The Future of CSP: Dispatchable Solar Power

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U.S. Direct Normal Resource Map & Transmission Interconnections
Decarbonizing the Power Sector

- Renewable deployment driven by both Federal and State policies.
  - Federal PTC & ITC drive economics
  - Federal PTC drives wind.
  - State policies and RPS mandates drive PV deployment
- Western states proposing more aggressive RPS targets
  - California 100% by 2045
  - Nevada 80% by 2040
  - New Mexico 80% by 2040
- The Duck Curve problem occurs in 2020 when CA achieves 33% RPS.

Source: SNL – S&P Global Market Intelligence
Flexible Generation Needed

- The California “Duck Curve” is a sign of success in terms of achieving a meaningful contribution of renewable power on the grid.

- Managing the Duck is one of the key challenges to moving to higher renewable contributions on the grid.

- Utilities are responding by:
  - Closing baseload plants.
  - Adding flexible or “Peaking” natural gas resources.

CAISO Duck Curve

Can a dispatchable CSP plant fill the need for flexible peaking capacity?
How can a dispatchable solar power plant help California?

Example based on Actual 2016/2017 CAISO System Load

- **Winter**

- **Spring/Fall**
  - 9 Apr. 2017

- **Summer**
  - 29 Sep. 2017
Option 1: Time of Delivery Power Purchase Agreement
- Preferred = 3X Less Preferred
- More Preferred = 9x Less Preferred
- No power during “No Must Take Energy"

Option 2: Thermal (Fossil) Tolling Power Purchase Agreement
- Capable of operating for 4 hours at 46°C at 100% contract capacity.
- Dispatchable by APS with AGC (load following capability)
- Stable operation at a 25% loading.
- Capable of at least 2 starts per day.
- Faster starts and ramp rates are better
Dispatchable Solar Power (DSP) Plant
Uses Conventional Molten-Salt Tower Technology
Dispatchable Solar Power Plant

- DSP Operational Requirements
  - Fast Starts & Ramps
  - Store solar energy during the day
  - Dispatch power anytime during next 24 hrs

- Cost Reduction
  - Standardized design
  - Power Parks
  - Compressed EPC schedule

- Commercialization
  - Conceptual engineering design and EPC cost estimate
  - Vendors identified for all key equipment
  - Address tower sensitive development issues
  - Outreach to Developers, EPCs, Utilities
## Dispatchable Solar Power Plant Design

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Summer On-Peak</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5 hours</td>
</tr>
<tr>
<td><strong>Turbine Nominal Gross Power</strong></td>
<td>250 MW&lt;sub&gt;e&lt;/sub&gt;</td>
</tr>
<tr>
<td><strong>Turbine Nominal Net Power</strong></td>
<td>230 MW&lt;sub&gt;e&lt;/sub&gt;</td>
</tr>
<tr>
<td><strong>Power cycle gross thermal efficiency</strong></td>
<td>44%</td>
</tr>
<tr>
<td><strong>Power cycle cooling system</strong></td>
<td>hybrid</td>
</tr>
<tr>
<td><strong>Power cycle design ambient temperature</strong></td>
<td>46°C</td>
</tr>
<tr>
<td><strong>Solar Receiver design duty</strong></td>
<td>400 MW&lt;sub&gt;t&lt;/sub&gt;</td>
</tr>
<tr>
<td><strong>Solar Multiple</strong></td>
<td>0.65</td>
</tr>
<tr>
<td><strong>Tower Optical Height</strong></td>
<td>170 m</td>
</tr>
<tr>
<td><strong>Total Heliostat Area</strong></td>
<td>700,000 m&lt;sup&gt;2&lt;/sup&gt;</td>
</tr>
<tr>
<td><strong>Solar Field Area</strong></td>
<td>256 ha</td>
</tr>
<tr>
<td><strong>Storage Capacity</strong></td>
<td>3,000 MWh&lt;sub&gt;e&lt;/sub&gt;</td>
</tr>
<tr>
<td><strong>Storage Capacity</strong></td>
<td>5 hr</td>
</tr>
<tr>
<td><strong>Annual Gross Capacity Factor</strong></td>
<td>16.5%</td>
</tr>
<tr>
<td><strong>1&lt;sup&gt;st&lt;/sup&gt; year Net Generation</strong></td>
<td>334.2 GWh&lt;sub&gt;e&lt;/sub&gt;</td>
</tr>
</tbody>
</table>
Fast Start Power Cycle

New Siemens SST900 Fast Start Steam Turbine +
Aalborg Molten-Salt Header Style Steam Generator

Steam Turbine Hot Start Ramp Rate

- Initial Roll
- Synch Speed
- Connect to Grid
- Minimum Load (6.4%)
- Start Ramp to 90% Load
- Start Ramp to 100% Load
- 100% Load

Time - Minutes
This shows the modeled output of a DSP plant optimized for a specific TOD schedule requested by Arizona Public Service (APS).

- The plant achieves very high capacity factors during the more preferred and preferred TOD periods.
- Approximately 82% of the total energy from the plant is delivered during these periods.
DSP Plant vs. Combustion Turbine in Arizona

All-In Capacity Cost [$/kW-yr]

- Frame CT @ 16.5% CF
- Aero Derivative CT @ 16.5% CF
- DSP Baseline Cost Case
- DSP Cost Reduction 30% ITC
- DSP Power Park Case 30% ITC
- DSP Power Park Case 10% ITC

Carbon - Mid
- Gas Infrastructure
- Fuel
- Variable O&M
- Fixed O&M & Ins.
- Taxes
- Capital
Summary

- Markets of the future need flexible renewable peaking capacity.
- Molten-salt tower technology can be used to be “dispatchable solar power” plants.
  - A reliable source of capacity
  - Can operate in flexible manner as a peaker
  - Can compete with new fossil plants in good resource locations.
- Different regions will have different needs.
  - Peaker CSP plants may make sense in some regions
  - Baseload CSP plants will continue to make sense in other regions.
  - Some regions could need both.
Thank you for your attention!

Questions?

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