Planned Improvements to MODSIM:
Integrating River Basin Operations Modeling with Power System Economic Dispatch

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Introduction

Water  Power
Introduction

• Presentation Outline
  – Operating challenges
  – Why integrate water and power models?
  – Objective of this work
  – Selected integrated model structure
  – Future work
Introduction

• Water System Operational Challenges
  – Uncertain inflows
  – Conflicting Purposes
  – Time delay
  – Complex legal agreements
  – Interconnected reservoirs

Figure source: President’s Water Resources Policy Commission, 1950
Introduction

• Power System Operational Challenges
  – Production = Consumption + Losses at all times
  – Contingencies $\rightarrow$ reserves and ramping rates
  – Uncertain renewables production
  – Multi-area power flow
  – Interconnections
  – Congestion
Introduction

• Why Operations Modeling and Optimization?
  – Infrastructure = Money + Time
    • Critical operations for critical infrastructure
    • Improved efficiency = more revenue
    • Accidents are too costly
  – Computers are needed
    • Large systems
    • Repeated tasks
Introduction

• Why Integrate Water and Power System Operations Modeling?
  – Segregated modeling framework
Introduction

Why Integrate Water and Power System Operations Modeling?
– Integrated modeling framework

Aren’t these generally two different entities?

Power Marketers

"Do this"

"Sorry, we can’t do that"

Transmission System Operator

River and Reservoir Modelers
Introduction

• Why Integrate Water and Power System Operations Modeling?
  – Unrealistic modeling in current renewable integration studies [1]-[4]
    • Transmission constraints (and other security issues)
    • Non-power water system constraints and objectives
    • Interrelated nature of multi-reservoir operations
  – Energy storage is essential
    • Hydropower provides large and long-term energy storage
    • Reduce uncertainty in renewable energy production
Introduction

• Why Integrate Water and Power System Operations Modeling?
  – Climate change impacts on operations
  – Emergency response plans
  – National economic security
  – Interdisciplinary analysis of economic and environmental tradeoffs
Introduction

• Hasn’t integrated water and power systems modeling already been done?
  – Previous models generally do not include ramping rate constraints and increased reserve capacity requirements
  – To our knowledge, no freely available, generalized model currently exists
Introduction

• How did Colorado State University (CSU) get involved in this project?
  – Fellowship from the Hydro Research Foundation
  – CSU has a customizable water operations model (called MODSIM)
  – CSU is a major research center for power system controls
Introduction

• Objective
  – Realize the full potential for both conventional and pumped storage hydropower to aid renewable energy integration with sufficient accuracy
    • Build model
      – Handles water AND power constraints adequately
      – Incorporates uncertainty
      – Multiple objectives
  • Apply the model to a test system
  • Examine operational improvements
Model Structure

• What type of model do we need to build?
  – Spatial and temporal scales

Figure taken directly from [10]
Model Structure

• What type of model do we need to build?
  – Spatial and temporal scales

Figure taken directly from [10]
Model Structure

• What type of model do we need to build?
  – Stochastic, dynamic optimization method
  – Incorporates energy storage
    • Introduces dispatchability
What type of model do we need to build?

- Conventional hydropower
Model Structure

• What type of model do we need to build?
  – Pumped storage hydropower (e.g., peak shaving)
Model Structure

Reinforcement Learning

Greedy vs. Exploratory

Optimal Policies
- Current Reservoir Levels
- Reservoir Inflow Forecasts
- Wind Power Forecasts

Optimal Policy
- Table
- Fuzzy rules
- Neural network

Targets
- Reservoir Levels
- Release Schedules
Model Structure

• First Level
  – Water network solution
    • MODSIM
      – Iterative network flow algorithm & Frank-Wolfe algorithm
  – Constrained Economic Dispatch
    • Open-ended design that allows for both:
      – Programmatic (or tightly coupled) interface
      – Loosely coupled interface (I/O to disk)
    • Light-weight addition to MODSIM
      – “Direct search” method seems promising [5]-[8] for active power dispatch problem
Model Structure

• First Level
  – Water network solution
    • Network flow algorithm
      – Solve mass balance
      – Distribute water according to priority
    • Successive approximations
      – Solve for evaporation, reservoir levels, lags, any nonlinear customized changes
  • Frank-Wolfe method
    – Solve quadratic formulations (power demand)
Model Structure

• First Level
  – Water network solution
    • Frank-Wolfe method

```
Initialize variables

Network Flow to obtain \( q^{(0)} \)

\( v += 1 \)

Converged?

Yes → Exit

No

Differentiate quadratic penalty function \( f(q) \) about \( q^{(v)} \)

Update link costs

Network Flow to obtain \( \hat{q}^{(v)} \)

Line search quadratic penalty function to find step size \( \alpha \)

\[
q^{(v+1)} = q^{(v)} + \alpha(\hat{q}^{(v)} - q^{(v)})
\]```
Model Structure

• Second Level
  – Lagrangian Relaxation Master Problem
    • Optimality Condition Decomposition [9]
Model Structure

- Second Level
  - Simulation Structure

Static Second-Level Optimization
Model Structure

• Second Level
  – Simulation Structure

Smaller timestep
Model Structure

• Second Level
  – Simulation Structure
    • Allows system approach
Model Structure

• Second Level
  – Simulation Structure
    • Dynamically updated ramping rate & reserve constraints
Model Structure

• Second Level
  – Simulation Structure
Model Structure

• Third Level
  – Reinforcement Learning

Dynamic Optimization
Model Structure

- Third Level
  - Reinforcement Learning
  - In other words...

- Set target level
- Update target level
- See how well the system performs
- Store the results
Model Structure

• Third Level
  – Reinforcement Learning

What about uncertainty?
Model Structure

Reinforcement Learning

Greedy vs. Exploratory

Optimal Policies
- Current Reservoir Levels
- Reservoir Inflow Forecasts
- Wind Power Forecasts

Optimal Policy
- Table
- Fuzzy rules
- Neural network

Targets
- Reservoir Levels
- Release Schedules

Integrated Model

First Level

Water Network Solution

Second Level

Power System Economic Dispatch

Third Level

“Static” Lagrangian Master Problem

Stochastic, Dynamic Unit Commitment

Reinforcement Learning

Greedy vs. Exploratory

Model Structure

Stochastic Optimal Policies

- Current Reservoir Levels
- Reservoir Inflow Forecasts
- Wind Power Forecasts

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Targets
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Model Structure

• Benefits to this approach
  – Incorporate uncertainty easily
    • No need to estimate explicit transition probabilities!
    • Optimal policies are inferred
    • Ensemble prediction
      (streamflow & renewables)
  – Parallel processing
  – Multiobjective analysis
  – System approach to firming renewables
  – Algorithms are similar to operators’ way of thinking
Test Systems

• Does anybody want to partner with CSU to provide actual test systems?
  – Wind-hydro-thermal mix
    • Wind power forecasts and actual production
    • Pumped and conventional hydropower
  – Transmission system constraints
    • Transmission data (under NDA perhaps)
  – Water system constraints
    • Legal/environmental agreements
    • Operating criteria
Future Work

• Parallelization & high-performance computing
• Interdisciplinary analysis of:
  – Climate change
  – Emergency response plans
  – Economic and environmental tradeoffs
• Integration with other critical infrastructure models
  – Natural gas and oil
  – Water and power distribution
  – Crop production and irrigation
  – Weather forecasting and climate change models
References