Benefits of Pumped Storage Hydro Use in the West

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1. Introduction & Background of WWSIS

NREL and research partner GE have conducted the Western Wind and Solar Integration Study (WWSIS) in order to provide insight into the costs and operational impacts caused by the variability and uncertainty of wind, photovoltaic, (PV) and concentrated solar power (CSP) employed to serve up to 35% of the load energy in the WestConnect region, see Figure 1 for study footprint. The estimated 2017 load being served is 60 GW, with up to 30 GW of wind power and 700 MW of existing pumped-storage-hydro (PSH).

3TIER developed the wind dataset, hour-ahead and day-ahead wind forecasts using the Weather Research and Forecasting (WRF) mesoscale Numerical Weather Prediction (NWP) model over the entire western U.S. at 2-km, 10-minute resolution for the consecutive years 2004-2006. Each domain was run in three-day blocks which were merged and smoothed together at the seams [1].

Historical load and weather patterns form years 2004, 2005, and 2006 were used to examine the details of the system operation and dispatch though an hourly cost production simulation of balancing areas using GE's Multi-Area Production Simulation (MAPS) model.

MAPS performs a day ahead unit commitment and an hourly dispatch recognizing transmission constraints within the system and individual unit operating characteristics using 106 separate load areas (each with their own load profiles, generating portfolios, and transmission capacities with adjacent areas) [2].

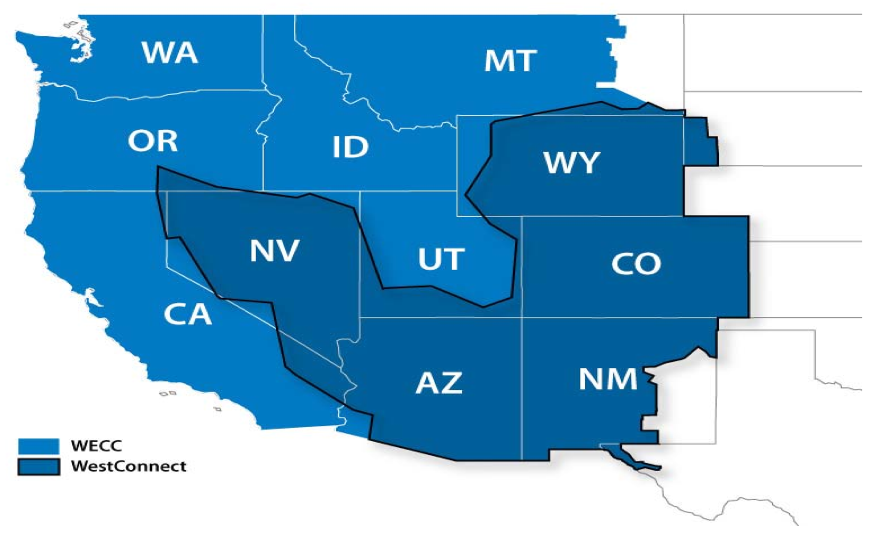

Figure 1: WestConnect Footprint as used in the WWSIS. (Source: WWSIS Final Report)

The entire system was committed and dispatched in a cost-effective, rational manner recognizing limits and cycling capabilities of the individual generators.

Three basic scenarios were considered concerning where the wind power was assumed to be installed. These scenarios are:

• *In-Area Scenario* – uses local resources within each transmission constrained area (defined roughly by state boundaries) by selecting the best sites in correspondence to a mix of energy value, geographic diversity and capacity factor.

•*Mega-Project Scenario* – created by trading out the lower ranked wind sites (by capacity factor) of the In-Area scenario by higher capacity factor remote resources (e.g. winds of Wyoming).

•*Local Priority Scenario* – uses a more realistic build-out of wind sites and transmission combining both in-state and remote resources.

Each scenario was run at three levels of wind power penetration (10%, 20%, and 30%), and three levels of solar power penetration (1%, 3%, and 5%). Seventy percent of the energy derived from solar power was from CSP with six hours of storage and 30% from distributed PV systems.

Due the large number of scenarios, a shorthand naming convention was devised to describe the various cases as shown in Table 1. For example, a case named L20R would refer to the Local Priority scenario with 20% penetration and using the state of the art forecast. Also noted is the preselected penetration level corresponding to renewables in existence or in the process of being built (also called the "No New Wind" case [3].

Table 1: Scenario naming convention for the various penetration levels and forecasting methods.

Scenario	Penetration Level	Forecast
I – In Area	Pre – Preselected Sites	P – Perfect Forecast
M – Mega Project	10 – 10%	R – State of the Art Forecast
L – Local Priority	20 – 20%	N – No Forecast
10%	20 20 – 20/20%	
	30 – 30%	

2. Objectives

An in-depth analysis was conducted to compare a series of MAPS simulations, and contrast the simulation data to actual production patterns seen at Mount Elbert PSH Plant (Name Plate Capacity of 200 MW). Figure 2 illustrates the PSH facility located in the upper Colorado region.

OBJECTIVES:

•How will renewable generation change PSH operations?
•How well was the PSH system modeled in the MAPS program?
•What is the economic impact on PSH operations as high levels of renewables are integrated into the grid system?

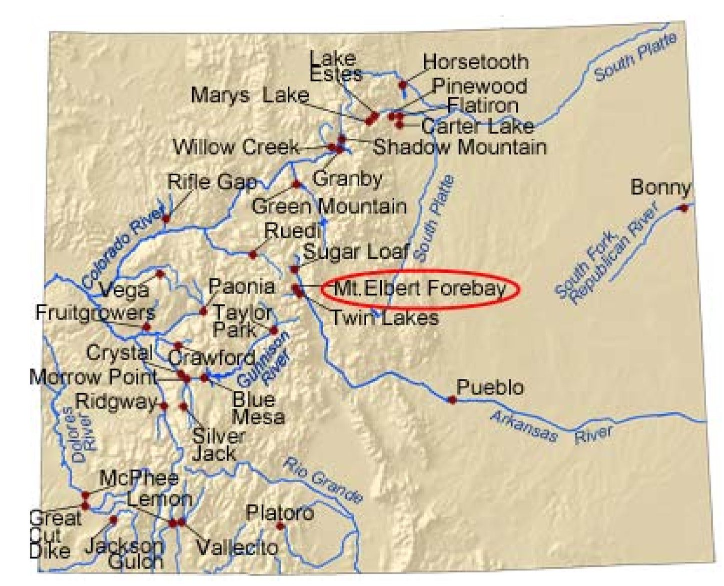

Figure 2: Mount Elbert PSH facility located in the upper Colorado region. (Source: United States Bureau of Reclamation)

3. Pumped-Storage-Hydro Operations

Pumped Storage Hydro relies one on the basic principle of "load factoring". The process of load factoring relies on the price differential between high-demand periods when the price of electricity is high, and low-demand periods, when the price of electricity is low. During high-demand periods, water is released from an upper reservoir via pipes which are connected to turbines located at the lower reservoir allowing electricity to be created. During low-demand periods, water is pumped back up to the upper reservoir to replenish reserves. Figure 3, illustrates a typical pumped storage plant.

Generally speaking, roundtrip electrical efficiencies of PSH can reach levels of 70% to 80%. As used in the WWSIS, pumped storage was assumed to have a round trip efficiency of 75%, thus the minimum price differential between the peak and off-peak periods required to break even is 1.33; that is, on-peak market prices would have to be 33% higher than off-peak pumping prices. If overall roundtrip electrical efficiencies increase, this percentage is reduced (e.g. 80% efficiency would result in a price differential of 1.25).

PSH can offer several benefits to the system including providing ancillary services required due to wind's variability and uncertainty. PSH also has the ability to provide some storage in the form of the upper reservoir in which it can be used to compensate for wind forecast uncertainty and thereby allow wind to bid into the day-ahead markets for commitment.

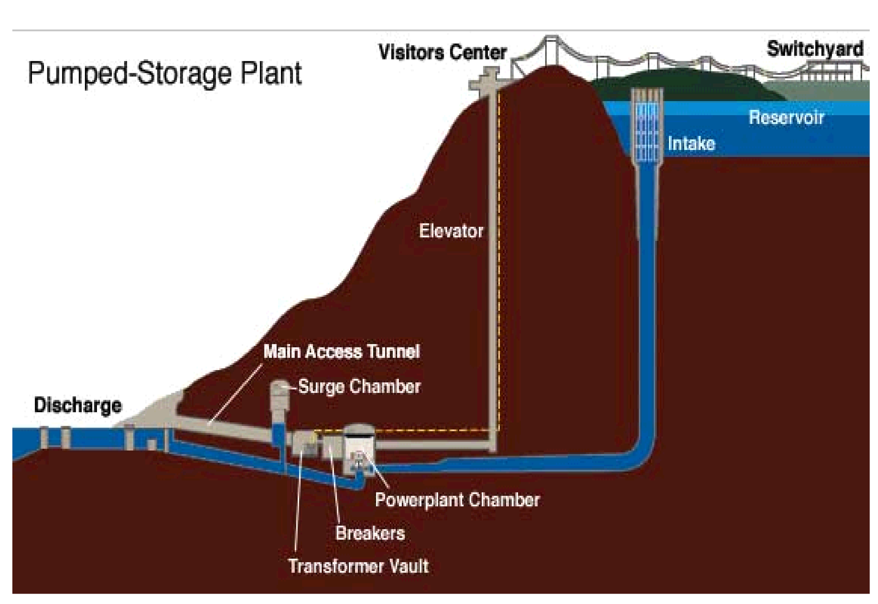

Figure 3: Example Diagram of Pumped Storage Plant (Source: Tennessee Valley Authority).

4. Methodologies

•*Baseline PSH Operations* – To investigate the changes in PSH operations over baseline (no-wind scenario has all renewables taken out of system) operations, modeled data from the MAPS program was used and compared to several scenarios of increased wind and solar generation.

•*Modeling Validation* – A modeling validation was conducted using actual production data from Mt. Elbert PSH plant and compared to MAPS simulated data for the no-wind scenario.

•*Impact of System Spot Price* – Results from the WWSIS show a investment of a new 100 MW PSH plant did not seem economically plausible. One effect of using wind power in a de-regulated market is wind will ultimately drive down spot price as penetration levels increase. Additionally system spot prices often fluctuate heavily throughout the day, thus making it more difficult for new generation resources like PSH to recover initial capital costs. To investigate this phenomenon, spot prices and a "utilization factor" or capacity factor at Mt. Elbert PSH plant are compared as wind and solar generation levels increase.

5. Results – Baseline PSH Operations

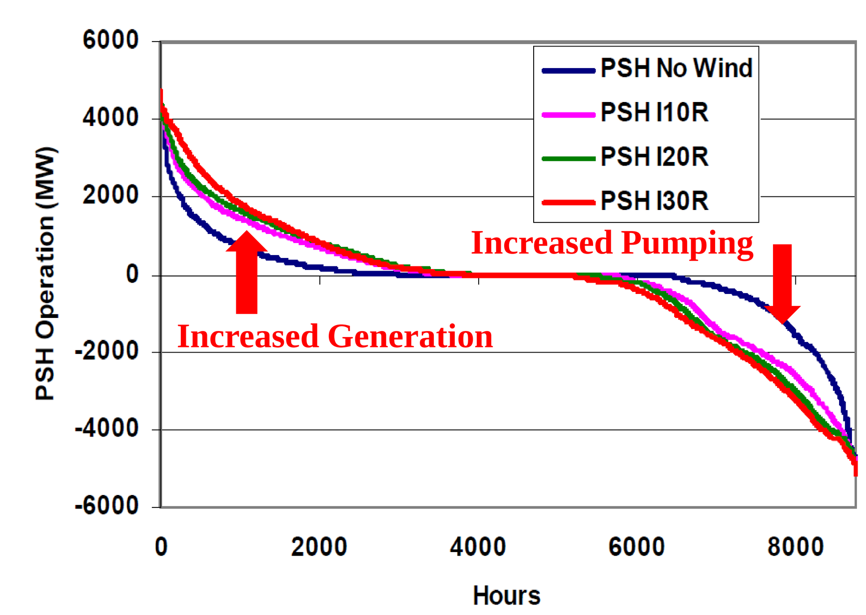

Figure 4: PSH annual duration curve, WECC (Source: WWSIS Final Report).

Results from the WWSIS show the annual duration curves for WECC PSH units over a range of renewable penetration levels for the in-area scenario using the professional forecast. As can be seen, as renewable penetration levels increase, the utilization of PSH increases slightly but does not push the usage to a point where more storage would seem required as would be indicated by the flat portions at either extreme of the curve (i.e. indicating saturation).

6. Results – Modeling Validation

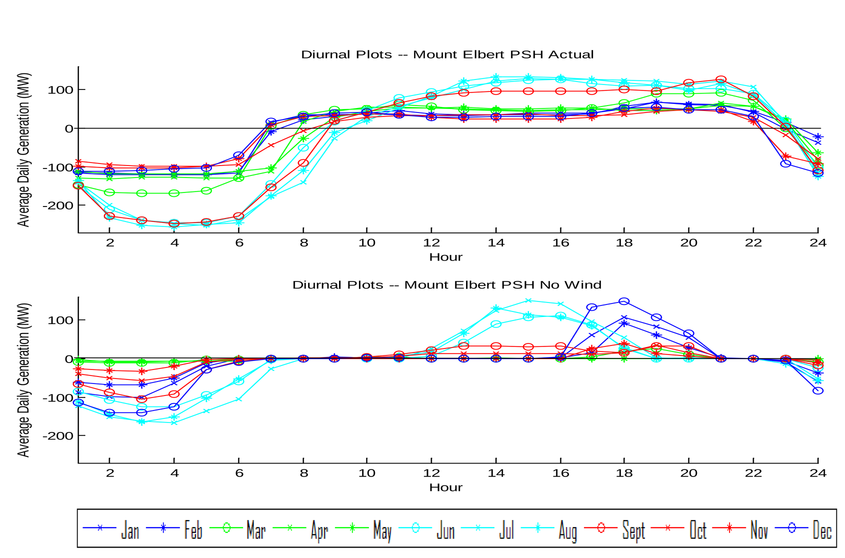

Figure 5: Monthly Diurnal distributions of Mt. Elbert PSH plant for actual and MAPS no-wind data sets.

As shown above, actual generation profiles show increased use throughout the day, especially during peak afternoon hours where MAPS opts to commit the majority of it generation resources during the peak afternoon-evening load periods. Furthermore, the MAPS simulation has several months where little generation occurs (e.g. spring and fall months).

7. Results – Economic Impact of Spot Price on PSH Operations

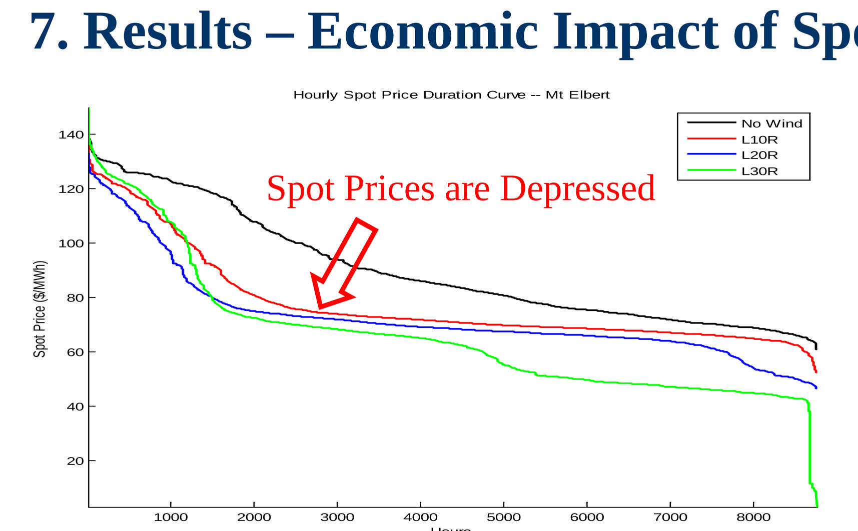

Figure 7: Hourly spot price duration curves for Mt. Elbert as seen in the MAPS simulation.

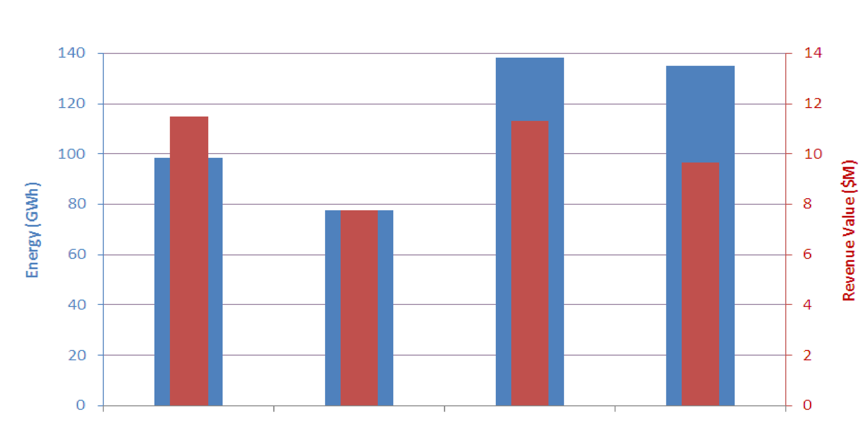

Figure 9: MAPS simulated revenue value and corresponding energy generated at Mt. Elbert PSH plat for local-priority scenario.

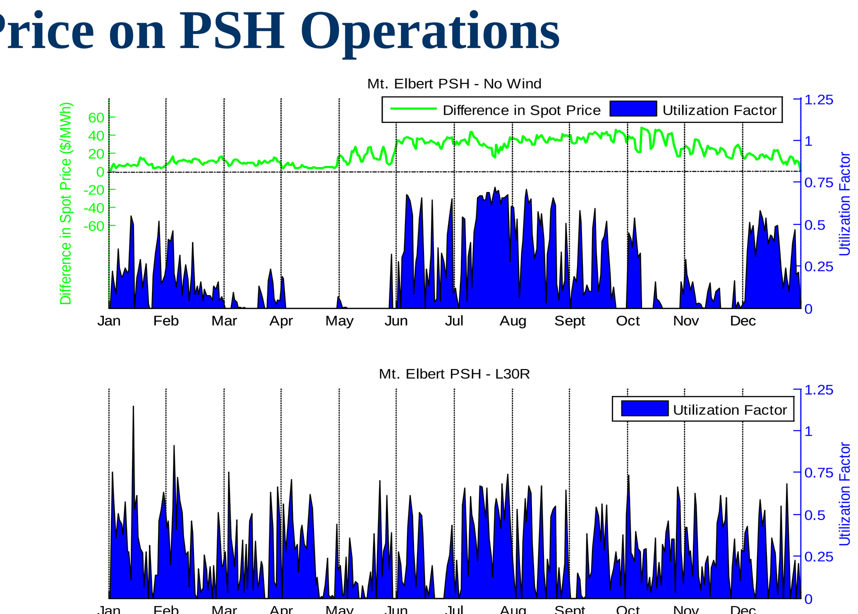

Figure 8: Differences in load factoring spot prices (top-graph) accompanied with daily utilization factor (blue area) at Mt. Elbert PSH plat between baseline operations (top) and 30% renewable penetration levels (bottom).

$$Utilization\ Factor = \frac{abs(Total\ Energy\ for\ Day)}{abs(Full\ Energy\ Capacity)}$$

$$\{with\ Full\ Energy\ Cap. = (8hr\ pumping\ @\ 210\ MW) + (8hr\ gen.\ @\ 200MW) = 3{,}280MWh\}$$

Results shown for the Mt. Elbert PSH plant indicate increased utilization of PSH resources as renewable penetration levels increase, however, revenue value does not surpass that of the no-wind case due to reduced system spot prices created by wind and solar generation.

8. Conclusions

Results from this study have shown PSH use to increase correspondingly with increased penetration levels of wind and solar generation. However, MAPS was not able to capture actual production patterns well. This discrepancy can be traced back to the models inability to capture actual ancillary service provided at Mt. Elbert (e.g. regulation, spinning and non-spinning reserves, frequency control, voltage support and other ancillary services that would cause units to run at a more constant rate) and additionally forebay feed allows some days to generate more then pumped.

Results from the WWSIS show the investment of a new 100 MW PSH plant did not seem economically plausible. The fact that the wind power generation drives down system spot prices with increasing penetration levels, new generation resources like PSH may not be able to recover initial capital costs, even with increased use. Upon further investigation to this phenomenon, results at Mt. Elbert PSH plant showed a dramatic increase in use, nearly 30% increase over baseline operations. However, the total revenue actually decreased in every case over no-wind operations.

Pumped storage hydropower may also have opportunities in wind integration, depending on the degree of balancing area coordination, although the proposal for new PSH plants will have to be justified by several potential revenue sources (i.e. energy arbitrage, ancillary services, and capacity value) with wind integration as one component.

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1. Potter, C.W. et al, 2008, "Creating the Dataset for the Western Wind and Solar Integration Study (U.S.A.)," Wind Engineering, 32(4), pp. 325-338.
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4. Pete, C., 2010, "Implications on hydropower from large-scale integration of wind and solar power in the West: results from the Western Wind and Solar Integration Study," Thesis Report, Northern Arizona University, Mech. Engr. Dept.