ADRESSING CALIFORNIA’S FLEXIBLE CAPACITY NEEDS WITH CONCENTRATED SOLAR POWER AND THERMAL ENERGY STORAGE

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Abstract
California has a renewable portfolio standard (RPS) that requires its utilities to procure 33% renewable energy generation by 2020. The increase in variable generation from solar and wind, has led to discussions of future ramping needs to maintain grid reliability. The fluctuating generation supply due to renewables will require adequate flexible generators that can ramp up and down to maintain grid balance at all times. Simulations by the California Independent Service Operator (CAISO) have shown ramping needs in excess of 12 GW for certain days in 2020. The majority of flexible generators currently in operation are natural gas-fired. This generation type cannot be relied on to provide future needs without risking environmental damage and contradicting the goal of reducing greenhouse gas emissions. In order to create a truly sustainable energy infrastructure solar and wind should be supported by other renewables. Concentrated solar power (CSP) with thermal energy storage is a dispatchable resource that should be considered when procuring future flexible resources.

Introduction
The creation of the renewable portfolio standard (RPS) has led to a rapid growth in renewable energy deployment in California in the past decade. The increase in solar and wind systems has increased the amount of variable generation in the California grid. New legislation by Assemblyman V. Manuel Perez entitled Assembly Bill 117 (AB 117) could increase renewable energy development after 2020. The key goals of the bill include requiring 51% of electricity generation from renewable resources by 2030 and to achieve greenhouse gas emission reductions of 80% below 1990 levels by 2050. The new plan will “…require electrical corporations to procure all available cost-effective energy efficiency, demand response, and renewable energy resources so as to simultaneously achieve the goals of renewable resource development, reductions in emissions of greenhouse gases, and sustain system reliability in the most cost-effective and affordable manner”. The passage of the bill could lead to further expansion of solar and wind to meet the 51% renewable energy goal. As more variable generation is integrated into the market, more flexible power plants are needed for the days in a year with large generation drops. Natural gas plants currently provide the majority share of flexible capacity to California. Flexible capacity that can generate renewable energy, reduce greenhouse gas emissions, and sustain system reliability should be emphasized in order to complement the goals of AB 117. Concentrated solar power (CSP) technology operates by focusing energy from the sun to produce steam for electric generation. Excess thermal energy can be transferred and stored in salt tanks for future energy production. Shown below is a list of approved CSP projects by the California Public Utilities Commission (CPUC) as of July 2013.

![Table 1: Approved CSP projects for the CAISO region](image)

1 Every four seconds it provides signals for individual plants to change their turbine speeds based on changes of the supply or load. The types of
process that ties turbine speeds of generators in the system with the frequency of the electric grid. When a large amount of generation drops quickly the AGC sends signals to the remaining generators online to increase generation to meet the demand. Each generator connected to the AGC has a ramp rate range which describes how quickly it can change power capacity for a given time interval. As more variable generation is added to the system, additional quick responding generators are needed in the fleet to compensate for instances of large power drops.

The 2020 net load profile simulations by CAISO have shown a large need for flexibility in the morning and afternoon hours. The early morning hours where wind usually decreases before solar production begins will require flexibility to account for a 4,500 MW in 2 hours. The late afternoon scenario of solar production dropping and demand increasing will require ramping needs of 12,500 MW in 2.5 hour time period. Ramping needs are currently being met by natural gas and hydro facilities. Further increasing the reliance on either resource can result in environmental damage. Hydroelectric generation varies based on rainfall levels in a year. Excessive ramping up and down of hydro units has environmental implications for downstream water levels. Additionally, if hydro was expanded future unexpected droughts can result in inadequate supply of flexible capacity. The increase is natural gas production results in increased amounts of greenhouse gas emissions. This makes the greenhouse gas emissions reduction 80% below 1990 levels by 2050 goal much more difficult to achieve. Also, the majority of the cost of energy from a natural gas unit is derived from fuel price as shown in Table 2. Natural gas prices have been shown to fluctuate greatly over the years and it is unknown how the California cap and trade program will affect natural gas prices in the future. This leaves the consumers at the risk of significantly higher electricity prices.

<table>
<thead>
<tr>
<th>Combi...</th>
<th>Combined Cycle</th>
<th>Advanced Combined Cycle</th>
<th>Combustion Turbine</th>
<th>Advanced Combustion Turbine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital Cost</td>
<td>15.8</td>
<td>17.4</td>
<td>48.2</td>
<td>30.4</td>
</tr>
<tr>
<td>Fixed O&amp;M</td>
<td>1.7</td>
<td>2</td>
<td>2.7</td>
<td>2.6</td>
</tr>
<tr>
<td>Fuel</td>
<td>48.4</td>
<td>45</td>
<td>90</td>
<td>68.2</td>
</tr>
<tr>
<td>Transmission</td>
<td>1.2</td>
<td>1.2</td>
<td>3.4</td>
<td>3.4</td>
</tr>
<tr>
<td>Total system cost</td>
<td>67.1</td>
<td>65.8</td>
<td>130.3</td>
<td>194.6</td>
</tr>
<tr>
<td>Fuel/Total Cost</td>
<td>72%</td>
<td>69%</td>
<td>61%</td>
<td>62%</td>
</tr>
</tbody>
</table>

Table 2: Levelized cost of new natural gas resources in 2018 by U.S. Energy Information Administration

Flexible Capacity Initiative

The lack of specific procurement of quick reacting plants within California resource adequacy program has resulted in CAISO launching a flexible capacity initiative. The initiative allows for capacity procurement of flexible generation that can be used to serve ramping needs for the region. Flexible capacity is the defined as the operational flexibility of a resource with respect to operator dispatch conditions. The degree of flexibility is mainly determined on how quickly and long a unit can ramp up or ramp down at any given instant. The flexibility is a combination of the load following and regulation capability of a resource. Load following is the ramping capability of a resource to match the maximum megawatts by which the net load is expected to change in either an upward or a downward direction in a given hour for the relevant resource adequacy compliance month. Regulation capacity is the capability of a generating unit to automatically respond during the intra-dispatch interval to the ISO’s four-second automatic generation control signal to adjust its output to maintain system frequency with neighboring balancing area authorities. Resources that provide these resources can create revenue streams from the ancillary services market. The ancillary services market provides compensation to units that can provide load following and regulation services when called upon. The initial proposal excludes intermittent generation from providing this service. The explanation for this is that intermittent resources can only produce energy when the fuel source is available and therefore have no inherent upward ramp capability. The operational capabilities provided by TES in CSP plants allow for storage to be controlled and used when available.

Capabilities of CSP technology

A CSP plant consists of three major components: the solar field (also known as solar multiple), the power block, and storage as shown in Figure 1. CSP produces energy using steam turbine technology. The operation and performance of steam-turbine technology is well known and understood by the energy industry from its use in conventional fossil-fuel generation.

CSP turbines have been built to ramp up and ramp down on a daily basis. A warm turbine in a CSP plant takes only 10 minutes to go from start to full power. The efficiency of a steam turbine at 50% load is 95% efficient.

The steam turbine technology used in CSP plants allows the resource to quickly change power when needed.
making it a flexible resource for the grid. It can also participate in AGC and be a resource that can optimize the CAISO generator fleet dispatch. CSP plants with their steam turbine technology do have the capabilities of providing load following, and regulation services. The lack of actual operational performance in this mode has prevented CSP participation in this market.

Previous studies have shown that the optimal operation of CSP with TES is providing dispatchable energy during the highest prices in any given day.9 The highest demand for energy in the California load profile occurs in the early morning and evening hours. During the winter, a CSP plant uses excess energy from the previous day to meet the morning load and then turn off for the day and increase output in the evening hours. During the summer, the plant operates continuously from morning into the evening, and generates at maximum output during the evening hours.

Ancillary Services Market Participation

Using PLEXOS, a production cost model it can be shown that CSP plants providing both energy and reserves (load following & regulation) can earn greater profits than by only providing energy.10 In order to simulate CSP providing 1% of CAISO demand in 2020 a 762 MW parabolic trough CSP plant with 6 hours of storage and a solar multiple11 of 2 was modeled. The first case did not allow the CSP plant to provide operating reserves. The plant ramp rate was set to allow ramping from minimum to maximum in 1 hour. The second case was a CSP plant that was allowed to provide energy and regulation reserves. The second plant was allowed to provide reserves while operating at or above its minimum generating point. The ramp rate of this plant was set to allow the ramping from minimum to maximum in 10 minutes. This allows the plant to offer its entire operating capacity (457 MW) as spinning reserve. The cost minimization modeling in PLEXOS optimizes the entire system to minimize the sum of operational costs which includes fuel, operations and maintenance, and startup costs.

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9 The analysis used the “Environmentally Constrained” scenario of CAISO 33% RPS scenarios. This scenario has the largest amount of generation from solar and reflects the promotion of distributed solar generation in California.

10 Solar multiple (solar field) is the ratio of the CSP plant’s solar plant with respect to the turbine capacity. A plant with a solar multiple of 1.0 would only be able to produce its nominal rated output at peak sun hours. Higher multiples allow the plant to store excess energy in TES when turbine is at maximum capacity.

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The simulations show the same type of CSP plant operating in two different ways. The first case shows CSP being optimized to deliver energy when the system marginal price is the highest. The second case shows CSP operating at minimum operating levels in order to be available to provide load following and regulation services when needed. An interesting note is that even though the software did not optimize CSP operation from the plant owner’s perspective the results show that CSP is still used during periods of highest system cost and therefore produces adequate revenue for the CSP operators.

Analyzing the revenue streams of both scenarios on the June 24th case in Table 3 the CSP plant providing energy and reserves generated a higher revenue stream. An important note to make is that even though less energy was produced in the energy and reserves case the offering of ancillary services for the majority of the day allowed for greater revenues. Figure 4 displays how the two cases achieved their profits in the June 24th simulation. The pricing of ancillary services reflect the need of those specific services in the system at that time interval. The expected need of flexible capacity will be reflected in future ancillary service prices. The lack of revenue loss from optimizing the system as a whole instead of optimizing a CSP plant makes participation of CSP plants in the ancillary services a viable option for the future.
Financial Incentives for CSP and TES

The high cost of CSP plants has made the implementation of TES in most locations uneconomical. The lack of value given to TES on a grid level should be compensated with better promotional incentives by the state. The California Public Utilities Commission’s recent mandatory energy storage procurement mandate could provide the right incentive. The purpose of the proposal “is to make storage a priority by virtue of setting targets.” The policy focuses on the optimization of the grid, including peak reduction, contribution to reliability needs, or deferment of transmission and distribution upgrade investments, integration of renewable energy; and the reduction of greenhouse gas emissions to 90 percent below 1990 levels by 2050. TES in CSP plants can potentially achieve all of the objectives described in the mandate and is a proven technology that should be advocated for.

Financing large CSP projects is a big barrier to deployment. Wind farms have benefited from pre-paid power purchase agreement that should be adopted by CSP developers. Pre-paid power agreements provide a upfront payment of expected generation by the purchaser of the energy. An accurate annual generation for a renewable with a variable fuel source can be generated using exceedance probabilities. Exceedance probability is the probability that a certain value will be exceeded. For example, a P50 value of 10,000 kilowatt hours (kWh) for the annual energy production means that there is a 50% likelihood that the system’s output will be greater than 10,000 kWh. A P90 value of 10,000 kWh would mean that system will most likely generate over 10,000 kWh 90% of the time. These values require many years of resource data in order to be calculated and provide accurate. The National Renewable Energy Laboratory (NREL)’s System Adviser Model has an in-depth weather data for several locations around the United States. A 100 MW Solar Power was modeled in the software to study P90 values. The location of Blythe, California was selected because it was within the CAISO region and there was 15 years of available weather data from the National Climate Data Center. Several cases were simulated based hours of storage and the solar multiple(SM) of the system. Figure 7 shows P90 production with respect to hours of storage and solar field size. The overall benefit of storage can be seen by the increase in P90 values with storage capacity hours in Table 4. The scenarios with the largest amount of storage coupled with an oversized solar field produce the greatest benefit. This can be attributed to an increase in the numbers of instances energy from the solar field exceeds the power block and get stored in the salt tanks for future use in the ancillary services market for reserves.
Conclusion
The continuing increase in variable renewable generation in California will require additional flexible capacity in order to maintain system reliability standards. The current methodology of providing flexible capacity in the California region is not sustainable for the future emission reduction goals. By enabling technologies such as CSP with TES to provide regulation and ramping through financial incentives, the CA region can reduce emissions, generate clean energy and maintain grid reliability.

Acknowledgements
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Future Research
- Analyze how hydro facilities operate in both energy and ancillary services market and apply principles to CSP with TES
- Determining the optimal storage capacity, solar multiple, and design parameters for CSP plants.
- Analyze the effects of CSP energy and reserves operation on turbine lifetime

Table 4: Increases in P90 energy production with respect to solar multiple and hours of storage

<table>
<thead>
<tr>
<th>Hours of Storage</th>
<th>Solar Multiple 2</th>
<th>Solar Multiple 2.5</th>
<th>Solar Multiple 3</th>
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<tbody>
<tr>
<td>1</td>
<td>14%</td>
<td>25%</td>
<td>37%</td>
</tr>
<tr>
<td>2</td>
<td>22%</td>
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</tr>
<tr>
<td>4</td>
<td>33%</td>
<td>55%</td>
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<tr>
<td>5</td>
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<td>6</td>
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<td>73%</td>
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</tr>
<tr>
<td>8</td>
<td>39%</td>
<td>76%</td>
<td>113%</td>
</tr>
<tr>
<td>9</td>
<td>40%</td>
<td>79%</td>
<td>120%</td>
</tr>
<tr>
<td>10</td>
<td>40%</td>
<td>81%</td>
<td>126%</td>
</tr>
</tbody>
</table>

Figure 7: P90 Energy Production with varying solar fields and hours of storage
1 2020 Flexible Capacity Needs California Independent System Operator  

2 Perez, Manuel. California Legislature. An act to mend Sections 345.5 and 454.55 of, and to add Sections 399.23 and 636 to, the Public Utilities Code, relating to renewable energy resources. http://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201320140AB177


5 http://www.eia.gov/forecasts/aeo/electricity_generation.cfm


