DE-EE0008782– Value and Role of Pumped Storage Hydro under High Variable Renewables

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Project Overview

Project Summary

- Pumped storage hydro (PSH) can accommodate the intermittency and seasonality of variable energy resources such as solar and wind power. New PSH plants in areas with recently increased wind and solar capacity are expected to improve grid reliability while reducing the need for new fossil-fueled generation.
- This project aims to overcome a range of market barriers for PSH by helping stakeholders understand the benefits of PSH that are not well understood or quantified, by demonstrating the capability of new variable speed PSH (VSPSH) technologies, and by helping developers improve PSH revenues with the development of a new PSH scheduling tool.

Intended Outcomes

The study is particularly intended for utilities, Public Utility Commissions (PUCs), developers and regional planner organizations, as it explores the values and impacts of PSH, specifically in high-renewable penetration systems:

- Develop a PSH scheduling tool to co-optimize energy and ancillary services
- Analyze and quantify the potential value of PSH under different system conditions.
- Develop a set of VSPSH models for transmission planners
- Investigate the dynamic capability of VSPSH and assess its impact on grid frequency response and transient stability.
- Investigate the PSH contribution to resource adequacy.

Project Information

Principal Investigator(s)

- Miaolei Shao, GE Research

Project Partners/Subs

- GE Energy Consulting
- GE Hydro

Project Status

Completed

Project Duration

- September 2019
- March 2021

Total Costed (FY19–FY21)

$1,250,000

Project Objectives: Relevance

Relevance to Program Goals:

- This project directly addresses the **untapped potential for pumped storage to support a rapidly evolving grid.**
  – **Optimize hydropower operations and planning to best utilize hydropower's capabilities**:
    - The PSH scheduling tool optimizes an individual PSH plant's operations, particularly in the under utilized/understood ancillary services space
  – **Understand the evolving needs of the rapidly changing grid**:
    - Analyzing and quantifying the potential value of PSH under different system conditions, especially a high renewable system, provides important insights into what will be needed and how PSH can best contribute
    - Investigating PSH's contribution to resource adequacy is critical to understanding how it can provide reliability as more variable resources are added to the grid.
  – **Accurate representation and system value of PSH capabilities in power system models**:
    - The new VSPSH models for transmission planners allow transmission planners to accurately model the latest PSH technology and its full capabilities
  – **Investigate PSH's full range of capabilities to provide grid services:**
    - Investigating the dynamic capability of VSPSH and assessing its impact on grid frequency response and transient stability highlights some of the grid services PSH can provide.

Project Objectives: Approach

Approach:

Utilizing the electrical system, modeling, and real equipment knowledge of GE Energy Consulting, GE Research, and GE Hydro we were able to create tools and models that accurately reflect PSH technologies and their capabilities.

- The PSH scheduling tool is first of its kind to incorporate price elasticity, the impact of variable height differences between reservoirs (‘head’) and variable speed machine behavior.
- Brand new PSLF models were created for variable speed PSH and dynamic modeling was performed for the first time using those models as well as integrated round-trip analysis with the production cost modeling.
- GE MAPS was used to evaluate a broad set of future conditions, specifically focused on PSH and how it competes with other storage
- GE MARS was updated to include dynamic storage modeling for this project and the capacity value of PSH was calculated under a variety of conditions.

Integrated scheduling, dynamic modeling, production cost, and capacity value analysis.

Project Objectives: Expected Outputs and Intended Outcomes

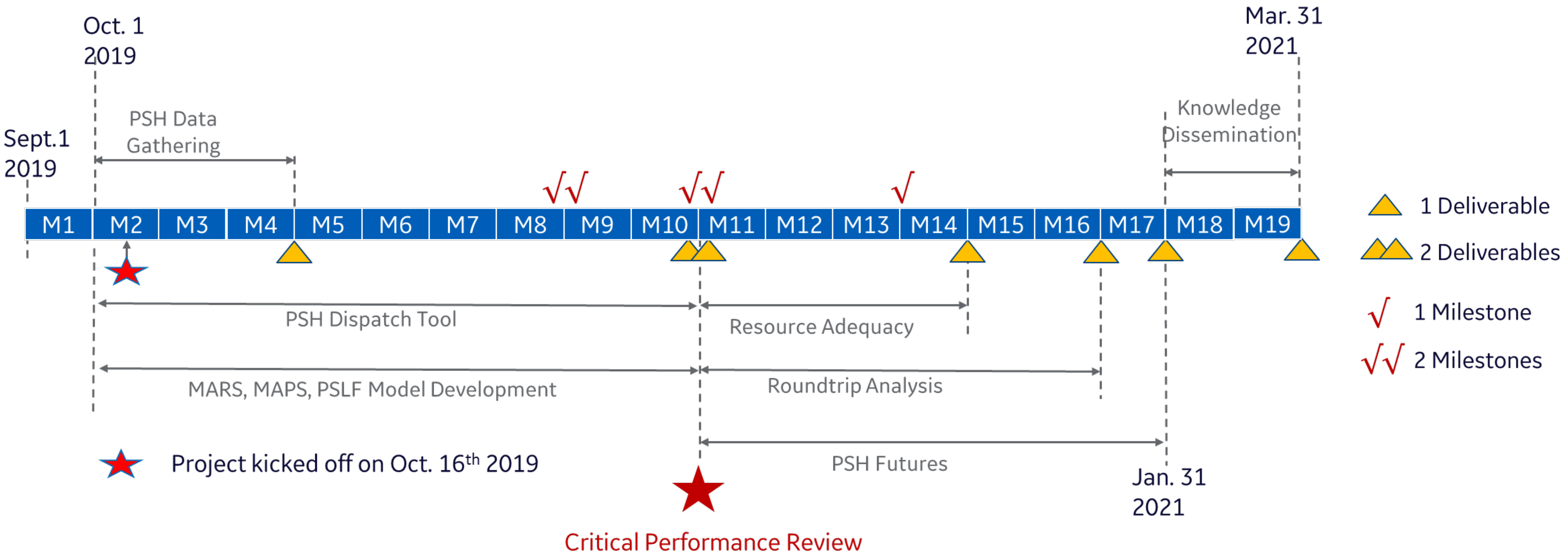
Outputs:

- PSH storage scheduling tool with price elasticity to optimize PSH dispatch across both energy and ancillary service value streams.
- Publicly available PSH models for system planning studies.
- Quantification of the frequency response and dynamics benefits from fixed and variable speed PSH.
- Quantified system benefits of PSH: production cost savings, avoided emissions, avoided curtailment, and cycling impacts in various future conditions
- Quantification of PSH capacity value of various durations for a range of future scenarios
- Disseminating models and results at other hydro industry conferences such as National Hydro Association’s Water Power Week.

Outcomes:

- Transmission planners can begin using the new PSH models immediately to better understand its impacts on their systems.
- PSH developers/owners can begin to use these results, and follow-up study work to define their projects value in the market.
- Regulators will be become familiar with these results and be more comfortable approving future PSH projects, knowing the possible system benefits.

Project Timeline



- Overall project was completed on schedule.
- Some internal delays due to:
  - First time implementation of Ancillary Services modeling in GE MAPS
  - Integrated production cost model with dynamic modeling for round trip analysis

Project Budget

Total Project Budget – Award Information		
DOE	**Cost-share**	**Total**
$1,000K	$250K	$1,250 K

FY19	FY20	FY21	Total Actual Costs FY19–FY21
Costed	**Costed**	**Costed**	**Total Costed**
$258K	$927K	$34K	$1,219K

- The project was overall under budget with some year-to-year changes in timing due to the schedule changes mentioned previously

End-User Engagement and Dissemination

- The final report for this project has been issues and is publicly available here: https://www.osti.gov/servlets/purl/1824300 or by searching "Value and role of pumped storage hydro under high renewables" in your favorite search engine.
- The results of this work have been presented at:
  - NHA Clean Currents 2021
  - ESIG Spring Technical Workshop 2022
  - GE Energy Consulting Knowledge Share Session Dec 2021
  - PSLF and GE MAPS User Group Meetings 2021/2022
  - IEEE PSEM tutorial
  - And more....

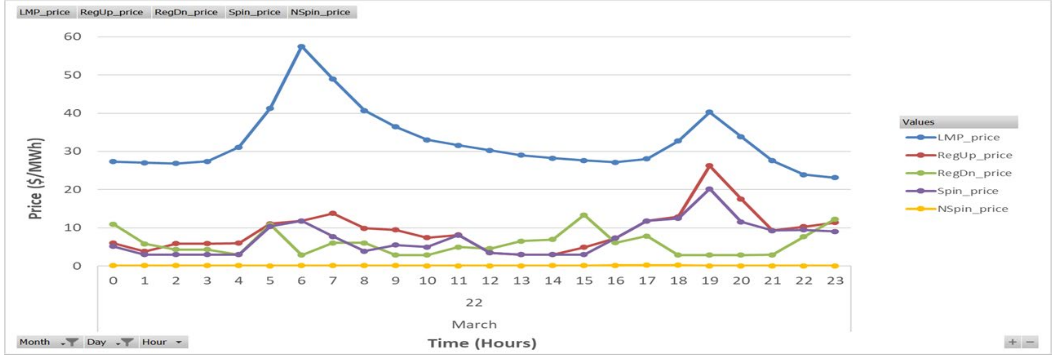
Performance: Accomplishments and Progress

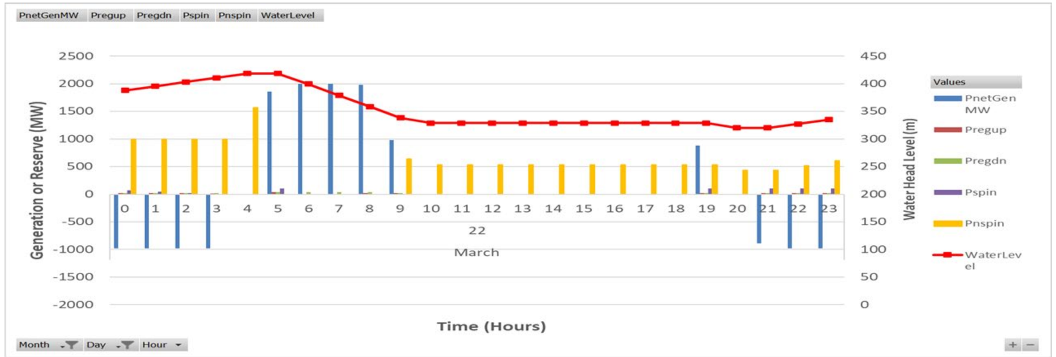
PSH Scheduling Tool

Goals: Maximize PSH operating profit on a given optimization horizon while respecting operational and scheduling constraints and enabling PSH developers and owners to unlock PSH value from both ancillary services and energy.

- A novel PSH Scheduling tool was developed, incorporating for the first time the impact of variable height differences between reservoirs ('head') and variable speed machine behavior.
- The tool is run in conjunction with a production cost optimization tool to allow for price elasticity effects to be captured.
- Developed in Python open source software and can be easily modified to meet future needs.

CAISO Market Prices for March 22, 2018



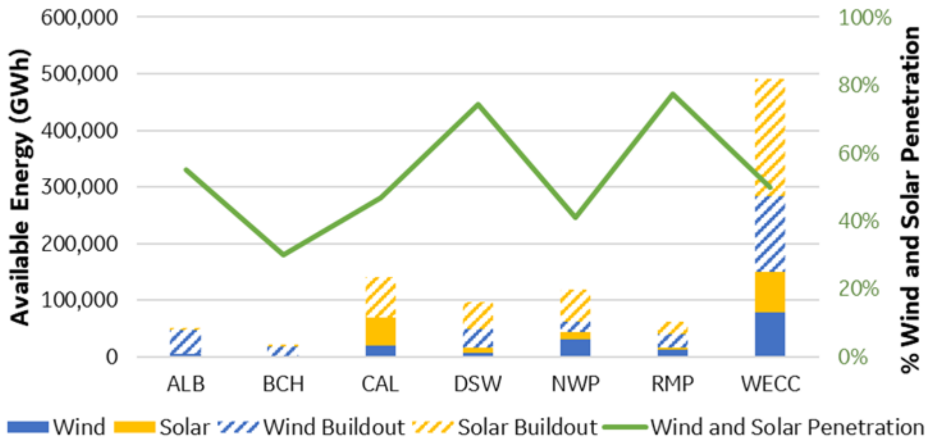


PSH optimal dispatch

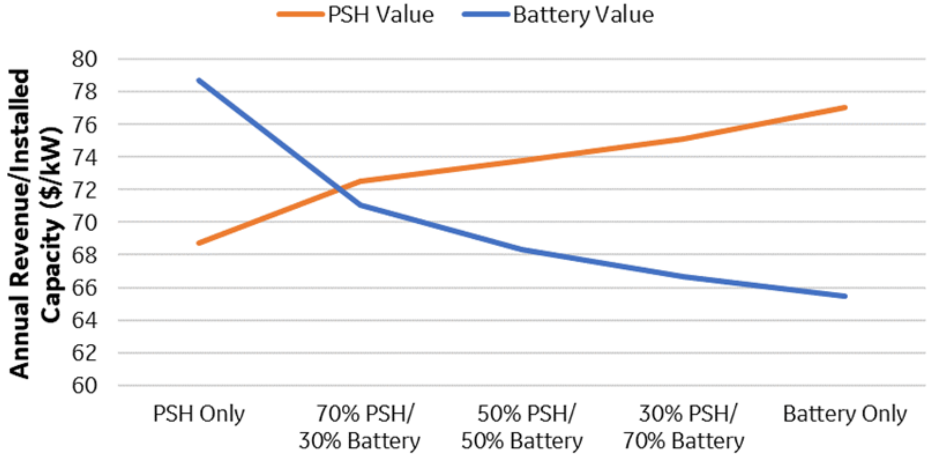
Performance: Accomplishments and Progress

PSH Future Scenarios: Assumptions

50% Renewable Penetration



High Storage Scenario



Real PSH Project Locations

	Big Chino	San Vicente
Capacity (MW)	2,000	500
Duration(hrs)/ Energy (MWh)	10/20,000	8/4,000
Location	AZ	CA
Revenue Streams	Energy	Energy & Ancillary Services

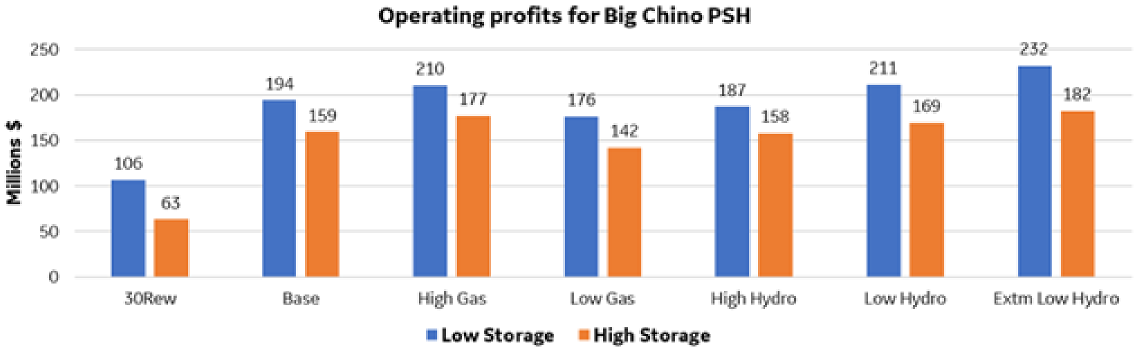
Sensitivities

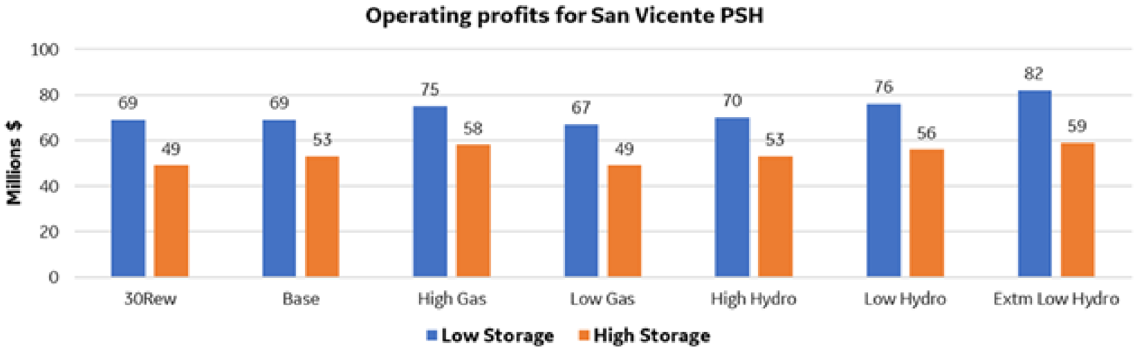
- Low and High Natural Gas Prices
- High, Low, and Extreme Low Hydro Generation
- 30% Renewable Penetration

Performance: Accomplishments and Progress

PSH Future Scenarios: Results

Delta From Case without Units	Production Cost ($/M)		CO2 Emissions (million tons)		Simple Cycle Peaker Cycling		Curtailment (GWh)	
	W/ Big Chino	W/ San Vicente	W/ Big Chino	W/ San Vicente	W/ Big Chino	W/ San Vicente	W/ Big Chino	W/ San Vicente
Base Low Storage	-182	-62	-1.82	-0.5	-4,762	-1,572	-4,753	-1,102
30% Renewables Low Storage	-93	-46	-0.15	-0.24	-5,936	-2,137	-1,406	-550
High Gas Price Low Storage	-194	-61	-1.72	-0.46	-4,587	-1,337	-4,790	-1,102
Low Gas Price Low Storage	-164	-56	-1.73	-0.43	-4,752	-1,625	-4,666	-1,114
High Hydro Low Storage	-184	-56	-1.68	-0.41	-5,676	-1,860	-4,811	-1,115
Low Hydro Low Storage	-195	-62	-1.62	-0.45	-5,387	-2,429	-4,399	-1,028
Extreme Low Hydro Low Storage	-202	-64	-1.55	-0.42	-4,820	-2,182	-4,324	-1,032
Base High Storage	-167	-48	-1.65	-0.39	-4,461	-2,132	-4,189	-806
30% Renewables High Storage	-58	-28	0.02	-0.07	-3,664	-2,637	-737	-278
High Gas Price High Storage	-181	-51	-1.74	-0.44	-4,707	-1,660	-4,312	-845
Low Gas Price High Storage	-143	-34	-1.74	-0.27	-3,023	-371	-4,274	-733
High Hydro High Storage	-165	-36	-1.71	-0.33	-5,073	-1,851	-4,412	-834
Low Hydro High Storage	-181	-48	-1.76	-0.29	-5,793	-1,700	-4,038	-772
Extreme Low Hydro High Storage	-184	-50	-1.7	-0.39	-5,302	-2,143	-4,118	-863





Positive system impact in all scenarios, no clear winner.

- Up to $202M/$64M reduction in Production Cost
- Up to 1.82/0.5 million tons of CO2 reduction
- Significant reduction in peak cycling and curtailment reduction

PSH plant revenue:

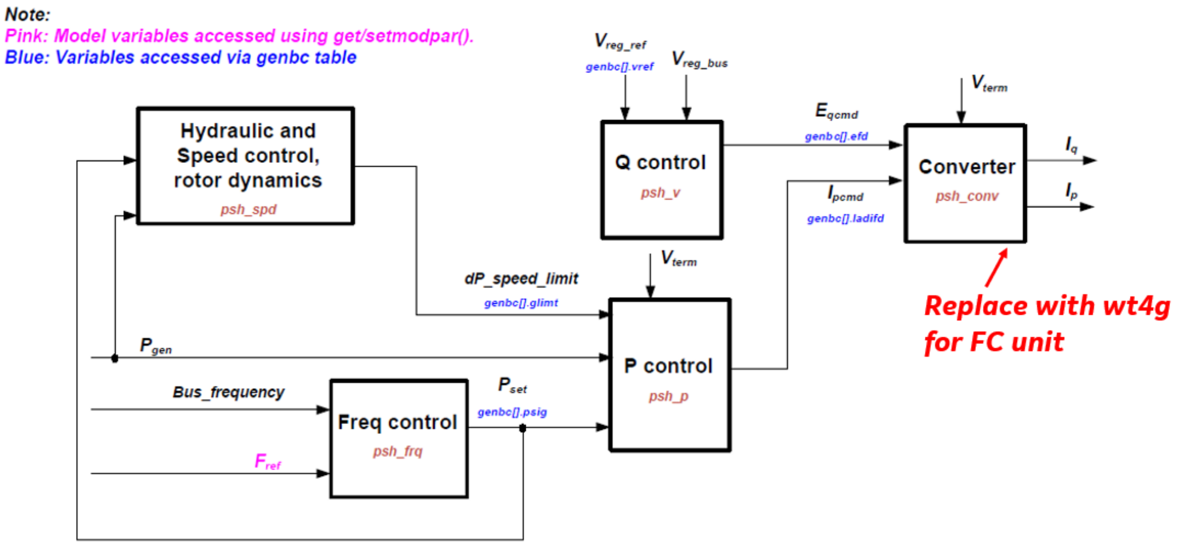
- Highest revenue in high renewable and high gas scenarios
- Reduced by more competing storage and lower renewables

Performance: Accomplishments and Progress

Dynamic Modeling

- Suite of models added to PSLF to represent variable speed pumped hydro storage units largely based on the models developed as part of a previous DoE project* with minor updates based on GE Hydro's Powerfactory model.
- Benchmarking done against previous DoE project's PSSE model and GE Hydro's Powerfactory model for small test cases
- All hours of the year from GE MAPS model filtered to select pinch points in frequency response capability
- The 2022 light load spring case load and generation were scaled to meet the average of these hours
- MW outputs of generators scaled to meet MAPS area/unit type targets.
- Loads scaled to meet the MAPS area loads
- Results showed no negative impact on critical interfaces and fault response.

* https://ceeesa.es.anl.gov/projects/psh/psh.html

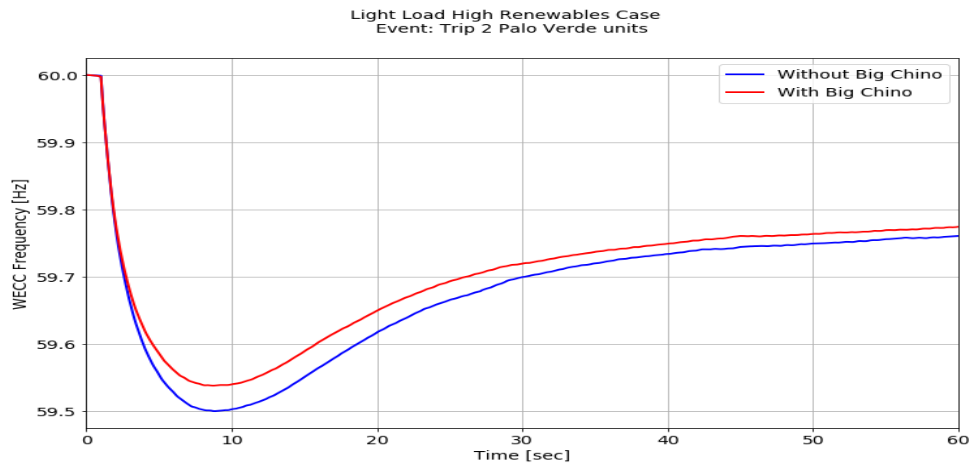


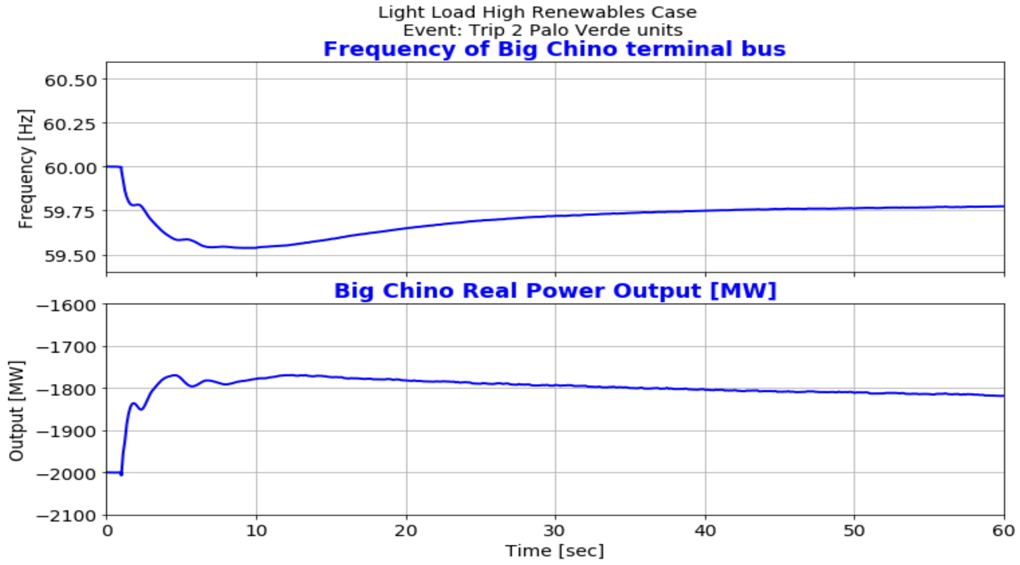
GE MAPS Model Frequency Pinch Point Criteria

- Spring
- between 10am and 3pm
- PSH Is pumping greater than 3000 MWh
- Wind + Solar generation > exceeds 60,000 MWh
- load is between 95,000 and 105,000 MWh
- Wind + Solar generation is 73% of load or more

Performance: Accomplishments and Progress

Dynamic Modeling: Assessment at Big Chino





Frequency response margin and RoCoF without Big Chino

Area	FRO [MW/0.1Hz]	FR [MW/0.1Hz]	FR margin [MW/0.1Hz]	ROCOF (between 1 and 1.125s) [Hz/s]
WECC	858	**739.73**	**-118.27**	0.31
CALIFORNIA	261.53	42.22	-219.31	0.44
DESERT SOUTHWEST	146.04	**67.17**	**-78.87**	0.93
NORTHEAST	149.85	21.22	-128.63	0.27
NORTHWEST	146.81	347.82	201.015	0.08

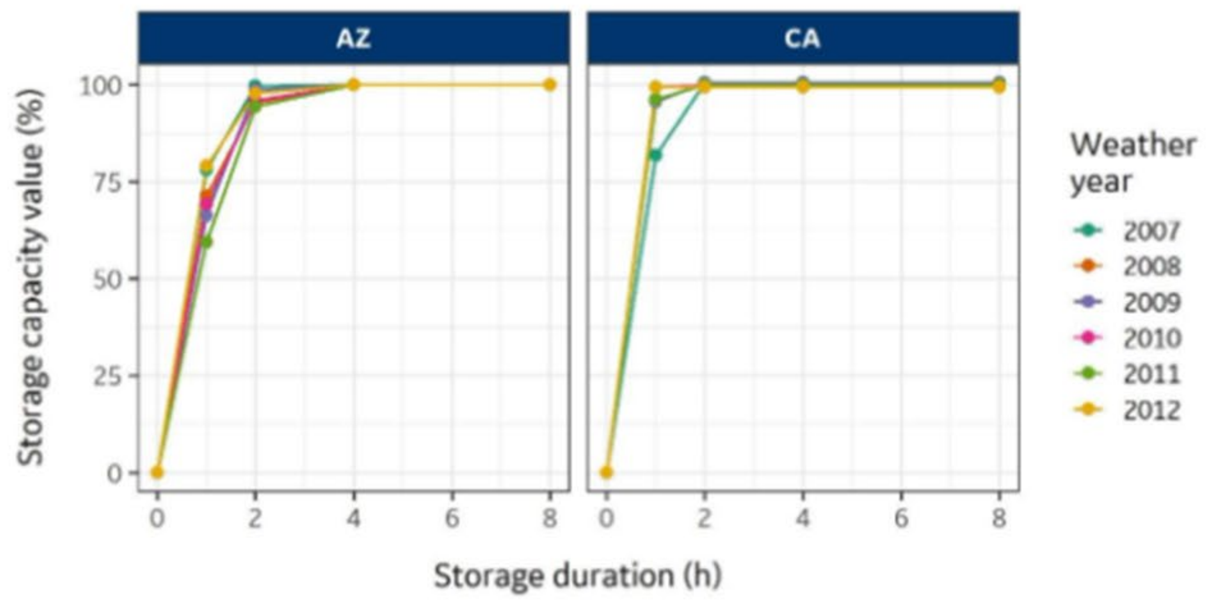
Frequency response margin and RoCoF with Big Chino

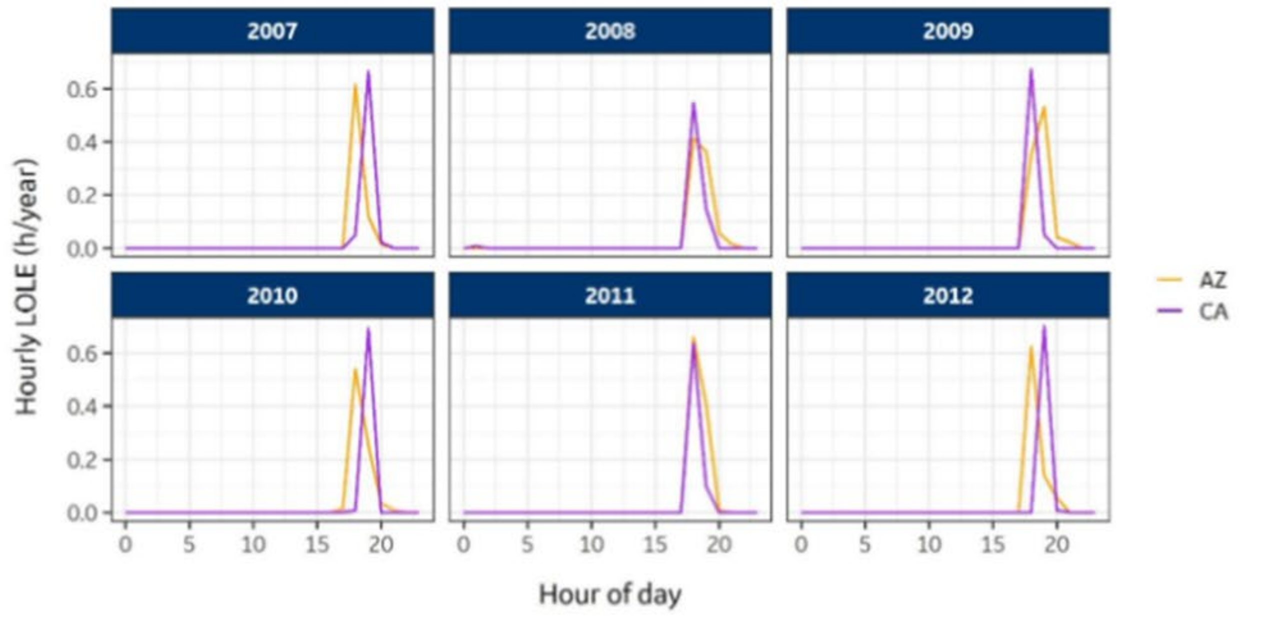
Area	FRO [MW/0.1Hz]	FR [MW/0.1Hz]	FR margin [MW/0.1Hz]	ROCOF (between 1 and 1.125s) [Hz/s]
WECC	858	**814.18**	**-43.82**	0.31
CALIFORNIA	261.53	42.21	-219.32	0.43
DESERT SOUTHWEST	146.04	**145.50**	**-0.54**	0.91
NORTHEAST	149.85	20.46	-129.39	0.26
NORTHWEST	146.81	346.33	199.52	0.08

Performance: Accomplishments and Progress

Capacity Value

- Calculate capacity value of storage, the resource's contribution towards meeting a reliability target, for different ratios of energy/capacity (hours of storage) using GE MARS.
- Loss-of-load expectation (LOLE)-based analysis determined the effective load carrying capability (ELCC) of the incremental storage
- Base case results are above 95% with 2 hours of storage in AZ and with 1 hour of storage in CA
- High renewable penetration caused LOLE to be for periods of ~1 hour

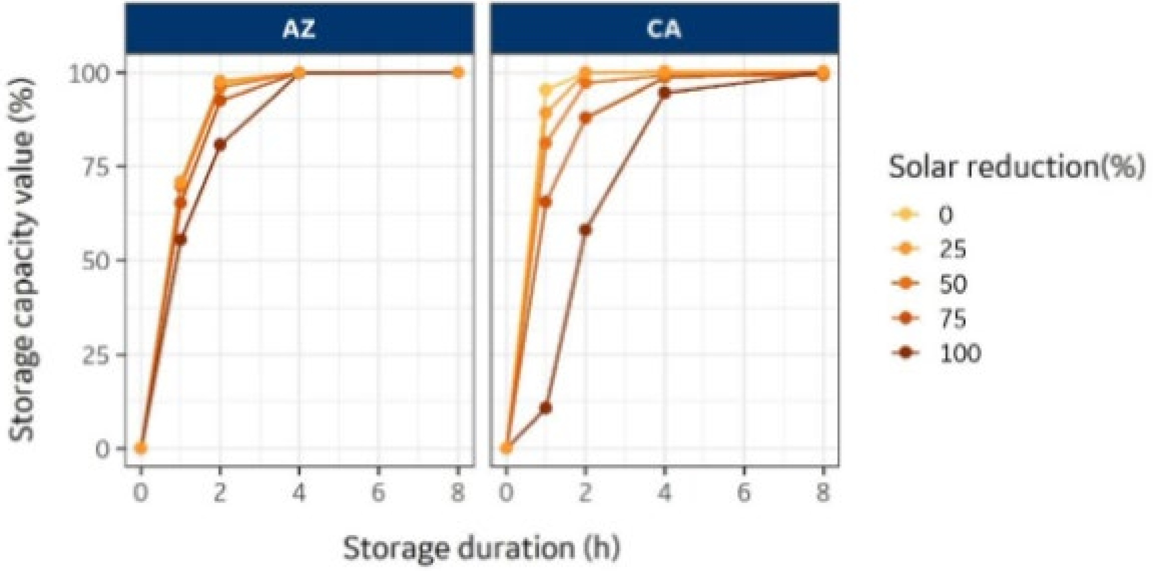


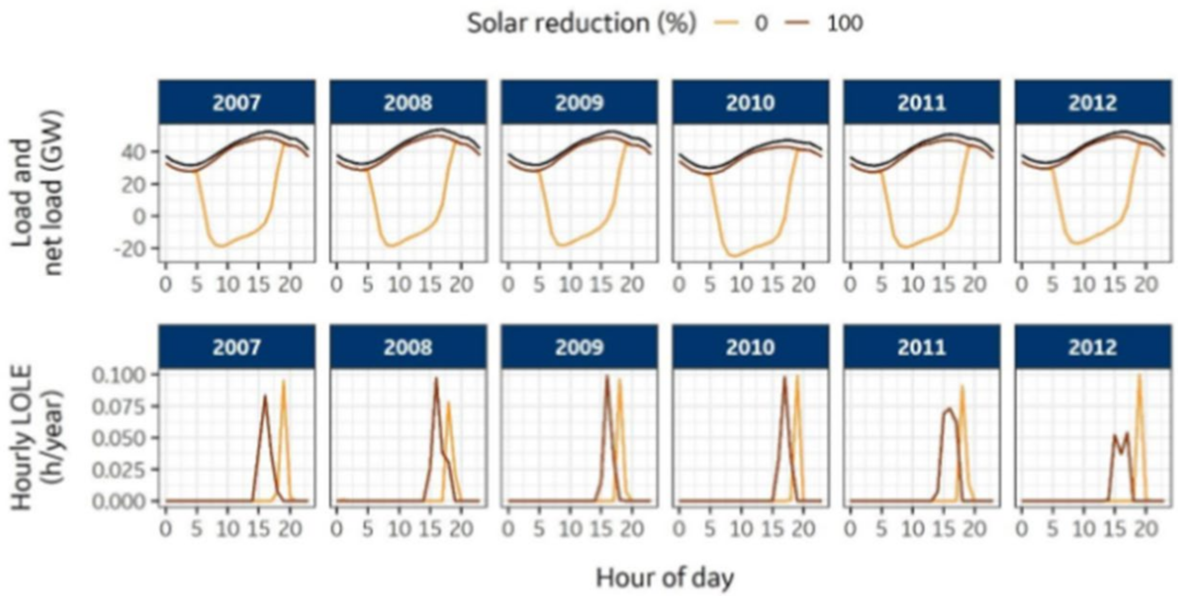


Performance: Accomplishments and Progress

Capacity Value

- Performed various sensitivities but solar reduction showed the only impact.
- Reduction of solar in the system reduces the Capacity Value of PSH at lower storage durations
- Biggest effect shown in CA where PSH CV only reaches ~95% with 4 hours of storage with no solar in the system
- Reduction of solar removes the duck curve, makes risky hours spread across multiple hours, so 1 hour of storage is no longer sufficient to cover all the LOLE





Q&A