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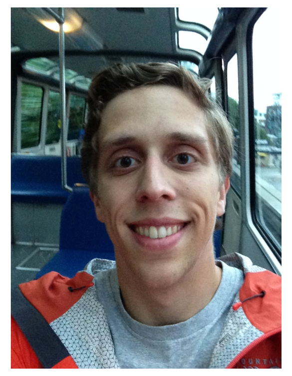


Using Cascaded Hydropower Like a Battery to Firm Variable Wind Generation

Andrew Hamann

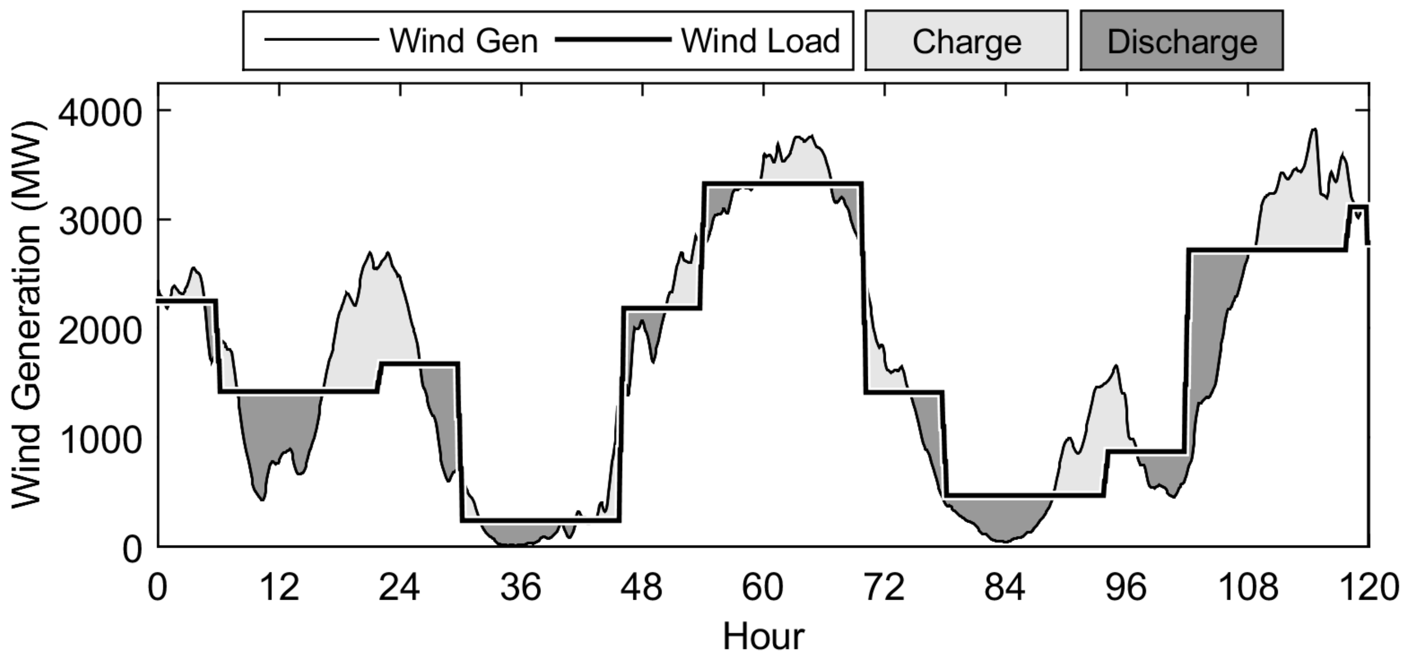
Background

- Balancing intermittency and variability of wind power is challenging, especially in load following time-frames (few minutes or hours)
- Flexible hydropower plants are viewed as an appropriate counterpart to variable renewable generation
- Hydropower is often referred to as a "battery"
- ***If a run-of-river hydropower system was a battery, what properties would it have?*** Power capacity, energy capacity, efficiency

Mid-Columbia Hydropower System

- Consists of five municipal hydropower plants on the Columbia River in the Pacific Northwest region of the United States
- Nameplate capacity of around 4500 MW
- Approximately 70 GWh of water storage (about one day's worth)
- Flows of several thousand cubic meters per second
- Water travel times of tens of minutes (strong coupling)
- Subject to numerous environmental and operational restrictions

Firming Wind Generation



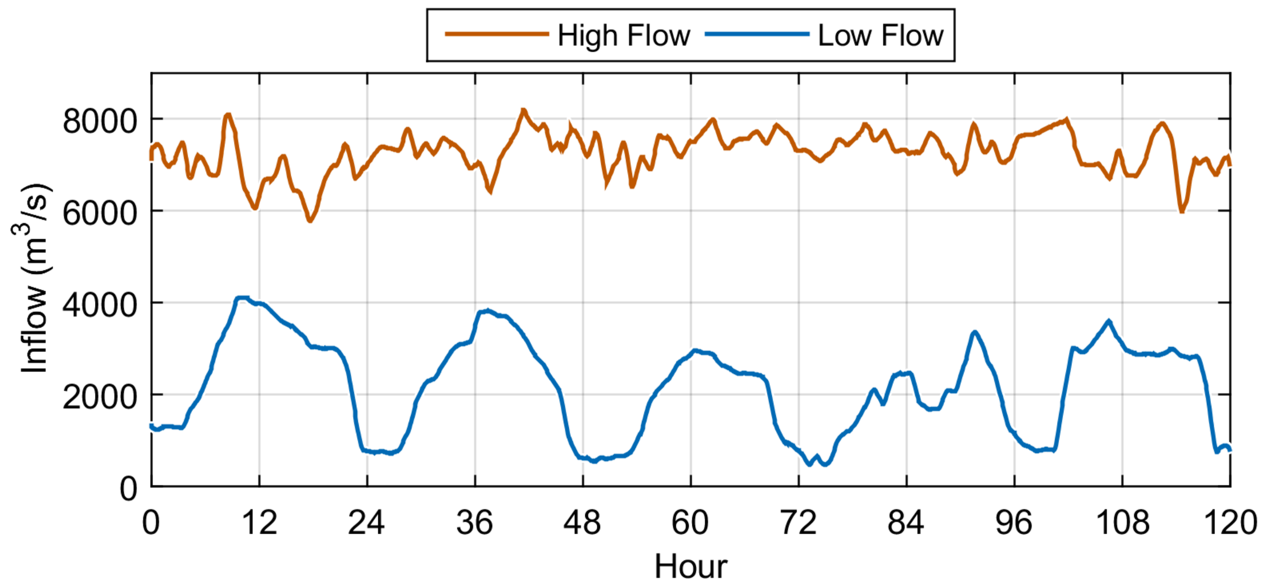
We can use hydropower to balance the difference between average and instantaneous wind generation, shown here when wind generation is firmed for on-peak and off-peak periods.

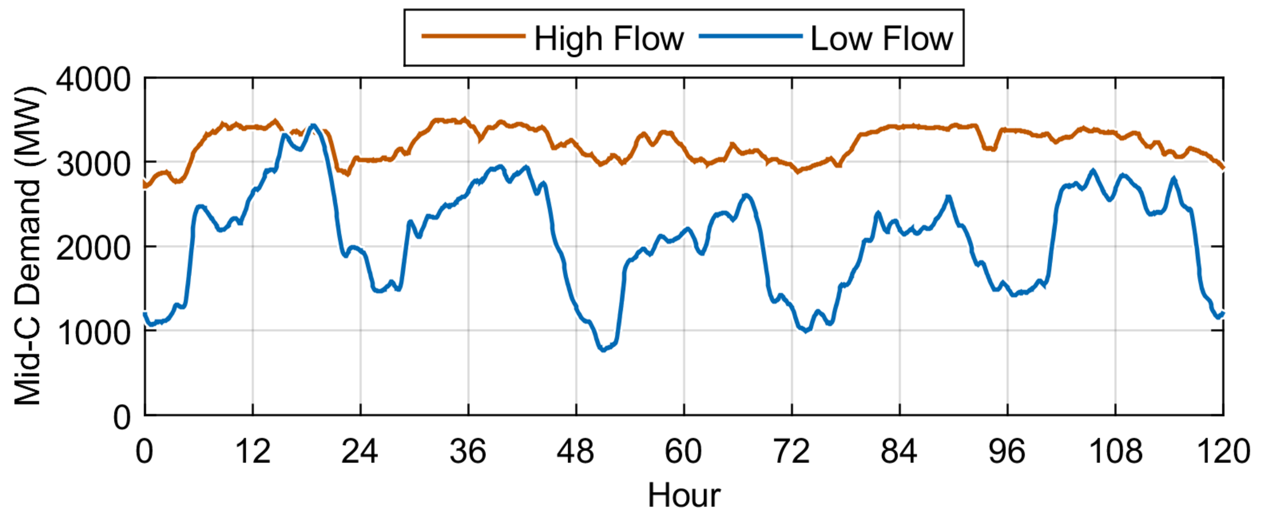
Real-Time Hydropower Optimization

- Minimize discharged water (turbine discharge and spill), with weights calculated according to the hydraulic head of each plant
- Meet the historical aggregate generation request from hydropower stakeholders while also balancing the net load from wind
- MPC-controller with 5-minute optimization interval and 3-hour receding horizon
- Constraints on flow, ramping, reservoir elevation, power balance
- Hydraulic coupling modeled using simple time delays
- Generation modeled using a piecewise planar function

Simulation Scenarios

- Excess water in the high flow case but less power capacity
- Less water in the low flow case but more power capacity

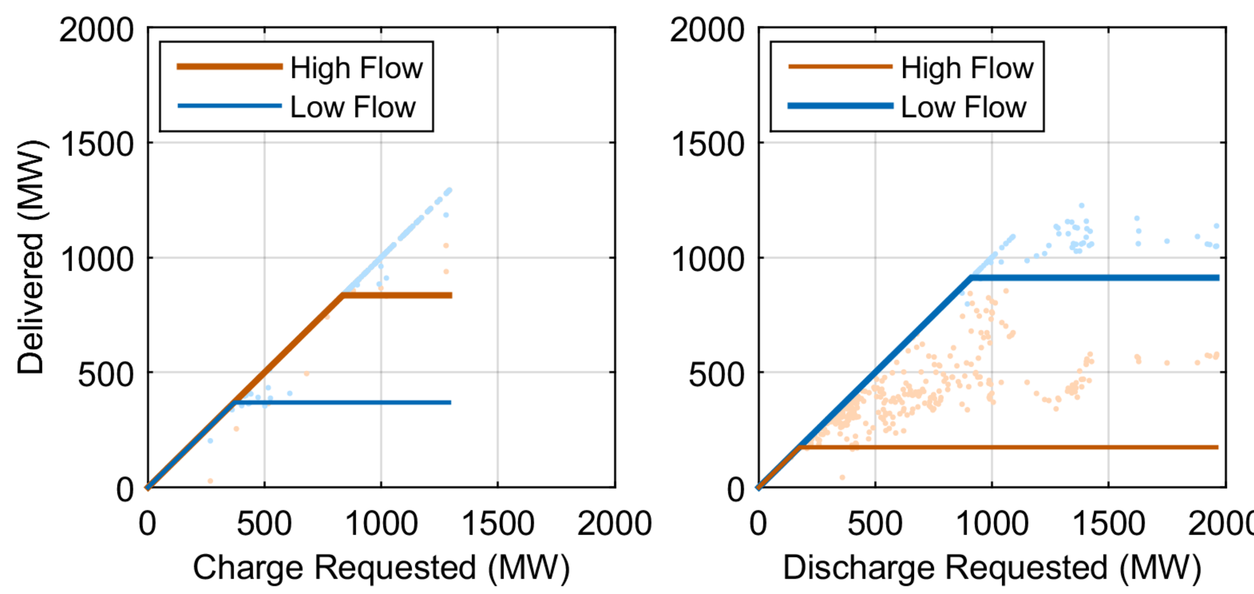




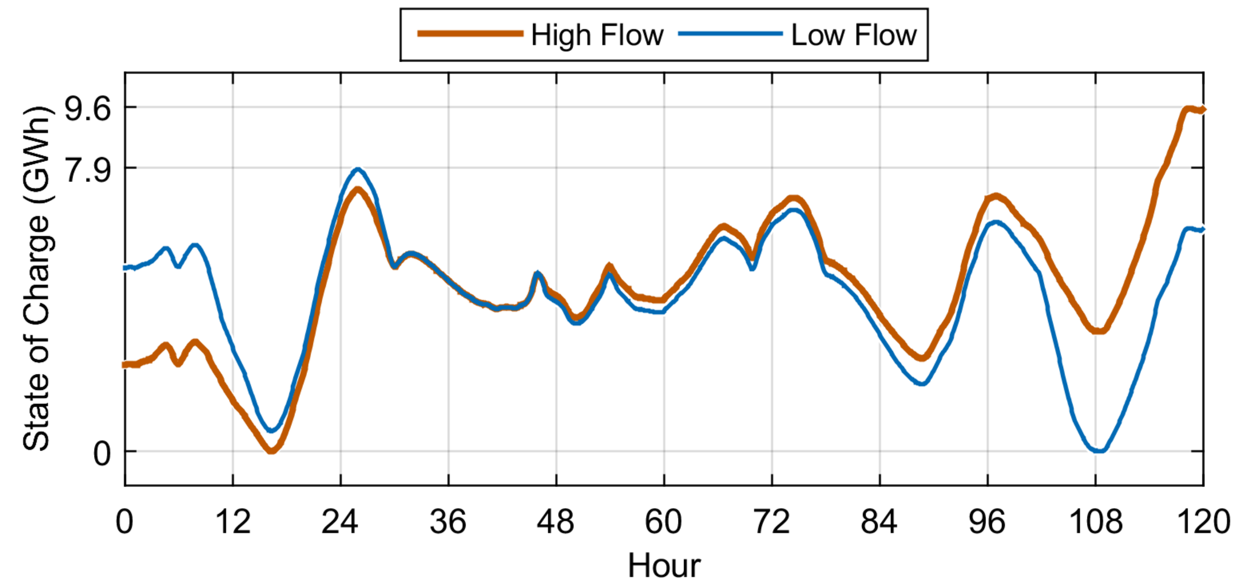
- Wind curtailments resulted from too little up or down power capacity, and other constraints (e.g., ramping, forebay) were not crucial, although turbine discharge ramping increased somewhat

Simulation Results and Conclusions

- How much **power capacity** was provided with 99% availability?



- If a battery mimicked the performance of the Mid-Columbia, what would its state-of-charge and **energy capacity** be?



- **Efficiency** is calculated from the amount of energy input and output, adjusting for curtailments and the energy state of the system
- Estimated power capacity was several hundred MW
- Estimated energy capacity was several GWh
- Estimated efficiency was 50-90%, depending on flow
- Turbine capacity expansion would increase balancing capability
- Run-of-river hydropower plants are most effective at balancing wind generation at hourly timescales
- Flexible run-of-river hydropower plants may be just as valuable as load following batteries as baseload electricity generation
- Storage and power capacity should be fully utilized, and the operational policies of run-of-river hydro will change in the future

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EPRI ELECTRIC POWER RESEARCH INSTITUTE

PSL Power Systems Laboratory