Goals for this Session

• Understand the relationships between different aspects of interconnection

• Discuss best practices and lessons from US states and utility territories

• Provide an update on technical advances and standards for interconnection
Motivations
Solar Energy: Cost

Source: Tracking the Sun IX: The Installed Price of Residential and Non-Residential Photovoltaic Systems in the United States
Type of system determined by local solar resource
Story: Strong rebates, implemented in May 2015, push solar into wide viability.

Story: Growing economic viability overcomes decline in state incentives to drive steady growth.

Story: Solar reaches economic “tipping point” in late 2014, attracting scale from national installers. Pre-Dec 2015 installs were granted grandfathering.
## Solar Energy: TVPPA Context

<table>
<thead>
<tr>
<th>Utility Name</th>
<th>Total Customers</th>
<th>Additional DG systems/mo for 10x growth over 3 yrs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nashville Electric Service</td>
<td>378,117</td>
<td>62</td>
</tr>
<tr>
<td>Johnson City - (TN)</td>
<td>77,025</td>
<td>18</td>
</tr>
<tr>
<td>Southwest Tennessee E M C</td>
<td>49,589</td>
<td>5</td>
</tr>
<tr>
<td>Joe Wheeler Elec Member Corp</td>
<td>42,812</td>
<td>2</td>
</tr>
<tr>
<td>Gibson Electric Members Corp</td>
<td>34,436</td>
<td>5</td>
</tr>
<tr>
<td>Fort Loudoun Electric Coop</td>
<td>31,571</td>
<td>8</td>
</tr>
<tr>
<td>Decatur Utilities</td>
<td>26,492</td>
<td>1</td>
</tr>
<tr>
<td>City of Newport</td>
<td>21,497</td>
<td>6</td>
</tr>
<tr>
<td>Tennessee Valley Electric Coop</td>
<td>19,442</td>
<td>2</td>
</tr>
<tr>
<td>Tri-State Electric Member Corp</td>
<td>18,475</td>
<td>12</td>
</tr>
<tr>
<td>City of Rockwood - (TN)</td>
<td>14,566</td>
<td>2</td>
</tr>
<tr>
<td>City of Hopkinsville</td>
<td>12,874</td>
<td>1</td>
</tr>
<tr>
<td>Bolivar Energy Authority</td>
<td>11,058</td>
<td>1</td>
</tr>
<tr>
<td>Forked Deer Electric Coop, Inc</td>
<td>9,871</td>
<td>1</td>
</tr>
<tr>
<td>McMinnville Electric System</td>
<td>8,002</td>
<td>0</td>
</tr>
<tr>
<td>Guntersville Electric Board</td>
<td>6,331</td>
<td>1</td>
</tr>
</tbody>
</table>
Intro to the Interconnection Process
What is the Interconnection Process?

- Outward-facing, customer service activity
- Technical assessment by the utility
- Internal business process for utility
- Coordination effort with local AHJ
Who does what?

**Installer**
- Submit building permit application and materials
- PV installer submits application for interconnection agreement
- Installer completes PV construction
- PV installer submits paperwork for utility PTO, including verification of passed building inspection

**AHJ**
- Building permit review and approval
- Final building inspection and approval

**Utility**
- Utility application review and approval
- Utility issues permission to operate (PTO)
What are the utility’s typical responsibilities?
Standards, Codes, and Interconnection Requirements
Standards & Codes are Foundational

AHJ
- Standards and codes affect what is submitted to the AHJ and utility

Installer
- PV installer submits application for interconnection agreement
- Installer completes PV construction
- PV installer submits paperwork for utility PTO, including verification of passed building inspection

Utility
- Utility application review and approval
- Utility issues permission to operate (PTO)
- Final building inspection and approval
- Building permit review and approval
Interconnection Codes & Standards

Electric Utility T&D Systems
- National Electrical Safety Code (NESC) and Utility Manual of Safe Practices
  - ANSI C84.1

PCC (Point of Common Coupling)
- IEEE 1547 & Family of Standards

Industrial, Commercial, Residential Buildings
- National Electrical Code (NEC)
  - UL 1741
  - UL 1703
• Often used as Utility Manual of Safe Practices

• Covers basic provisions for safeguarding persons from hazards arising from installation, operation, and maintenance of conductors

• Typically applies to utilities and industrial users under the control of qualified persons

• Note: Section 444 of the NESC details “De-energizing equipment of lines to protect employees”
- **Service Voltage** – voltage at the point of delivery

- Range A (114-126V) is favorable, Range B (110-127V) is tolerable
IEEE 1547™ (under full review/revision)

- Provides a uniform standard for interconnection of DR with EPS
- Set of standards govern performance, operation, testing, and safety
National Fire Protection Association (NFPA) 70

- Adopted as law in most U.S. states, other areas
- Applies to Residential, Commercial, and Industrial facilities
- Often used in utility power plants, service centers
- Articles 690 (PV systems) & 705 (Interconnected Electric Power Production Sources)
- New Article 691 in next code cycle (Utility-Scale PV)
UL 1741

Inverters, Converters, Controllers, and Interconnection System Equipment for Use with Distributed Energy Resources

- Adopted as Legal Requirement in most U.S. states
- Applies to the inverter and interconnection equipment
- Inverters should be “listed” to this standard
- Harmonized with IEEE 1547
- Underwriters Laboratories – Standard for Safety
- UL 1741 has been updated for “Smart Inverter Use”
  - UL 1741 Supplement A (SA)
Dependencies in Technical Standards

**Equipment Safety**

Prior to Supplement A, **UL 1741** did not have a testing procedure for advanced inverters

Without a developed testing program under UL 1741, advanced inverters could not achieve **UL listing**

Installations using advanced inverters which are not UL-listed cannot comply with the **National Electrical Code**

Installations which do not comply with the National Electrical Code will violate **state or local building codes**

**Interconnection Performance**

**IEEE 1547-2003** does not allow inverters to perform "advanced" functions beyond those in IEEE 1547a-2014

In most states, an inverter which violates **IEEE 1547-2003** does not meet **state interconnection standards**

Inverter deployments which do not meet state standards will not pass **utility interconnection processes**
Technical Screens
Technical Screens are Key to Application Review

**Installer**
- Submit building permit application and materials
- PV installer submits application for interconnection agreement
- Installer completes PV construction
- PV installer submits paperwork for utility PTO, including verification of passed building inspection

**AHJ**
- Building permit review and approval
- Final building inspection and approval

**Utility**
- Utility application review and approval
- Utility issues permission to operate (PTO)
1. Aggregated DG <15% of peak load on line section (Penetration Screen)

2. For connection to a spot network: DG is inverter-based, aggregated DG capacity is <5% of peak load & <50 kW

3. Aggregated DG contribution to maximum short circuit current is <10%

4. Aggregated DG does not cause protective device to exceed 87.5% of short circuit interrupting capability

5. DG interface is compatible with type of primary distribution line (Wye/Delta)

6. For a single-phase shared secondary, aggregated DG capacity <20kW

7. Resulting imbalance <20% of service transformer rating of 240 V service

8. Aggregated transmission connected DG capacity <10 MW for stability-limited area

9. Construction not required for interconnection
Supplemental Review May Occur if Fast-Track not Achieved
Supplemental Screen Examples

• Evaluate transformer serving customer (Is it sufficient, can it be easily changed)
• Evaluate secondary lines serving customer
• Consider location of proposed PV to substation (short distance, large conductors, etc.)
• If Penetration Screen failed, consider other metrics such as 100% of minimum daytime load on line section (recommended by FERC)
Tension in Screening Process

Electrical Issues Associated with Proposed DG Projects

- No issues exist
  - No issues, pass
- Potential issues exist
  - Potential issues, pass (false negatives)
  - Potential issues, fail
  - Utility concerns

Technical Screening Outcomes for Proposed DG Projects

- Passed technical screens
- Failed technical screens

Developer concerns

Application pool
Interconnection Studies and Mitigations
Impact Studies Are Triggered if Screens are Failed
Major Utility Concerns

Voltage Regulation  76%
Reverse power flow  52%
Protection system coordination  48%
Increased duty of line regulation equipment  38%
Unintentional islanding  38%
Secondary network protection  29%
Variability due to clouds  24%
Increased switching of capacitors  19%
Voltage Regulation – No PV
Voltage Regulation – w/ PV
Voltage Regulation – w/ PV
Most utilities employ one or more of the following:

- **Power Flow** (common)
- **Short Circuit** (common)
- **Voltage** (common)
- **Feasibility**
- **Facility**
- **Flicker**
- **Power Quality**
  - **Dynamic/Transient Stability**
  - **Electromagnetic Transient**

**Most Commonly used Distribution Software**

- **SynerGi**
- **CymDist**
- **Milsoft Windmil**
- **ASPEN**
Mitigation Tools Available

Tools in the “Toolbox”

• Upgrade Line Section
• Modify Protection Scheme (breakers & fuses)
• Voltage Regulation Devices (Add or change control)
• Direct Transfer Trip
• Advanced Inverters Required
• Communication & Control Technologies
• Power Factor Controls (Often advanced inverters)
• Grounding Transformers
• Static VAR Compensators
• Capacitor Control Modifications
• Volt/VAR Controls
Interconnection as Business Process
How Can a Utility Improve Customer Service?

1. Be clear
2. Be quick
1. Be Clear

- Provide easily accessible guidance based on accepted standards
- Have a designated point of contact for questions
- Consolidate submission of applications to single channel (electronic)
- Provide a way to track progress and/or maintain clear communication
Be clear

- Easily accessible interconnection guidelines based on accepted standards
  - Model procedures: FERC Small Generator Interconnection Procedure (SGIP), IREC
- Designated points of contact at utilities
  - Ideally, a real person, not a generic inbox
- Single channel for submission of application materials (electronic)
  - Eliminates coordination of mail, fax, e-mail applications
- Provide a way for installers to track progress and/or clear communication of decisions, timelines, and cost
  - Email templates of standard updates
2. Be Quick

Resolve application completeness quickly

Use screens to speed processing, reduce burden on staff

Consider fast-track process (e.g. inverter-based, under 10 kW)

Process PTO paperwork quickly, last touch-point in the process
How Can a Utility Improve Customer Service?

Be clear
- Easily accessible interconnection guidelines based on accepted standards
- Designated points of contact at utilities
- Single channel for submission of application materials (electronic)
- Provide a way for installers to track progress and/or clear communication of decisions, timelines, and cost

Be quick
- Use checks for completeness
  - Engaging installers quickly can avoid long, frustrating waits
- Fast-track process (e.g. inverter-based systems under 10 kW)
  - Included in FERC SGIP and IREC model procedures
- Use screens to analyze systems quickly, reduce analytical burden on staff
- Move paperwork quickly and efficiently
  - Permission to Operate is simply confirming documents received and in order, last touch-point with customer in the process

- Bonus points: coordinate with local permitting process
Municipal utilities may have unique opportunities to streamline the interconnection, incentive and building permit approval process as a result of having one centralized authority in control of the processes.
Municipalities Can Merge Permitting and Interconnection

Installer
- Submit building permit application and materials
- PV installer submits application for interconnection agreement
- Installer completes PV construction
- PV installer submits paperwork for utility PTO, including verification of passed building inspection

AHJ
- One application, same-day in-person review and approval
- Building permit review and approval
- Final building inspection and approval

Utility
- Utility application review and approval
- Utility issues permission to operate (PTO)
Advanced or “Smart” Inverters
## What is a “Smart” Inverter - Functions

Multiple efforts have been made to standardized function set for smart inverters

**Key capabilities include (but not limited to):**

<table>
<thead>
<tr>
<th>Function</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connect/disconnect</td>
<td>Electrically connects to or disconnects from the grid</td>
</tr>
<tr>
<td>Maximum generation limit</td>
<td>Constrains real power output</td>
</tr>
<tr>
<td>Volt-VAR function</td>
<td>Adjusts reactive power output based on service voltage</td>
</tr>
<tr>
<td>Volt-Watt function</td>
<td>Adjusts real power output based on service voltage</td>
</tr>
<tr>
<td>Frequency-Watt function</td>
<td>Adjusts real power output based on service frequency</td>
</tr>
<tr>
<td>Low/high frequency ride-through</td>
<td>Defines frequency range for which inverter remains on-line</td>
</tr>
<tr>
<td>Low/high voltage ride-through</td>
<td>Defines voltage range for which inverter remains on-line</td>
</tr>
<tr>
<td>Event/history logging</td>
<td>Log and report standardized set of events</td>
</tr>
<tr>
<td>Status reporting</td>
<td>Report current device status</td>
</tr>
</tbody>
</table>

---

**For More:**
- EPRI, Common Functions for Smart Inverters, Version 3, Report # 3002002233
- Distributed Energy Management (DER): Advanced Power System Management Functions and Information Exchanges for Inverter-based DER Devices, Modelled in IEC 61850-90-7
• Increased grid stability
  o Local – voltage control from volt-VAR and volt-Watt functions
  o System – greater resiliency during frequency deviations

• Increased visibility into distribution system conditions via data collection

• Potential to defer investments in other distribution system hardware
Key Standards for Advanced Inverters

• **UL 1741**
  - Developed by Underwriter’s Laboratory (UL)
  - Primarily an *equipment safety* standard
  - Sets design requirements and testing procedures

• **IEEE 1547**
  - Developed by Institute of Electrical and Electronics Engineers (IEEE)
  - Primarily an *interconnection performance* standard
  - Governs how inverters affect electrical conditions at the point of common coupling (PCC) with the grid
Standards acted as a barrier because other regulations rely on these measures

**Equipment Safety**

Prior to Supplement A, **UL 1741** did not have a testing procedure for advanced inverters

Without a developed testing program under UL 1741, advanced inverters could not achieve **UL listing**

Installations using advanced inverters which are not UL-listed cannot comply with the **National Electrical Code**

Installations which do not comply with the National Electrical Code will violate **state or local building codes**

**Interconnection Performance**

**IEEE 1547-2003** does not allow inverters to perform "advanced" functions beyond those in **IEEE 1547a-2014**

In most states, an inverter which violates IEEE 1547-2003 does not meet **state interconnection standards**

Inverter deployments which do not meet state standards will not pass **utility interconnection processes**
Updated to include advanced functions
Approved September 2016
Several inverters have been certified to date

The UL 1741 SA consists of the following advanced inverter grid support utility interactive test plan:

<table>
<thead>
<tr>
<th>Required Tests (utilized by all SRDs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anti-Islanding (with advanced features active during test)</td>
</tr>
<tr>
<td>Low/High Voltage Ride Through</td>
</tr>
<tr>
<td>Low/High Frequency Ride Through</td>
</tr>
<tr>
<td>Must Trip Test</td>
</tr>
<tr>
<td>Ramp Rate (Normal &amp; Soft-Start)</td>
</tr>
<tr>
<td>Specified Power Factor</td>
</tr>
<tr>
<td>Volt/Var Mode</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Optional Tests (depends on SRD being utilized)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency Watt</td>
</tr>
<tr>
<td>Volt Watt</td>
</tr>
</tbody>
</table>
Complete overhaul of interconnection requirements
New content on:
• Reactive power
• Ride-through requirements
• DER on secondary networks
• Interoperability and communications
• Test and verification requirements

In balloting now, publication anticipated summer 2017
Communications bring challenges and benefits

Challenges

• Many layers of physical and software infrastructure
• Standardization to maximize value requires coordination across many parties

Benefits

• Enables certain high-value functions
  o E.g. real power curtailment
• Supports more frequent updates to otherwise-autonomous functions
• Increases visibility for distribution management
<table>
<thead>
<tr>
<th>Communications Level</th>
<th>Inverter Functions</th>
<th>Proceedings and Standards</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Autonomous</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>– No communications architecture needed</td>
<td>Low-/ High-voltage ridethrough</td>
<td>SIWG Phase 1</td>
</tr>
<tr>
<td>– Behavior controlled by operating parameters</td>
<td>Low-/ High-frequency ridethrough</td>
<td>IEEE 1547a-2014</td>
</tr>
<tr>
<td>– Parameters defined at system commissioning</td>
<td>Volt-var control</td>
<td></td>
</tr>
<tr>
<td>– Parameters can be adjusted, behavior activated or deactivated at later date via remote or on-site changes</td>
<td>Anti-islanding</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ramp-rate controls</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Provide reactive power (via fixed power factor)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Reconnect via “soft-start”</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Frequency-watt</td>
<td>SIWG Phase 3</td>
</tr>
<tr>
<td></td>
<td>Voltage-watt</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Dynamic current support</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Smooth frequency deviations</td>
<td></td>
</tr>
<tr>
<td><strong>Non-Autonomous</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>– Communications and control infrastructure required</td>
<td>Command DER to connect/disconnect</td>
<td>SIWG Phase 3</td>
</tr>
<tr>
<td>– Direct control of inverter behavior</td>
<td>Limit real power</td>
<td></td>
</tr>
<tr>
<td>– Control from remote operator commands or feedback, based on conditions at point of common coupling</td>
<td>Set real power</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Provide black-start capability</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Respond to real power pricing signals</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Participate in automatic generator control (AGC)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Provide spinning reserves or bid into market</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Update static set points for autonomous functions (fixed power factor, volt-var curves, voltage ride-through, frequency ride-through)</td>
<td></td>
</tr>
</tbody>
</table>
Distributed Generation Interconnection Collaborative

- Funded by DOE SunShot Initiative
- Peer exchange on interconnection
- 17 webinars produced to date
- Next webinar: May 18, 2017 on interconnection for small utilities

Utilities
Southern California Edison
Pacific Gas and Electric (PG&E) (x2)
San Diego Gas and Electric (SDG&E)
Sacramento Municipal Utility District (SMUD)
Hawaiian Electric Companies (HECO) (x2)
Arizona Public Service (APS) (x2)
Salt River Project (SRP)
Tucson Electric Power (TEP)
Xcel Energy
PEPCO
Con Edison
National Grid
Pasadena Water and Power
Fremont (NE) Dept of Utilities

Research Organizations
RMI
EPRI
SEPA (x2)
City Univ. of New York (CUNY)

National Laboratories
NREL (x2)
Sandia

Utility Associations
NRECA
WAPA

Other Presenters
Borrego Solar (x2)
Enphase Energy
ERCOT

www.nrel.gov/dgic/
Thank You!

Emerson Reiter
emerson.reiter@nrel.gov
www.nrel.gov/dgic/