SCE Experience with PV Integration

EPRI High Penetration PV Grid Integration Workshop

April 19, 2012

Tucson, AZ
Leading the Nation in Renewable Power Delivery

Actual 2010 Renewable Resources
14.5 billion kWh
19.4% of SCE’s portfolio

- Small Hydro 5%
- Solar 6%
- Biomass 7%
- Wind 29%
- Geothermal 53%
CA will have 3 times the amount of intermittent resources in 2020 as we had in 2010

<table>
<thead>
<tr>
<th>Year</th>
<th>Nameplate Capacity (MW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>7,699 MW</td>
</tr>
<tr>
<td>2020</td>
<td>22,669 MW</td>
</tr>
</tbody>
</table>
Background

- Significant amount of generation is being “proposed” to be interconnected to SCE’s distribution systems
- High influx of proposed generation has resulted from state sponsored programs such as:
  - Solar Photovoltaic Program (SPVP) – 500MW of PV generation mostly installed on roofs of large warehouse buildings
  - Feed In programs such as the California Renewable Small Tariff (CREST)
  - Net Generation Metering Program – Primary a residential and commercial program
  - 12,000MW of Localized Energy Resources Initiative
- Distribution systems were not originally design for generation injection at the distribution level
- System operations, planning, and standards need updates to accommodate distributed generation being connected to distribution feeders
- New technology operating characteristics are not very well known
Incentivized and Mandated Renewable Energy Programs in California

**Customer**
- Net-Energy-Metering (NEM)
- California Solar Initiative (CSI)
- CA Renewable Energy Small Tariff (CREST)
- Self-Generation Incentive Program (SGIP)
- Multifamily Affordable Solar Housing (MASH)
- New Solar Homes Partnership (NSHP)

**Supply**
- 33% Renewables Portfolio Standard (RPS)
- SB 32 Feed-in-Tariff (FiT)
- Renewable Auction Mechanism (RAM FiT)
- QF Settlement
- AB 1613 – FiT for combined heat and power
- Solar Photovoltaic Program (SPVP)
Interconnection Issues
“Active” Interconnection Requests to SCE’s Distribution System

<table>
<thead>
<tr>
<th></th>
<th>CA Tariff</th>
<th>FERC Tariff</th>
<th>Running Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>3</td>
<td>36</td>
<td>39</td>
</tr>
<tr>
<td>2010</td>
<td>80</td>
<td>101</td>
<td>220</td>
</tr>
<tr>
<td>2011</td>
<td>281</td>
<td>52</td>
<td>553</td>
</tr>
<tr>
<td>2012</td>
<td>43</td>
<td>36</td>
<td>632</td>
</tr>
</tbody>
</table>

Chart showing the increase in interconnection requests from 2009 to 2012, with total requests increasing from 39 to 632.
California Interconnection Tariff (CPUC Rule 21)

- Projects studied in a sequence as they apply and each project is studied individually to determine impacts and cost responsibilities
  - This can lead to issues as developers cancel their projects and re-studies are triggered
- Projects are responsible for the upgrades that the project triggers
- Recent changes to this Tariff which will change the study process
FERC Interconnection Tariff (SCE WDAT)

- Projects can be studied under various methods
  - **Cluster Study Process**
    - Study as a group and share the cost of the upgrades
  - **Independent Study Process**
    - Study on a serial manner
    - Projects are responsible for the upgrades it triggers
  - **Fast Track Process**
    - Evaluation consists of 10 screens
    - Supplemental review is further used if one of the screens fails
    - Designed for simplest of the projects – connecting to highly loaded circuits
CA Tariff and FERC Tariff Interaction

- These are two separate tariffs with their own processes
  - Can be difficult to manage and study projects which are in two track (tariffs) but yet affect the same distribution system

- Can be difficult to determine distribution cost upgrades
  - Distribution cost certainty is difficult to achieve

- Timelines associated with the study process in one tariff may create problems for projects interconnecting in the other tariff
  - Especially if projects are proposing to interconnect to the same circuit/substation
Typical Distribution Upgrades

- Areas with low penetration
  - Switching devices
  - Line extensions

- Areas average penetration
  - Cable/Conductor upgrades
  - Protection devices
  - Voltage regulating devices

- Areas with high penetration
  - New distribution circuits

- Areas with very high penetration
  - Substation transformer upgrades

- Areas with extreme penetration
  - Sub transmission/transmission upgrades
Existing Solar Photovoltaic Program (SPVP) Overview

- Existing SPVP Program (250 MW UOG + 250 MW PPAs) approved June 2009

- 250 MW of Utility-Owned Generation
  - Primarily 1 to 2 MW projects installed on commercial warehouse rooftops, with up to 10% (25 MW) ground-mount
  - 50 MW per year with an average cost of $3.97/Watt ($ ’11)*

- 250 MW from IPP PV Solicitation
  - RAP coordinates annual solicitations for up to 50 MW per year for 5 years
  - Price capped at the utility LOCE, 26 cents per kWh
  - Other terms similar to UOG constraints

* Reasonableness cap approved in 2008 is $3.85/w dc installed. $3.97/w is escalated to 2011 dollars.
Current SPVP Status

- UOG SPVP has 71 MW of projects completed and interconnected
  - 23 sites – 22 rooftops and 1 ground-mount
  - There is one project under construction, Dexus in Perris a 10 MW rooftop – largest single rooftop in the US.
  - Future plans call for 3 additional rooftops and 2 ground mounts totaling 30 MW
  - Total Program expected to be 111 MW

- IPP SPVP awarded 29 contracts. 50.8 MW in 2010 solicitation
  - 24 rooftop contracts for 28.4 MW
  - 5 ground sites for 22.4 MW
  - Projects must be on-line within 18 months of approval by CPUC
    - Two Projects to come on-line in April, 2012 (2 MW total)
Interconnection Experience

☐ SCE SPVP projects are “Merchant Plants” interconnected under WDAT Process through direct connections to SCE’s distribution grid. (Not NEM - Not connected to Host building’s load)

☐ Interconnection costs vary with location and state of existing system. Costs have ranged from $100K – $500K per facility.

☐ No Fast Track Sites (9 to 12 months). Most sites Independent Study (12 to 18 months). One site was cluster study (3 years plus upgrade time).

☐ Ongoing Research includes:
  ☐ SCE / NREL Hi Penetration of PV Study
  ☐ FSU Inverter Study
  ☐ Site “Trip Tests” found high voltage concerns
  ☐ AT Inverter Study using PV and Grid Simulator

☐ EPRI Lessons Learned Report in progress, publicly available 6/12
## PV SITE SPECIFICATIONS

<table>
<thead>
<tr>
<th>Quantity (at Fontana 2MW AC site)</th>
<th>Description</th>
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<tbody>
<tr>
<td>30,472 panels</td>
<td>Complete solar module including cells, casing, bracketing, wiring</td>
</tr>
<tr>
<td>256</td>
<td>Combines DC output for 24 panels</td>
</tr>
<tr>
<td>12</td>
<td>Master Fuse box</td>
</tr>
<tr>
<td>4</td>
<td>500kW DC/AC inverter</td>
</tr>
<tr>
<td>4</td>
<td>208/408 Volt KVA transformer</td>
</tr>
<tr>
<td>1</td>
<td>408 Volt switchgear, breakers, metering, relay protection</td>
</tr>
<tr>
<td>1</td>
<td>480/12,000 Volt 1,000 kVA transformer</td>
</tr>
<tr>
<td>1</td>
<td>Includes CAISO connection, data measuring, weather, etc.</td>
</tr>
<tr>
<td>1</td>
<td>Distribution system interconnection</td>
</tr>
</tbody>
</table>
SPVP Data Acquisition System

- Approximately 400 data points gathered in near real-time:
  - Generation data
  - Meteorological information
  - System status and monitoring
- Data Customers are ISO, GCC, ES&M, O&M and R&D
- Costs are $50K in Capital and $2K/Mo in O&M per site. Considerably Reduced.
- Scheduled outside PIRP as manual intervention in real time results in less imbalance charges.
- Monitoring is only to Inverter Level – benefit for string monitoring not cost effective.
- Possible Cost Reductions
  - Aggregation of Data has produced considerable cost savings
  - Redundant T-1 line requirements for ISO and Power System Controls results in additional $1,000/mo O&M expense
  - Corporate Pi Data Base License.
Possible Interconnection Changes to Improve SPVP Integration

- **Penetration Level**
  - Originally 15% circuit rule would have limited SPVP to 1-2 MW per circuit
  - Latest studies allow for up to 8 MW on a circuit if near the substation
  - Dedicated circuits needed if PV exceeds circuit capacity.
  - Costly ($100K/site) Remote Controlled Disconnect Switches current requirement. Inverters can be controlled via internet if deemed reliable.

- **Active Voltage Regulation**
  - Rule 21, Para D2a – prohibits the generator from any active voltage regulation –
  - Utilities don't want DG units to control voltage is because our "not smart" grid has no way to monitor & control customer generation.
  - Customers will want to be paid for their services and we have no CPUC approved way to do this.
  - Possible solution is to have utility owned generation - even DG- to be treated and considered differently from customer or IPP units.

- **System Disturbance Ride-through**
  - Rule 21, Para D2b3 – has tight voltage limits which basically prevent any ride thru of a distribution system disturbance.
  - PV systems may have value during disturbances that we want to keep them on-line.

- **Harmonics**
  - Concerns over harmonics from PV Inverters seemed to have allayed, Further study may be needed to guarantee this concern.

- **Intermittency**
  - SCE / NREL Study may allay concerns.
  - Overall distributed PV “smoothing effect” reduces impact.

Smoothing Effect of Multiple PV
DER Technology Integration Issues and Concerns

Safety and Reliability
- Impact of generation on the ability to transfer load between distribution circuits/substations
- Real power control to curtail excessive generation
- Unintentional “Islanding” (unintentionally isolated systems)
- Lack of “low voltage ride through” (LVRT) where temporary faults can shut down large amounts of generation
- Line management and service

Voltage
- Steady state voltage regulation, and or insufficient voltage support
- Transient over-voltages caused by connecting generation to systems with little or no load
- Short circuit duty (the amount of energy produced during fault conditions that may exceed circuit breaker duty ratings)

Power Quality, including high/low transient voltages, harmonics
- Harmonics, or power line distortion due to electronic loads, can interfere with utility protection and equipment; in addition to causing damage to equipment.
- Transient voltages can interfere and interrupt sensitive equipment; problems typically are seen at customer facilities.

Intermittency
- The output of renewable generation varies with the energy source. Examples include variable solar production during cloud cover, or intermittent wind speeds.
- Produces challenges with managing demand on specific parts of the grid and ensuring adequate capacity.

Integration
- Increasing difficulties to regulate voltage with significant penetration of variable and intermittent generation.

Protection
- Requirements will need to be revised to accommodate increasing generation on utility systems that were not designed to serve local generation in large quantities.
SCE Advanced Technology (AT) Group Research & Testing Program

- Models have not properly being developed or validated
  - Short Circuit Duty Models
  - Voltage Characteristics Models
  - Harmonic Models
  - Load flow Models

- SCE’s Advanced Technology (AT) group is working with NREL, WECC, Sandia NL, and others to:
  - Help develop/validate computer models for PV impact studies
  - Assist with testing of large inverters

- AT has begun laboratory testing and evaluation of inverters
High Penetration of PV Systems

**SCE Feeder Transient Studies are being conducted**

- **Scenario 1:** Change in solar radiations sudden drop from 100% to 0% change with pre-specified ramp up/down rates
- **Scenario 2:** Load rejection Disconnecting adjacent feeder load

**Target studies:**
- Impact on feeder flow (P & Q)
- Impact on feeder voltage
- Impact on short circuit capacity of the feeder
- Interaction with capacitor banks
Testing and Modeling of Inverters to Address Integration Issues at the Distribution Circuit Level

- Tested three 3-Phase commercial inverters in the AT Labs at the EVTC in Pomona. The inverters were tested for:
  - Fault current
  - Transient overvoltage
  - Harmonic levels
  - Response to voltage/frequency transients of various depths and durations
  - Response to voltage and frequency oscillations
- Constructed inverter models for PSLF and PSCAD programs
- Modeled selected circuits with high penetrations of inverters using the models built based on the testing to date
- Identified a list of grid integration questions that needed to be answered to allow high penetration of inverter-based generation and storage.
- Tested 14 single phase residential inverters in the lab using the same tests specified for the 3-phase inverters
- Worked with Distribution Engineering to identify information needed from inverter manufacturers so that proper interconnection studies can be accomplished.
- Arrangements are being made to test a 500 kW inverter at Florida State where the team will perform the same tests done on the 3-phase inverters. The results will help validate inverter models and allow proper interconnection studies to be performed by Distribution Engineering.
SCE’s Advanced Technologies Research

- Developed Inverter Test procedure
  - Shared with NREL, SANDIA, EPRI, WECC, etc
  - NREL, SANDIA, EPRI testing 1-phase inverters
- Tested 4 three-phase 30KW 480V inverters and one parallel combination of three-phase inverters
- Tested 1 three-phase 500KW 208V inverter at laboratory
- Testing 1-phase USA (~20) inverters (including XMRLESS)
- Testing German 1-phase and 3-phase inverters with advance features (LVRT and VAR support)

<table>
<thead>
<tr>
<th>Inverter #</th>
<th>Manuf.</th>
<th>Ratings</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>$V_{AC}$</td>
<td>$\Phi$</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>480</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>480</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>480</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>3</td>
<td>1&amp;2</td>
</tr>
</tbody>
</table>
Short Circuit Test Diagram

- Grid Simulator
  - CB_GRID
  - CB

- Contactor
  - N
  - G
  - CB
  - CB
  - CB
  - CB

- Load Bank

- Inverter
  - CB_INVERTER
  - CB
  - CB
  - CB

- DC Source
  - FUSE (80 A)
  - SHUNT

- Connections
  - #4/0 (287 A)
  - 30 kV (30 kVA) @ 480 VAC 3Φ 36 Amps
  - 100 A / 100 mV

- Specifications
  - (62.5 kW) 50 kW
  - 480 VAC 3Φ
  - 60 Amps
  - I_{SC} = 134 AMPS
Short Circuit Duty Behavior
(Source – Inverter Manufacturers)

<table>
<thead>
<tr>
<th>Type</th>
<th>SCD Contribition (P.U)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inverter Manufacturer 1</td>
<td>1.11</td>
</tr>
<tr>
<td>Inverter Manufacturer 2</td>
<td>1.2</td>
</tr>
<tr>
<td>Inverter Manufacturer 3</td>
<td>1.25</td>
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<tr>
<td>Inverter Manufacturer 4</td>
<td>1.2</td>
</tr>
<tr>
<td>Inverter Manufacturer 5</td>
<td>1.06</td>
</tr>
</tbody>
</table>

- Short Circuit Testing Results for various inverters
- Based on data provided from inverter manufacturers
- Testing based on UL testing procedures 47.3
Temporary Overvoltage

- Impacts to
  - customers
  - Operations
- Tested 5 SPV plants
  - 480V
  - 12KV
- Plant sizes 1.5MW ~ 6.5MW

Voltage phase-ground (both sides of the switch)

Voltage Across the Switch
## DER Integration – Enabling Infrastructure & Technologies

<table>
<thead>
<tr>
<th><strong>Advanced Load Control System (ALCS)</strong></th>
<th>Release 3 is planned for 2014 to support future concepts such as integration with the DMS for event dispatch, distributed energy resources and electric vehicles.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DMS</strong></td>
<td>The main management system required to enable SCE’s distribution and substation automation capabilities. A DMS is required to configure and coordinate operation of the field equipment deployed to support DER integration and advanced outage management. A DMS also includes the software required for SCE to deliver advanced volt/var control.</td>
</tr>
<tr>
<td><strong>Smart Inverters</strong></td>
<td>Intelligent control systems incorporated into inverter connected devices, as PVs, to address circuit overloading and voltage fluctuation at the distribution level</td>
</tr>
<tr>
<td><strong>Geographical Information System (GIS)</strong></td>
<td>Will serve as a comprehensive data repository that stores information regarding the physical, electrical, and spatial attributes of all transmission and distribution assets. GIS will contribute to the development of smart grid capabilities such as integrating renewable energy resources and distributed energy resources.</td>
</tr>
<tr>
<td><strong>Distributed Energy Storage</strong></td>
<td>Has the potential to resolve issues related to the integration of intermittent generation and transmission congestion. SCE is conducting 2 major DOE co-funded pilots or demonstration projects incorporating energy storage: the Irvine Smart Grid Demonstration (ISGD) and the Tehachapi Wind Energy Storage Project (TSP).</td>
</tr>
<tr>
<td><strong>FACTS Devices - DSVCs</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Advanced Protective (4-Quadrant) Relays</strong></td>
<td>Relays designed to adjust dynamically to grid conditions in any power flow direction.</td>
</tr>
</tbody>
</table>
Thank You!

George D Rodriguez
Consulting Engineer