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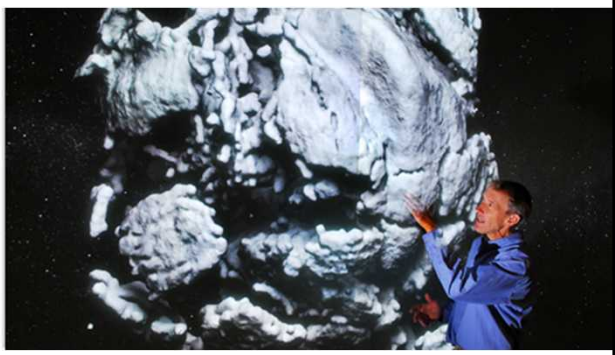

# Specifications for Advanced PV Inverters:

## Functions, Settings, and Communications

**Jay Johnson**

**Photovoltaics and Distributed Systems Integration Department**

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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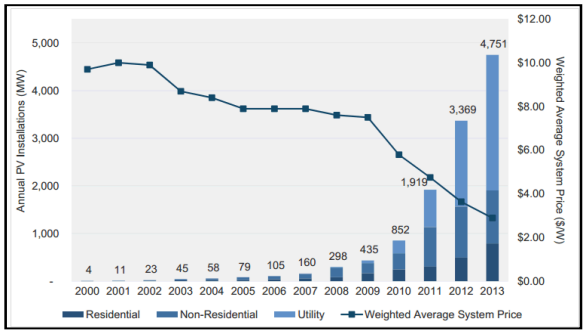
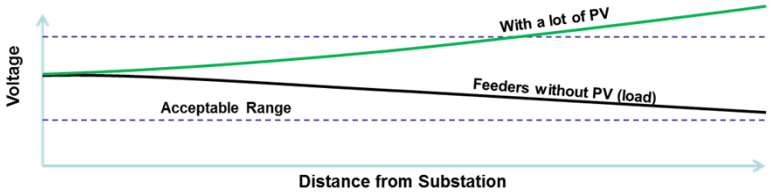
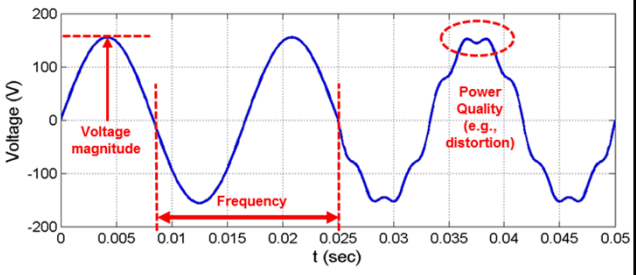
# Outline

- The context
  - Total installed capacity of PV is growing fast
    - Aiming for 12 GW of grid-connected renewable energy in CA by 2020!
  - Large growth expected in distribution systems
- New problems
  - Voltage & frequency control
  - Protection and disturbance recovery
  - System stability
- Advanced inverters are a big part of the solution, but we need:
  - Definitions for advanced grid **functions**
  - Recommendations for default **settings** for advanced functions
  - Reliable and secure **communication** methods for interoperability




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



# Current Electricity Grid

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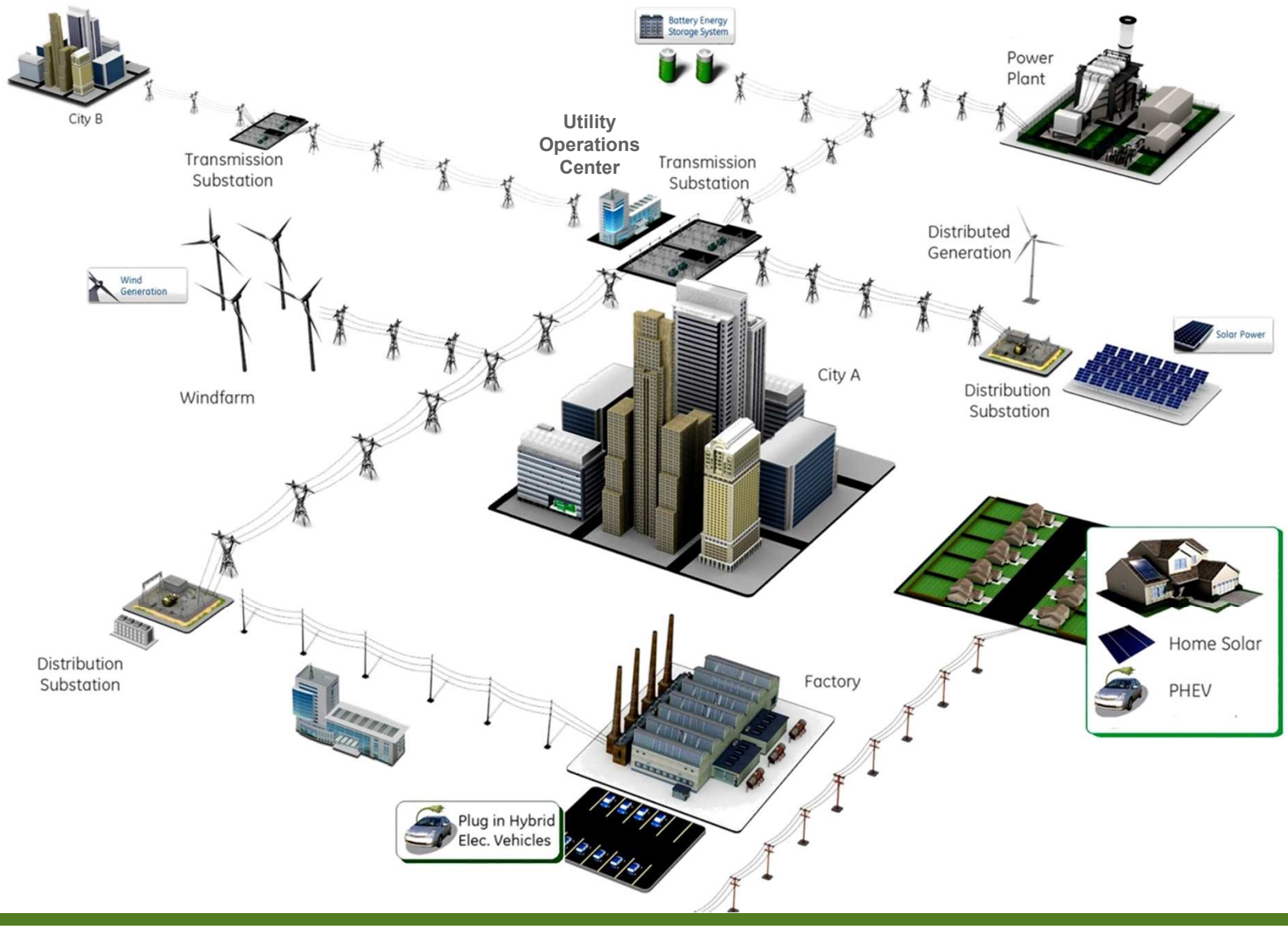




Image: Forbes India

# Current Electricity Grid Communications

Sandia National Laboratories

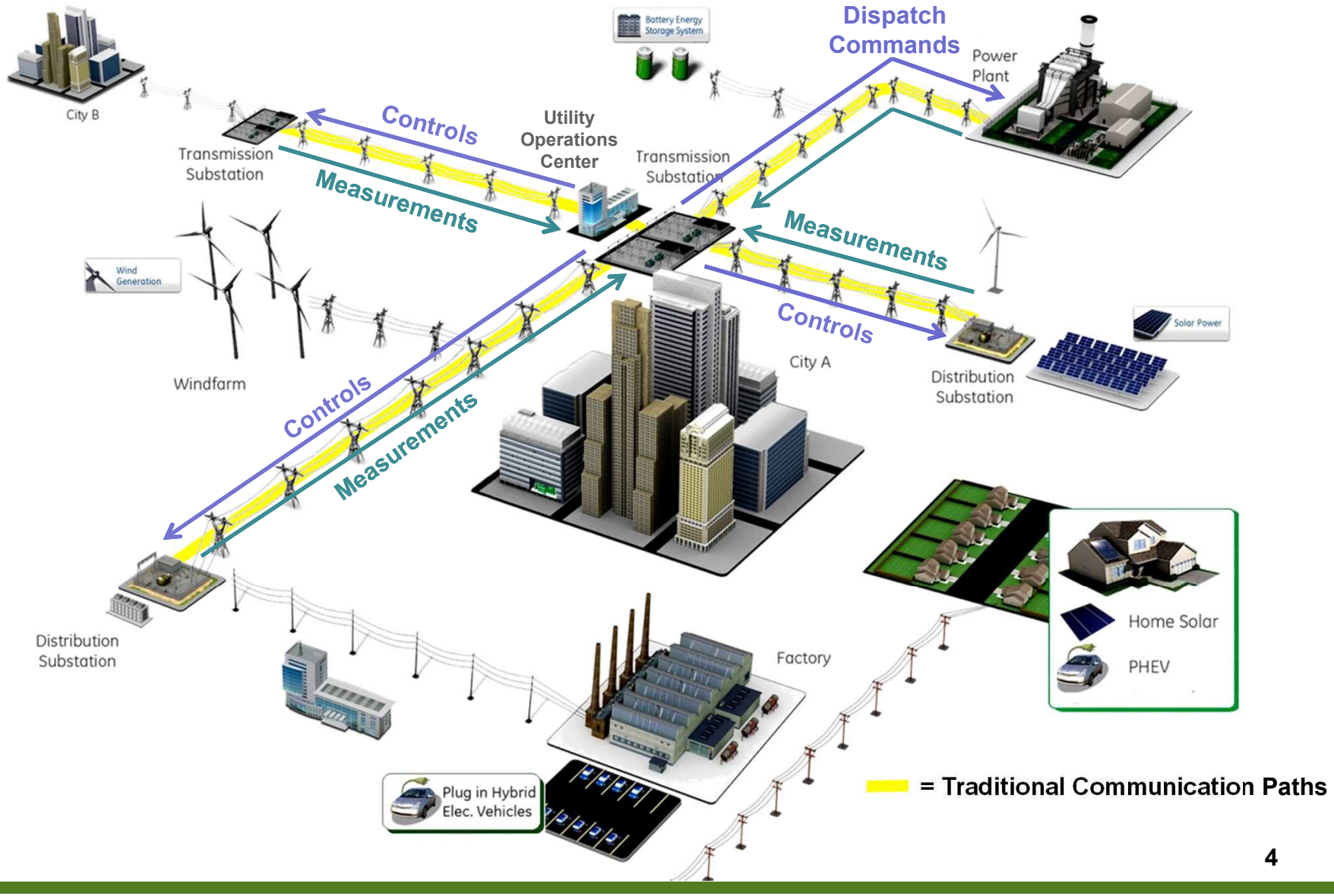




Image: Forbes India

# Smart Electricity Grid Communications

Sandia National Laboratories

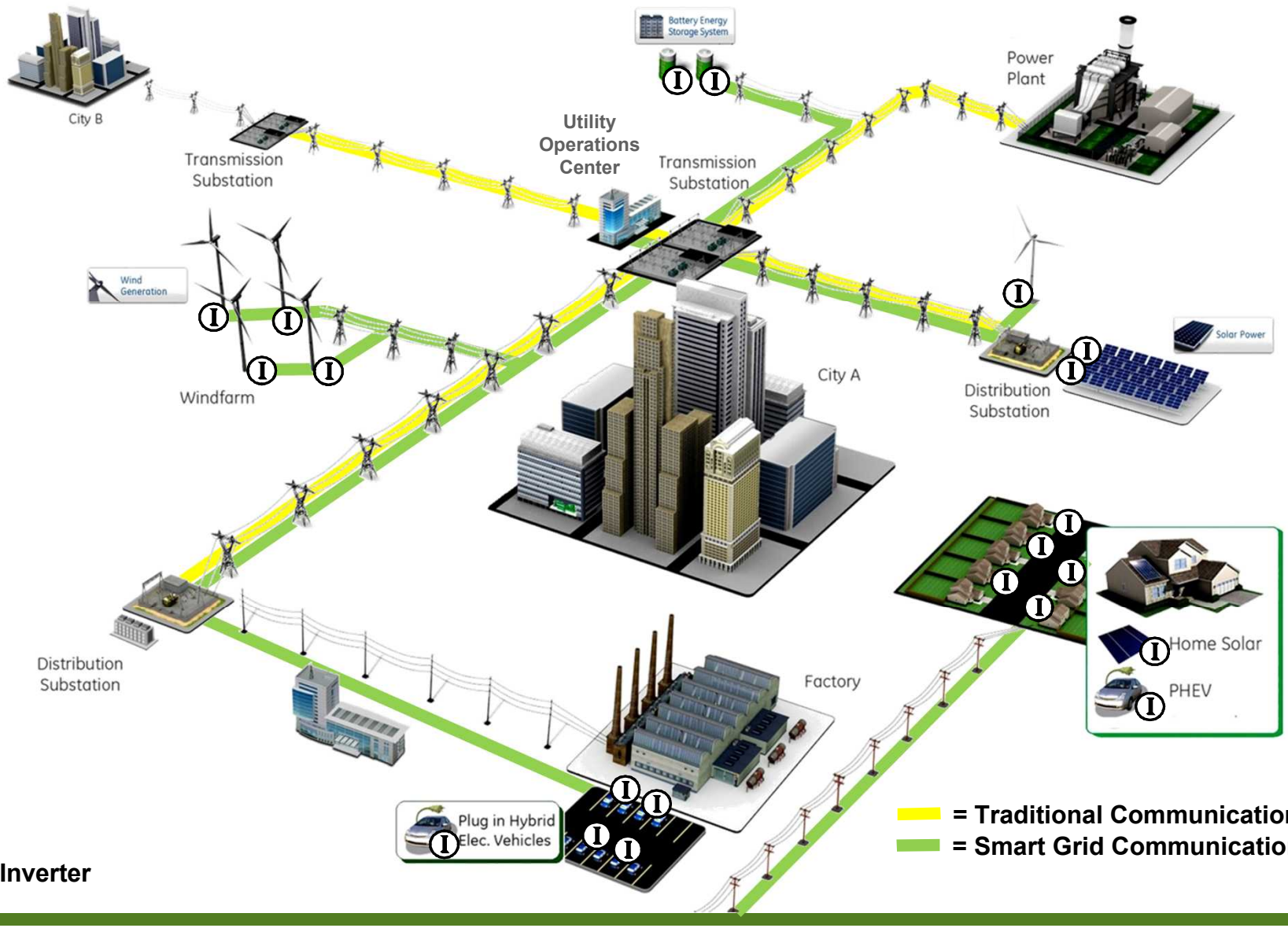




Image: Forbes India

# Smart Electricity Grid Communications

Sandia National Laboratories

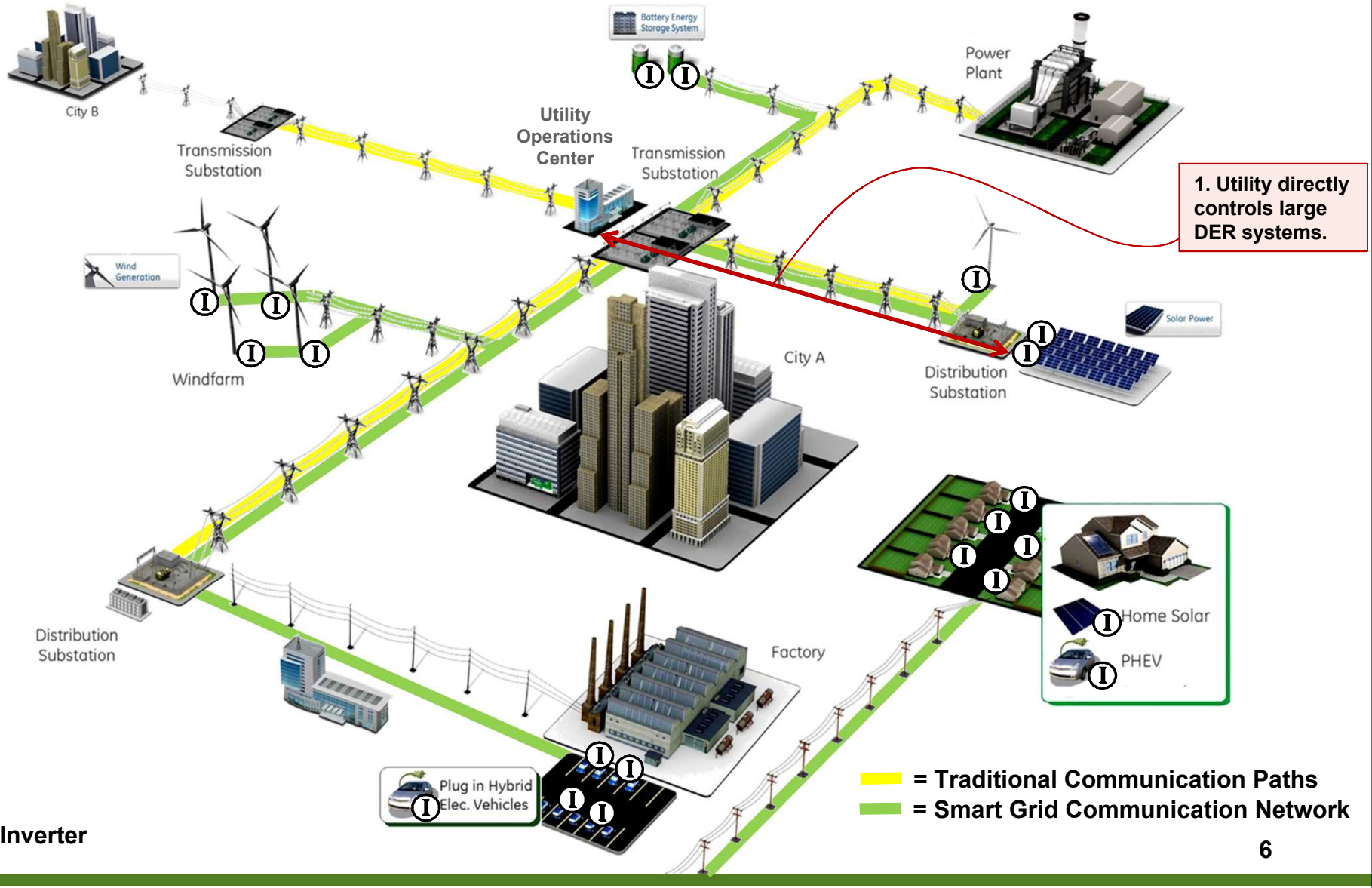




Image: Forbes India

# Smart Electricity Grid Communications

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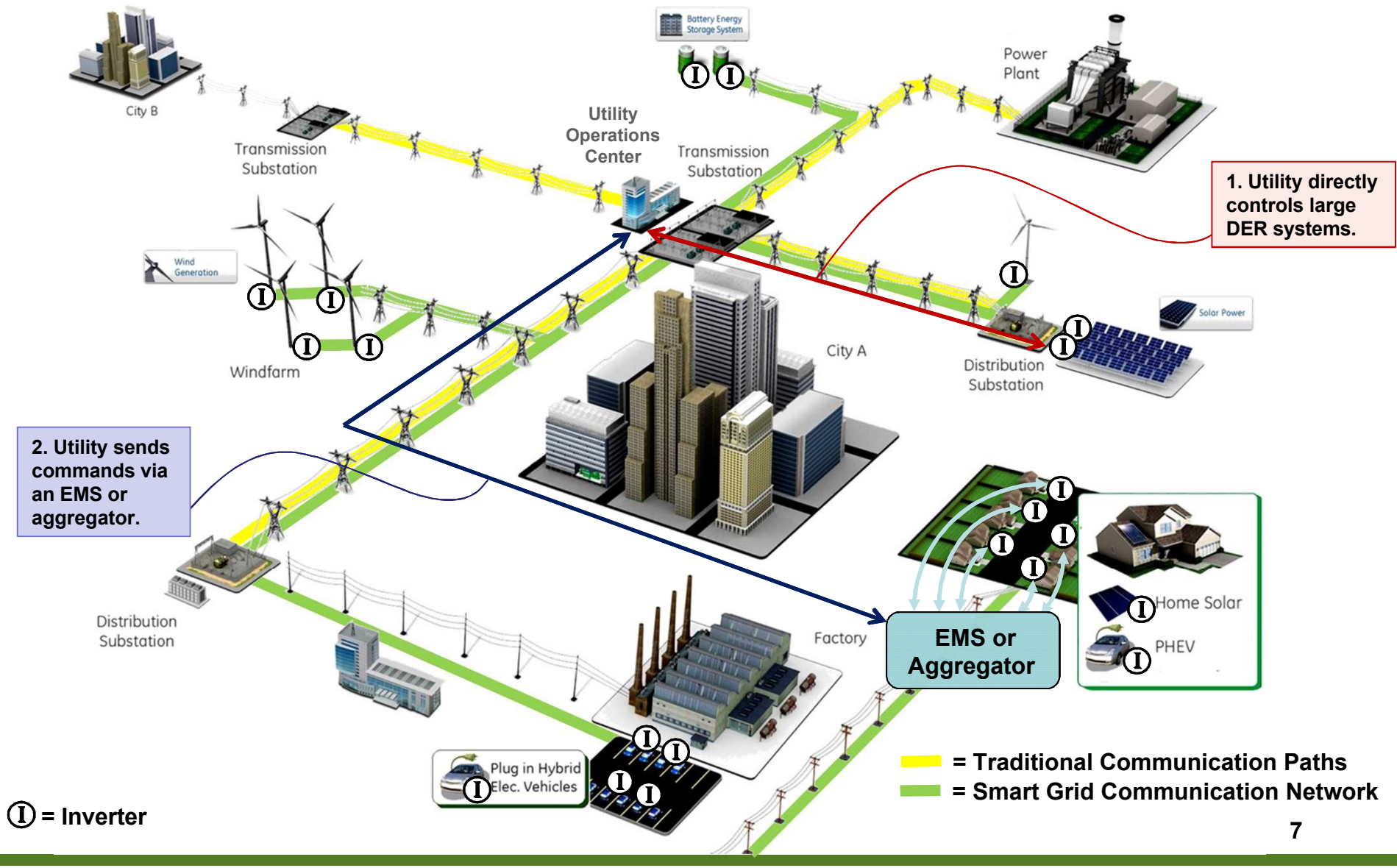




Image: Forbes India

# Smart Electricity Grid Communications

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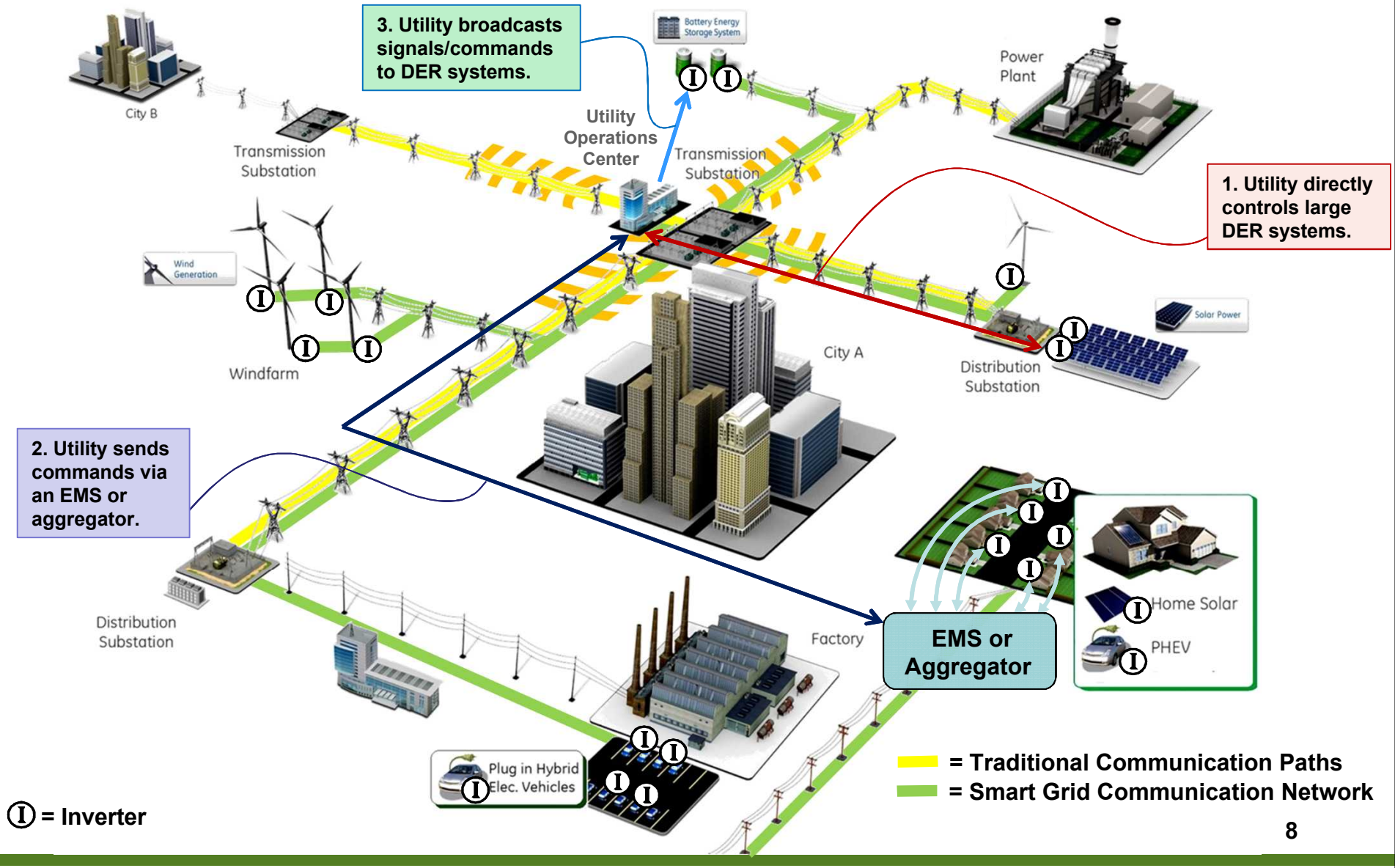




Source: Forbes India

# Types of Advanced Inverter Functions

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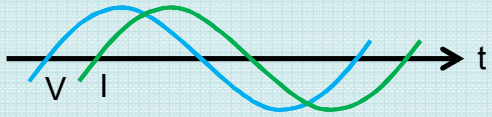
**Advanced functions defined in IEC Technical Report 61850-90-7:**

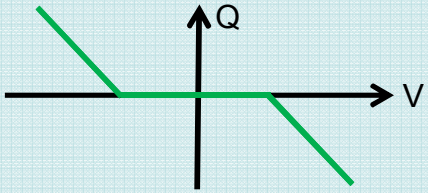
**NOTE: CA Rule 21 SIWG defined similar functions.**

## Voltage Support

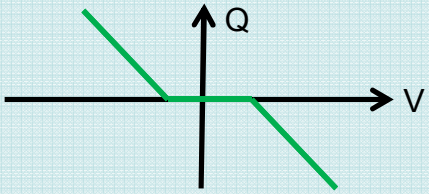
- **Adjust Power Factor (INV3)**



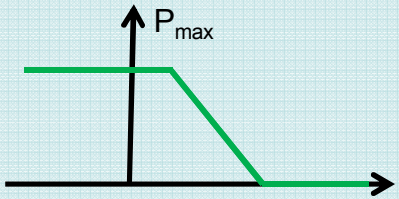

- **Volt-Var Mode (VV11, VV12, VV13)**




- **Dynamic Reactive Power (TV31)**

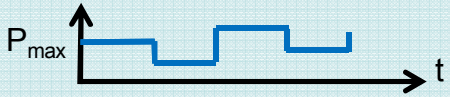



- **Volt-Watt Mode (VW51; VW52)**

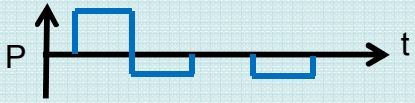



## Frequency Support

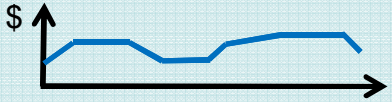
- **Adjust Maximum Active Power (INV2)**



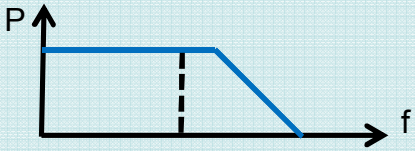

- **Request Active Power from Storage (INV4)**



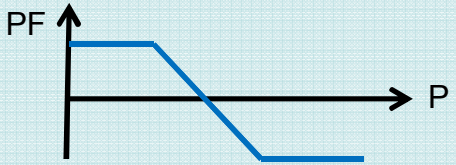

- **Signal for Charge/Discharge (INV5)**




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

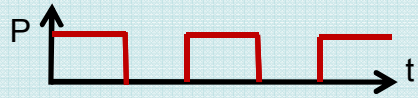



- **Watt-Power Factor (WP41, WP42)**

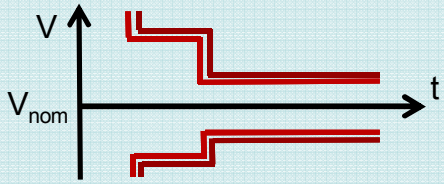



## Grid Protection (Response to Disturbances)

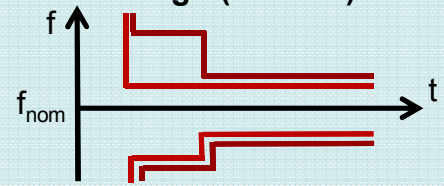
- **Connect/Disconnect (INV1)**



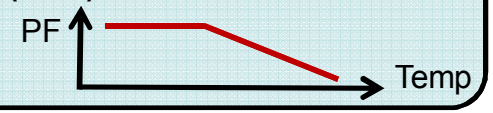

- **Low and High Voltage Ride Through (L/HVRT)**




- **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.

# Sandia Advanced Inverter Test Protocols

- General guidelines for harmonized equipment testing across different laboratories.
- Precursor to equipment certification procedures.
  - No pass/fail criteria
  - Only suggestions for advanced function parameter sets
- Two distinct phases for most functions:
  - Communication
    - Send the signal from the Utility Management System (UMS) Simulator
    - Verify the communications reached the EUT
  - Electrical behavior characterization
    - Measurement of the DC and AC characteristics to verify the inverter updated its operation

# Example Function: INV1 (Connect/Disconnect)

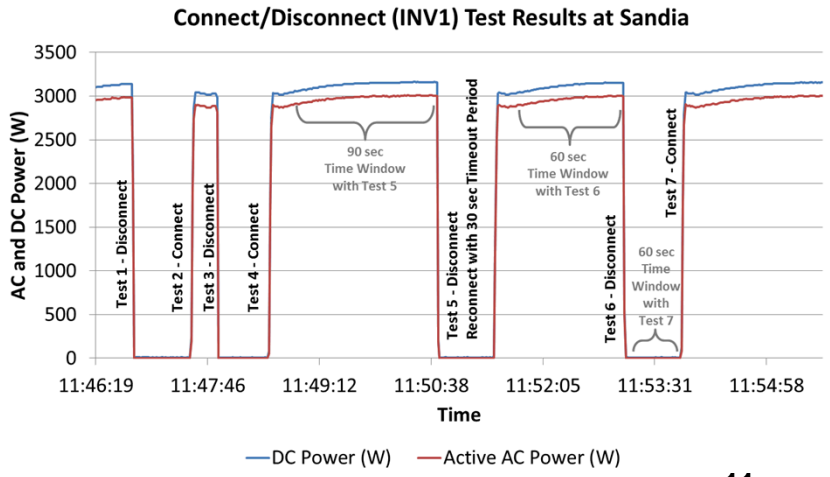
- Advanced functions include multiple settings in additional to the curves/activation
  - e.g., time window, timeout period, and ramp rate

**INV1 Test Protocol Sequence.**

| | Step | Task | Function | Notes |
|---|---|---|---|---|
| Communication | 1 | Utility Requests Inverter Status | | |
| | 2 | Utility Receives Inverter Status | | |
| | 3 | Utility Logs Inverter Status | | |
| | 4 | Utility Issues INV 1 Command to Inverter | | |
| | 4 | Inverter Changes Operation and Confirms | | |
| Electrical Behavior | 5 | Electrical Output is Monitored, Verify Operation | | |
| | 6 | Repeat INV1 Tests with Range of Parameters | | |
| Analysis | 7 | Analyze Electrical Behavior (Assign Pass/Fail) | | |

**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) |



# Advanced Inverter Communications

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- Data transfer from the utility/aggregator to the DER is a major challenge!
  - Interoperability
  - Cybersecurity
  - Communication latency, network dropouts, etc.
  - Competing communications solutions
    - Protocol: DNP3, SEP, IEC 61850, Modbus, OpenADR, SunSpec
    - Medium: Wi-Fi, PLC, Ethernet, Zigbee, Bluetooth
    - Method: Direct, Broadcast

- Sandia has partnered with EPRI, SMA, Fronius, SCE, SMUD, and SunSpec to develop communications specifications for interchange over Modbus, SEP, and Zigbee gateways. Sandia will:
  - Create test protocols for the certification/conformance of CA Rule 21 inverter functions and interoperability requirements.
  - Address cybersecurity concerns by establishing the underlying rules for the utility-to-DER communications.

**CA Electric Rule 21**
**Phase 1 Autonomous Functions**

| | Function |
|---|---|
| 1 | Anti-Islanding Protection |
| 2 | Low/High Voltage Ride-Through |
| 3 | Low/High Frequency Ride-Through |
| 4 | Dynamic Volt/Var Operations |
| 5 | Ramp Rates (Normal, Emergency, Soft Disconnect) |
| 6 | Fixed Power Factor |
| 7 | Reconnect by “Soft Start” (Ramp and/or Random Start) |

# SunSpec-Sandia Collaboration

- SunSpec has defined Modbus map specifications for DER devices so 3rd parties can adjust functions/settings

- Sandia and the SunSpec Alliance are collaborating to establish tools for verifying IEC 61850-90-7 functions:
  - Works for all SunSpec-Compliant PV Inverters (and other devices)
  - Modes of operation: direct manipulation of Modbus registers, python scripting, and interaction via a graphical user interface.

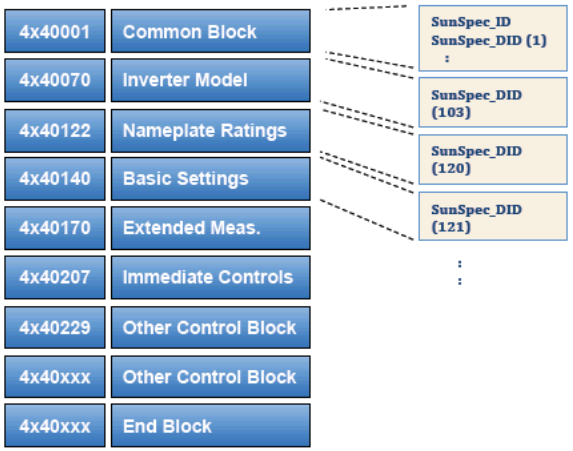
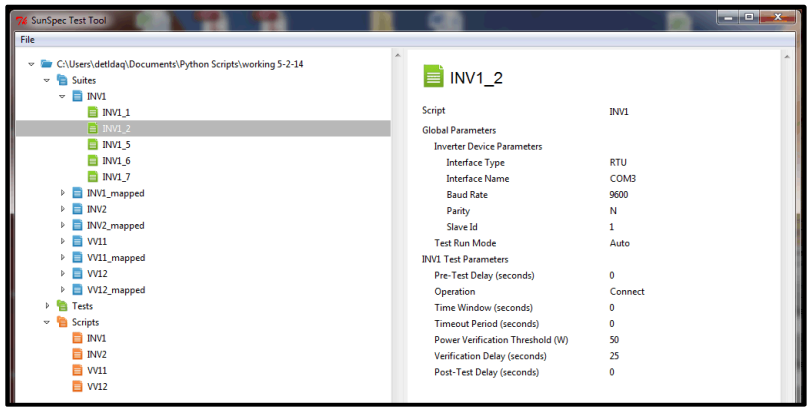



Figure 1: Chained Inverter Control Blocks




**GUI Version of the SunSpec Test Tool**

Members

Champions

Strategic Partners

# Video of SunSpec Test Tool at Sandia

Sandia National Laboratories

- Demo of the SunSpec Test Tool communicating with and verifying the operation of a connect/disconnect command.

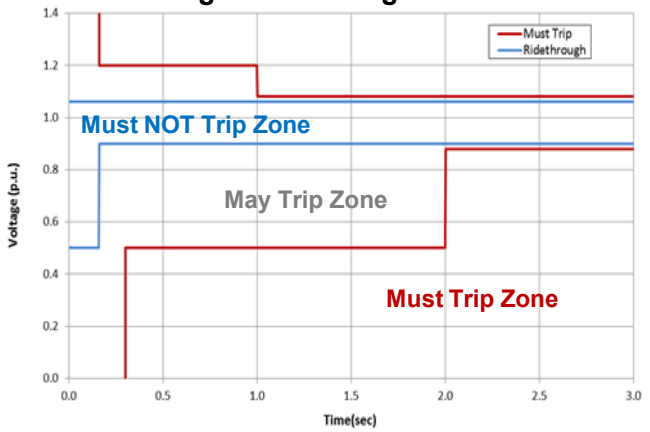
# Default Deployment Settings

- CA Rule 21 Phase 1 has only autonomous functions.
  - No communication methods for updating the values.
  - Settings will remain for the lifetime of the inverter.

- WHAT SETTINGS SHOULD MANUFACTURERS USE?
- **Voltage and frequency ride-through**
  - 1547a sets stage for jurisdiction-specific requirements.
  - Will V/FRT vary with location (e.g., state-to-state)?
- **Volt-var**
  - How much deadband is necessary to maintain grid stability?
  - Some advanced function reduce inverter reliability, e.g., non-unity power factor increases IGBT switching losses

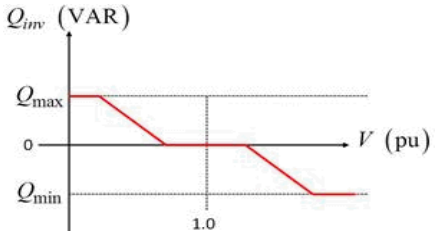
- **Modeling is critical** to determine appropriate ranges for the advanced function settings.

**Voltage Ride-through Function**




| | Default settings | | Ranges of adjustability | |
|---|---|---|---|---|
| Function | Frequency (Hz) | Clearing time (s) | Frequency (Hz) | Clearing time (s) |
| UF1 | 57 | 0.16 | 56 – 60 | 0 – 10 |
| UF2 | 59.5 | 20 | 56 – 60 | 0 – 300 |
| Power reduction | 60.3 | 10 | 60 - 64 | 0 - 300 |
| OF1 | 60.5 | 20 | 60 – 64 | 0 – 300 |
| OF2 | 62 | 0.16 | 60 - 64 | 0 - 10 |

**1547a FRT has large adjustment range.**



# UL 1741 Certification Settings

- **UL 1741 STP working groups are determining settings for the advanced inverter functions.**

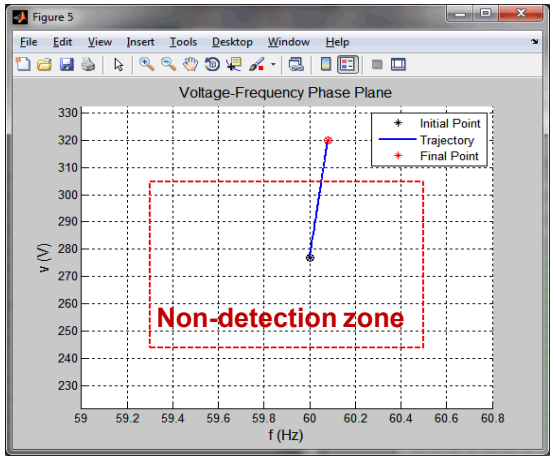
**UL 1741 Advanced Grid Function Settings**

**Anti-islanding Tests**
**Advanced grid function settings → *most severe* configuration, e.g. smallest volt/var deadband, steepest volt/var and freq/watt slopes, wide-open V/FRT.**

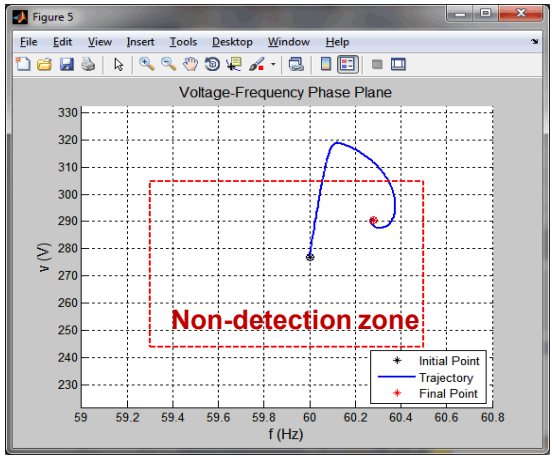
**Advanced Inverter Function Tests**
**Minimize number of permutations → only test maximum, minimum, and default settings.**

**Pass/fail criteria are being developed based on manufacturers' stated accuracy**

**Without volt/var and freq/watt.**




**With volt/var and freq/watt.**




Volt/var & freq/watt functions make certain anti-islanding methods less effective. Simulations of an inverter using Sandia Frequency Shift AI method shows that inverter returns to the non-detect zone with volt/var & freq/watt .

# Future Work

- UL STP to develop test protocols with the UL 1741 STP for Rule 21 advanced inverter functions
  - Update anti-islanding tests and advanced function tests
- Exercise and update the UL recommendations and Sandia Test Protocols
  - Smart Grid International Research Facilities Network (SIRFN) members are testing residential inverters and comparing results.
- Create, test, and release the SunSpec Test Tool
- Create, exercise, and update energy storage systems
- Development of cybersecurity measures for the interoperability