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Hydropower Value and Opportunities in Future Grid States

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Agenda

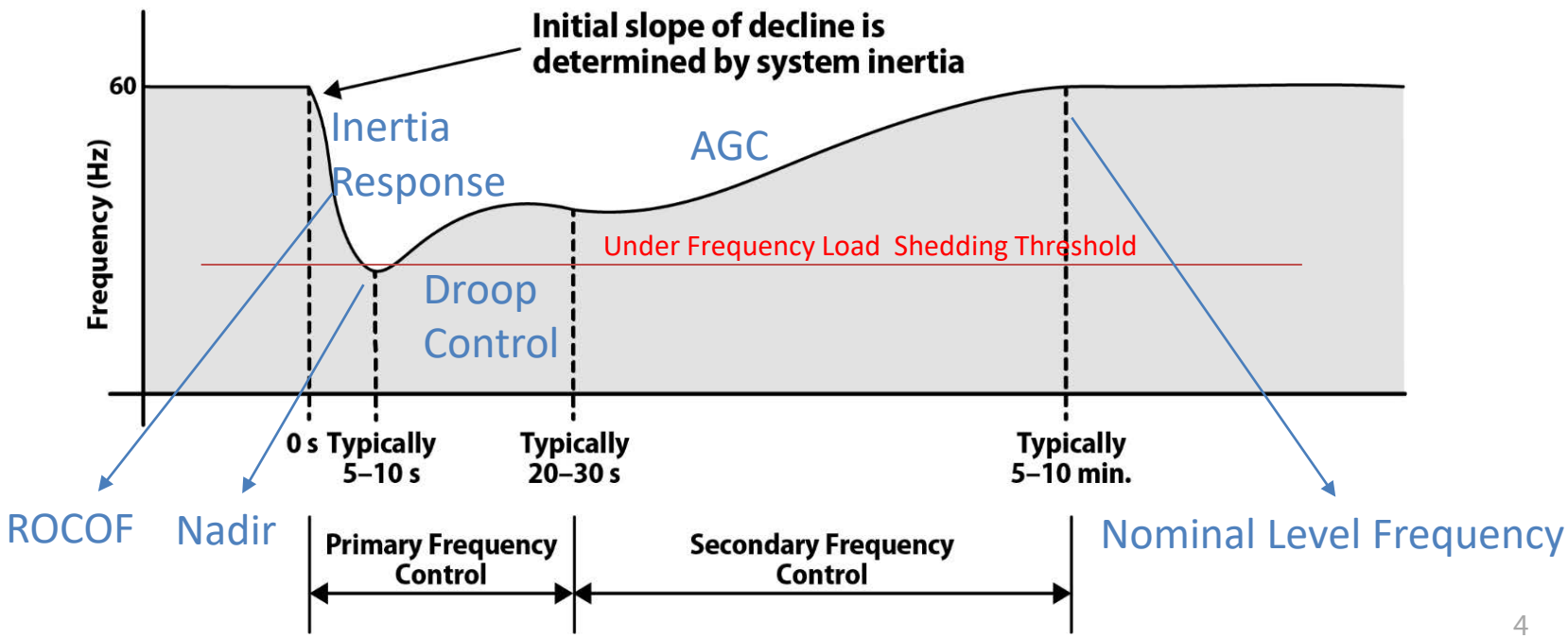
- Project Objectives
- Relevant Power System Metrics
  - Stability
  - Reliability
  - Ancillary Service
  - Flexibility
  - Economics.
- Hydropower Analysis Studies
- Recommended Future Works.

Project Objectives

- Infer the value of hydropower based on the impacts and requirements identified in the literature review and Grid Modernization Laboratory Consortium renewable integration studies.
- Analyze the modeled characteristics of hydropower for dispatchable and nondispatchable capacity services.

Stability: Frequency Response

Lacking natural inertia, power systems with large amounts of inverter-based technologies might introduce several stability-related issues.

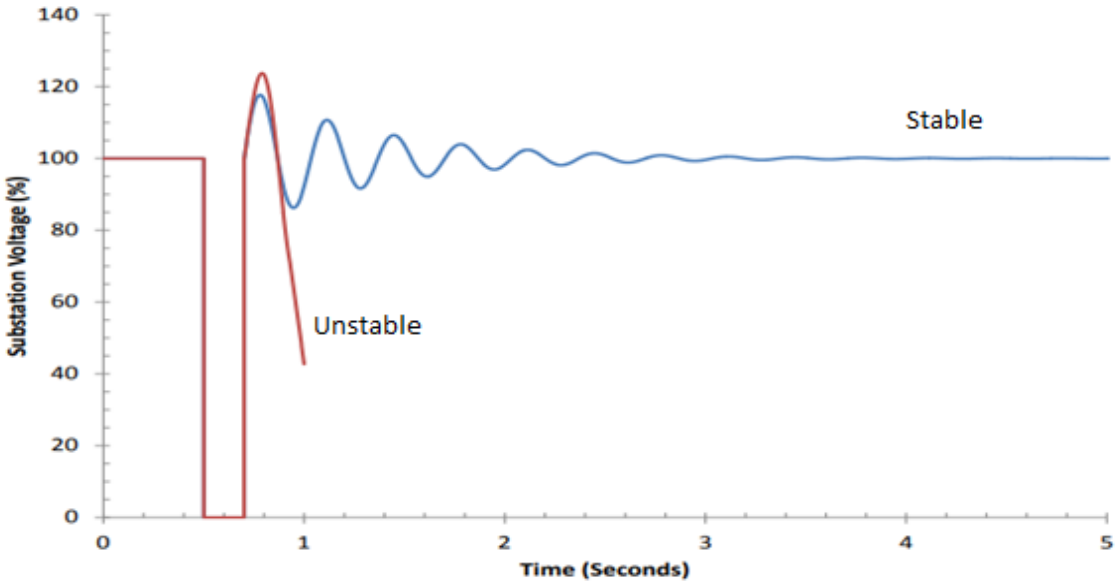


System frequency response to a generator outage

Stability: Transient Stability

High levels of renewable energy might alter transient stability:

- Impact on angle/speed swing bus behavior due to reduced inertia
- Different power flow patterns (e.g., possible bidirectional flows).



Example response of a substation after an outage event

Reliability: Black Start

An important reliability consideration for a power system is its ability to be restored after a large-scale unplanned outage. Black start requires the ability to energize that generation locally without access to external power sources (e.g., the grid).

The black start of a power system can be generally categorized into three steps:

- Prepare/plan.
- Re-energize the system gradually.
- Reconnect customers.

Type of Generator	Startup Power [%]
Nuclear	7–8
Thermal	7–8
Gas Turbine	1.5–2
Hydro	0.5–1

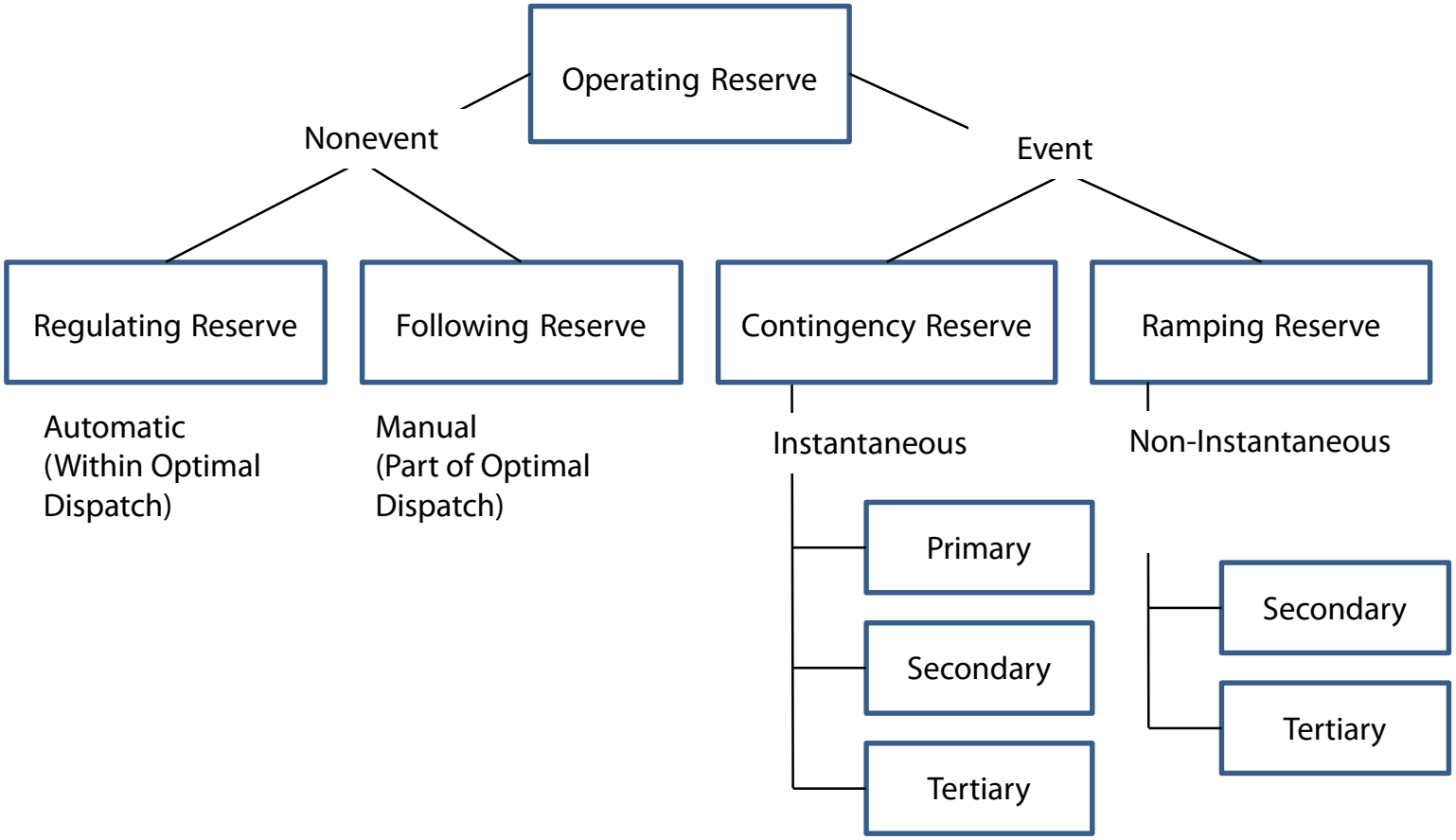
Summary of black-start energy requirements by generation type

Source: Kulkarni, A.M.. "Power System Restoration," NPTEL lecture.

Reliability: Reactive Power Support

- Power systems with large amounts of inverter-based technologies might introduce several stability-related issues, including maintaining stability-compliant voltage levels.
- Reactive power support is considered an essential reliability service.
- Hydropower plants equipped with "traditional" wind turbine machines, such as doubly-fed induction generators and self-excited induction generators, could help fulfill system reactive power requirements, and they improve the ability to restore system voltage levels in response to disturbances.

Ancillary Services: Operating Reserves



Classification of different types of generic operating reserves

Source: Ela, E., M. Milligan, and B. Kirby. 2011. Operating Reserves and Variable Generation *(NREL/TP-5500-51978). Golden, CO: National Renewable Energy Laboratory, August.*

Ancillary Services

The following table summarizes the percentage contributed to the total operating reserve requirement per generation type under high VGs.

Type	High	Higher Baseload	Higher VG
Hydropower	32%	32%	32%
Storage	19%	18%	18%
Gas CC	13%	9%	11%
CSP	12%	16%	12%
Wind and PV	11%	13%	14%
Other thermal	8%	7%	7%
Gas CT	3%	3%	4%
Demand Response	2%	2%	2%

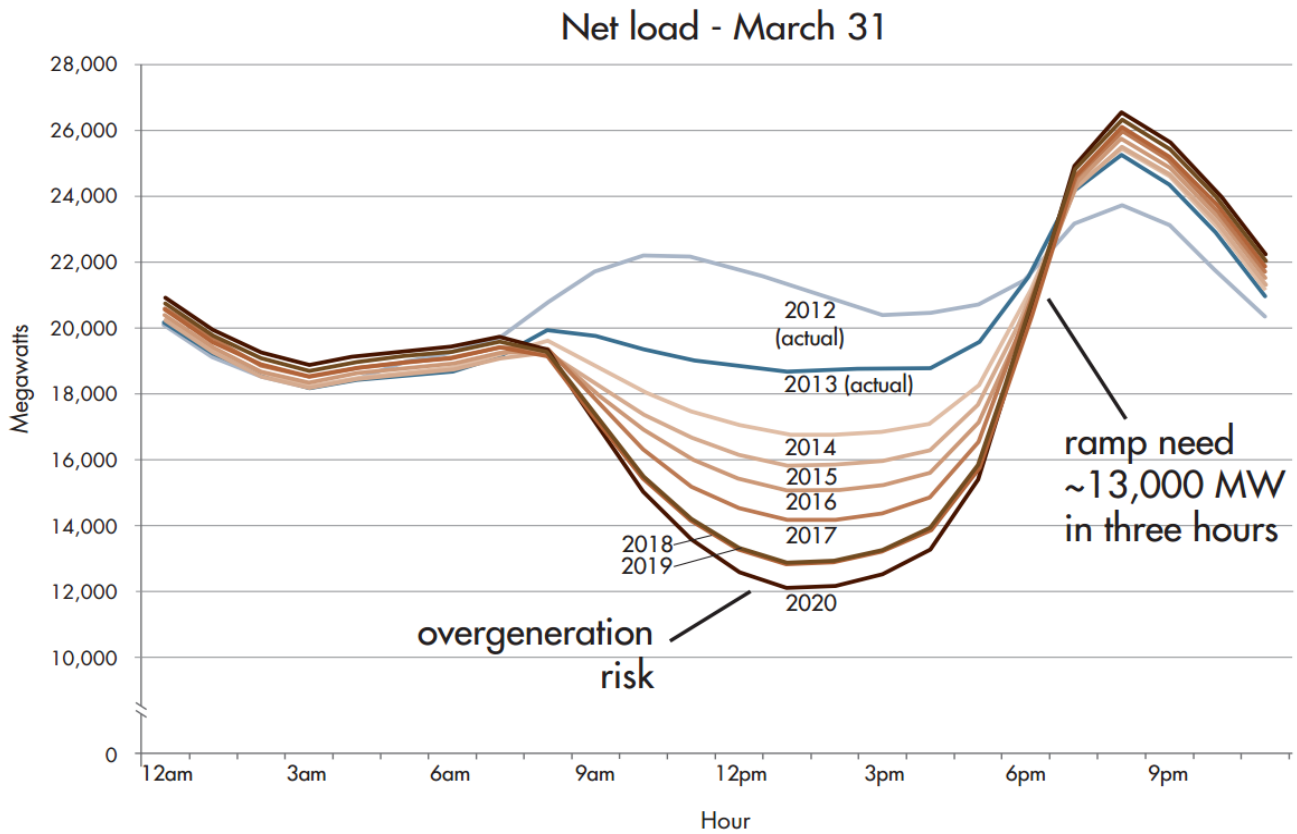
Hydropower resources can serve up to nearly one-third of the system operating reserve requirements.

Fraction of reserves procured by technology type per high future renewable penetration scenario

Source: Brinkman, Gregory. 2015. Renewable Electricity Futures: Operational Analysis of the Western Interconnection at Very High Renewable Penetrations *(NREL/TP-6A20-64467). Golden, CO: National Renewable Energy Laboratory, September.*

Flexibility

The "duck curve" demonstrates the need for flexibility.



As the solar penetration increases, the net load profile becomes increasingly like a "duck" shape.

The CAISO Duck Chart Source: CAISO 2013

Economics

An insightful understanding of hydropower costs and economic value is required to understand its future role in the U.S. power grid.

- Cost:
  - Capital and "fuel" costs
  - Fixed and variable operation and maintenance costs
  - Levelized cost of energy (LCOE).
- Economic value
  - Power markets
  - Environmental markets.

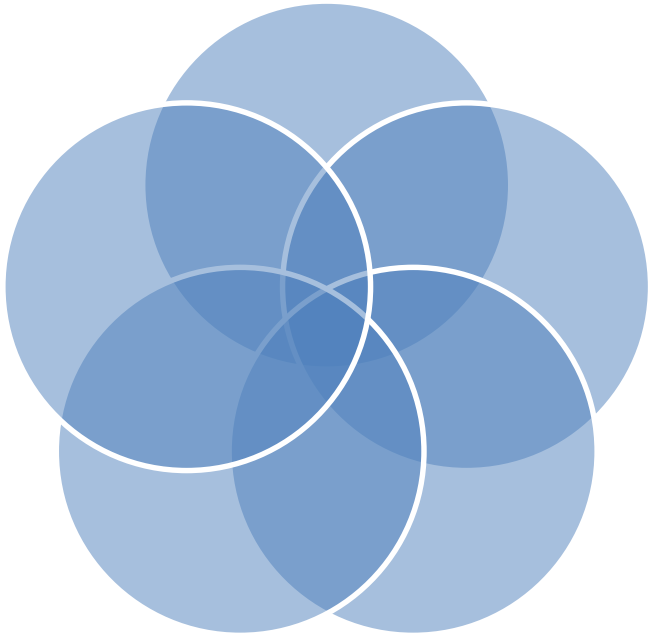
Relevant Power System Metrics

Reliability

- Black start
- Reactive power support

Stability

- Frequency response
- Transient stability



Ancillary Service

- Operating reserves

Economics

- Operational costs
- Value

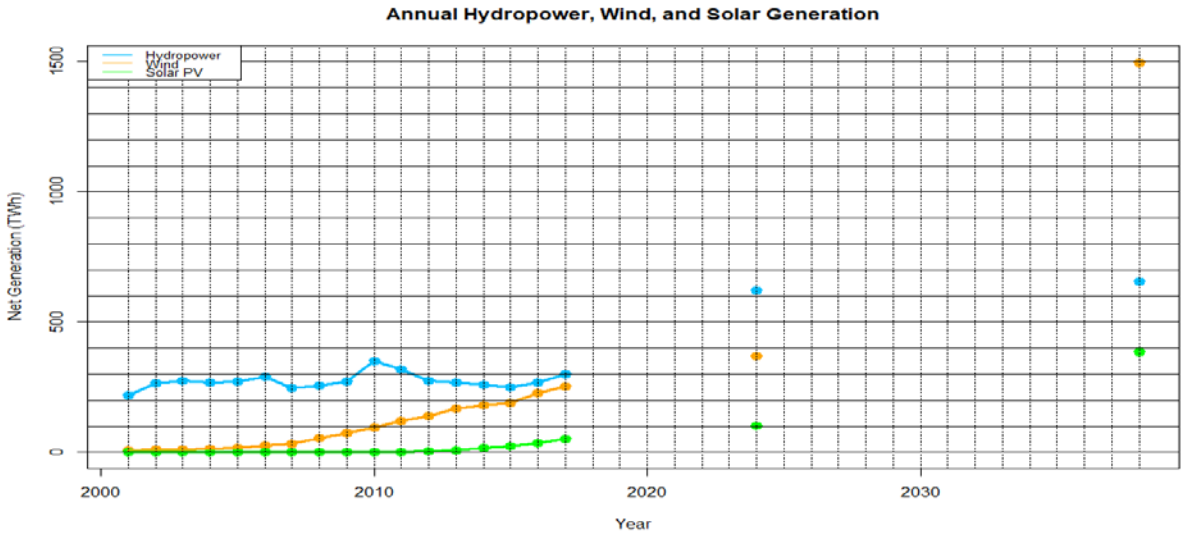
Flexibility

- "Duck" curve

Scope of Hydropower Analysis Studies

- Renewables Integration Study

Case Names/ Energy (TWh)	2024-Year 10% Case	2038-Year 30% Case	2038-Year 40% Case
Wind	370.5	954.4	1,495.1
Solar	102.1	433.8	384.5
Conventional Hydro	621.4	653.1	654.9
PSH	169.6	169.6	169.6
Total Energy	4,571.9	4,921.8	4,924.2
Penetration	10.34%	28.21%	38.17%

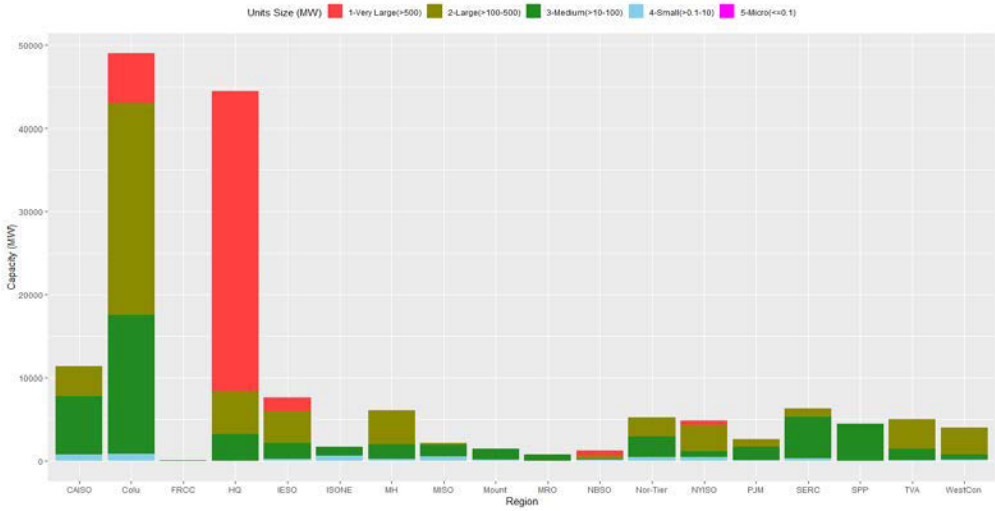


Annual generation from 2000 to 2038 Source: EIA Electricity Database

Objectives

– Interconnections Seam Study Capacity Review

Case Names/ Capacity (GW)	Hydropower Vision			2024-Year 10% Case	2038-Year 30% Case	2038-Year 40% Case
	2015	2050 : scenario #1	2050 : scenario #2			
CH [a]	79.99	85.27	92.99	84.55 (158.21 [b])	84.55 (158.21 [b])	84.55 (158.21 [b])
PSH	21.60	22.08	57.60	19.37	19.37	19.37
Total	101.59	107.35	150.59	103.92 (177.58 [b])	103.92 (177.58 [b])	103.92 (177.58 [b])



Regional conventional hydro capacity in SEAMS study

Limits of Hydropower Analysis Studies

Reliability

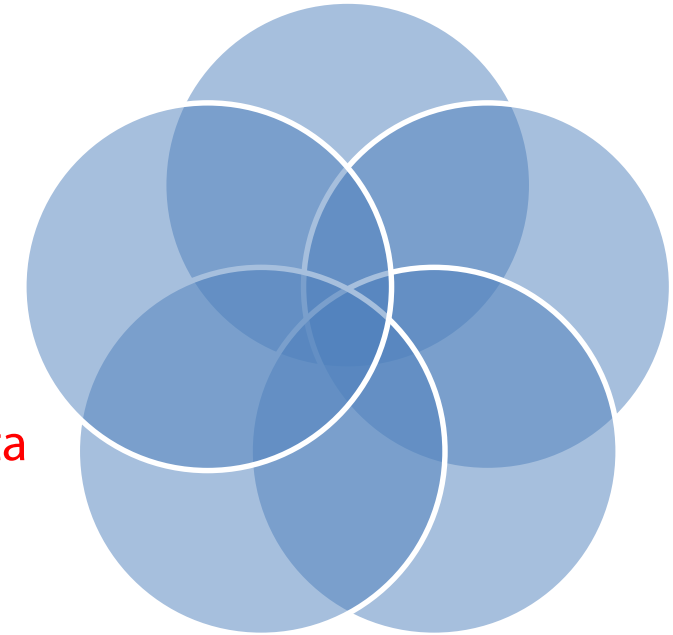
- Data are not available

Stability

- Data are not available

Ancillary Service

- Data are not available



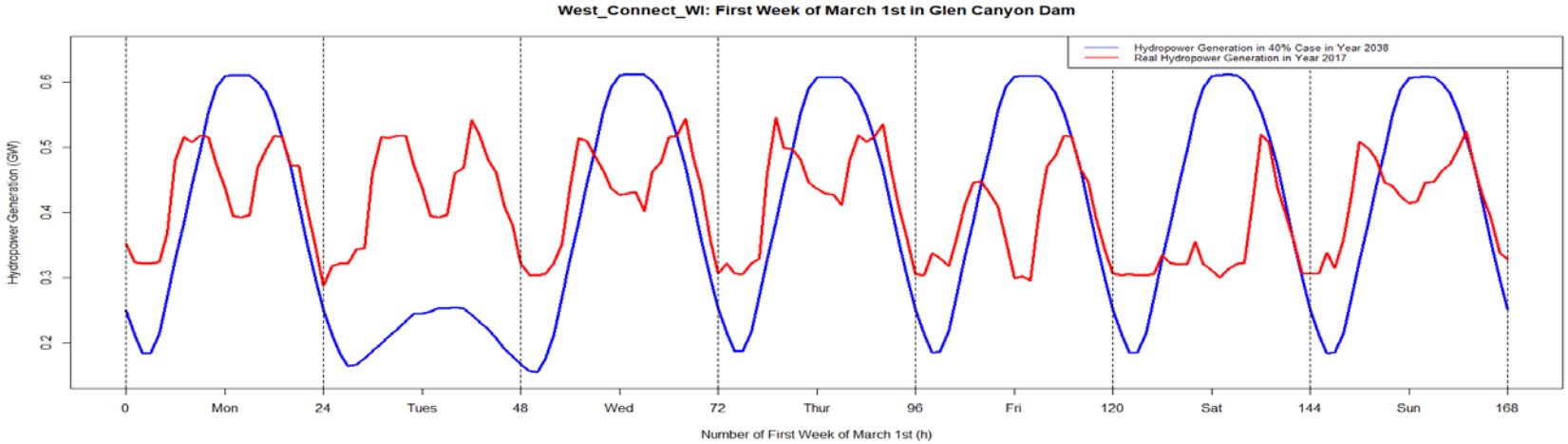
Economics

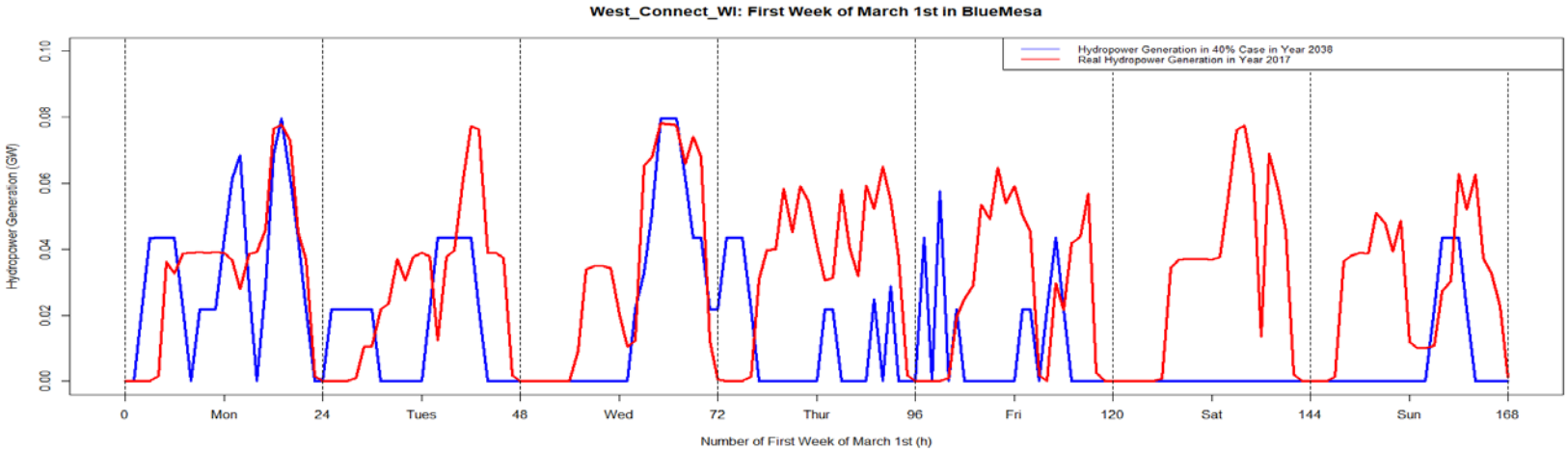
- Operational costs and emission payment (data are not available)
- Revenue is based on regional prices.

Flexibility

- Statistical analysis on conventional hydropower and PSH operations.

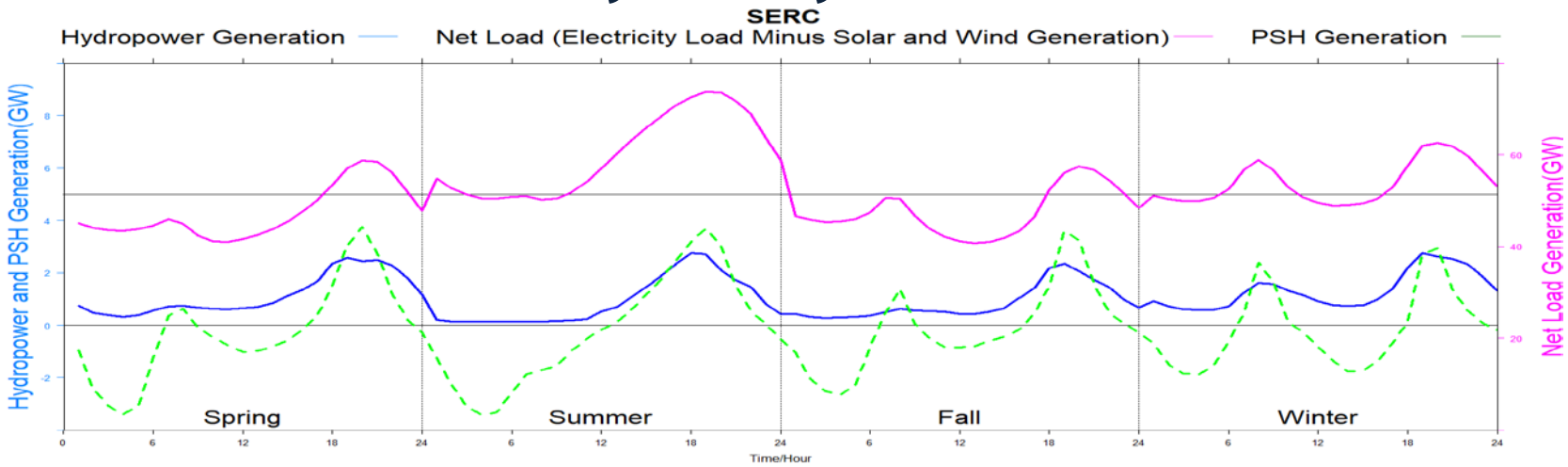
Examples: Model vs. Actual

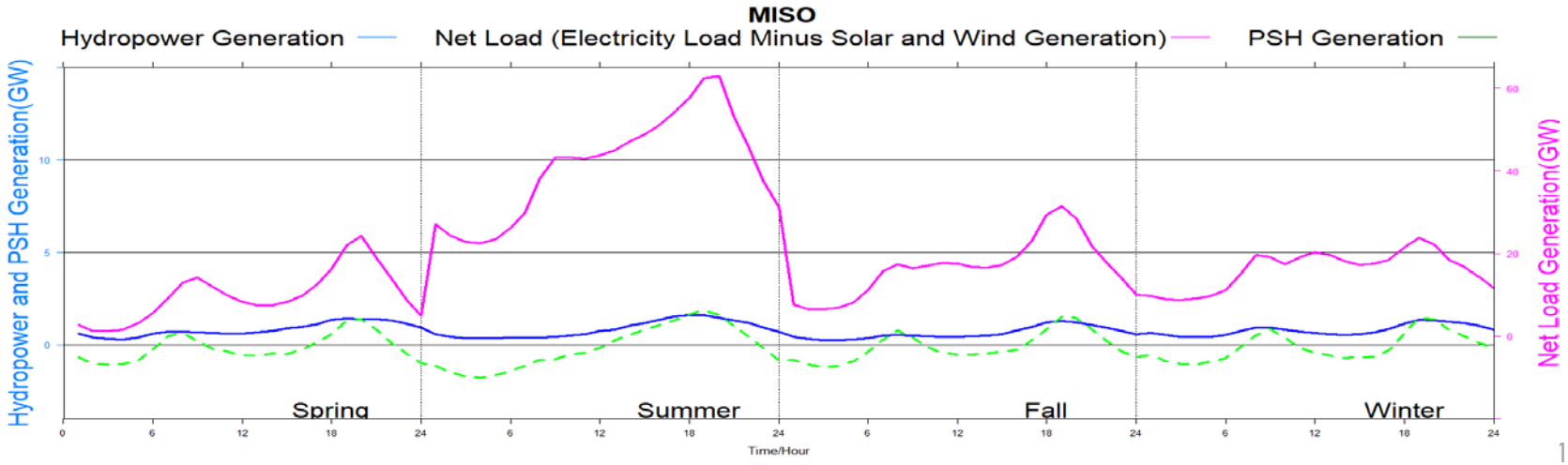




First week of March at Glen Canyon Dam and Blue Mesa

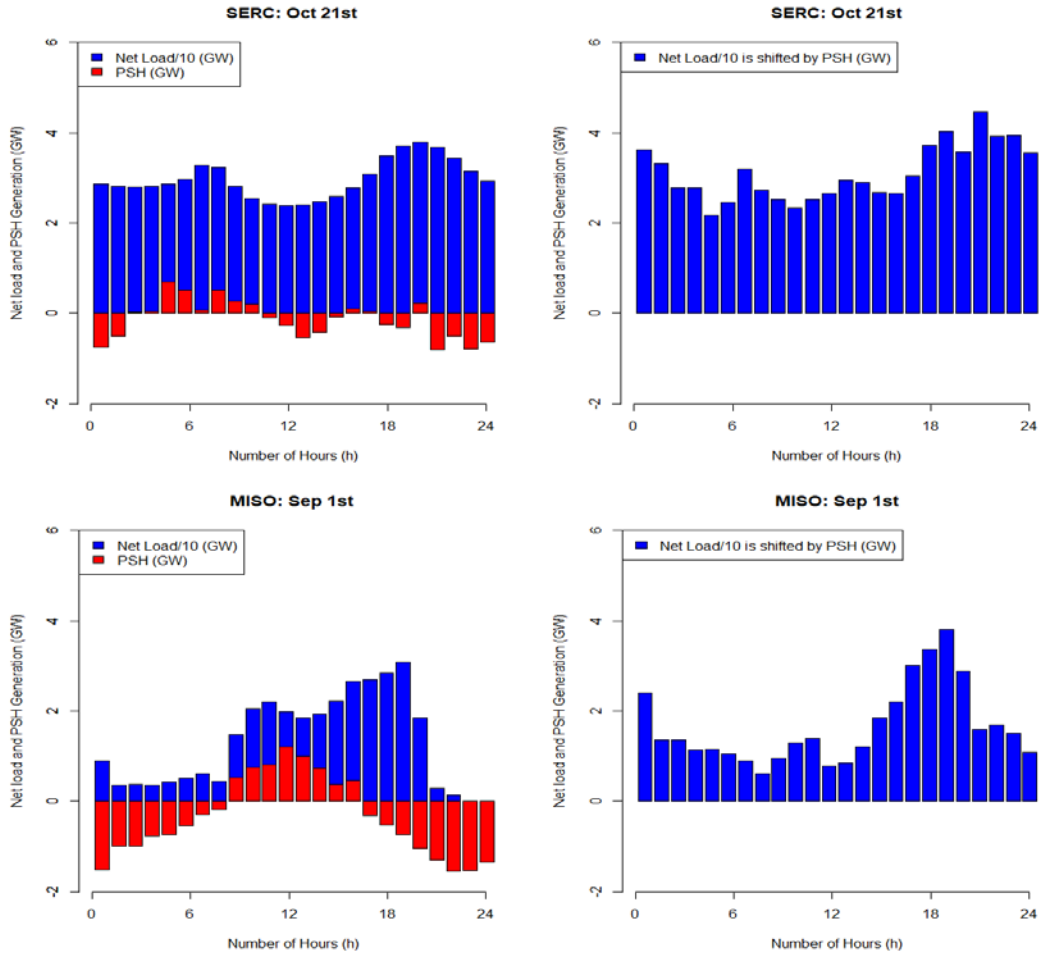
Seasonal Flexibility Analysis in 40% Case





Average hourly hydropower and PSH generation, electricity load, and net load by season in SERC and MISO

Interval-day Flexibility Analysis in 40% Case



PSH energy shifting in SERC and MISO

Observations: Analysis of Hydropower studies

- The flexibility of hydropower is an important value to help integrate high penetration levels of variable generation into the system.
  - Figures of average seasonal flexibility show that conventional hydropower and pumped storage hydropower (PSH) follow the net load well in the model.
- Load following, variable generation balancing, and energy shifting are three ways to see the value PSH provides.
  - Generally, PSH shifts energy from off-peak hours to peak hours according to market price.
- Analysis shows that when the variable generation penetration levels increase, the hydropower generation profile changes.

Observations: Analysis of Hydropower studies

- Hydropower provides not only flexibility but also reserves and economics to the system as the variable generation penetration levels increase. Flexible hydropower can follow load.
  - Spinning reserves is the only reserves in this modeling.
- There are two different hydropower operation patterns in PLEXOS:
  - Fixed: it follows a historical hourly pattern.
  - Optimized: we give the model a max generation, min generation, and max production constraint for a time period (usually 1 month) and then let the model decide the most optimal way to dispatch the dam based on those constraints.

Recommended Future Works

- Due to the above-mentioned limitations and observations, there are three main future works to complete a comprehensive hydropower analysis:
  - Short-term modeling:
    - » Flexible Energy Scheduling Tool for Integrating Variable Generation (FESTIV)
    - » Multi-area Frequency Response Integration Tool (MAFRIT).
  - Sensitivity analysis with long-term modeling:
    - » Expansion planning modeling in PLEXOS.
  - Water resources capital and "fuel" cost modeling:
    - » System perspectives (water capital and "fuel" cost)
    - » Resource perspectives (locational marginal pricing [LMP]).

Recommended Future Works

- These recommended future works should consider the following research questions:
  - Is hydropower increasingly in demand, too much or too little?
    - » New installed capacity could be considered in sensitivity analysis (e.g., Hydropower Vision forecast).
    - » Introduce emerging technologies such as ternary in short-term modeling.
  - Is it operated differently in these future studies?
    - » For example, FERC Order 755 requires power system operators to compensate hydropower for quick response times. To consider the potential benefits to hydropower, future studies should employ LMPs instead of general regional prices.

Recommended Future Works

- Is it operated differently in these future studies? (cont.)
  - » Additionally, there are pronounced trends of high inertia units retiring and not being replaced in kind; short-term modeling is needed to analyze the physical response (inertia and governor responses) and long-term modeling to incorporate different operational constraints.
- Do the same trends affect hydropower as every other fuel type?
  - » Prior PLEXOS-based studies do not include "fuel" cost for hydropower.

Q & A

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