Optimization of Hydropower Security, Reliability, and Value – National Laboratory Capabilities

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A Broad Range of Hydropower Capabilities

From Development of Advanced Algorithms and Models to Applications and Technology Transfer

Advanced Algorithms
- Agent-based modeling
- Advanced forecasting
- Genetic algorithms
- Neural networks
- Machine learning
- Advanced math/solvers
- Scalable solutions for optimization

Model Development
- Resource optimization
- Stochastic UC/operations
- Power market tools
- Large-scale grid tools
- Integrated frameworks

Model Applications
- Optimization of hydropower plant and reservoir operations
- Management of cascades
- Power market analyses
- Environmental impact assessments and mitigation
- Technology assessment
- Reliability and flexibility
- Resiliency analysis
- Storage value/impacts
- Climate impacts

Technology Transfer
- GTMax
- GTMax Lite
- WUOT/CHEERS
- WUOT/IRF
- EMCAS
- EZMT
- Etc.

Useful Useable USED
Modeling and Simulation of Hydropower

- Over 35 years of experience in hydropower analysis in domestic and international applications (20+ countries)

- Argonne developed analytical tools to optimize the operations and maximize the value of hydropower and pumped-storage plants in different market settings
  - 25+ years of power market analyses for Western Area Power Administration (WAPA)
  - Financial analyses of day-ahead market rules/structures
  - Evaluations of impacts of Energy Imbalance Market (EIM) on hydropower
  - Argonne tools (GTMax, CHEERS, EMCAS, etc.) used by private/public sector worldwide

- Research and analysis to identify solutions that minimize the effects of hydropower operations on critical environmental resources
  - Environmental assessments
  - Environmental impact statements (EIS)
  - Environmental performance models and analysis

- Research and analysis to enhance infrastructure resilience and reduce the risk of disruption or destruction from natural hazards, accidents, or security threats.
  - Regional Resiliency Assessment Program (RRAP)
  - Physical and cybersecurity protection
Develops, Applies, and Transfers Analytical Tools

- **GTMax** – Generation and Transmission Maximization Model
  - Hourly simulation and optimization of hydropower and grid operations
  - Co-optimization of energy and ancillary services
  - Referenced by the World Bank, European Union, and USAID as preferred tool for regional interconnection, electricity market analysis, and generation & transmission planning studies
  - Licensed to 39 organizations throughout the world

- **CHEERS** – Conventional Hydropower Energy and Environmental Resources Systems
  - Optimizes day-ahead scheduling and real-time operations for hydropower
  - Can consider multiple objectives: cost, power, environment
  - Supports decision-making on unit commitment and turbine-level operating points
  - Applies system-wide approach to increase hydropower efficiency and value of power generation and ancillary services

- **IRF** – Index of River Functionality
  - Calculates environmental performance (IRF) scores based on how well river conditions accomplish user-defined objectives in terms of timing, magnitude, duration, and frequency of occurrence
  - Computes environmental performance for multiple objectives/locations based on time series of flow conditions

- **EMCAS** – Electricity Market Complex Adaptive System
  - Utilizes agent-based modeling to simulate the behavior of market participants in restructured power markets
  - Simulates various bidding strategies in day-ahead and hour-ahead markets
  - Includes VALORAGUA (Value of Water) model for hydropower optimization and reservoir management
Example: Optimization of CRSP’s Aspinall Unit cascade

**Actual Operation**

**CHEERS Optimization**

**Blue Mesa**

- Less ramping
- Higher efficiency

**Morrow Point**

- Fewer unit starts & stops
- Higher efficiency

**Crystal**

- Virtually identical
Colorado River Storage Project (CRSP) System – Actual and CHEERS Results

Actual Operation

- Balancing Purchases
- Other CRSP Gen
- Interchange In (MW)
- LTF AHP Purchases (MW)
- LTF WRP Purchases (MW)
- Total Load

Real-time Purchases

- STF (Day-ahead) Purchases
- LTF Purchases
- Aspinall Generation

CHEERS Optimization

- STF Variable Purchase
- Other CRSP Hydro Gen
- Interchange In (MW)
- LTF AHP Purchases (MW)
- STF Block Purchase
- LTF WRP Purchases (MW)
- Total Load
DOE/WPTO-funded study on the value of advanced PSH technologies:

- Developed detailed models of advanced PSH technologies (adjustable speed and ternary units), analyzed their capability to provide various grid services, and assessed the value of these services under different market structures.

- Key findings: Storage reduces system operating costs (production cost of electricity), cycling and ramping of thermal generating units, curtailments of variable renewables, and provides a large amount of operating reserves.
From Scenario Definition to System Restoration: EXAMPLE for Electric Power

Scenario Definition
• Describe plausible triggering event, such as weather/climate (hurricanes, ice storms, tornados), earthquakes, cyber, others

Physical Impact Assessment
• Using fragility curves, assess physical damage to relevant infrastructure, including generators, towers/poles, wires, substations, fuel infrastructure (natural gas, coal, petroleum, etc.)

System Modeling
• Model impact of loss of fueling infrastructure
• Model impact of loss of multiple grid assets
• Determine potential islanding and extent of blackout

System Restoration Modeling
• Physical restoration/repair time; optimized repair crew scheduling and staging
• Electrical restoration at transmission-level
• Electrical restoration at distribution level
Available Tools for Resiliency Analysis

Prepare
- Self-assessment/maturity (ERAP-D)
- Emergency planning (onVCP/SyncMatrix, SpecialPop, LPAT)
- EP/PSR exercise/drill (Scenarios, Threat-Damage, Impact Models)

Mitigate
- Mitigation assessment (EPfast, NGfast, POLfast, others)
- Resource mitigation measures, dependencies (IST-RMI)
- Power system restoration planning (EGRIP)
- Blackstart resource planning (EGRIP)

Respond
- Impact assessment (Threat-Damage, Impact Models)
- Hurricane assessment (HEADOUT)
- Emergency management/response (onVCP, vBEOC)

Recover
- Real-time PSR analysis (EGRIP)
- Emerge-Manage., Communication, Collaboration (onVCP/vBEOC)
Integrated Hydro and Storage Systems

Run-of-River Hydro and Energy Storage Systems

- Develop integration strategies for run-of-river (ROR) hydropower plant (HPP) and energy storage technologies to provide ancillary services and enhance revenue streams
- Control and integration of Energy Storage Systems (ESS), coordinated response to grid events, interaction of multiple ROR HPPs with grid, and its equivalence to a large HPP are other objectives of this project

The Challenge

- A significant amount (~65 GW) of untapped, small head, hydro resource in the U.S. is ROR type, characterized by limited operational flexibility
- How to make these resources more flexible and enable them to provide grid services as well?
- Is it possible to emulate the behavior of a large hydropower plant by combining and coordinating the operation of multiple small ROR plants with energy storage?
• Siemens Smart Energy Box – a control platform to coordinate the assets
• Example of CAISO ancillary service participation requirements:
  – Capacity equivalence: minimum 300 MW
  – Ramping rate equivalence: maximum rate should reach 6 MW/min (100kW/second)
• Real-time coordination of ROR HPP & ESS operating at 10.05 MW, EMS directs an addition of 0.31 MW within the next 4 seconds
Problem Statement: In U.S. wholesale electricity markets, it is typically up to the PSH operator, not the market operator, to determine the operation mode of the plant. The PSH plant owners do not have the information required to make the most efficient decisions to reduce costs and maintain reliability. For the market operator to perform this however, is a challenging modeling task.

This project seeks to:
- Optimize existing hydropower technology, flexibility, and/or operations
- Enable next generation pumped storage technologies to facilitate renewable integration

Impact of Project: The results from this project can be used to inform independent system operators, regional transmission organizations, and regulated utilities to utilize PSH in their systems more efficiently.

Approach:
- Full optimization in day-ahead markets and real-time markets
- Development of proxy algorithms in real-time markets using values from day-ahead market
- Incorporating the potential uncertainty in load and variable generation
• Developed dynamic model of Adjustable Speed (AS) Pumped-Storage Hydropower (PSH) units
• Outcome – validated dynamic model of AS-PSH is now available to power engineers in the US to facilitate power system studies with AS-PSH under high penetration of renewables.

• Why is it important:
  • AS-PSH is an enabler technology to allow a higher penetration of variable RE (high flexibility and controllability as generator, storage, ancillary services provider)
  • No AS-PSH exists in the U.S.
  • Potential to convert many existing conventional PSH plants in the U.S. to AS-PSH technology
Integrating River System and Power System Models

- Use RiverWare to redispatch hydro resources based on system prices from PLEXOS
  - RiverWare: more variation in total generation
  - Modeled costs can be reduced by up to $4m for a sample spring week
- For redispatch of Columbia River basin
Hydropower Cost Modeling

Supporting national-scale market and policy analysis

“Baseline Cost” reports improve modeling of hydropower by policy community (e.g. EIA, EPA) and studies like the Hydropower Vision.

Modeling site economics and technology and R&D Impacts

Integrated Design and Economic Assessment Model supports DOE LCOE analysis.

Reducing O&M costs through fleet benchmarking

EUCG Hydroelectric Productivity Committee partnership gains DOE access to data from 20+ Utilities (450+ plants, 140+ GW).

Analysis efforts identify O&M cost drivers and best performing plants, enabling the dissemination of best practices.

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Water Use Efficiency, Flexibility, and Reliability Tradeoffs

A long and winding road to data-driven decisions

Fleet-wide analysis of component failure and consequence with GADS data

Analysis of unit ramp rates for selected periods by Dr. Paul Wolff, consultant to ORNL

Case studies of flexibility and unit dispatch patterns at specific facilities

Analyses by University of Tennessee doctoral candidate Stephen Signore

Additional analyses and insight provided by Paul Wolff, L. Jim Miller and Patrick March, consultants to ORNL
• Plant availability and dispatch need not change to realize benefits
• Efficiency penalty not correlated with water availability
• Greater unit flexibility → less efficiency penalty
• Specific flexibility constraints exist for many units
• Optimized UC-LA → more starts/stops (for this scheme)

Data synthesis → Insight
We need start-stop costs!

Thanks to CCPUD; Primary analysis by HPPi (Pat March) and WolffWare (Paul Wolff)
Expert opinion elicitation, failure event data, and operating history are combined to discern reliability and risk for a specific component and unit.

Future efforts will combine multi-component risk estimates in overall powertrain failure.
Hydropower Optimization PNNL Portfolio

Provide hydro-climate information from basin scale to regional scales for application toward plant scale optimization to grid operations.

- Package hydro-climate information with characterization of uncertainty relevant to optimization of unit commitment. (WUOT)
- Enhance water-quality modeling capacity to inform hydropower investment and operations under changing hydrologic conditions. (EWN)
- Collaborate with several key partners to improve optimization:
  - WECC SPSG: Derive climate change scenarios to understand future environmental constraints at the grid scale.
  - CEATI HOPIG: Understand the technology maturity level of utilities for generating and implementing flow forecast in hydropower operations, and optimize generation portfolio management with the energy market.
  - Utilities: Visualization of river constraints on hydropower dispatch (BPA).
  - Academia: Collaborate on multiple projects and proposals to integrate water-energy models with the food, land, and social security sectors.
Hydropower Optimization PNNL Portfolio

Implementation into grid operations:

– Develop inter-annual and seasonal boundary conditions of water-dependent electricity generation to Unit Commitment and Economic Dispatch models, which affects hydropower optimization (IM3).

– Quantify the vulnerability of seasonal electricity grid operations to different drought characteristics to be used in trade offs and multi objective optimization (IM3).

Risk distribution as a function of drought conditions

This is how bad it could get, 3% chance it could be worse.
Transition to planning and operations:

– Identify climate patterns associated with higher cost electricity operations to link optimization and grid expansion to climate forecast research (RIAM).

– Develop a siting model that takes into consideration fine resolution water availability along with other economics to complement existing electricity expansion models and evaluate scenarios for different penetration levels of renewables (IM3).

– Evaluate the economic value of hydropower under different grid expansion pathways (including extreme climate events and technology shocks) (IM3).
Hydropower Optimization PNNL Portfolio

Extreme events

At the regional scale, PNNL combines integrated water modeling, building energy demand, and electricity grid models to quantify the regional value of hydropower under drought conditions compounded with other extreme events such as heat waves (LDRD, IM3).

Normal water year

- California meets 70% of the heat wave stress, mostly with natural gas.
- 25% of heat wave stress is met with hydropower.
- Change in regional generation portfolio (generation versus capacity).

Daily and peak hourly energy demand anomalies

Regional contribution for heat wave stress

- Rest of WECC: 23%
- PNW: 7%
- California: 70%

Technology contribution for heat wave stress

- Other source: 22%
- Gas turbines: 53%
- Hydro power: 25%

Production cost model, baseline conditions for generation