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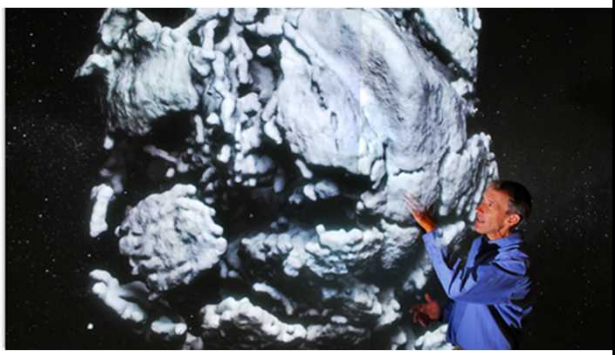

U.S.-Korea Smart Grid Research on Advanced Inverter Interoperability and Functionality

29 Aug, 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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Smart Electricity Grid

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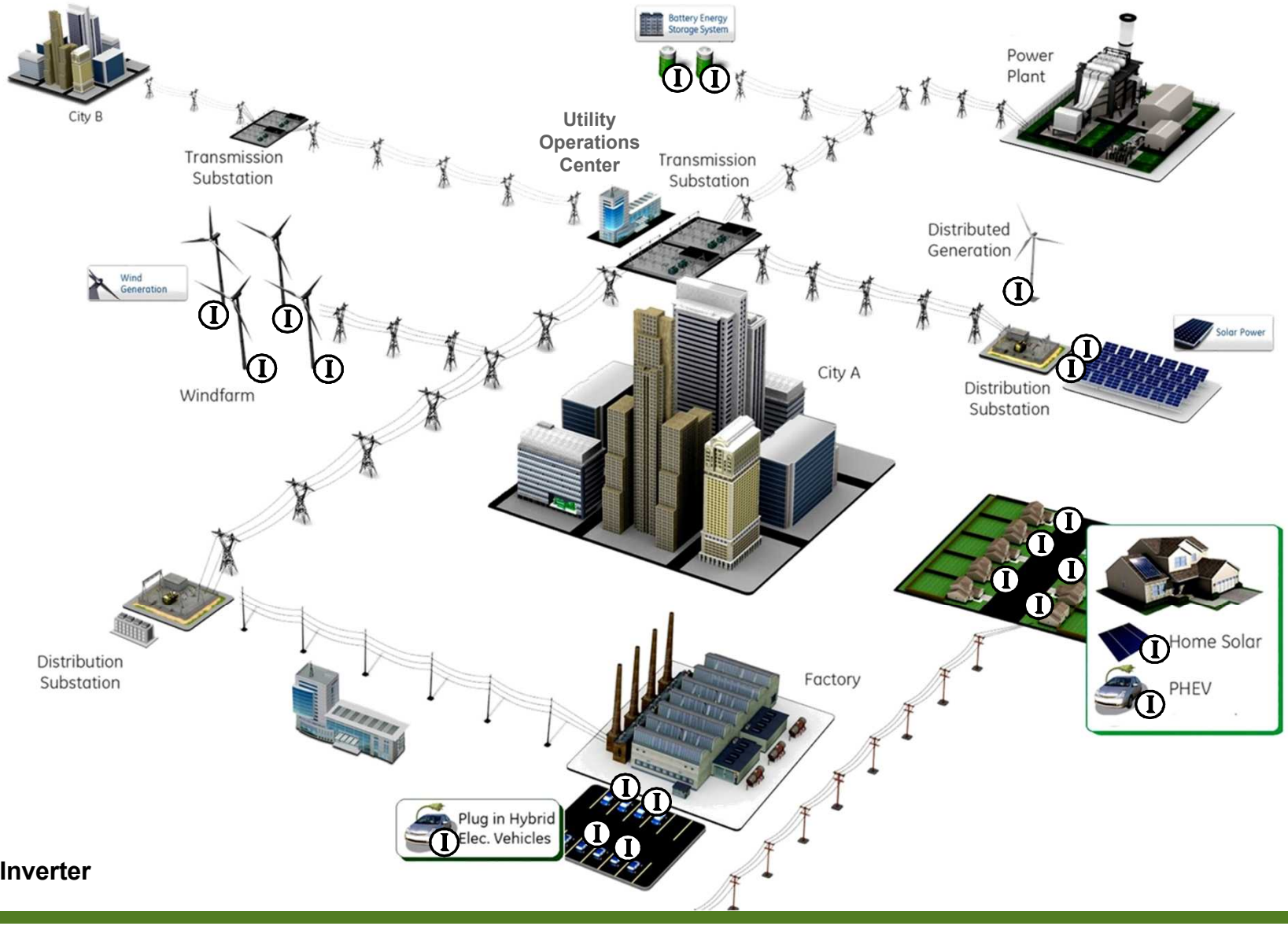

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Smart Electricity Grid Communications

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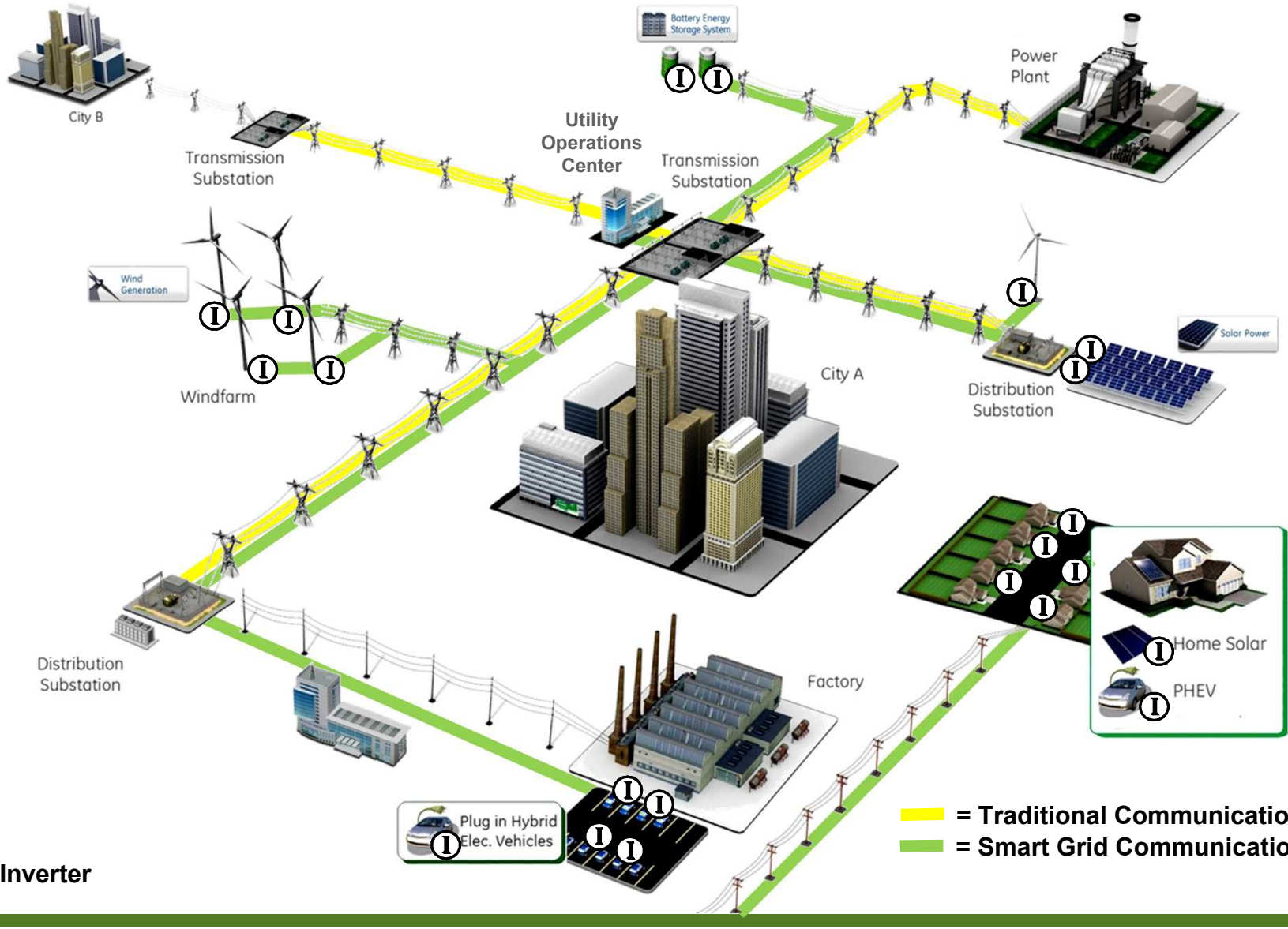

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Smart Electricity Grid Communications

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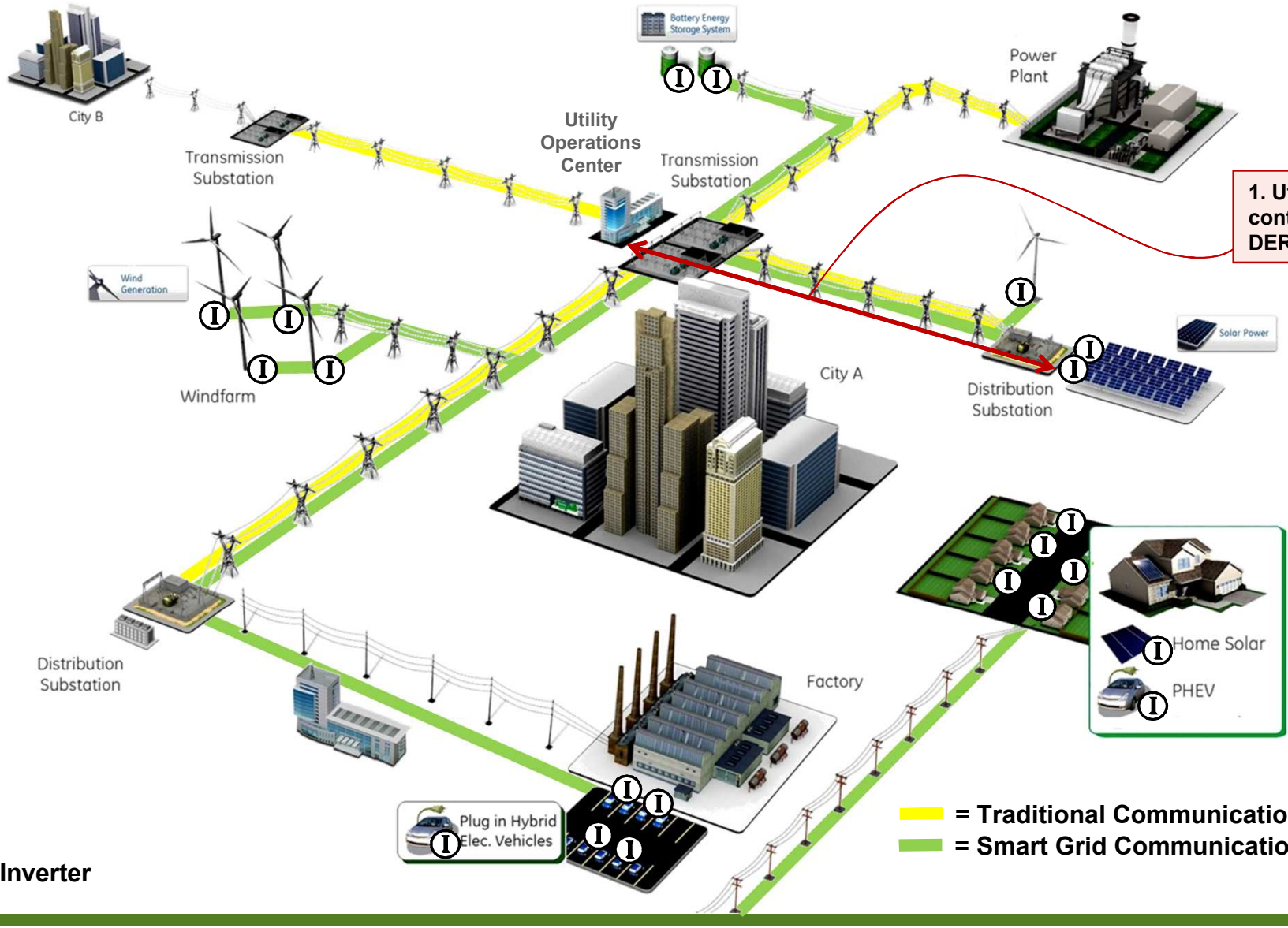

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Smart Electricity Grid Communications

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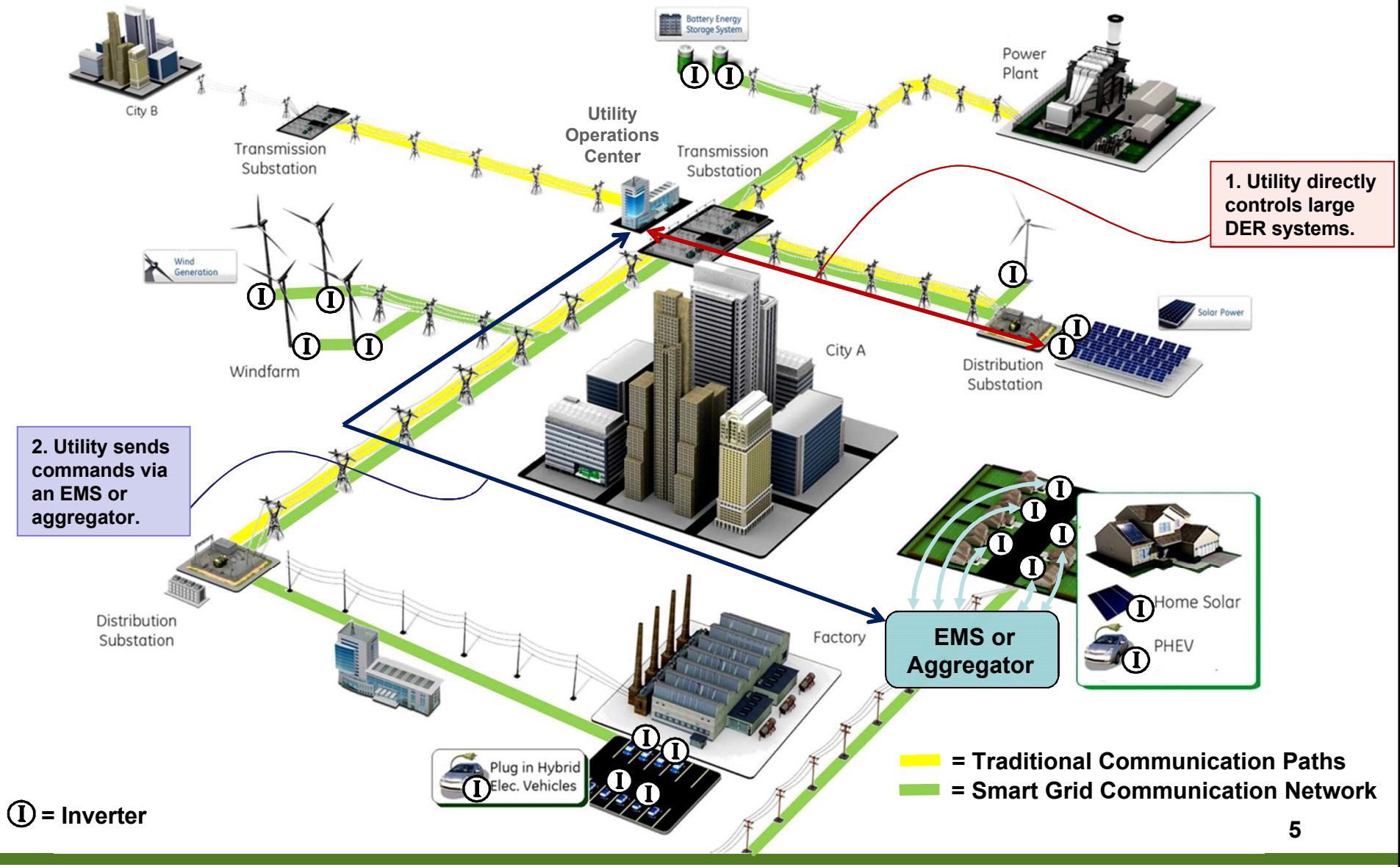

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Smart Electricity Grid Communications

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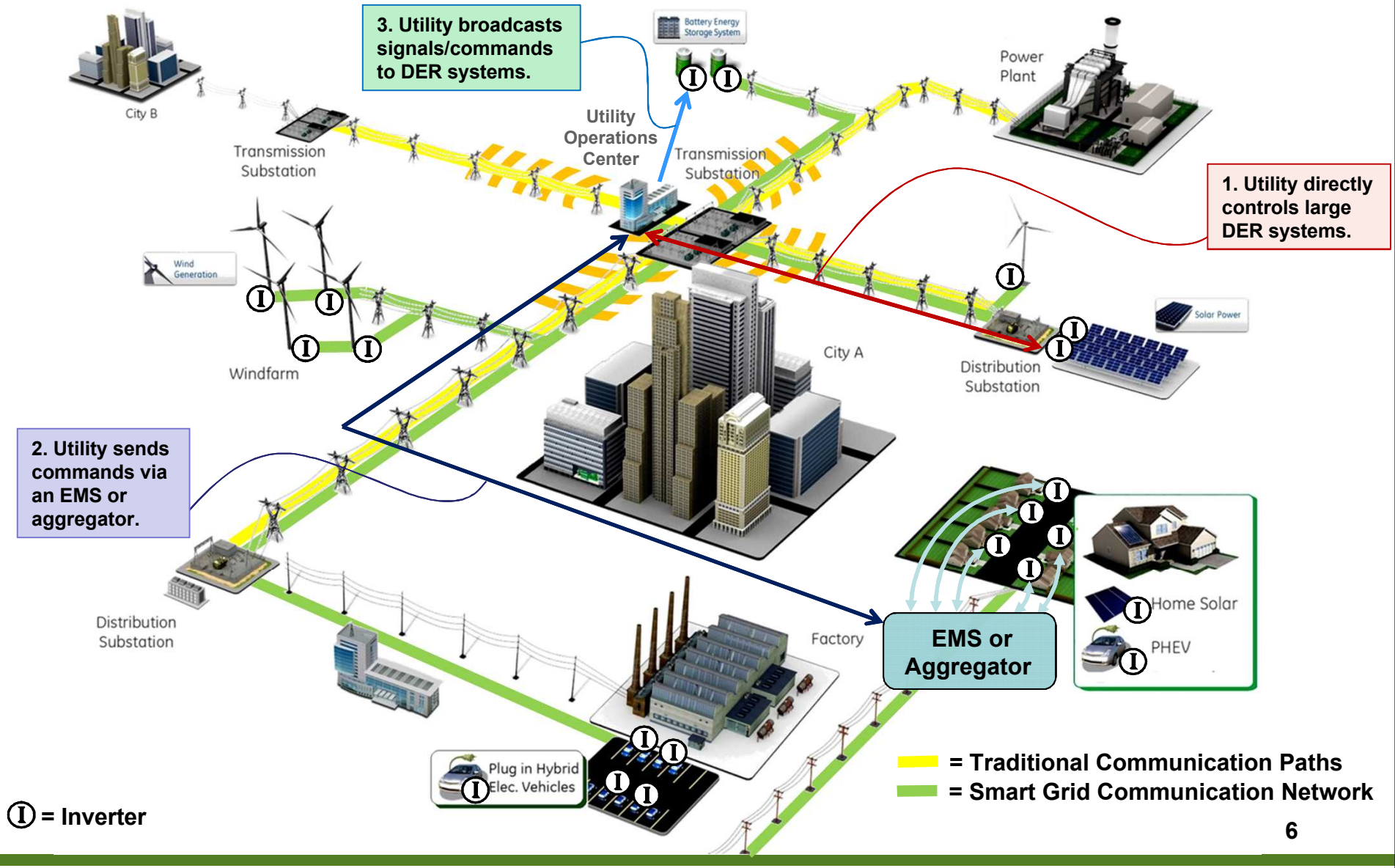
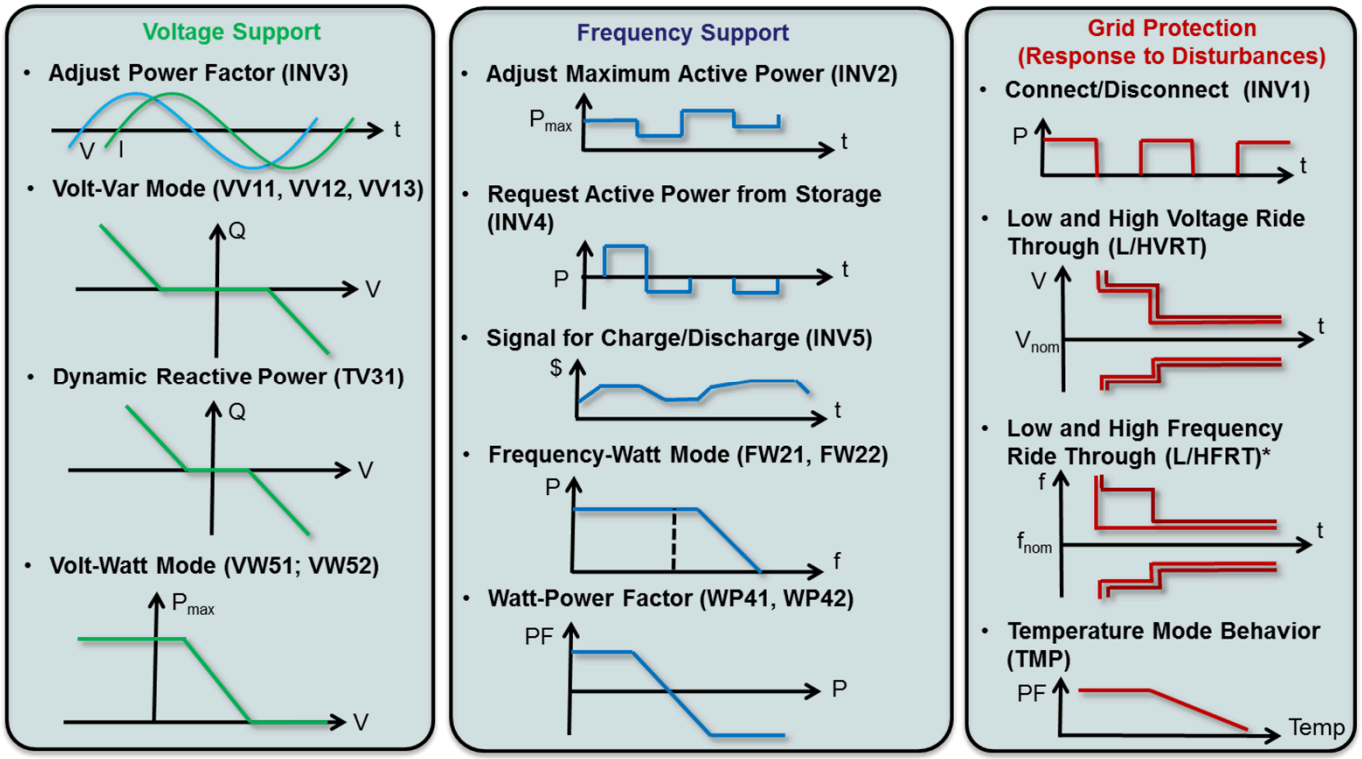


Source: Forbes India

Advanced Interoperability Functions

- New 'smart' inverters will include multiple advanced functions
  - Autonomous: Inverter response to local voltage and frequency conditions
  - Commanded: Remote control (e.g., on/off, set fixed power factor)
- Utilities will modify distributed energy resource (DER) behavior using interoperability communications



Advanced functions as defined in IEC TC 61850-90-7.
*FRT not included in IEC 61850-90-7, but is in Sandia Test Protocols.

Sandia-KERI Smarter Grid Collaboration

- 3-year project started in 2013
  - **Primary goal**: build and demonstrate a consensus-based testing standard for the interoperability of Distributed Energy Resource (DER) devices.
    - Design and construct advanced interoperability test-beds at SNL and KERI.
    - Standardize advanced function testing of PV inverters and energy storage systems.
    - Compare test results, communications methods, and automation procedures.
  - Biannual face-to-face meetings
    - March 2013 - KERI visited Sandia National Labs for project kickoff meeting.
    - Aug 2013 - Sandia attended the Energy Tech Insight Meeting and visited KERI laboratories to provide project updates.
    - April 2014 - KERI visited Sandia National Labs. SNL provided laboratory demonstration of the advanced inverter test-bed and automation platform.
    - Aug 2014 - Sandia visited KERI and attended 2014 Energy Tech Insight Meeting .

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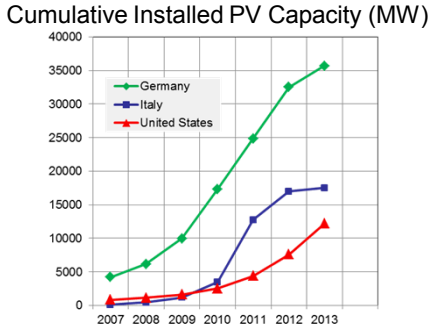
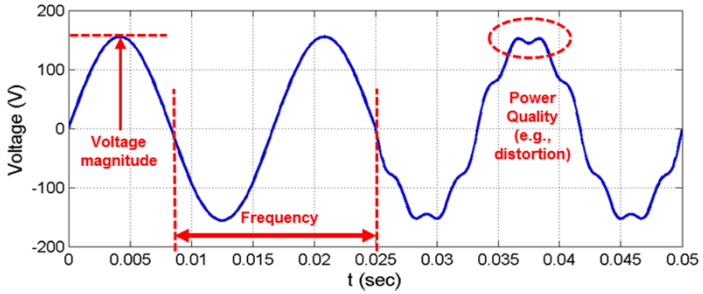
Korea Electrotechnology Research Institute

Importance of SNL-KERI Collaboration

- **SNL-KERI collaboration is important to the deployment of renewable energy in the US, Korea, and rest of the world**
  - More variable renewable energy penetrations
    → grid voltage and frequency stability concerns
  - Inverters must support/stabilize the grid
    - Requirements in Europe and California soon
  - URGENCY to certify inverters for new functionality
    - Sandia National Labs created Advanced Inverter Interoperability Test Protocols as basis for certification
    - SNL and KERI are excising the protocols to verify and improve procedures

- **Goal**: develop a robust consensus certification procedure for advanced inverter functions for adoption by an international standards organization





Sandia and KERI Test-Bed Hardware Comparison

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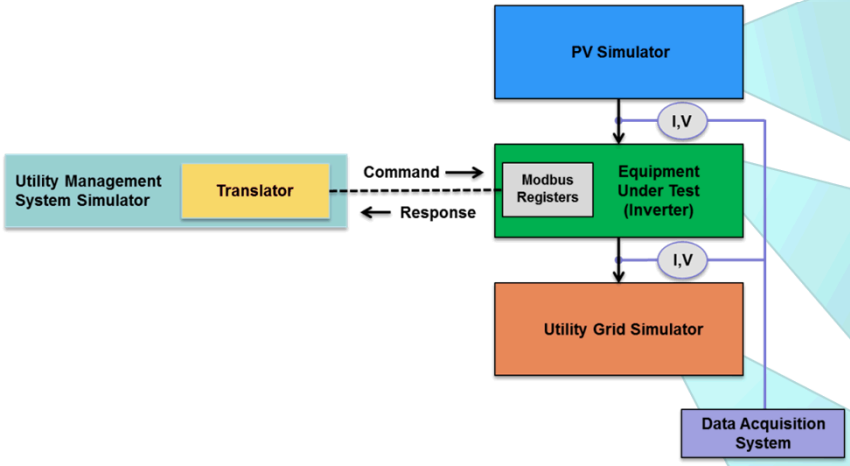
Both Sandia and KERI have built interoperability test-beds. These facilities are running inverter tests in parallel. As difficulties are identified, labs collaborate to address the issues.



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, RS-485, SunSpec

Inverter: Korean Partner
Power: 3 kW
Communications: Modbus, RS-485, 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-L}
3ϕ, 4-wire

Differences in testing hardware demonstrate the robustness of the testing protocols.

SNL and KERI Test-Bed Designs

- Collaboration seeks to compare different laboratory communication methods and automation software

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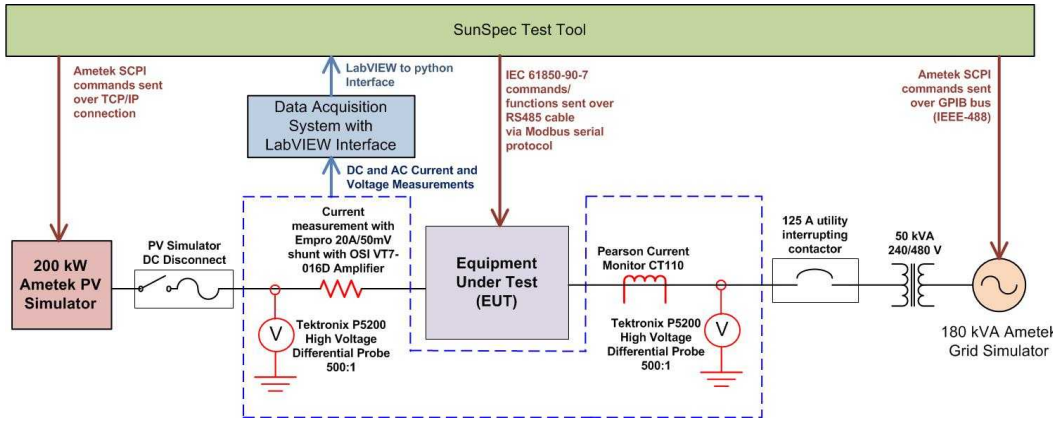
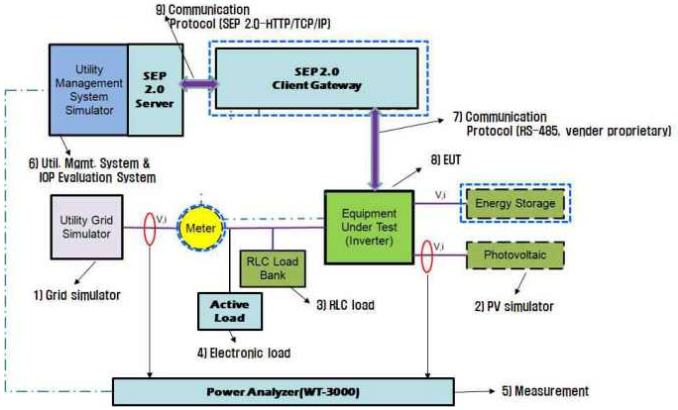
- Equipment Under Test (EUT) communications
  - IEC 61850-90-7 functions/commands via Modbus RTU over RS-485
- Utility to DER gateway
  - SunSpec translator module for DNP3, SEP, and OpenADR
- Data Acquisition
  - National Instruments LabVIEW program connected to instrumentation
- Automation
  - SunSpec test tool graphical user interface (GUI) programmed in python



SNL automated advanced inverter test-bed design

Korea Electrotechnology Research Institute

- EUT communications
  - IEC 61850-90-7 functions/commands via Modbus RTU over RS-485
- Utility to DER gateway
  - SEP 2.0 gateway created by KERI
- Data Acquisition
  - Stand-alone data acquisition system
- Automation
  - Man-machine interface (MMI) GUI designed by KERI

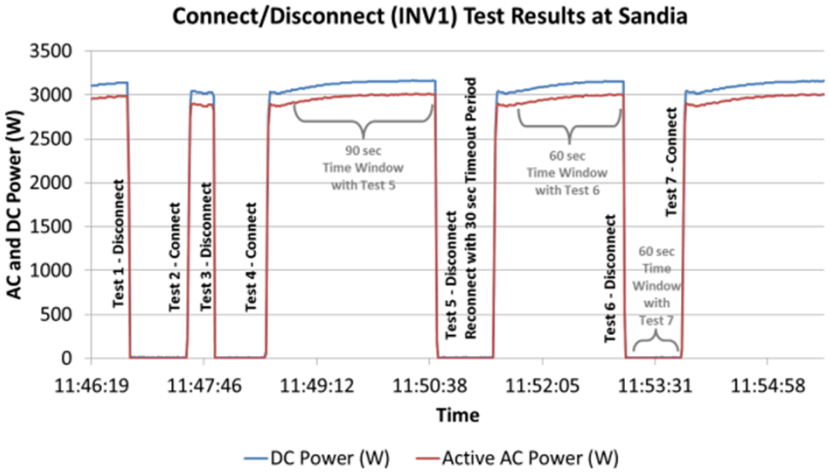


KERI advanced inverter test-bed design

Example Test Protocol (Procedure)

- The Sandia Test Protocols test matrix for the connect/disconnect command.
  - Seven tests with different operating points and parameters.

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



J. Johnson S. Gonzalez, M.E. Ralph, A. Ellis, and R. Broderick, "Test Protocols for Advanced Inverter Interoperability Functions – Appendices," Sandia Technical Report SAND2013-9875, Nov. 2013.

Operator Actions for Fixed PF Testing

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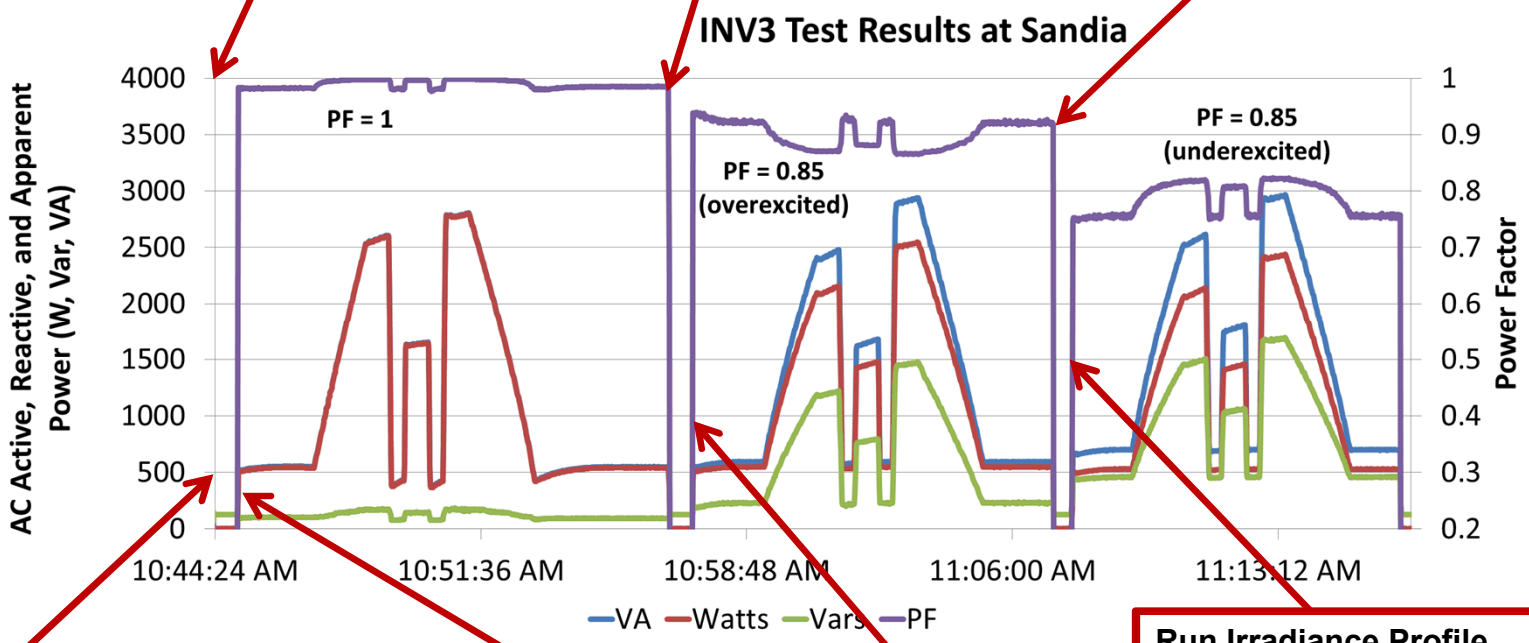


Turn on Inverter

Set Parameters for Test 1

Set Parameters for Test 2

Set Parameters for Test 3

Turn on and configure the grid simulator

Turn on PV Simulator

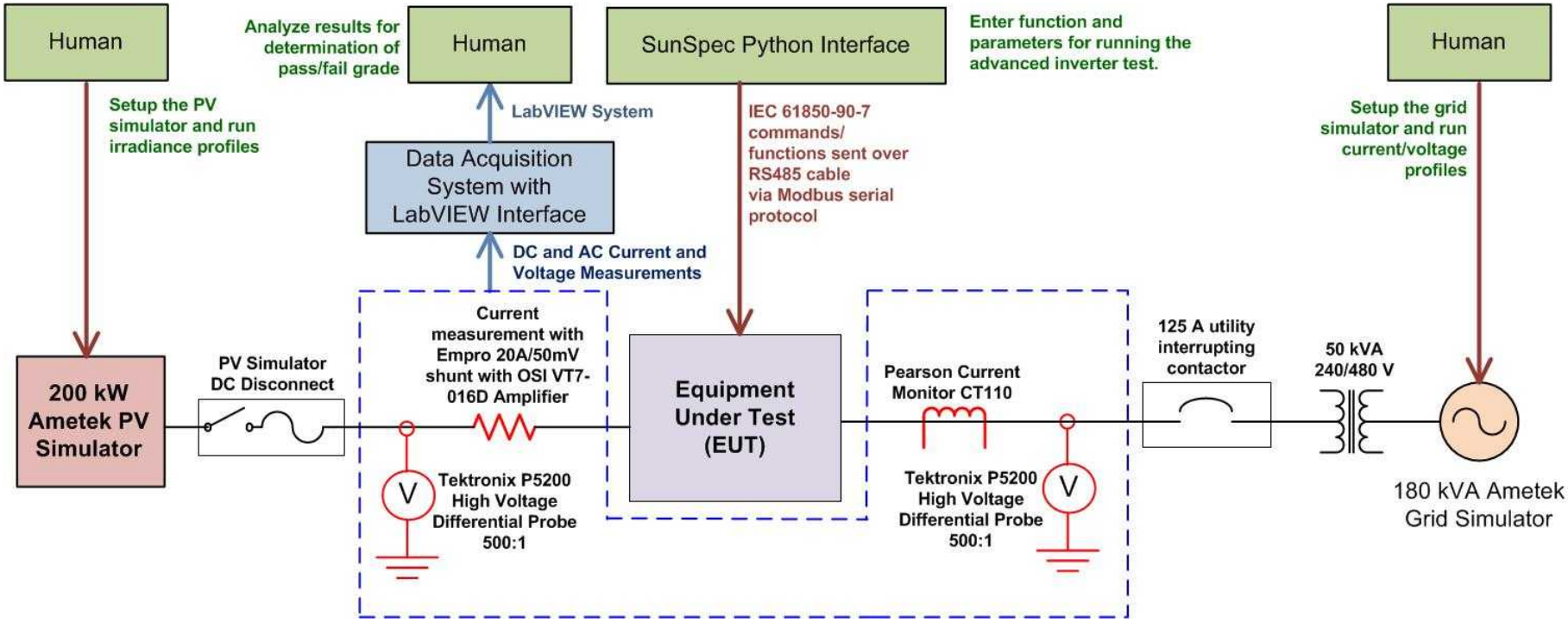
Start Irradiance Profile

Run Irradiance Profile

Run Irradiance Profile

Previous Testing Operations

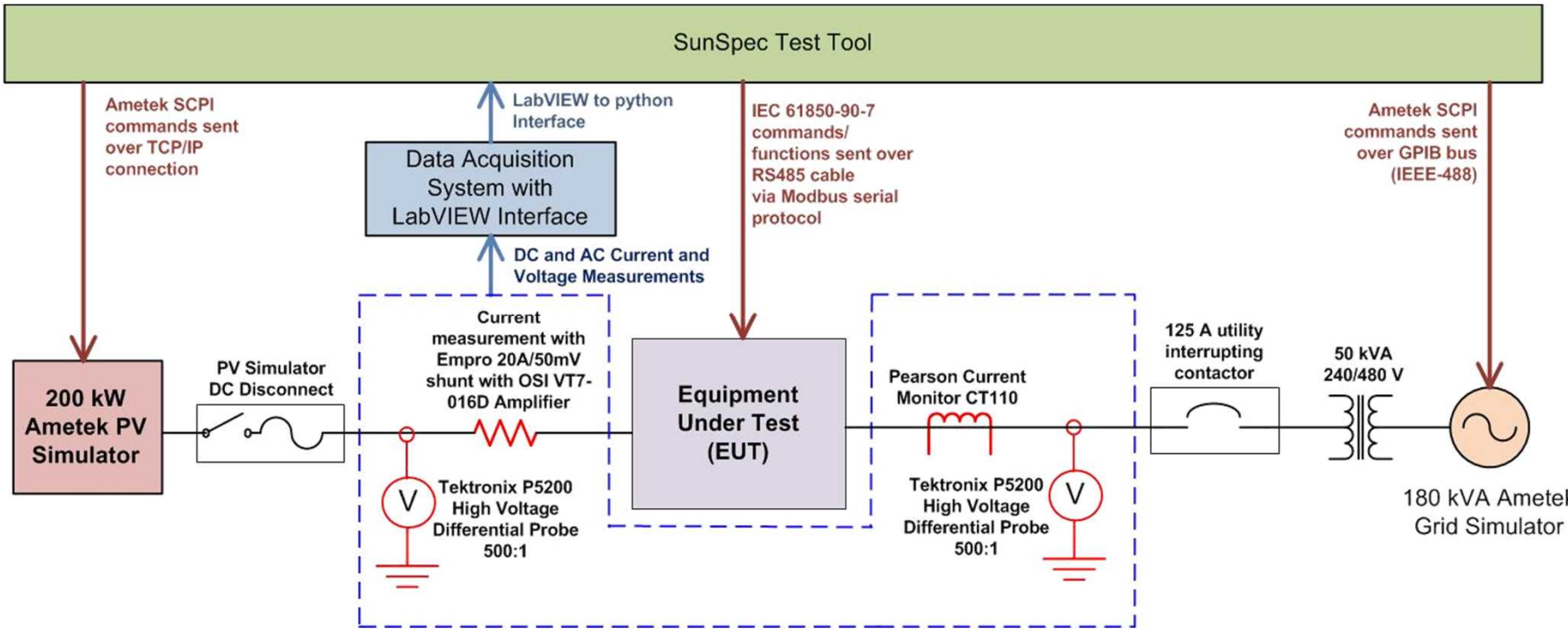
- Requires human interaction with each device.



J. Johnson, B. Fox, "Automating the Sandia Advanced Interoperability Test Protocols," 40th IEEE PVSC, Denver, CO, 8-13 June, 2014.

Sandia/SunSpec Test Tool

- Provides a means to automate the testing process.



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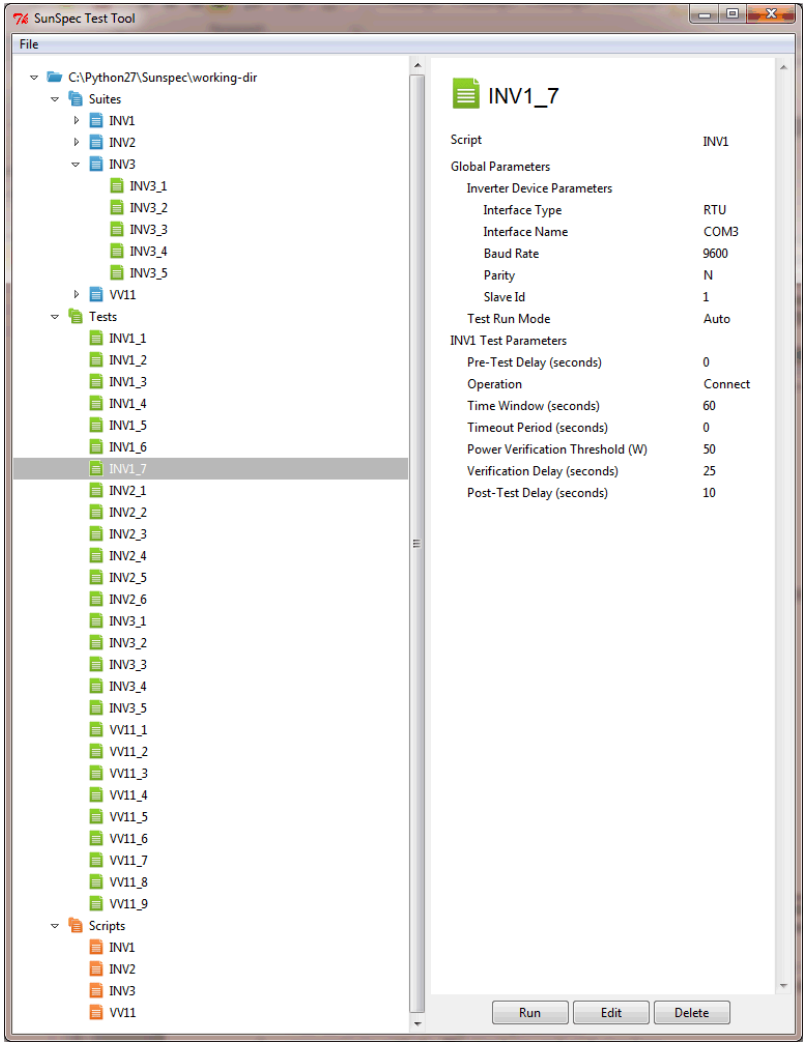
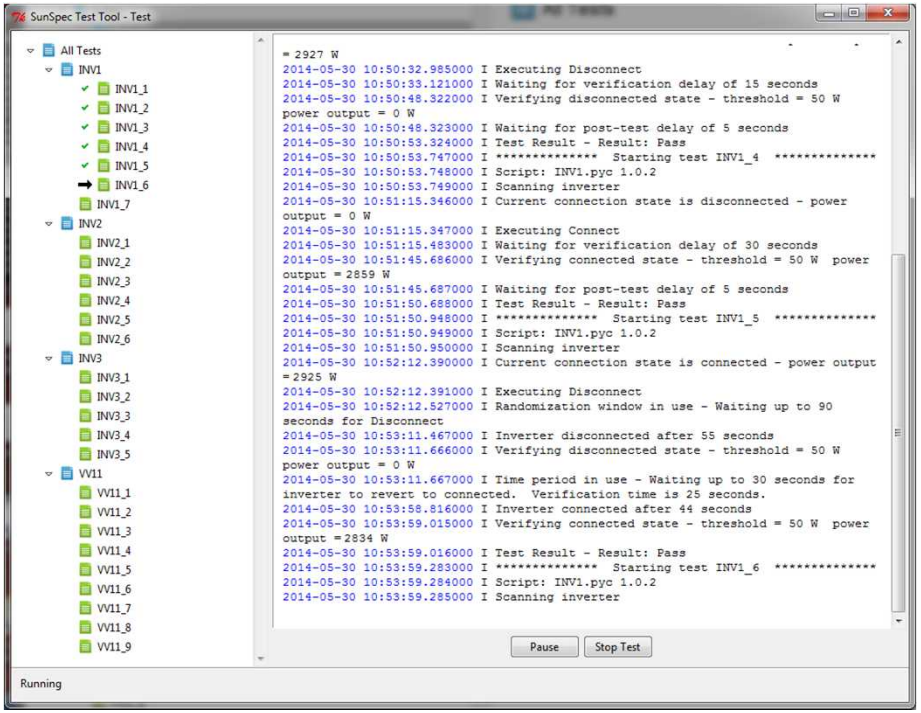
SunSpec Test Tool Graphical User Interface



- Advanced functions written as python *scripts*.
- *Tests* are parameter sets associated with specific functions (scripts).
- *Suites* are collections of multiple tests.



J. Johnson, B. Fox, "Automating the Sandia Advanced Interoperability Test Protocols," 40th IEEE PVSC, Denver, CO, 8-13 June, 2014.

Sandia and KERI advanced function test results

- Sandia and KERI are comparing experiences exercising the Sandia Test Protocols and modify the test procedures and test matrices (parameters) based on the experiments.
- Comparison of results of 3-7 advanced functions planned for the end of the FY.
  - Testing limited by inverter manufacturers - new capabilities being added as grid codes require the functions.

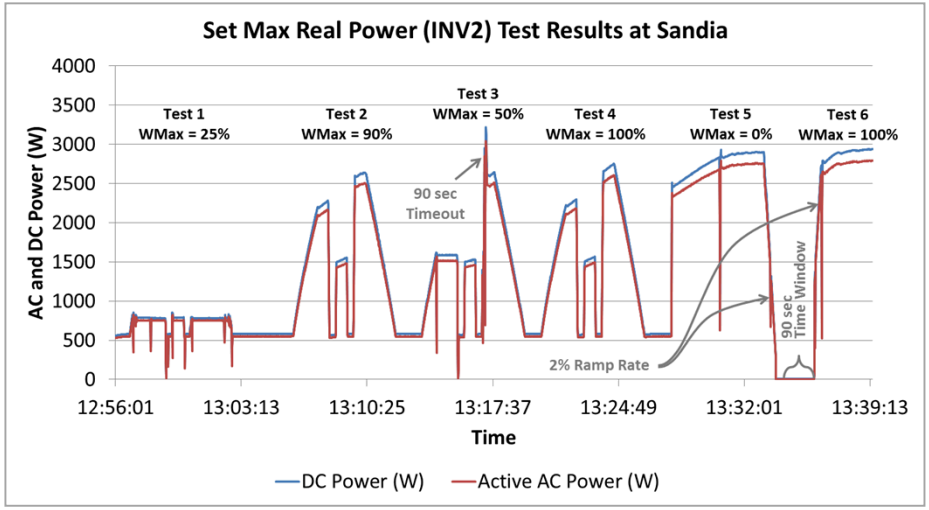
Command	Function
INV1	Connect/Disconnect
INV2	Adjust Max Generation Level
INV3	Adjust Power Factor
INV4	Request Active Power
INV5	PV/Storage Functions
VV11	Volt-Var mode
VV12	Volt-Var mode
VV13	Volt-Var mode
VV14	Volt-Var mode
FW21	Set maximum power output
FW22	Set maximum power output
TV31	Dynamic reactive power support
L/H VRT	Stay connected/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

Implementation Successful

Implementation Partly Successful

Implementation Unsuccessful

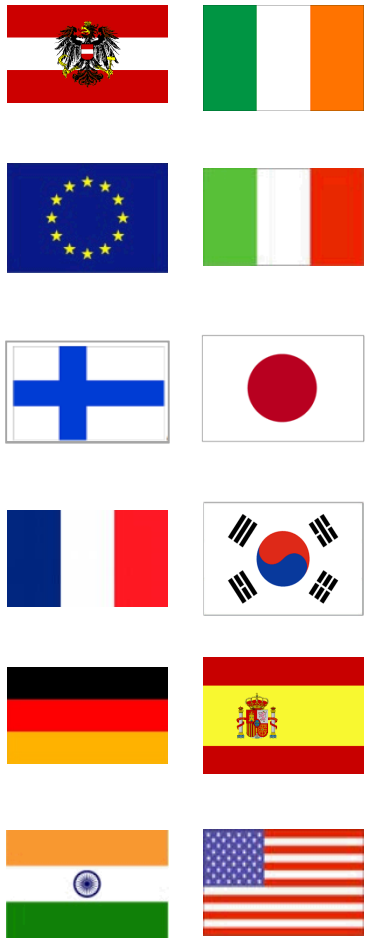
Implementation by the end of FY14



Opportunities for KERI in SIRFN

- Sandia National Laboratories and the US Department of Energy encourage KERI to join SIRFN (Smart Grid International Research Facilities Network)
  - SIRFN is a coordinated network of Smart Grid research and test-bed facilities and selected projects in countries participating in ISGAN (International Smart Grid Action Network)
- SIRFN activities are closely aligned with the SNL-KERI collaboration
  - Improves test procedures for advanced PV inverters with the goal of becoming an internationally-accepted basis
  - Performs round-robin testing of the Sandia Test Protocols with 3 kW PV inverters
- SNL, NREL, AIT, RSE, Tecnalia, and AIST are active in this project—would like to have KERI participate!
  - Currently KATS (Korean Agency for Technology and Standards) is the only Korea representative to SIRFN, but they do not have a research test laboratory for advanced inverter testing.
  - <u>We recommend KERI join SIRFN to participate in this research collaboration.</u>

SIRFN Participants



Conclusions

- Advanced functions in PV inverters and energy storage systems can stabilize the grid
  - —especially with greater penetrations of variable renewable energy sources
- Need a standardized method for verifying the functionality
  - Sandia Test Protocols are acting as the starting point
- Sandia and KERI are:
  - Building test-beds for advanced inverter testing
    - Hardware – PV and grid simulators, data acquisition system, etc.
    - Software – communications tools, utility simulators, automation routines, data analysis, etc.
  - Comparing results from inverters to improve certification test protocols
    - Collaboration demonstrates test protocols are effective worldwide
  - SNL and KERI are systematically modifying the testing procedure
    - Improved protocols will be recommended as an international standard

Thank you. 감사합니다.

Additional Questions or Comments to:

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Extra Slides

Scope of Work and Timeline

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Project Title		Development of Test Bed for DER Interoperability and Certification System			
Period of Performance		FROM: 01-12-2012 TO: 30-11-2015			
		Year 1	Year 2	Year 3	**Total**
Project Period		01-12-2012 ~ 30-11-2013	01-12-2013 ~ 30-11-2014	01-12-2014 ~ 30-11-2015	**1-12-2012~30-11-15**
Total Budget (1000 KRW = 1 USD)	KERI	KRW 373,700,000	KRW 300,000,000	KRW 300,000,000	**KRW 973,700,000**
		- Design and **construct PV/ESS testbed** - Establish utility to DER communication - Review & revise of draft standardized test procedure and data acquisition protocol - **Develop standardized analysis procedure and test reporting** - **Compare Korean and U.S. results** - Test PV inverters: 2 to 4 functions	- Construct testbed for PV/ESS (continued) - Amplification of PV inverter tests: **3-10 new inverter functions; residential to commercial scale** **- Revise interoperability protocol based on prior results** - Compare Korean and U.S. results - Status report on program and results.	- Amplification of PV and ESS tests: complete set of inverter functions **- Use experimental results to propose a test protocol standard (IEC)** - Final report on program and results.	
	SNL	200,000 USD-	200,000 USD-	200,000 USD	**600,000 USD**
		- Design and construct testbed - Establish utility to DER communication **- Draft standardized test procedure and data acquisition protocol** - Develop standardized analysis procedure and test reporting - Compare Korean and U.S. results **- Test PV inverters: 2 to 4 functions**	**- Amplification of PV inverter tests: 3-10 new inverter functions; residential to commercial scale** - Revise interoperability protocol based on prior results **- Compare Korean and U.S. results** - Design, construct, exercise testbed for ESS incorporation - Status report on program and results.	- Amplification of PV and ESS tests: complete set of inverter functions **- Use experimental results to propose a test protocol standard (IEC)** - Final report on program and results	

KERI communications