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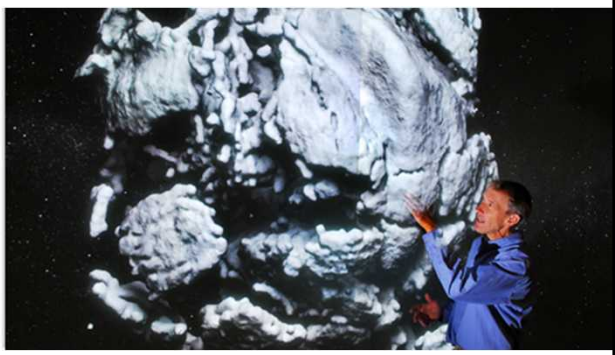

U.S.-Korea Smart Grid Research on Advanced Inverter Interoperability and Functionality

21 Aug, 2015

Jack Flicker and Jay Johnson

Sandia National Laboratories

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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Smart Electricity Grid

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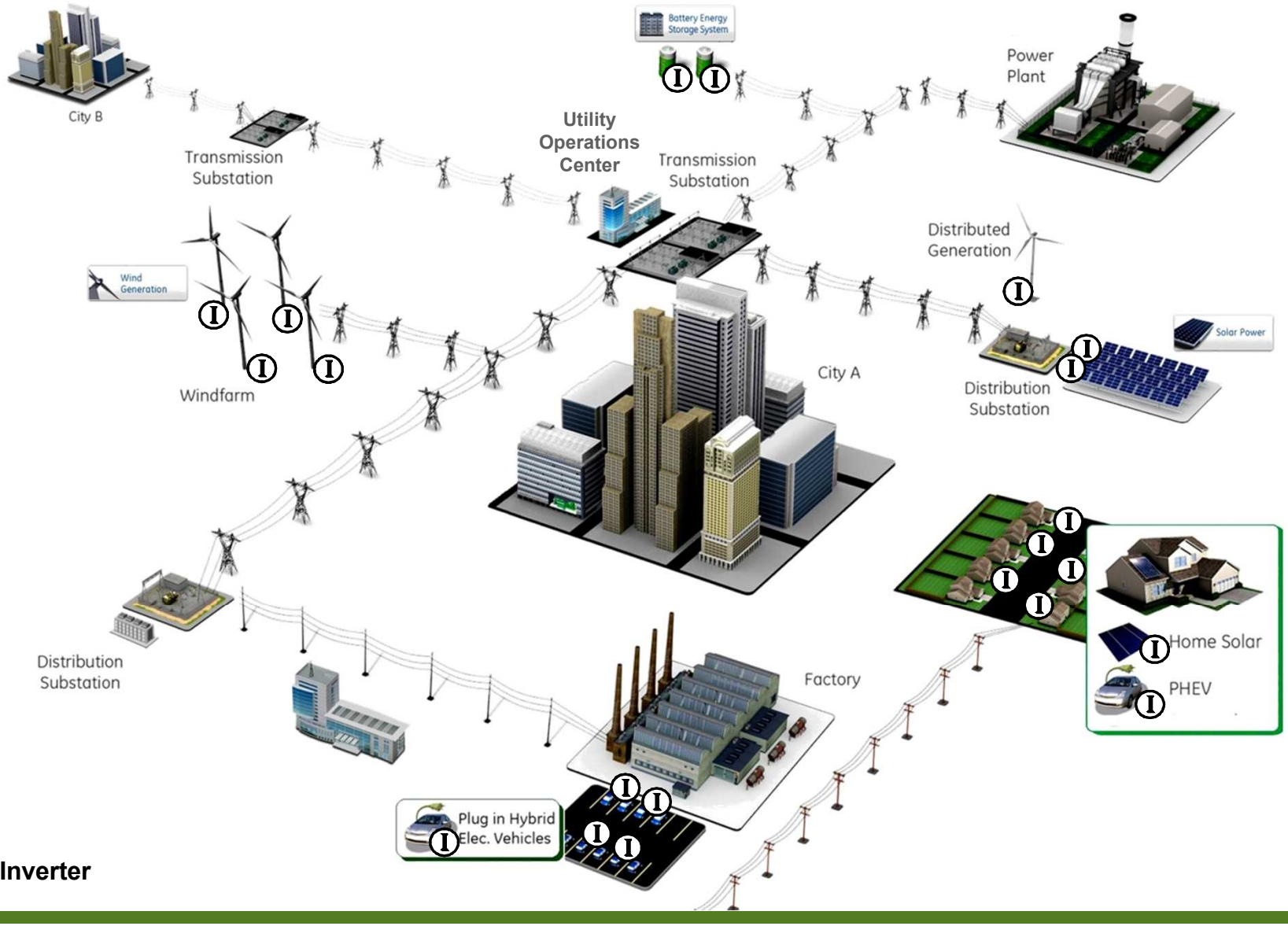

Image: Forbes India

Smart Electricity Grid Communications

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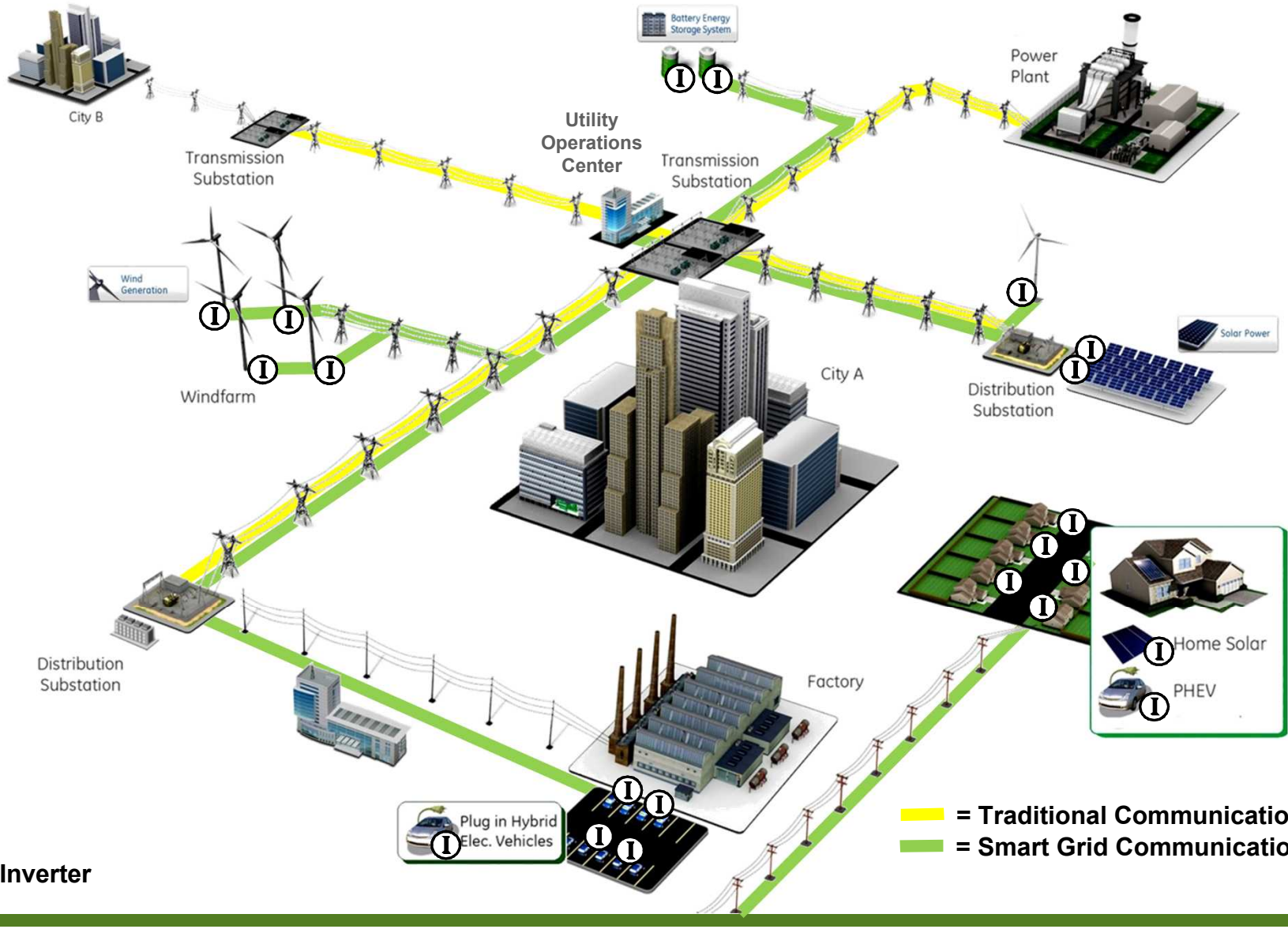

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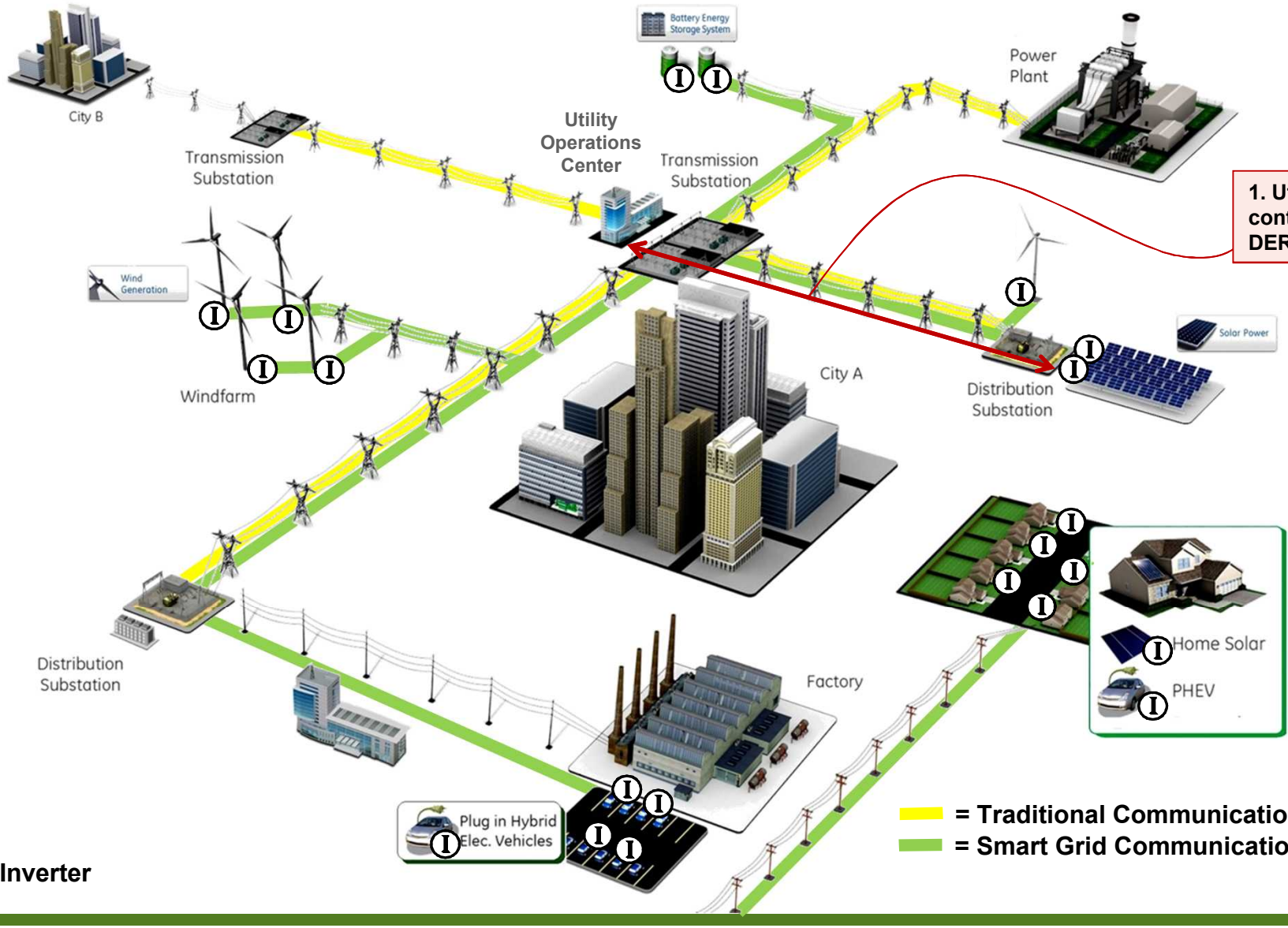
Smart Electricity Grid Communications

Sandia National Laboratories



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Smart Electricity Grid Communications

Sandia National Laboratories

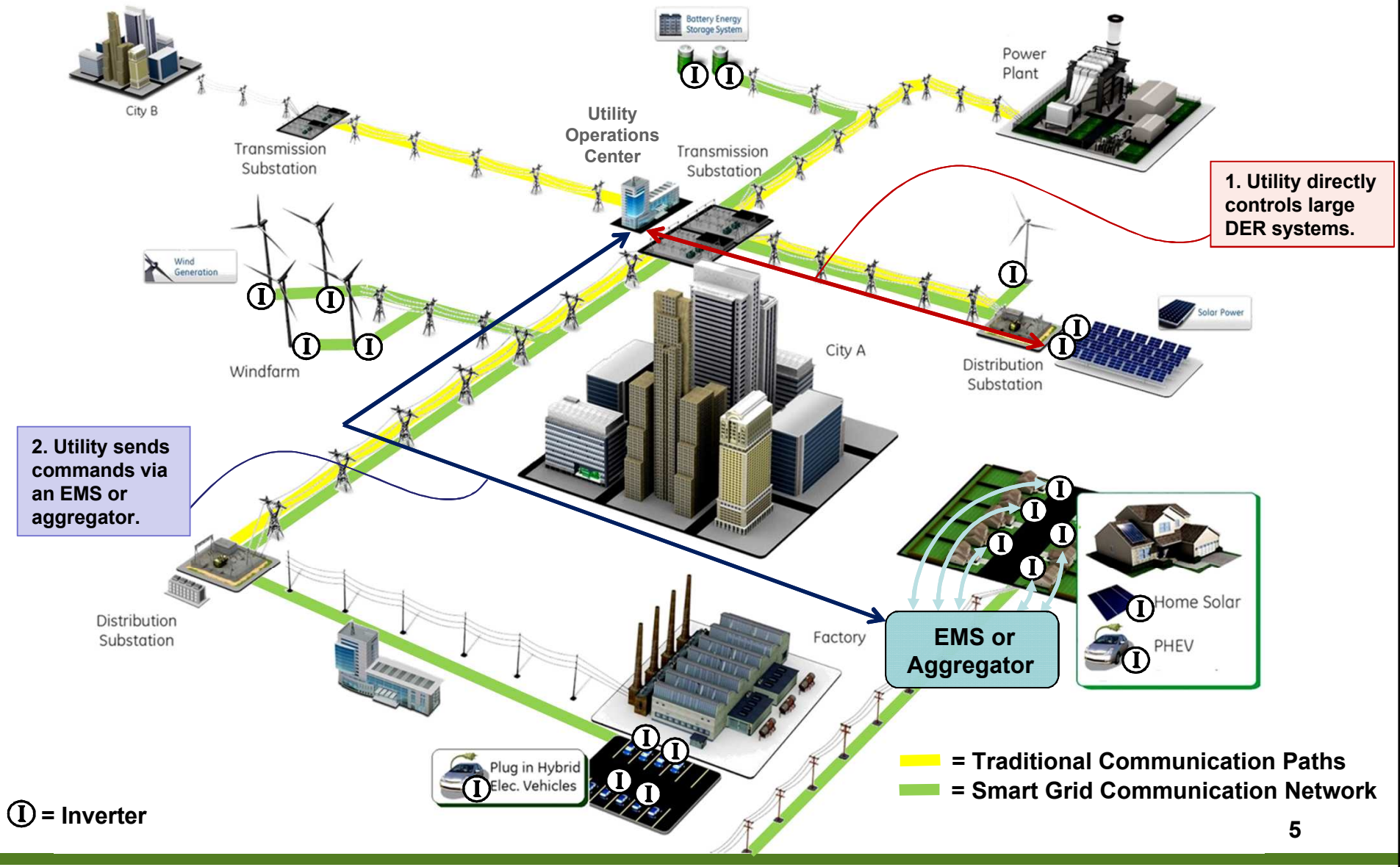

Image: Forbes India

Smart Electricity Grid Communications

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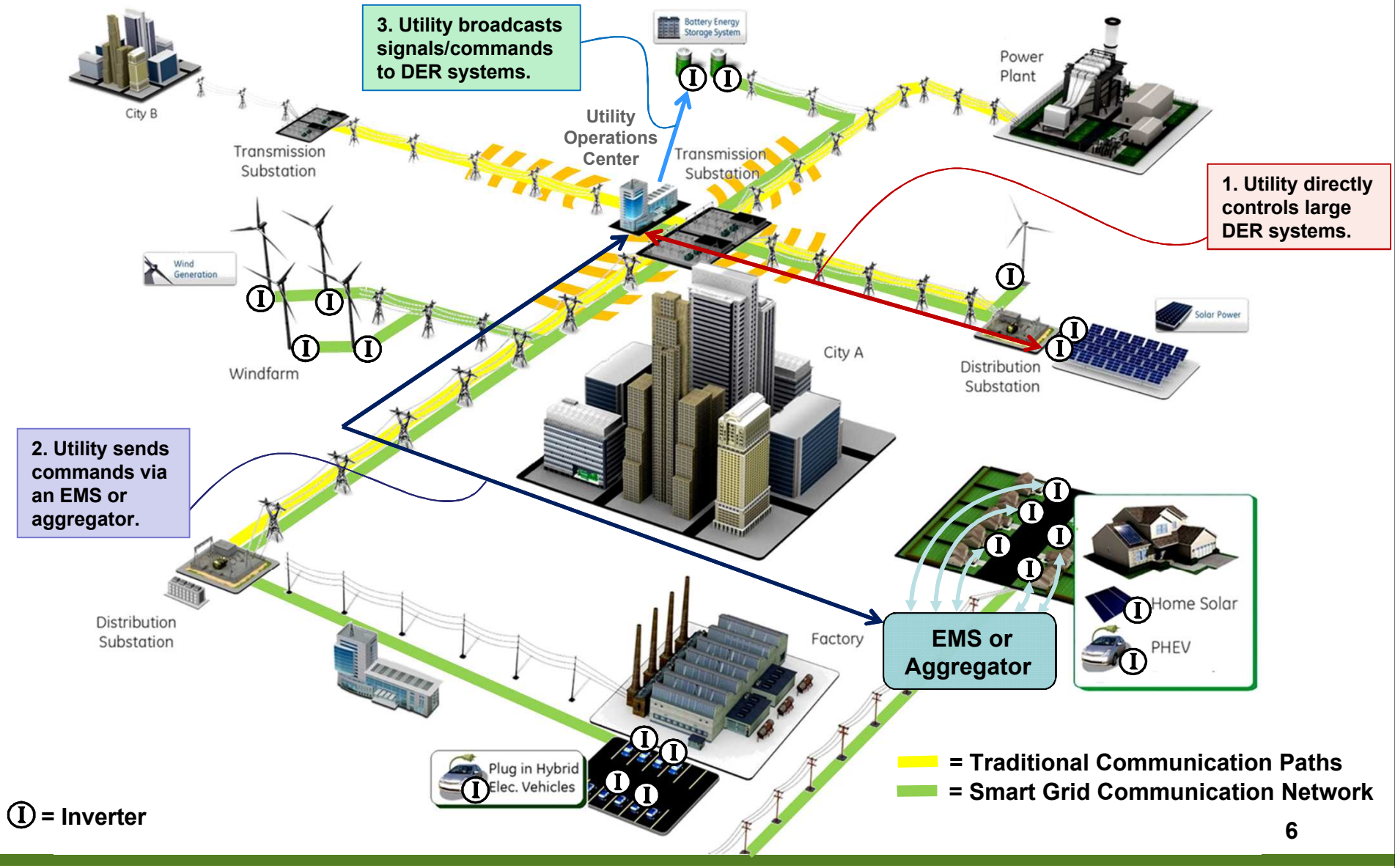
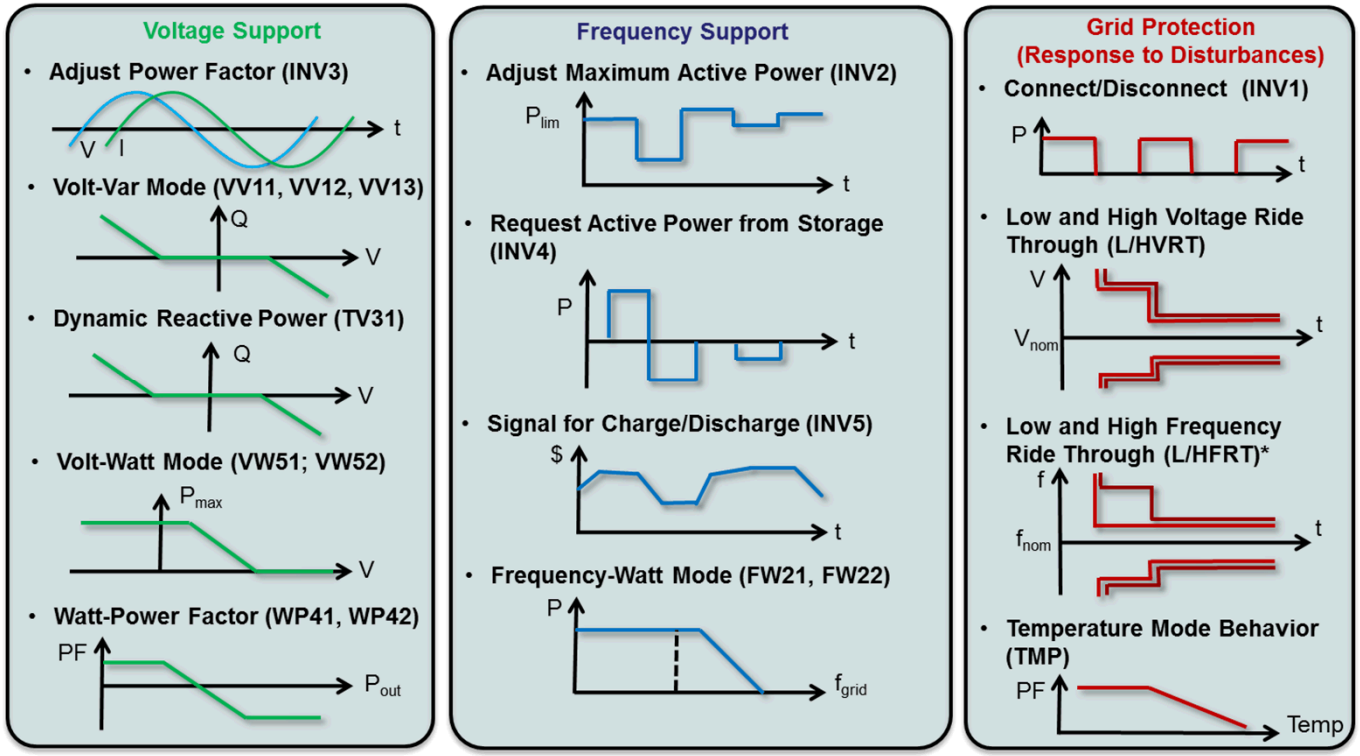


Source: Forbes India

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 power factor)
- Utilities will modify distributed energy resource (DER) behavior using communications. Reliable interoperability will be required.



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

Sandia-KERI Smart Grid Collaboration

- 3-year project started in 2013
  - **Primary goal**: develop 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.

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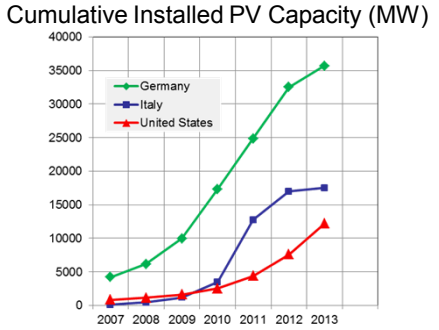
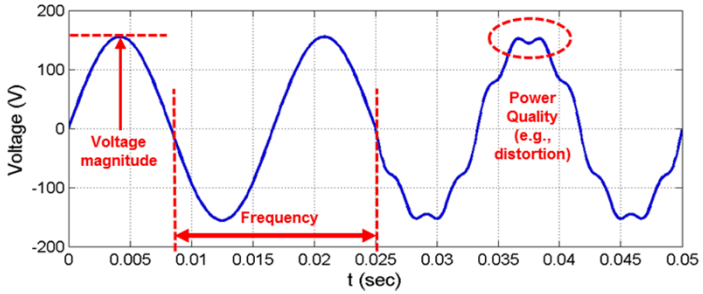
Importance of SNL-KERI Collaboration

- **SNL-KERI collaboration is helping accelerate the deployment of renewable energy in the US, Korea, and rest of the world**
  - Higher renewable energy penetrations
    → grid voltage and frequency stability concerns
  - Inverters must now support/stabilize the grid
  - **Urgency in U.S. to certify inverters for new requirements** – both electrical performance and communications
    - Need advanced inverter test protocols for CPUC Electric Rule 21
    - Sandia protocols act as basis for updates to UL 1741
  - **Goal**: develop a robust consensus certification procedure for advanced inverter functions for adoption by international standards organizations





Sandia and KERI Test-Bed Hardware Comparison

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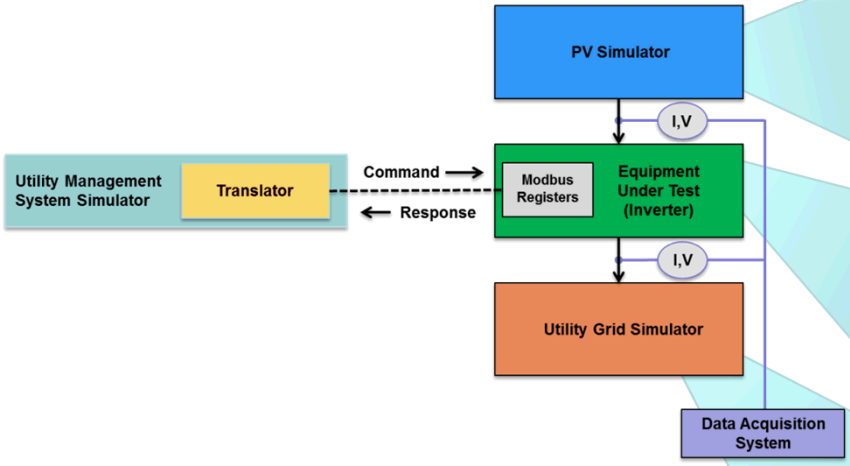
Both Sandia and KERI have built advanced inverter test-beds. These facilities are running inverter tests in parallel. As difficulties are identified, both partners collaborate to address the issues.



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: 250 A/Phase

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

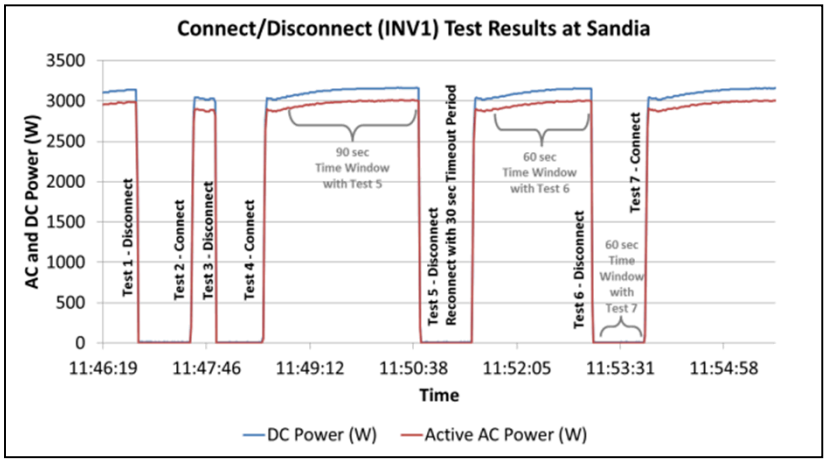
Differences in testing hardware demonstrate the robustness of the testing protocols.

Test Protocol Development

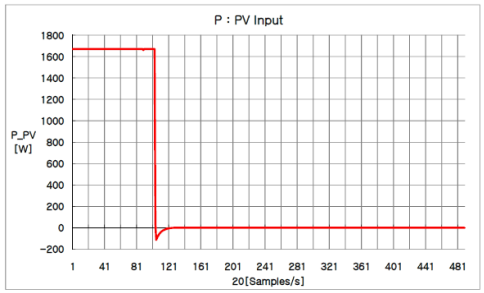
- The Sandia Test Protocols were the basis for the tests.
  - Based on the limitations of test hardware, only some AGFs were tested by both laboratories:
    - INV1: Connect/Disconnect
    - INV2: Active Power Curtailment
    - INV3: Fixed Power factor

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

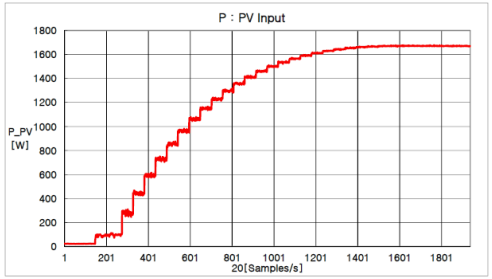
INV1 Test Matrix



Sandia INV1, Tests 1-7



KERI INV1, Test 1



KERI INV1, Test 2

Sandia Test Protocols

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.

INV2 and INV3 Results

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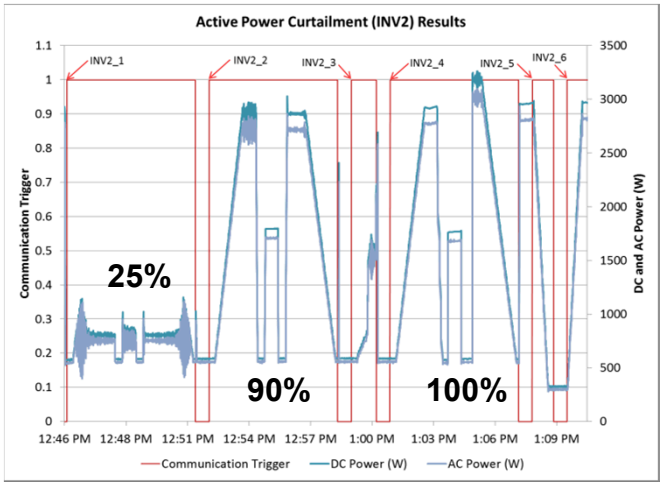
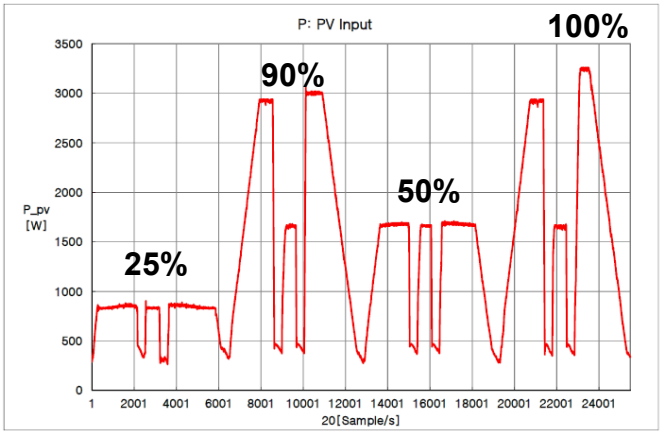
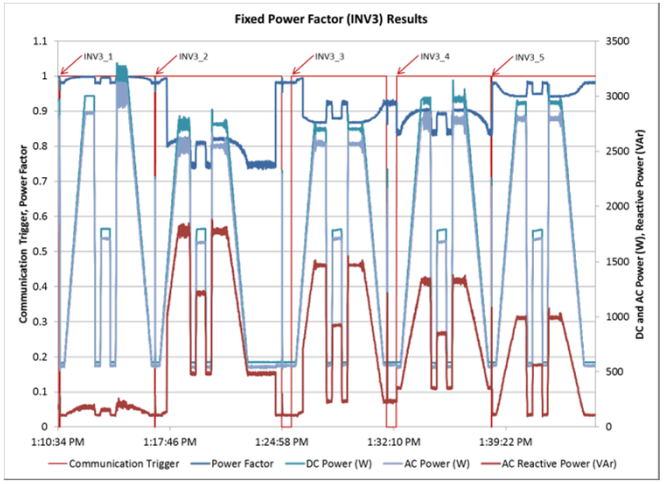
Sandia Test Results

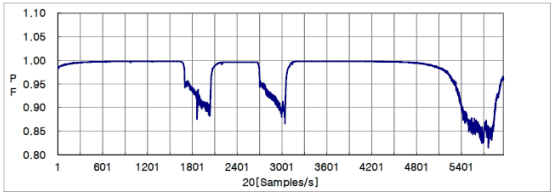


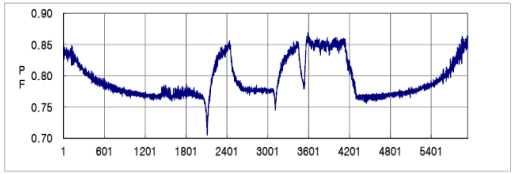
KERI Test Results

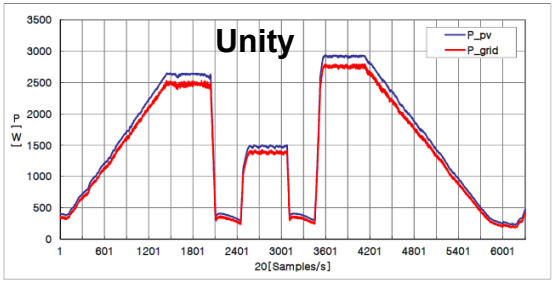


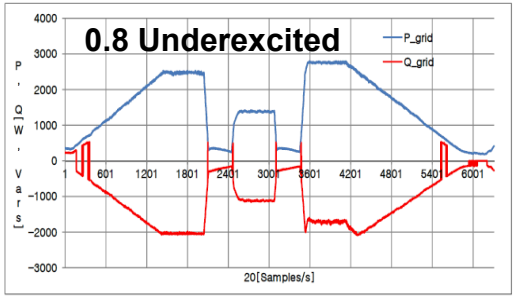


Fixed Power Factor Tests



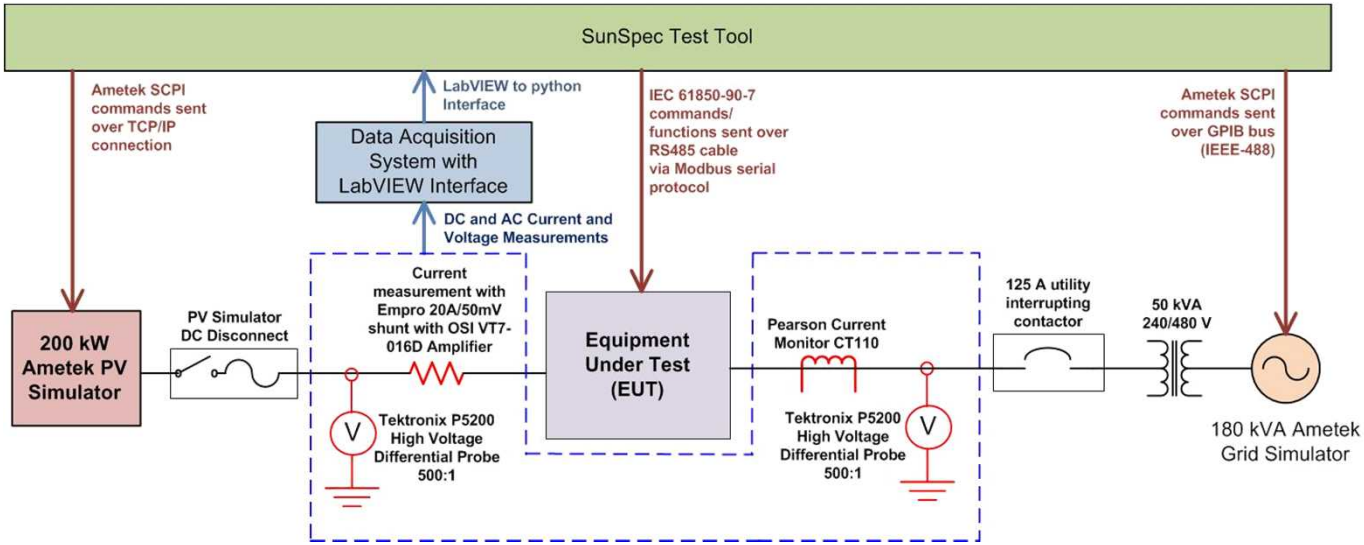






Program Impact

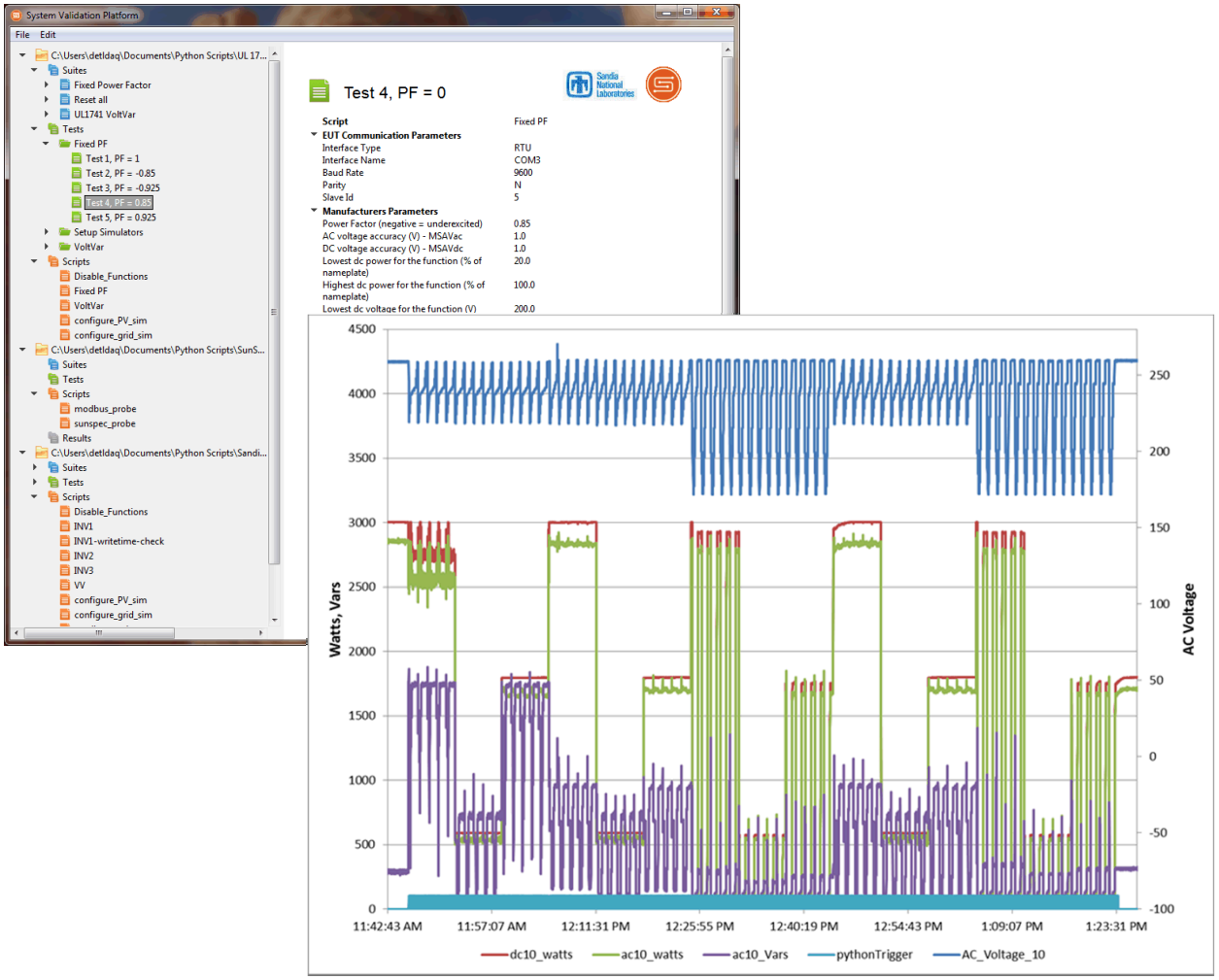
- The research project has resulted in many successes!
  - The refined test protocols for the project have acted as **the basis for** the new testing requirements in the United States known as **UL 1741 Supplement A**.
  - As part of the project, Sandia has worked with the **SunSpec Alliance** to create an automated **System Validation Platform (SVP)**.
    - This software allows test scripts to be passed between laboratories.
      - KERI and Sandia have copies of the software program.
    - Underwriters Laboratories is investigating the SVP for certification testing



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

SunSpec/Sandia System Validation Platform

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



Automated UL 1741 SA volt-var tests. 375 measurement points.

Conclusions

- PV inverter **advanced functions help support** the **electricity grid**.
- **Standardized test methods** for verifying **DER functionality** and **interoperability** are **critical**.
  - In the U.S., many **jurisdictions** are **considering smart DER requirements**
- **Sandia and KERI** are **improving certification protocols** 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.
- Program is expected to continue under the multi-lateral Smart Grid International Research Facilities Network (SIRFN).

Thank you. 감사합니다.

Additional Questions or Comments to:

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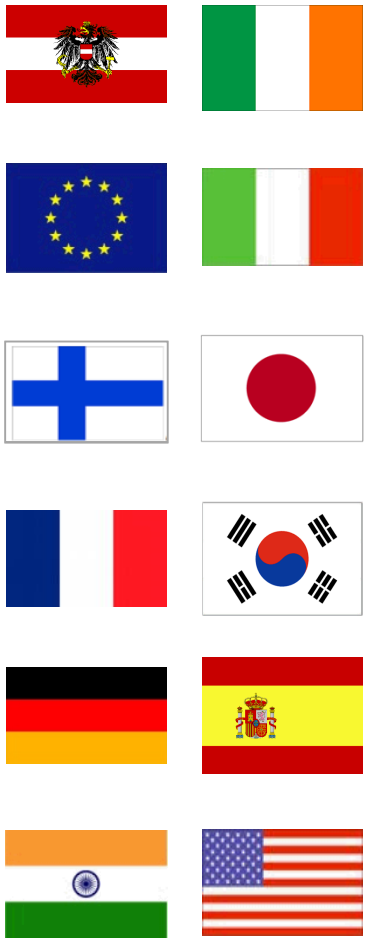
Future Steps: KERI participation in SIRFN

- Sandia National Laboratories and the US Department of Energy are working on similar efforts under 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 residential PV inverters
- SNL, NREL, AIT, RSE, Tecnalia, and AIST are active with the project
  - 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 (KERI does).
  - KERI's participation in SIRFN would be beneficial to all parties

SIRFN Participants



Communications at SNL and KERI

- Collaboration seeks to also compare different laboratory test-bed communication methods and software (not only hardware)

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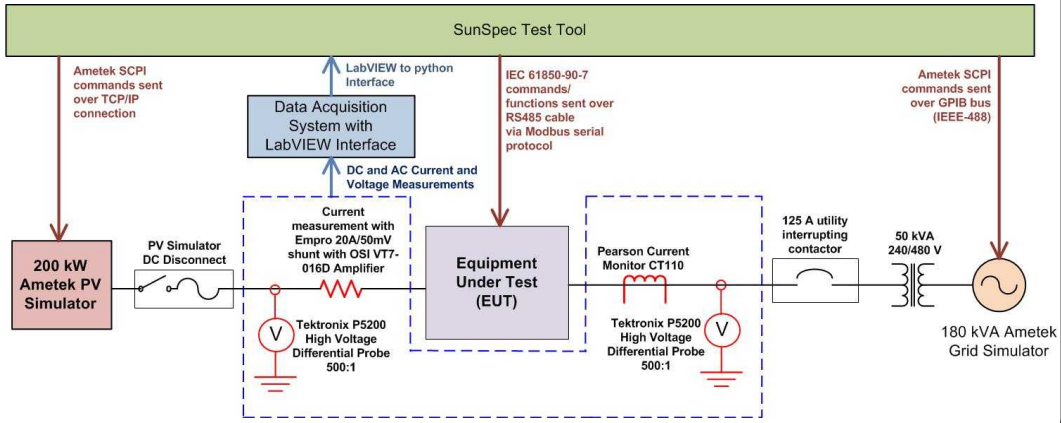
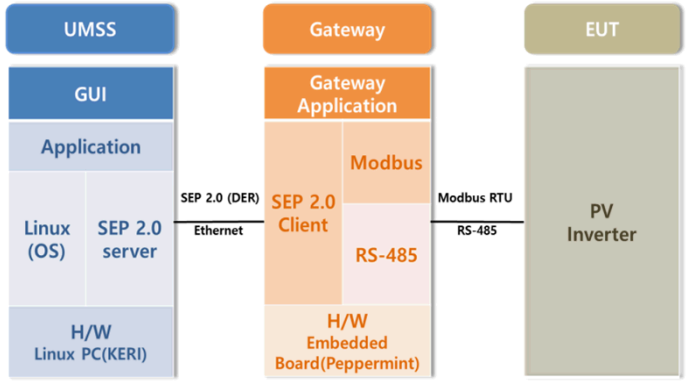
- Equipment Under Test (EUT) communications
  - IEC 61850-90-7 functions/commands via Modbus RTU over RS-485
- Utility to DER gateway
  - SunSpec translator module for DNP3, SEP 2.0 (IEEE 2030.5), and OpenADR
- Data Acquisition
  - National Instruments LabVIEW program connected to instrumentation
- Automation
  - 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 communications system design