0 (No Timeout)
Test 7	Inverter off	Connect 4	60 seconds	0 (No Timeout)



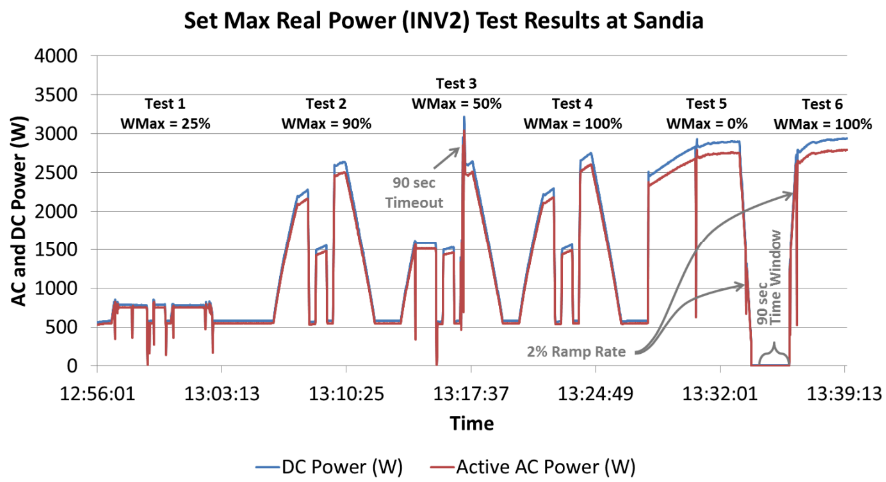
INV3: Set Constant PF – Electrical Characterization Results

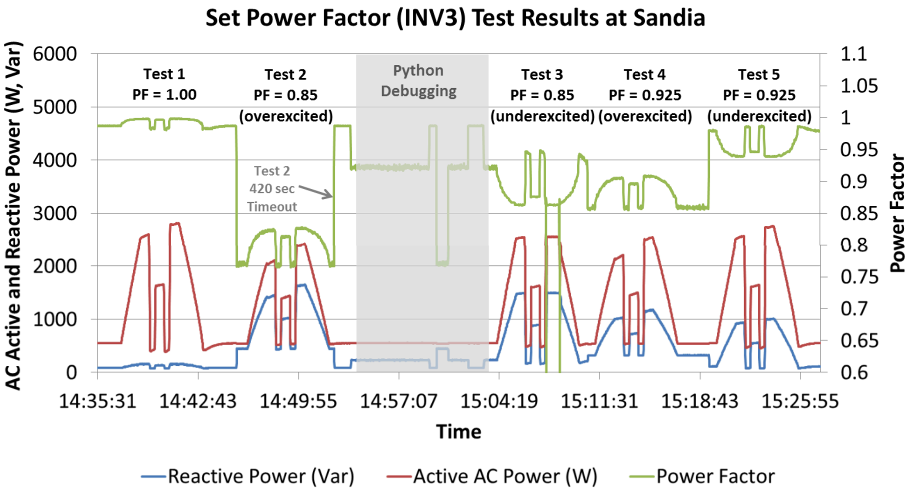
New INV2 Test Matrix.

Test	WMax (% nameplate)	Ramp Rate (% nameplate watts/sec)	Time Window (sec)	Timeout Period (sec)	Input PV Power Curve
Test 1	25	0	0	0	Figure A2- 1
Test 2	90	0	0	0	Figure A2- 1
Test 3	50	20	0	90	Figure A2- 1
Test 4	100	0	0	0	Figure A2- 1
Test 5	0	2	0	0	Constant at 100%
Test 6	100	2	90	0	Constant at 100%

New INV3 Test Matrix.

Power Factor (INV3)	Ramp Rate (%/sec)	Timeout Period (sec)	Time Delay (sec)
1.00 (default)	0	0	0
MaxPFAval (overexcited)	0	60	420
MaxPFAval (underexcited)	0	90	0
0.5+MaxPFAval/2 (overexcited)	10	0	0
0.5+MaxPFAval/2 (underexcited)	0	0	480

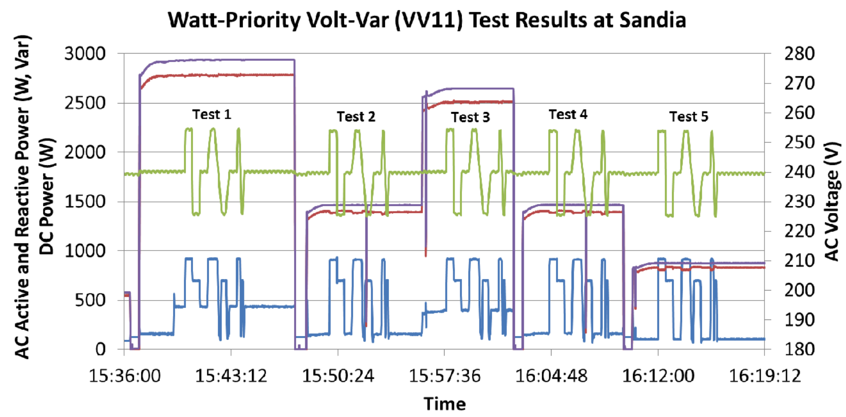


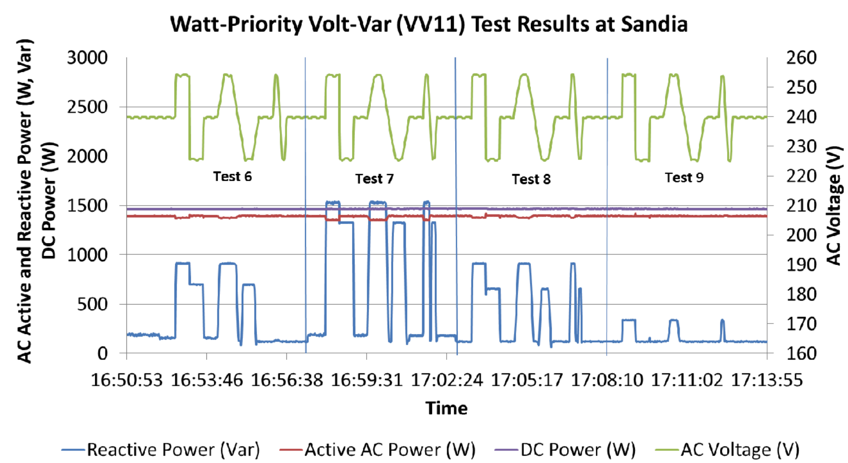


VV11 – Watt-priority volt-var

New VV11 Test Matrix.

Test	EUT Initial Operating State	Volt/Var Initiation	Volt/Var [V,Q] Array				Requested Ramp Time (% VArAval/s)	Time Window (seconds)	Timeout Period (seconds)
1	100% rated power, unity power factor	Binary, 1	V1	97	Q1	50	0	0	0
			V2	99	Q2	0			
			V3	101	Q3	0			
			V4	103	Q4	-50			
2	50% rated power, unity power factor	Binary, 1	V1	97	Q1	50	0	0	0
			V2	99	Q2	0			
			V3	101	Q3	0			
			V4	103	Q4	-50			
3	90% rated power, unity power factor	Binary, 1	V1	97	Q1	50	10	0	0
			V2	99	Q2	0			
			V3	101	Q3	0			
			V4	103	Q4	-50			
4	50% rated power, unity power factor	Binary, 1	V1	97	Q1	50	0	0	0
			V2	99	Q2	0			
			V3	101	Q3	0			
			V4	103	Q4	-50			
5	30% rated power, unity power factor	Binary, 1	V1	97	Q1	50	0	0	300
			V2	99	Q2	0			
			V3	101	Q3	0			
			V4	103	Q4	-50			
6	50% rated power, unity power factor	Binary, 1	V1	97	Q1	50	10	0	180
			V2	99	Q2	0			
			V3	101	Q3	0			
			V4	103	Q4	-50			
7	50% rated power, unity power factor	Binary, 1	V1	97	Q1	100	0	0	0
			V2	99	Q2	0			
			V3	101	Q3	0			
			V4	103	Q4	-100			
8	50% rated power, unity power factor	Binary, 1	V1	95	Q1	50	0	120	0
			V2	98	Q2	0			
			V3	102	Q3	0			
			V4	105	Q4	-50			
9	50% rated power, unity power factor	Binary, 1	V1	80	Q1	100	0	0	0
			V2	95	Q2	0			
			V3	105	Q3	0			
			V4	120	Q4	-100			





IEC 61850-90-7 Inverter Interoperability Functions

Sandia National Laboratories

Command	Function	Description	Type
INV1	Connect/Disconnect	Physically connect or disconnect from grid	Command
INV2	Adjust Max Generation Level	Set maximum generation level at Electrical Coupling Point	Command
INV3	Adjust Power Factor	Issues a power factor angle value	Command
INV4	Request Active Power	Request charging or discharging of the storage system	Request
INV5	PV/Storage Functions	Change the signal parameters for the storage system	Request
VV11	Volt-Var mode	Provide vars with no effect on watts	Set Parameter
VV12	Volt-Var mode	Provide maximum vars constrained by WMax	Set Parameter
VV13	Volt-Var mode	Establish fixed var settings	Set Parameter
VV14	Volt-Var mode	No var support	Set Parameter
FW21	Set maximum power output	Active power reduction due to high frequency	Set Parameter
FW22	Set maximum power output	Modify frequency-watts-delivered or watts-received curve	Set Parameter
TV31	Dynamic reactive power support	Provide var support at times of abnormally high or low voltage	Set Parameter
L/H VRT	Connect/disconnect settings	Set voltage ride-through or disconnect requirements	Set Parameter
WP41	Power factor settings	Set power factor in response to feed-in power	Set Parameter
WP42	Power factor settings	Modify power factor-watts curve	Set Parameter
VW51	Set output to smooth voltage	Voltage-watt curve of generator output	Set Parameter
VW52	Set output to smooth voltage	Voltage-watt curve of storage charge/discharge output	Set Parameter
TMP	Temperature mode behavior	Temperature-based curves	Set Parameter
PS	Signal mode behavior	Mode curves based on utility signal	Set Parameter
DS91	Modify DER Inverter Settings	Set default ramp rate, min./max. storage charge/disch. rate	Command
DS92	Event/History Logging	Request event logs	Command
DS93	Status Reporting	Request inverter status	Command
DS94	Time Synchronization	Set inverter time	Command

Implementation Successful (green: INV1, INV2, INV3, VV11) | **Implementation Partly Successful** (yellow: FW21, DS91, DS93) | **Implementation Unsuccessful** (red: L/H VRT) | **Near-term Implementation** (blue: WP42, VW51)

SunSpec Alliance Specifications

- SunSpec has released a number of specifications format for Modbus registers on SunSpec-compliant devices:
  - Common Elements v1.4
  - Inverter Models v1.1
  - String Combiner Model v1.1.1
  - Inverter Controls DRAFT 10
  - ….

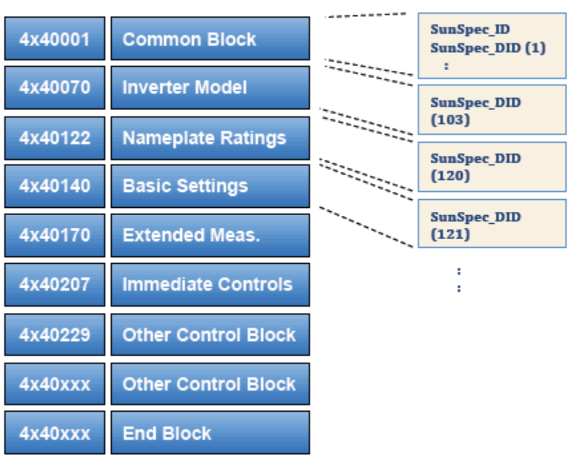


Figure 1: Chained Inverter Control Blocks

SunSpec Protocol Implementation Conformance Statement (PICS)

Sandia National Laboratories

Example SunSpec specification for volt-var. These are listed in the PICS excel file (on Basecamp).

// 126-Static Volt-VAR : Static Volt-VAR Arrays (Ref 3: 8.8.1.2)

Start Offset	End Offset	Size	R/W	Name	Label	Type	Units	SF	Description	M/O
1	1	1	R	ID		unit16			A well-known value 126. Uniquely identifies this as a SunSpec Static Volt-VAR Model	M
2	2	1	R	L		uint16			Variable # of 16 bit registers to follow : 12+N*34	M
// 126 Static Volt-VAR Fixed Block (12)										
3	3	1	R	NCrv	NCrv	uint16			Number of curves supported (recommend min. 4).	M
4	4	1	R	NPts	NPts	uint16			Maximum number of points in array (recommend min. 10).	M
5	5	1	RW	ModEna	ModEna	bitfield16			Is Volt-VAR control active.	M
6	6	1	RW	ActCrv	ActCrv	uint16			Index of active curve. 0=no active curve.	M
7	7	1	RW	WinTms	WinTms	uint16	Secs		Time window for volt-VAR change.	O
8	8	1	RW	RvrtTms	RvrtTms	uint16	Secs		Timeout period for volt-VAR curve selection.	O
9	9	1	RW	RmpTms	RmpTms	uint16	Secs		The time of the PT1 in seconds (time to accomplish a change of 95%).	O
10	10	1	R	V_SF	V_SF	sunssf			Scale factor for percent VRef.	M
11	11	1	R	WPct_SF	WPct_SF	sunssf			Scale factor for power output percent.	M
12	12	1	R	VArPct_SF	VArPct_SF	sunssf			Scale factor for reactive power percent.	O
13	13	1	R	RmpIncDec_SF	RmpIncDec_SF	sunssf			Scale factor for increment and decrement ramps.	O
14	14	1	R	Pad	Pad	pad			Pad register.	O
// 126 Static Volt-VAR Repeating Block (34)										
15	22	8	RW	CrvNam	CrvNam	string			Optional description for curve. (Max 16 chars)	O
23	23	1	RW	ActPt	ActPt	uint16			Number of active points in array.	M
24	24	1	RW	DeptRef	DeptRef	enum16			Meaning of dependent variable: 1=%WMax 2=%VArMax 3=%VArAval.	M
25	25	1	RW	RmpTms	RmpTms	uint16	Secs		The time of the PT1 in seconds (time to accomplish a change of 95%).	O
26	26	1	RW	RmpDecTmm	RmpDecTmm	uint16	% ref value	RmpIncDec_SF	The maximum rate at which the VAR value may be reduced in response to changes in the voltage value. %refVal is %WMax %VArMax or %VArAval depending on value of DeptRef.	O
27	27	1	RW	RmpIncTmm	RmpIncTmm	uint16	% ref value	RmpIncDec_SF	The maximum rate at which the VAR value may be increased in response to changes in the voltage value. %refVal is %WMax %VArMax or %VArAval depending on value of DeptRef.	O
28	28	1	RW	V1	V1	uint16	% VRef	V_SF	Point 1 Volts.	M
29	29	1	RW	VAr1	VAr1	int16		WPct_SF or VArPct_SF	Point 1 VARs.	M
30	30	1	RW	V2	V2	uint16	% VRef	V_SF	Point 2 Volts.	O
31	31	1	RW	VAr2	VAr2	int16		WPct_SF or VArPct_SF	Point 2 VARs.	O
32	32	1	RW	V3	V3	uint16	% VRef	V_SF	Point 2 Volts.	O
33	33	1	RW	VAr3	VAr3	int16	Various	WPct_SF or VArPct_SF	Point 3 VARs.	O
34	34	1	RW	V4	V4	uint16		V_SF	Point 4 Volts.	O
35	35	1	RW	VAr4	VAr4	int16		WPct_SF or VArPct_SF	Point 4 VARs.	O
48	48	1	R	Pad	Pad	pad			Pad register.	O

Automating Certification Tests

- Using the SunSpec Modbus mapping and python scripting tool, the interoperability test procedure can be quickly executed on any SunSpec-compliant device.

INV1 Main Program

```
if __name__ == "__main__":

    prompt_resp = raw_input('Do you want to run the script with prompts for connect/disconnect (y/n)?')

    print 'Talking to the inverter... hold on a sec'
    f = client.SunSpecClientDevice(client.RTU, 1, 'COM3')

    print f.models
    print f.controls

    for model in f.models:
        print model, '\n\n'
        print f[model]

    # Test 1
    #parameters: time_window, timeout_period, test_num, prompt_resp
    disconnect(0, 0, 1, prompt_resp)
    time.sleep(5)
    verify_disconnect(50)

    # Test 2
    #parameters: time_window, timeout_period, test_num, prompt_resp
    connect(0, 0, 2, prompt_resp)
    time.sleep(25)
    verify_connect(50)

    # Test 3
    #parameters: time_window, timeout_period, test_num, prompt_resp
    disconnect(0, 0, 3, prompt_resp)
    time.sleep(5)
    verify_disconnect(50)

    # Test 4
    #parameters: time_window, timeout_period, test_num, prompt_resp
    connect(0, 0, 4, prompt_resp)
    time.sleep(25)
    verify_connect(50)

    # Test 5
    #parameters: time_window, timeout_period, test_num, prompt_resp
    disconnect(90, 30, 5, prompt_resp)
    # timeout is 30 seconds
    still_on = True
    count = 0
    print 'Randomization window in use. Wait up to 90 seconds for disconnect'
    while still_on == True:
        time.sleep(1)
        count += 1
        f.controls.read()
        if f.controls.Conn == 0:
            still_on = False
            print 'Inverter disconnected after %d seconds' % (count)
            print 'Please wait 30 seconds for the revert time to reconnect the inverter'
    time.sleep(55)
    verify_connect(50)

    # Test 6
    #parameters: time_window, timeout_period, test_num, prompt_resp
    disconnect(60, 0, 6, prompt_resp)
    still_on = True
    count = 0
    print 'Randomization window in use. Wait up to 60 seconds for disconnect'
    while still_on == True:
        time.sleep(1)
        count += 1
        f.controls.read()
        if f.controls.Conn == 0:
            still_on = False
            print 'Inverter disconnected after %d seconds' % (count)
    time.sleep(5)
    verify_disconnect(50)

    # Test 7
    #parameters: time_window, timeout_period, test_num, prompt_resp
    connect(60, 0, 7, prompt_resp)
    still_off = True
    count = 0
    print 'Randomization window in use. Wait up to 60 seconds for connect'
    while still_off == True:
        time.sleep(1)
        count += 1
        f.controls.read()
        if f.controls.Conn == 1:
            still_off = False
            print 'Inverter is in the process of connecting after %d seconds' % (count)
    time.sleep(25)
    verify_connect(50)
```

Parameters from Sandia Test Protocols INV1 Test Matrix

Main Program Runs through the Test Procedure

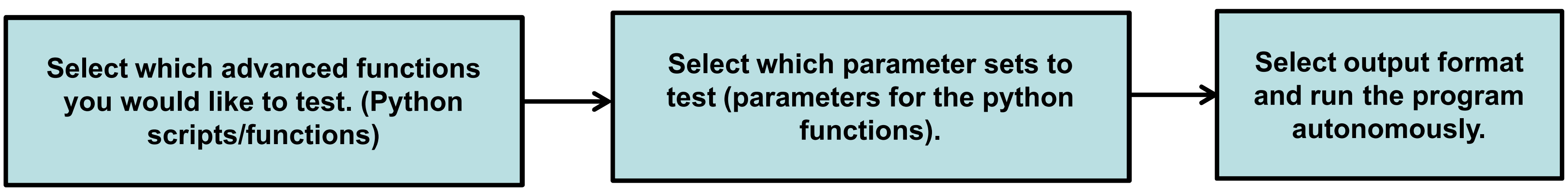
```
# Test 1
#parameters: time_window, timeout_period, test_num, prompt_resp
disconnect(0, 0, 1, prompt_resp)
time.sleep(5)
verify_disconnect(50)

# Test 2
#parameters: time_window, timeout_period, test_num, prompt_resp
connect(0, 0, 2, prompt_resp)
time.sleep(25)
verify_connect(50)
```

Disconnect Function

```
def disconnect(time_window, timeout_period, test_num, prompt_resp):
    #Put EUT in connected state - Initialize test
    f.controls.read()
    if f.controls.Conn == 0:
        f.controls.Conn = 1
        f.controls.write()
        time.sleep(25)

    # Request status from EUT and display connection status
    f.controls.read()
    con_stat = f.controls.Conn
    print 'Current connection status is ', con_stat

    #Inverter output is measured and logged
    f.inverter.read()
    print 'Current power output is ', f.inverter.W

    #UMS issues a disconnect command
    if prompt_resp == 'y':
        prompt("\nExecute disconnect? (Test number is %s)" % str(test_num), prompt_resp)
    else:
        print "\nExecuting disconnect (Test number is %s)" % str(test_num)
    f.controls.Conn_WinTms = time_window
    f.controls.Conn_RvtTms = timeout_period
    f.controls.write()
    f.controls.Conn = 0
    f.controls.write()
```

SIRFN Group license for SunSpec Inverter Control

- Everyone in the SIRFN group can use the pysunspec 1.0.3 release.
  - Sandia can provide python scripts for INV1, INV2, INV3, and VV11.
  - Soon we will have a reset.py script for return the EUT to default operation and scripts for WP42 and WV51
- Sandia purchased 3 ‘group’ licenses of the SunSpec Inverter Control Tool for SIRFN, so we should be careful who is using this when it’s uploaded to basecamp. (Share them between Sandia, RSE, AIT, AIST, etc.)
  - Sandia is actively working the SunSpec to develop this software.



CPUC Proposed Rule 21 Rollout

- CPUC Smart Inverter Working Group (SIWG) recommendations for gradually phasing in the advanced functions.

California SIWG Proposed Phase 1 Process

Development of DER requirements: Smart Inverter Working Group defines the capabilities and default values for Phase 1 inverter-based DER autonomous functions

2013

Testing and certification: UL modifies UL 1741 test procedures to test and certify the autonomous functions in DER products

Mar 2014

Permissive testing period: Manufacturers start testing and certifying their products for the Phase 1 autonomous functions

3/2014-7/2015

Pilot Projects: California utilities start installing DER systems with autonomous functions in pilot projects to study the effects of different settings

7/2014-7/2015

Commercial Installations: Commercial implementations of DER systems must include the Phase 1 autonomous functions

Expected to be October 2015

CPUC Actions:

- CPUC Rule 21 modification requires manufacturers to have their products able to perform the Phase 1 autonomous functions according to the Phase 1 Testing Plan timeframe
- After Phase 1 Testing Period, all DER systems will include autonomous functions but not necessarily enabled.

Testing Group A:

Phase 1 Autonomous Functions for:

- Larger individual DER systems > 10kW

Testing Group B:

Phase 1 Autonomous Functions for:

- Smaller individual DER systems < 10 kW

Testing Group C:

Phase 2 Communications Capabilities:

- IEC 61850 Information Model
- Mapping to Protocols
- Cyber Security

Testing Group D:

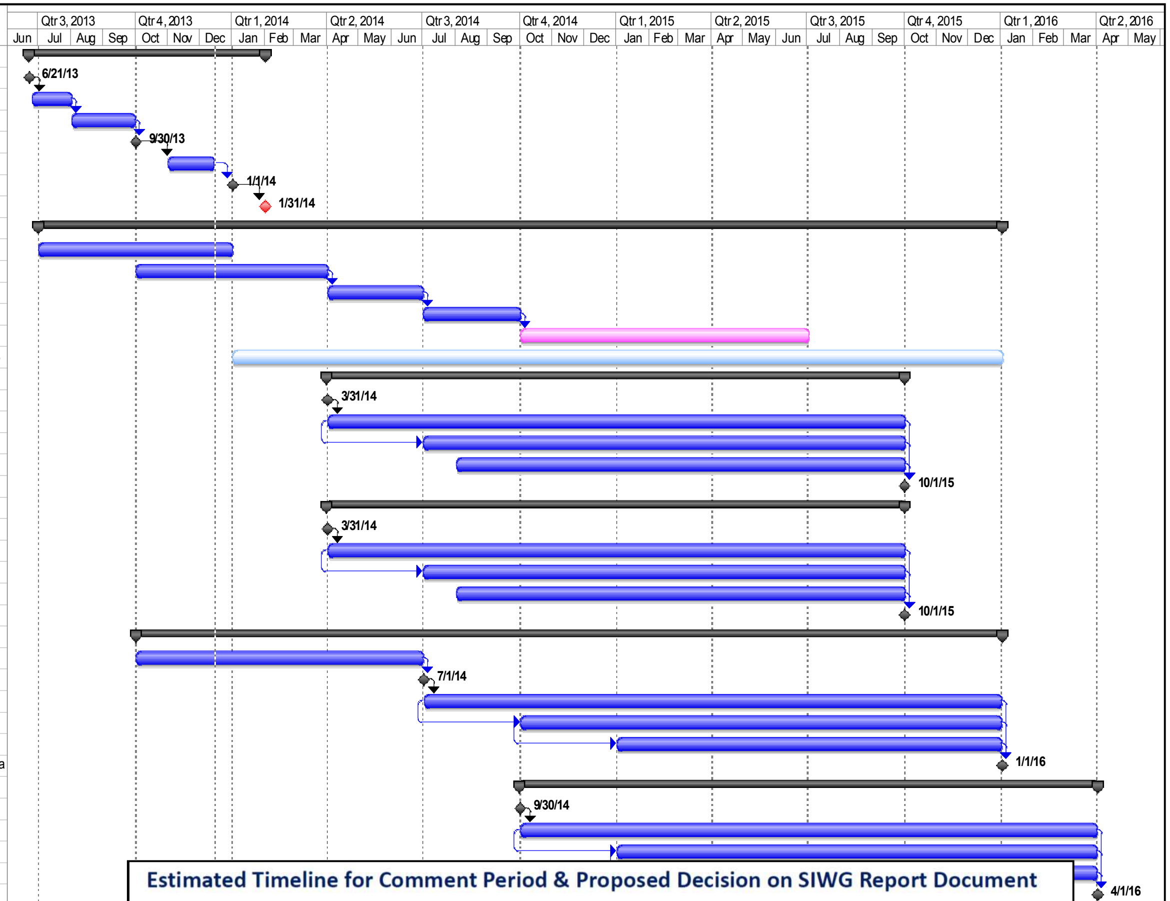
Phase 3 Additional DER Functions for:

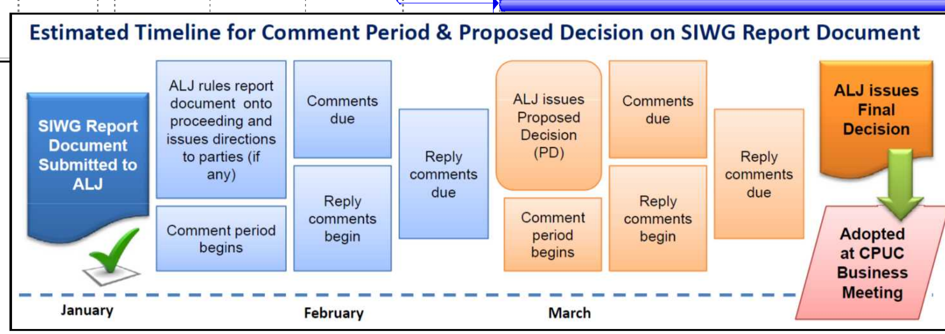
-

CPUC SIWG Timeline

Sandia National Laboratories

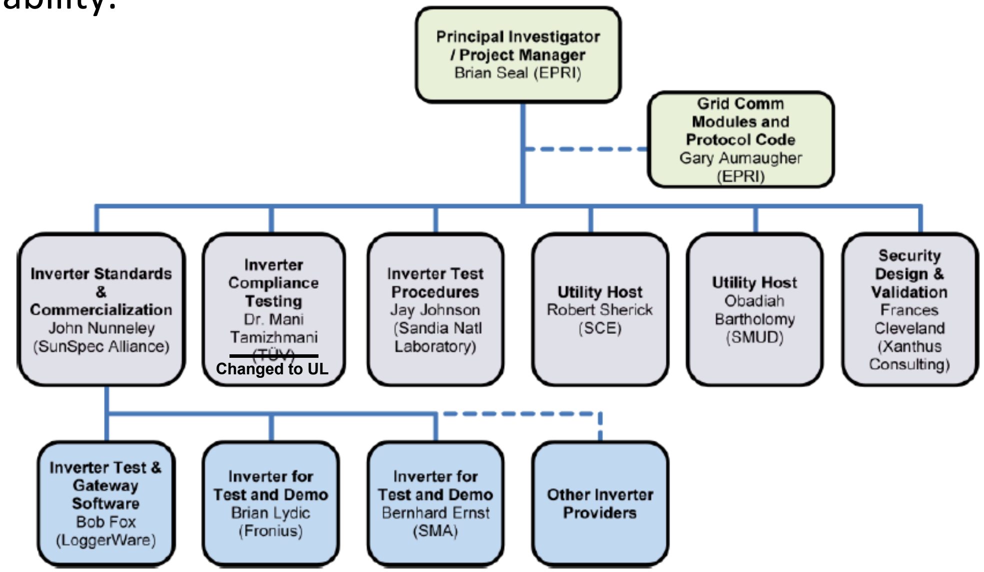
ID	Task Name
1	**Rule 21 Recommendations for DER Functions**
2	Draft Smart DER Functions and Test Plan Published
3	Stakeholder comments prepared
4	Response to DER Functions Comments
5	Updated DER Functions and Test Plan Published
6	Second round of Comments/Responses
7	CPUC Rule 21 document finalized
8	Tentative - ALJ makes ruling
9	**Smart Inverter Working Group Tasks**
10	Under UL sponsorship, develop Phase 1a Testing Procedures
11	Develop Phase 2 Communication Requirements
12	Under UL sponsorship, develop Phase 2 Testing Procedures
13	Under UL sponsorship, develop remaining Testing Procedures
14	Update Testing Procedures
15	(Optionally) Assess Utility Operational Issues with Smart DER Systems
16	**Testing Group A for Phase 1 Larger DER Systems**
17	Grp-A-1 UL publishes revised UL 1741 for Phase 1
18	Grp-A-2 Manufacturers permitted to perform Phase 1 testing
19	Grp-A-3 Utilities expect to start pilot installations
20	Grp-A-4 Utilities expect to commission pilot DER systems
21	Grp-A-5 Start commercial implementations of Phase 1
22	**Testing Group B for Phase 1 Smaller DER**
23	Grp-B-1 UL publishes revised UL 1741 for Phase 1
24	Grp-B-2 Manufacturers permitted to perform Phase 1 testing
25	Grp-B-3 Utilities expect to start pilot installations
26	Grp-B-4 Utilities expect to commission pilot DER systems
27	Grp-B-5 Start commercial implementations of Phase 1
28	**Testing Group C for DER Phase 2 Communications**
29	SIWG Develops Phase 2 Communication Requirements
30	Grp-C-1 UL publishes 2nd UL1741 revision
31	Grp-C-2 Manufacturers permitted to perform Phase 2 testing
32	Grp-C-3 Utilities start installations of pilots
33	Grp-C-4 Utilities commission pilots
34	Grp-C-5 Start commercial implementations of communications Phase 2a
35	**Testing Group D for Phase 3 Additional DER Functions**
36	Grp-D-1 UL publishes UL 1741 for Phase 3 DER functions
37	Grp-D-2 Manufacturers permitted to perform Phase 3 testing
38	Grp-D-3 Utilities install pilots
39	Grp-D-4 Utilities commission pilots
40	Grp-D-5 Start commercial implementations of Phase 3 functions





California Solar Initiative (CSI) Proposal

- Sandia partnered with EPRI, SMA, Fronius, SCE, SMUD, and SunSpec on the “Standard Communication Interface and Certification Test Program” to develop communications specifications for the utility-to-DER interchange over Modbus, SEP 2.0, and Zigbee gateways.
- Sandia portion of the grant will:
  - Create test protocols for the certification/conformance of CA Rule 21 inverter control and interoperability requirements.
  - Address cybersecurity concerns by establishing the underlying rules for the utility-to-DER interoperability.



CPUC Smart Inverter Working Group Functions

- Sandia will map the following functions into a Certification Test Standard for implementation in California. Testing will be performed at UL using the SunSpec Advanced Inverter Control Tool.

Phase 1 Autonomous Functions

	Function	Description
1	Anti-Islanding Protection	Modified L/HVRT and L/HFRT settings.
2	Low/High Voltage Ride-Through	Defines “Stay Connected Until” and “Disconnect By” areas.
3	Low/High Frequency Ride-Through	Expands frequency range for remaining connected over WECC settings
4	Dynamic Volt/Var Operations	Default Volt-Var curve with dead-band
5	Ramp Rates	Establishes default ramp up and ramp down rates for: a. Normal b. Emergency c. Soft disconnect
6	Fixed Power Factor	New allowed PF ranges.
7	Reconnect by “Soft Start”	Ramp up and/or random start time after 15 seconds of V&F in range.

Phase 2 Communication-Related Functions

	Function	Description
1	Control	Adjustment of default parameters associated with the functions identified in Phase 1 above.
2	Monitoring	Ability to read the identified set of parameters (see SWIG document)
3	Functionality upgradeability	Ability to download new firmware to inverter
4	Emergency direct control	Ability to directly set functions

Future Phase 3 Functions

Not yet defined. Could include:

- Emergency Alarms
- Current status
- Commanded Max power limit
- Connect/disconnect
- Optional/alternative settings configurations
- Self-test of new software
- Dynamic frequency-watt
- Dynamic volt-var
- Preset Max power limit
- Volt-watt curves
- Set power level
- Schedule power level
- Dynamic frequency-watt
- Schedules for energy and ancillary services
- Schedules for storage charge/discharge

Advanced Inverter Collaboration

- Within the SIRFN group
  - Initial testing presented here, should be recreated (with the addition of the communication testing piece) at AIT, RSE, and other SIRFN laboratories to compare results. Sandia proposes that the same 3.0 kW inverter used at Sandia is used for the tests at the other laboratories because it is inexpensive, easier to test (using smaller PV and grid simulators), from an international inverter manufacturer, SunSpec compliant, and contains many of the IEC functions. Other inverters can be tested as they become available.
  - Sig Gonzalez (Sandia) visited NREL in May 2013 to begin advanced inverter function testing with a domestic company's 500 kW inverter.
- SIRFN Collaborations with other groups
  - SIRFN is updating SGIP (Smart Grid Interoperability Panel) on implementation of test protocols for advanced inverter functions—ensuring there is good coverage of smart grid interoperability standardization. Note, SGIP PAP7 (Priority Action Plan 7) "Energy Storage Interconnection Guidelines" helped to draft IEC 61850-90-7.
  - Collaborating with the California Public Utilities Commission (CPUC) to determine which functions will be listed as Mandated, Recommended, and Optional DER functions for California's new Rule 21.
  - SIRFN is coordinating with IEC TC57 (Frances Cleveland) to provide testing feedback and suggesting new functions to be added to IEC 61850-90-7.

SIRFN Collaboration - Codes and Standards Survey

- Thanks to this group, we have a presentation at the International Conference on Standards for Smart Grid Ecosystem covering gaps in codes and standards.
- Sandia asked SIRFN experts to provide references for any of the following codes and standards for each of the advanced functions:
  1. *Grid code* - requires grid-interconnected DER to have certain advanced functionality.
  2. *Advanced function definitions standard (Adv. Fcn Std.)* - defines the advanced function (parameters and operation).
  3. *Advanced function certification standard (Adv. Fcn Cert. Std.)* - defines a test procedure/protocol to verify equipment functionality and certifies the DER for field deployment.
  4. *Interoperability definition standard (IOP Std.)* - defines the utility-to-DER or energy management system-to-DER communications.
  5. *Interoperability certification standard (IOP Cert. Std.)* - defines a test procedure/protocol to verify the communications to/from DER.
- Based on this study there is a clear gap in certifications standards for these functions in U.S., Spain, Austria, Italy, and the United Kingdom (and elsewhere).
- Sandia Test Protocols have the potential to become the basis for the certification tests for the functions defined in IEC TR 61850-90-7.
- If the Sandia Test Protocols are used for all national and international certification test requirements, the testing procedures will be harmonized and manufacturers will not need to preform multiple versions of the certification test.

Codes and Standards for the US and Spain

= gaps in standards which the Sandia Test Protocols could fill.

	United States					Spain				
Grid Function	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]	

Codes and Standards for Austria, UK, and Italy

= gaps in standards which the Sandia Test Protocols could fill. (light blue shading = gaps)

	Austria					UK					Italy				
Grid Function	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]	

Future work: advanced ESS test protocols

- Sandia and the SIRFN group would like to start shifting toward testing DER functionality on more than just PV inverters.
- Some IEC TR 61850-90-7 functions are specifically designed for energy storage systems. SIRFN will need battery or other controllable ESS in order to evaluate them.
  - INV4 – Request Active Power from Storage
  - INV5 –Signal for Charge/Discharge Action
  - FW22 - limits active power generation and charging in the case of a storage system
  - VW52 - limit energy storage charging rates in response to low grid voltage.
- Sandia is partnering with a SunSpec-compliant power conditioning system designer to start advanced ESS functionality testing with their 3-port design this summer.

SIRFN Goals

- Goals from Grenoble meeting:
  - Goal 1: Establish communications with the inverter through a 3rd party platform. **Complete.**
  - Goal 2: Begin collaborative testing and compare results for the same inverter to demonstrate/exercise the Sandia Test Protocol. **Begun.**
  - Goal 3: Standardize testing for SIRFN members (data collection, etc.) and standardize reporting for interoperability results. **Just started.**
- Goals for next meeting:
  - Goal 1: Finish testing standardization between SIRFN members (e.g., define methods for presenting results).
  - Goal 2: Develop advanced ESS test bed at multiple test laboratories (Sandia, RSE, AIST, etc.)
  - Goal 3: Automate the test protocols using SunSpec, Matlab, or some other software tool at multiple laboratories.
  - Goal 4: Continue to build SunSpec python test scripts for the functions as they become available in inverter/ESS devices.

Thank you

Congratulations to DERlab for becoming the SIRFN Operating Agent