Maximizing the Market Value of Flexible Hydro Generation
Content

- Growing grid flexibility needs
- Hydro resource flexibility
- Factors currently limiting hydro value
- The bSTORE tool for maximizing hydro value
  - Case Study: Optimizing pumped hydro into RTO markets
- Managing transmission constraints
The Resource Mix is Changing Rapidly

U.S. Retirements and Additions (2010 – 2020)

Cumulative U.S. Retirements and Additions (GW)

-250 -200 -150 -100 -50 0 50 100 150 200 250

Other
Wind
Solar
Nuclear
Gas CT
Gas CC
Coal
Gas ST
Coal
Nuclear
Oil
Other

Source: The Brattle Group analysis of data compiled by ABB, Inc., The Velocity Suite
Changing Supply Mix = Need for More Flexibility

Flexible resources that can respond quickly and efficiently as system conditions change are needed to operate with an increasing share of variable generation. Hydro is uniquely able to provide this flexibility.

Electricity Demand and Traditional Supply Mix

Electricity Demand and Supply Mix with High Renewable Generation

Source: The Brattle Group
Complements: Batteries and Flexible Hydro

All storage and flexible resources will be needed to meet the systems’ growing flexibility needs cost effectively.

- Where available, flexible hydro plants are successfully employed to balance regional power systems:
  - Daily and seasonal storage to meet peak loads and help integrate large baseload plants (nuclear, coal, run-of-river hydro)

- Battery storage is gaining momentum as markets begin to recognize their capabilities and contribution
  - Brattle Study: 50 GW of battery storage potential at cost of $350/kWh installed
  - Declining battery costs make them suitable to address:
    - Fast regulation and ramping needs
    - Peaking energy and capacity (only up to several hours)
    - Distributed local T&D needs
    - Customer bill savings and outage reduction

Together with battery deployment, increasing the operational flexibility of hydro resources will be a low-hanging fruit to help address growing flexibility needs in some regions.
Hydro is a Major Provider of Op. Flexibility

Flexible hydro plants are becoming more valuable as system needs for reliability and flexibility “attributes” increases.

Where available, existing (and some new) hydro plants are a very cost-effective source of flexibility, although different hydro plants have varying degrees of versatility

In addition to these system flexibility attributes, batteries provide value streams such as local T&D benefits, customer bill savings, and outage reduction

The vast majority of conventional hydro resources offer grid flexibility.

Even pondage hydro plants, sometimes labeled as run-of-river, usually have a dam that enables them to control water flow and generation on an hourly, daily, and occasionally weekly timeframe.

Sources and Notes: The Brattle Group analysis based on SNL and other data of existing hydro plants over 25 MW.
Opportunities to Increase Hydro Value

The potential value of hydro plants is rarely realized in the energy and ancillary services markets today.

- **Market limitations:**
  - Market design, rules, optimization systems
  - The U.S. energy markets developed with a focus on thermal resources

- **Bidding and operational practices:**
  - Heuristic procedures developed to address the physical resource constraints

- **Resource constraints:**
  - Pumped-storage hydro: min output, min pump, time to switch, and others
  - Pondage and reservoir hydro: minimum flow constraints, cascading hydro operation, environmental, public safety, and public recreation constraints

- **Transmission congestion:**
  - Some hydro facilities are located in areas subject to frequent transmission limitations

Hydro resource owners will need to re-evaluate these constraints to create additional flexibility that could be offered into the market.
RTO Market Rules and Software Challenges

RTO rules and operational tools often limit hydro resources’ market participation and ability to capture their full wholesale market value.

Case Study: PJM

- Although opportunity costs are generally allowed, it does not appear that they are well-defined or actively used for hydro units.
- Pumped-storage hydro can be optimized by PJM in the day-ahead market.
- Hydro plants not scheduled by PJM (including all pondage plants) cannot submit price-based offers,* i.e., they must self-schedule.
- Market enhancements have not yet focused on hydro plants.

Potential Improvements

- Allow offering hydro energy at a price.
- Optimize hydro scheduling as part of market clearing, including pondage plants.

Sources:
Hydro plants: The Brattle Group analysis based on SNL and other data.

Notes:
* Other resources can submit price-based offers even if they do not have “fuel costs.”
Brattle’s bSTORE Storage Modeling Platform

bSTORE MODELING PLATFORM

MARKET FORCES
- End Users’ Objectives
- Policies and Regulations
- Market Rules and Operations
- Storage Capabilities and Costs
- Energy Company Strategic Issues

ASSET OWNERS
- T&D System Benefits

SYSTEM
- Market Impact
- Capacity Expansion
- Optimal Bidding and Dispatch

CUSTOMER RETAIL COST
- Customer Reliability Benefits

POWERFUL INSIGHTS
- Storage Valuation
- Investment Strategies
- Operational Approaches
- Design of Regulation and Market Rules

CUSTOMERS

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bSTORE Use in Hydro E&AS Market Optimization

Optimal Bidding and Dispatch

- Markets Sequence
  - Co-optimize Day-Ahead and Real-Time participation

- Market Uncertainty
  - Imperfect foresight, develop strategies with recourse

- Market Constraints
  - Account for RTO Rules and Software limitations

- Product Selection
  - Co-optimize revenues from Energy and Ancillary Services

- Price Impacts
  - Locational market response to change in plant operations

- Resource Constraints
  - Quantify impacts of Plant & Environmental constraints

- Transmission
  - Full network model supports nodal simulations

Module Features

- Mixed Integer Programming (MIP) solver as used by RTOs
- Rolling-horizon simulation with look-ahead optimization
- Sequential model of DA, RT and other decision cycles with feedback loops
- Scenario-based & heuristic-based uncertainty modeling
- Hydro modeling
  - Generation constraints
  - Reservoir constraints
  - Cascaded plants w/ delays
  - Value of water: calculate (long-horizon problems) or specify (short-horizon)
**bSTORE Case Study: Pumped Hydro**

**Optimized Pumped Hydro E&AS Performance**

**Illustrative Example:** Pumped Storage Hydro plant operating in an RTO market

- **Optimized DA Market:** RTO-optimized energy schedule
- **Optimized RT Market:** Price-based offers and bids (imperfect foresight)
- While existing equipment and constraints preserved
- Modeling included market response/elasticity

**Optimized Performance:** 2-3x of Historical Performance
Equipment upgrades can further increase the value of hydro plants.

- Legacy plants may be subject to costly constraints:
  - Time to switch pump/generate modes can be too long
  - Limits AS and RT energy market opportunities

- Equipment upgrades to enable fast mode switching enables substantial AS and RT market gains

**Performance with Upgrades:**
4-5x of Historical Performance
Transmission Congestion Relief Strategies

Congestion affecting hydro storage projects can usually be relieved cost-effectively employing advanced transmission technologies.

- Congestion is often seen by the plant owner as an erratic price signal
- Advanced transmission technologies provide cost effective and timely means to relieve plant congestion under these conditions
  - Transmission reconfigurations (topology control/line switching)
  - Power flow control devices
  - Dynamic line ratings

Case Study: PJM

✓ Extreme peak conditions with outages
✓ Reconfiguration can increase transfer capacity by 5% to 10% (500-1000 MW)
✓ 50% reduction in congestion cost
✓ Similar impacts for more localized congestion in PJM, SPP, MISO, ERCOT

PJM Real Time Prices, 18/7/2013, 15:30 (pjm.com)
Resource flexibility is becoming more important on the grid. As the major provider of system flexibility, pumped, reservoir, and pondage hydro plants can offer a significant value. Our experience shows that the full value potential of hydro resources often is not realized today. Maximizing the market value of flexible hydro resources requires a review of the constraints that a plant faces with respect to operations, market design, market rules, and transmission congestion. In our engagements we found opportunities and developed strategies to increase the market value of existing hydro storage plants by 200% to 500%.

- If not optimized by RTO, this requires co-optimization of bidding (or self scheduling) into day-ahead energy, real-time energy, and ancillary services markets, considering uncertainty.
- Our analyses also found significant additional value offered by plant modifications that increase operational flexibility.

**Conclusions**
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The Brattle Group provides consulting and expert testimony in economics, finance, and regulation to corporations, law firms, and governmental agencies worldwide.

We combine in-depth industry experience and rigorous analyses to help clients answer complex economic and financial questions in litigation and regulation, develop strategies for changing markets, and make critical business decisions.

Our services to the electric power industry include:

- Climate Change Policy and Planning
- Cost of Capital
- Demand Forecasting Methodology
- Demand Response and Energy Efficiency
- Electricity Market Modeling
- Energy Asset Valuation
- Energy Contract Litigation
- Environmental Compliance
- Fuel and Power Procurement
- Incentive Regulation
- Rate Design and Cost Allocation
- Regulatory Strategy and Litigation Support
- Renewables
- Resource Planning
- Retail Access and Restructuring
- Risk Management
- Market-Based Rates
- Market Design and Competitive Analysis
- Mergers and Acquisitions
- Transmission
Brattle’s Storage Experience

**Asset Valuation**
- Valuing and sizing renewables + storage facilities
- Valuing storage across multiple value streams
- Developing bid/offer strategies to maximize value
- Accommodating storage into IRPs
- Supporting due diligence efforts of investors

**Market Intelligence**
- The state and federal policy landscape
- Electricity market fundamentals and opportunities
- Storage cost and technology trends
- Current and emerging business models

**Policy, Regulatory, and Market Design**
- Wholesale market design
- Market and regulatory barriers
- Utility ownership and operation models
- Retail rate implications of distributed storage
- Implications of storage on wholesale markets

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Additional Reading

“Getting to 50 GW? The Role of FERC Order 841, RTOs, States, and Utilities in Unlocking Storage's Potential,” Roger Lueken, Judy Chang, Johannes P. Pfeifenberger, Pablo Ruiz, and Heidi Bishop, February 22, 2018

“Battery Storage Development: Regulatory and Market Environments,” Michael Hagerty and Judy Chang, Presented to the Philadelphia Area Municipal Analyst Society, January 18, 2018

“U.S. Federal and State Regulations: Opportunities and Challenges for Electricity Storage,” Romkaew P. Broehm, Presented at BIT Congress, Inc.'s 7th World Congress of Smart Energy, November 2, 2017

“Stacked Benefits: Comprehensively Valuing Battery Storage in California,” Ryan Hledik, Roger Lueken, Colin McIntyre, and Heidi Bishop, Prepared for Eos Energy Storage, September 12, 2017

“The Hidden Battery: Opportunities in Electric Water Heating,” Ryan Hledik, Judy Chang, and Roger Lueken, Prepared for the National Rural Electric Cooperative Association (NRECA), the Natural Resources Defense Council (NRDC), and the Peak Load Management Alliance (PLMA), February 10, 2016


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