Specifications for Advanced PV Inverters: Functions, Settings, and Communications

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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
Current Electricity Grid
Current Electricity Grid Communications

- Dispatch Commands
- Controls
- Measurements
- Controls
- Measurements
- Controls
- Measurements

City A
- Distribution Substation
- Factory
- Home Solar
- PHEV

City B
- Transmission Substation
- Windfarm
- Wind generation
- Transmission Substation

Utility Operations Center
- Battery Energy Storage System

Power Plant

= Traditional Communication Paths
Smart Electricity Grid Communications

= Inverter

= Traditional Communication Paths
= Smart Grid Communication Network

Image: Forbes India
Smart Electricity Grid Communications

1. Utility directly controls large DER systems.

= Inverter

= Traditional Communication Paths

= Smart Grid Communication Network
1. Utility directly controls large DER systems.

2. Utility sends commands via an EMS or aggregator.

= Inverter

= Traditional Communication Paths
= Smart Grid Communication Network

Image: Forbes India
Smart Electricity Grid Communications

1. Utility directly controls large DER systems.

2. Utility sends commands via an EMS or aggregator.

3. Utility broadcasts signals/commands to DER systems.

源: Forbes India
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/HVVRT)
- 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.

NOTE: CA Rule 21 SIWG defined similar functions.
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 addition to the curves/activation
  - e.g., time window, timeout period, and ramp rate

INV1 Test Protocol Sequence.

<table>
<thead>
<tr>
<th>Step</th>
<th>Task</th>
<th>Function</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>Request Status to EUT.</td>
<td>DS93 (Status Reporting) &amp; Direct Measurement (DM) - EUT output is monitored &amp; logged</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>UMS receives response to DS93 command.</td>
<td>Inverter output is measured and logged</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>Utility Receives Inverter Status</td>
<td>Utility Logs Inverter Status</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>UMS issues a Disconnect/Connect Command to EUT.</td>
<td>INV1 – Connect/Disconnect Command may include the following parameters: time window (optional) timeout period (optional) ramp rate (optional)</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>EUT responds to the command.</td>
<td>DS92 – change in status is noted</td>
</tr>
<tr>
<td>6</td>
<td>5</td>
<td>Verify command was received.</td>
<td>DM – EUT output is measured &amp; logged</td>
</tr>
<tr>
<td>7</td>
<td>6</td>
<td>Repeat test with varying parameters (see Table A1-3). Each test must be repeated at least once as needed.</td>
<td>Repeat INV1 Tests with Range of Parameters</td>
</tr>
<tr>
<td>8</td>
<td>7</td>
<td>Characterize EUT’s response.</td>
<td>DS92: DM Determine how command was executed</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>Analyze Electrical Behavior (Assign Pass/Fail)</td>
<td></td>
</tr>
</tbody>
</table>

INV1 Test Matrix.

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

Connect/Disconnect (INV1) Test Results at Sandia

- DC Power (W)
- Active AC Power (W)
Advanced Inverter Communications

- 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

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Anti-Islanding Protection</td>
</tr>
<tr>
<td>2</td>
<td>Low/High Voltage Ride-Through</td>
</tr>
<tr>
<td>3</td>
<td>Low/High Frequency Ride-Through</td>
</tr>
<tr>
<td>4</td>
<td>Dynamic Volt/Var Operations</td>
</tr>
<tr>
<td>5</td>
<td>Ramp Rates (Normal, Emergency, Soft Disconnect)</td>
</tr>
<tr>
<td>6</td>
<td>Fixed Power Factor</td>
</tr>
<tr>
<td>7</td>
<td>Reconnect by “Soft Start” (Ramp and/or Random Start)</td>
</tr>
</tbody>
</table>
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.
Video of SunSpec Test Tool at Sandia

- 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.
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