Utility Scale Solar PV Project Experience

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Outline

- Utility Scale Solar PV
  - Introduction to SunPower
  - SunPower Project Examples
  - OASIS: Tracking Solar PV Power Plant Blocks

- Grid Integration of Solar PV
  - Voltage Support
  - Fault Ride Through
  - Active Power Management
  - Frequency Support
  - System Impact Studies
SunPower 2011 – The World’s Standard for Solar

- 2010: Revenue $2.15-$2.25B
- 5,500+ Employees
- 550+ MW 2010 production
- >1.5 GW solar PV deployed
- 5 GW power plant pipeline

- World-leading solar conversion efficiency
- Diversified portfolio: roofs to power plants
- 1,500 dealer partners, #1 R&C USA

Residential  Commercial  Power Plants
SunPower To Open Operations Center in Austin, TX

- SunPower is expanding into Texas with a new operations center in Austin

- SunPower will create 450 jobs in the region by 2015, beginning with 115 jobs created in 2011

- The new Austin facility will house operations including marketing, legal, and finance functions
Over 250 MW of power plants installed in Europe

- Serpa, PORTUGAL 11 MW
- Isla Mayor, SPAIN 8 MW
- Olivenza, SPAIN 18 MW
- Jumilla, SPAIN 23 MW
- Montalto, ITALY 72 MW
- Muehlhausen, GERMANY, 6 MW
## SunPower Utility Solar PV Power Plants

### Examples of Project Experience

<table>
<thead>
<tr>
<th>YEAR</th>
<th>MARKET</th>
<th>MW</th>
<th>NAME</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>Germany</td>
<td>10</td>
<td>Solar Bavaria</td>
</tr>
<tr>
<td>2006</td>
<td>Portugal</td>
<td>11</td>
<td>Serpa</td>
</tr>
<tr>
<td>2007</td>
<td>U.S. - Nevada</td>
<td>14</td>
<td>Nellis Air Force Base</td>
</tr>
<tr>
<td>2008</td>
<td>Spain</td>
<td>18</td>
<td>Olivenza</td>
</tr>
<tr>
<td>2009</td>
<td>U.S. - Florida</td>
<td>35</td>
<td>DeSoto (FPL)</td>
</tr>
<tr>
<td>2010</td>
<td>Italy</td>
<td>72</td>
<td>Montalto di Castro</td>
</tr>
<tr>
<td>2010</td>
<td>U.S. - Colorado</td>
<td>19</td>
<td>Greater Sandhill (Xcel)</td>
</tr>
<tr>
<td>2011</td>
<td>U.S. - California</td>
<td>250</td>
<td>CVSR (PG&amp;E)</td>
</tr>
</tbody>
</table>
Montalto 72 MW
Lazio, Italy
Nellis AFB 14 MW: NV energy
Las Vegas, NV, U.S.
Greater Sandhill 19 MW: Xcel Alamosa County, Colorado, U.S.
California Valley Solar Ranch (CVSR)

- 250 MW PPA with PG&E

- Target Schedule
  - Q3/Q4 2011 – Start of Construction
  - Q4 2011/Q1 2012 – Phase I Complete/First 25MW on-line
  - Q4/2013 – Project Completion

- Permit recently approved by San Luis Obispo county supervisors 5-0
SunPower Oasis Power Plant

The SunPower Oasis power plant is a modular utility solar platform consisting of configurable 1.5 MW PV power blocks coupled with a sophisticated plant operating system.
The SunPower Oasis Tracker & 425 W Panel

SunPower T0 Tracker

Most installed solar tracker in the world – 400MW over 10 years

Increases capacity factor by up to 25%

Simple control system = lowest O&M of any PV power plant fixed or tracking

SunPower 425W panel has today’s highest efficiency

Jeonju, Korea
2 MW

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Oasis Power Block Enhances Production

Up to 25% more energy delivery
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  - System Impact Studies

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Progress in Solar PV Integration

- Solar PV’s initial application was residential and commercial
  - Standards (UL1741, IEEE 1547) intended for distribution networks
  - Inverters for use on distribution networks initially designed without LVRT, voltage control, etc. to meet these requirements

- SunPower Utility Scale PV plants have the technical capabilities to provide features similar to modern wind plants:
  - Ride Through (Voltage and Frequency)
  - Over Frequency Droop Response
  - Real Power Curtailment
  - Reactive Power Support

- Grid integration products in the market are evolving
OASIS Grid Integration Options

- Reactive Power
  - +/- 0.95 PF at POI
  - Voltage, Power Factor, or Reactive Power Control

- Fault Ride-Through
  - Configurable Voltage and Frequency Ride though Windows

- Over Frequency Droop Response

- Active Power Curtailment from 0 to 100%
Reactive Power Requirements

Illustration of Example Reactive Power Requirement at POI

- Leading
- Lagging

Shaded Area 1

P < 20% \( P_{\text{max}} \)

\( P_{\text{max}} = 1 \text{ pu} \)

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Reactive Power as Function of Voltage at POI

Illustration of Reactive Power as Function of POI Voltage

<table>
<thead>
<tr>
<th>Voltage at POI [pu]</th>
<th>Reactive Power (Q) [pu]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.85</td>
<td>-0.4</td>
</tr>
<tr>
<td>0.9</td>
<td>-0.3</td>
</tr>
<tr>
<td>0.95</td>
<td>-0.2</td>
</tr>
<tr>
<td>1</td>
<td>-0.1</td>
</tr>
<tr>
<td>1.05</td>
<td>0</td>
</tr>
<tr>
<td>1.1</td>
<td>0.1</td>
</tr>
<tr>
<td>1.15</td>
<td>0.2</td>
</tr>
<tr>
<td>0.3</td>
<td>0.3</td>
</tr>
<tr>
<td>0.4</td>
<td>0.4</td>
</tr>
</tbody>
</table>

PF=0.95
## Example Reactive Power Testing Procedures

<table>
<thead>
<tr>
<th>Test</th>
<th>Condition</th>
<th>Test</th>
<th>Requirement</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Maintain voltage setpoint</strong></td>
<td>( P = 25% ) to ( &gt;92.5% ) of Available Capacity</td>
<td>Set voltage setpoint to 1.02 pu</td>
<td>Voltage held within +/- 1%, subject to p.f. limits and Available Capacity. New voltage setpoint(s) may be selected.</td>
</tr>
<tr>
<td><strong>Compensate for changing transmission conditions</strong></td>
<td>( Q = \sim 0 ) MVAR output after LTC is adjusted several steps</td>
<td>Set voltage setpoint as necessary</td>
<td>( Q \leq 0 ) MVAR at POI</td>
</tr>
<tr>
<td><strong>Lead/Lag 0.95 limits</strong></td>
<td>( P = 25%, 50%, 75% ) and ( &gt;92.5% ) of Available Capacity, limited to 9.4 MVAR at POI.</td>
<td>Set voltage to demonstrate 0.95 p.f. Lead</td>
<td>Meter shop test equipment indicates 0.95 or less</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Set voltage to demonstrate 0.95 p.f. Lag</td>
<td>Meter shop test equipment indicates 0.95 or less</td>
</tr>
<tr>
<td><strong>Raise/lower setpoint</strong></td>
<td>( P &gt; 50% ) of Available Capacity</td>
<td>Series selected at time of test (ex: Raise/Lower voltage 0.005pu)</td>
<td>Voltage at POI is consistent with change in setpoint, subject to p.f. limits and within the ability of the plant to influence the voltage</td>
</tr>
</tbody>
</table>

- Available Capacity = Total plant power output correcting for environmental variables (e.g. irradiance, temperature).
Example of Test Demonstration

- Successful test of reactive power tests for SunPower Utility Scale Solar PV Plant
- Demonstrated at range of Power outputs during the morning
- Reaches Full Reactive Power Requirements (+/- 0.95 pf)
Voltage Control

(1) Rise in transmission system voltage

(2) SunPower PV Plant absorbs reactive power to reduce transmission voltage

(3) Transmission voltage returns to setpoint

SunPower PV Plant operational in North America with automated voltage control on the transmission system

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Summary of Reactive Power Requirements

- SunPower Utility Scale PV Plants have demonstrated ability to provide reactive power support and help maintain voltage

- Shared goal of grid reliability and stability
  - Requirements that are designed to promote grid stability and reliability while avoiding market barriers
  - Utility Testing and Operational Requirements
Regulatory Ride Through Requirements

- Rules on Ride through still evolving in U.S. and elsewhere
  - OASIS has configurable Voltage and Frequency Ride though Windows
  - Ex: FERC Order 661-A, NERC PRC-024 (Draft), WECC ONF, MV BDEW
- Example of LVRT Requirement: Ride through three phase faults on transmission grid with normal clearing times (4-9 cycles)

<table>
<thead>
<tr>
<th>Under-frequency Limit</th>
<th>Over-frequency Limit</th>
<th>WECC Minimum Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 59.4 Hz</td>
<td>60 Hz to &lt; 60.6 Hz</td>
<td>N/A (continuous operation)</td>
</tr>
<tr>
<td>≤ 59.4 Hz</td>
<td>≥ 60.6 Hz</td>
<td>3 minutes</td>
</tr>
<tr>
<td>≤ 58.4 Hz</td>
<td>≥ 61.6 Hz</td>
<td>30 seconds</td>
</tr>
<tr>
<td>≤ 57.8 Hz</td>
<td></td>
<td>7.5 seconds</td>
</tr>
<tr>
<td>≤ 57.3 Hz</td>
<td></td>
<td>45 cycles</td>
</tr>
<tr>
<td>≤ 57 Hz</td>
<td>&gt; 61.7 Hz</td>
<td>Instantaneous trip</td>
</tr>
</tbody>
</table>

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Ride Through

- Example of operational SunPower Solar PV Plant riding through a disturbance
  - Voltage and Frequency Ride Through
  - Plant remains online and continues providing power as the grid recovers

Lanai (Hawaii) 1.2 MW Project

- Lanai peak net load: 4.7 MW
- Operational since: December, 2008
Example of Active Power Curtailment

Utility sets plant output from 150kW to 200kW.

Ramp rate is 4.3 kW/s.

Setpoint reduced to 50kW to 200kW.

Over Frequency Droop

- OASIS has the option of a configurable droop response

- Example: Project currently in late stage development
  - Project expected to start construction this year
  - Specific voltage and frequency issues for local grid
  - Utility interested in option of Over-Frequency Droop Response

- Not aware of any requirements for over frequency droop for a currently operational Solar PV Plant in U.S.
Example Simulation: Over Frequency Droop

Example Simulation of Over Frequency Droop Response

- Time (s)
- Frequency (Hz)
- Total Real Power Output (pu)

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System Impact Studies for Solar PV Plants

- Assess impacts on system reliability and stability

- California ISO Cluster Process
  - Over 16,000 MWs of Solar PV in Interconnection Queue
  - Power flow, dynamic stability, and short circuit studies

- SunPower has provided Plant Level Equivalent Models for System Impact Studies
  - Proprietary positive sequence models (PSSE/PSLF) exist today for Solar PV inverters
  - WECC Renewable Energy Modeling Task Force (REMTF)
Summary of Grid Support

- SunPower Utility Scale PV plants have demonstrated ability to provide:
  - Voltage Support
  - Ride through disturbances on the grid
  - Active power management
  - Over frequency droop response

- Models of Solar PV Plants available for System Impact Studies

- Shared goal of requirements that promote grid reliability and stability while avoiding market barriers
Summary

- Thank you for the opportunity to present our experiences!
- SunPower has over 1.5 GW of solar PV deployed worldwide
- The OASIS Power Plant with grid integration options:
  - Ride Through (Voltage and Frequency)
  - Over Frequency Droop Response
  - Real Power Curtailment
  - Reactive Power Support
- A thank you for all the helpful support to: Kari Smith, Alan Comnes, Carl Lenox, Chris Barker, Robert Johnson, Lars Johnson, and many others from the SunPower team
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