Session 5: Hydro in a Power System

Instructor

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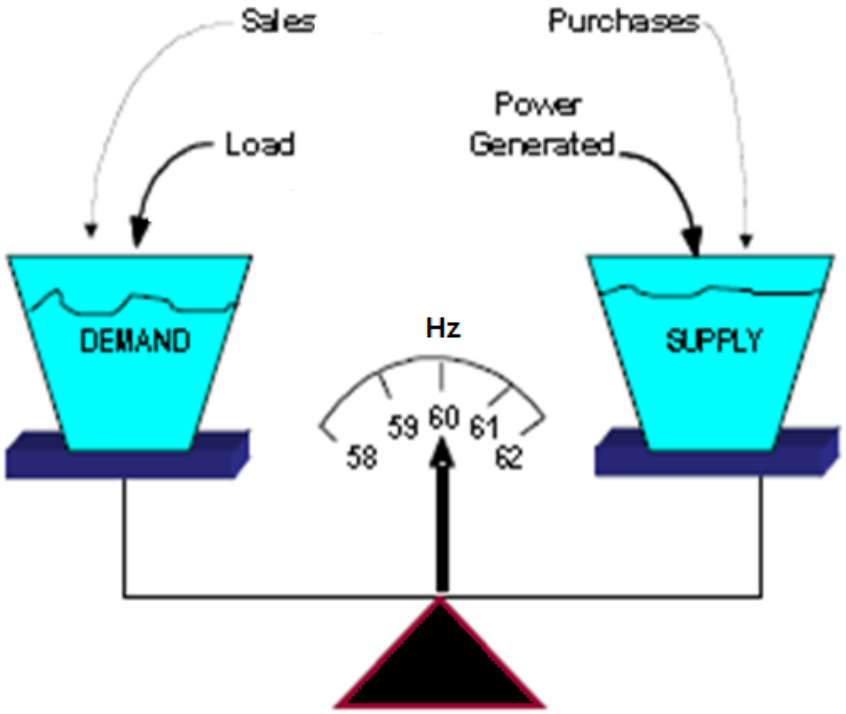
Session 5: Hydro in a Power System - Overview

- Power System Operation Basics
- Power System Controls
- Dispatch of Generating Sources
- Effects of Renewables on Power System Operations
- Capabilities of Generation Sources
- System Operations Planning
- River Operations
- Unique Capabilities of Hydro
- Impacts of Alternative Generation Sources

Frequency Control

Balancing Power Systems

Frequency controlled by Real Power

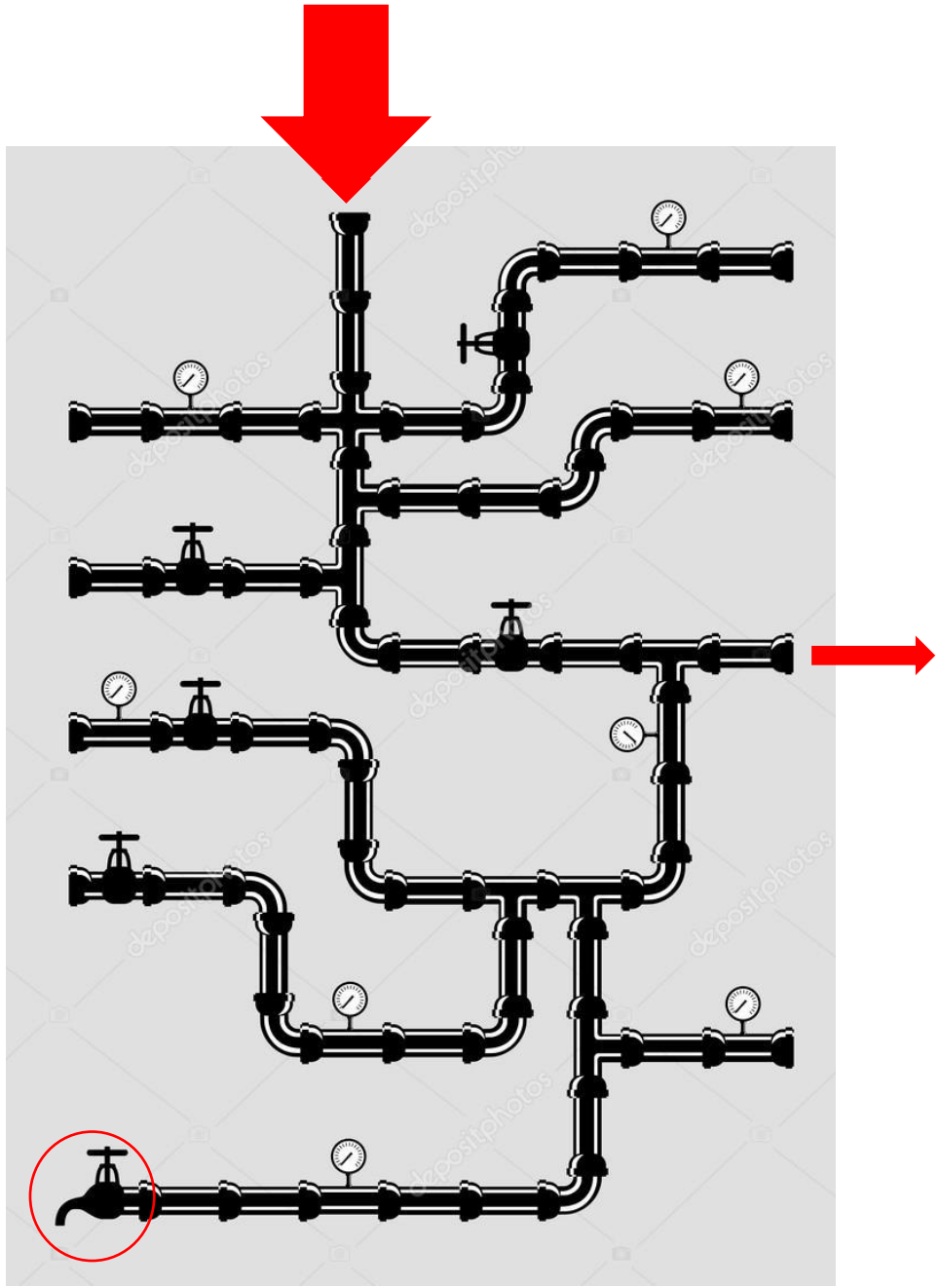


Balancing Supply and Demand

Reactive Power

An analogous example can be a water system. With all the valves closed, it requires a certain amount of pressure to deliver a flow at the outlet of the system.

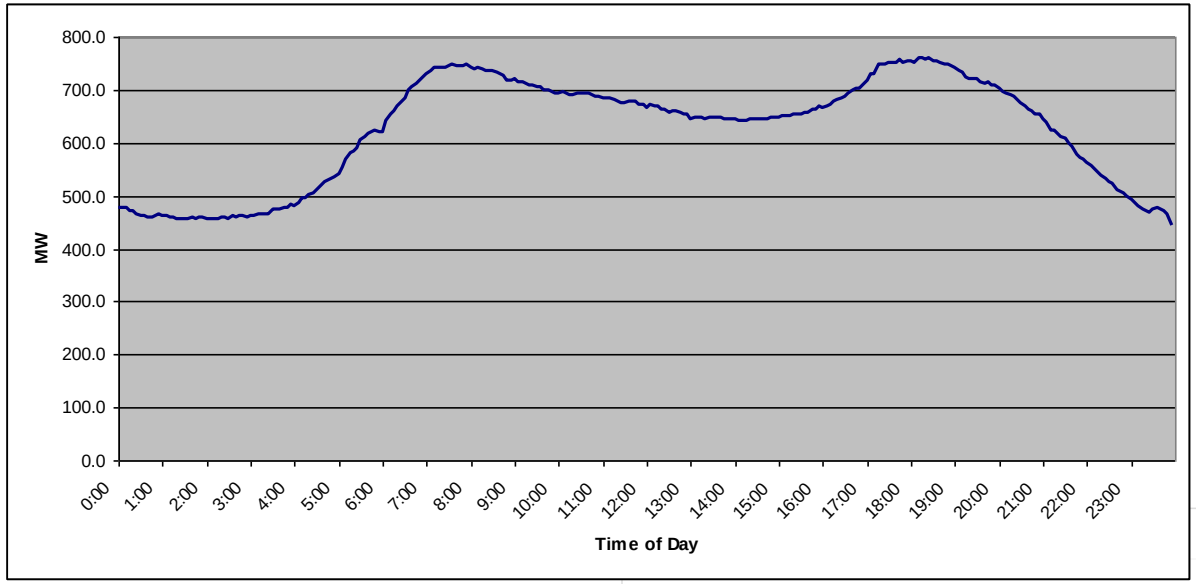
If you open a valve, the pressure will decrease in the system and you need to increase the source pressure to continue to deliver the pressure at the outlet.



Power System Operation Basics

- Electrical energy cannot be stored
  - The original “just in time” process!
- Real and Reactive power loads are always changing
  - But there are patterns for similar types of loads
- Generation must be equal to load for stable operation
  - Continuous adjustments are required for balance
    - Manual, by operators
    - Automatic, by control systems like AGC
- **What happens if you don’t always match source to loads?**

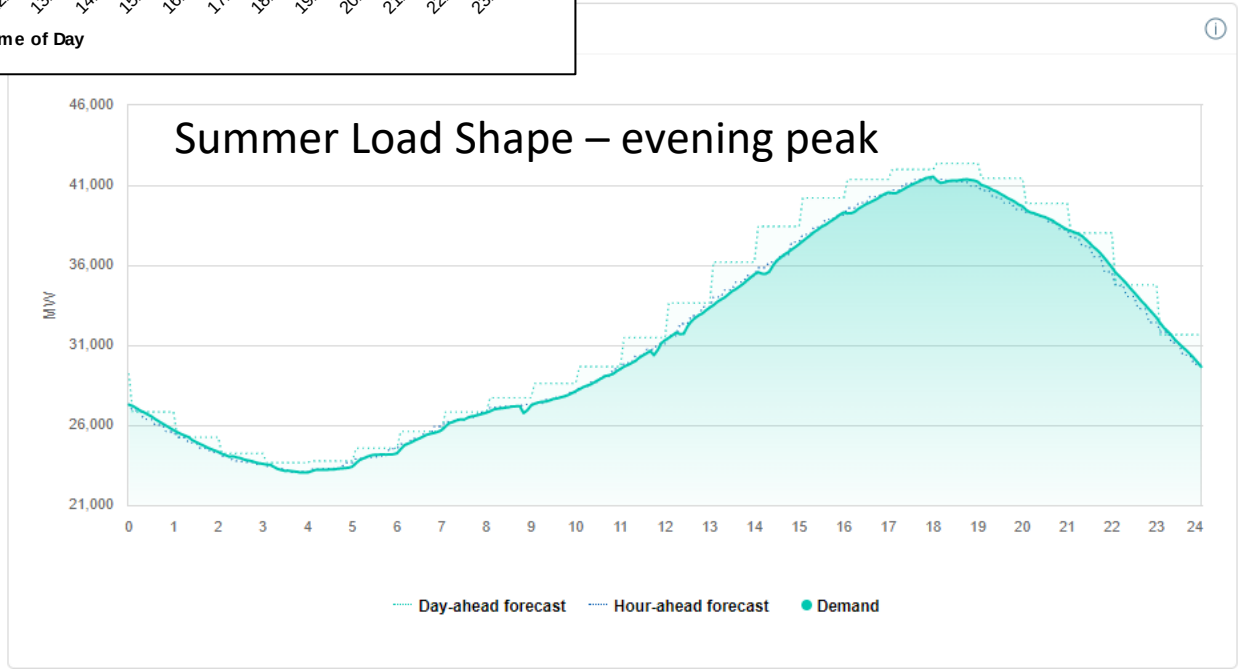
Typical Load Curves



Winter Load Shape – two peaks

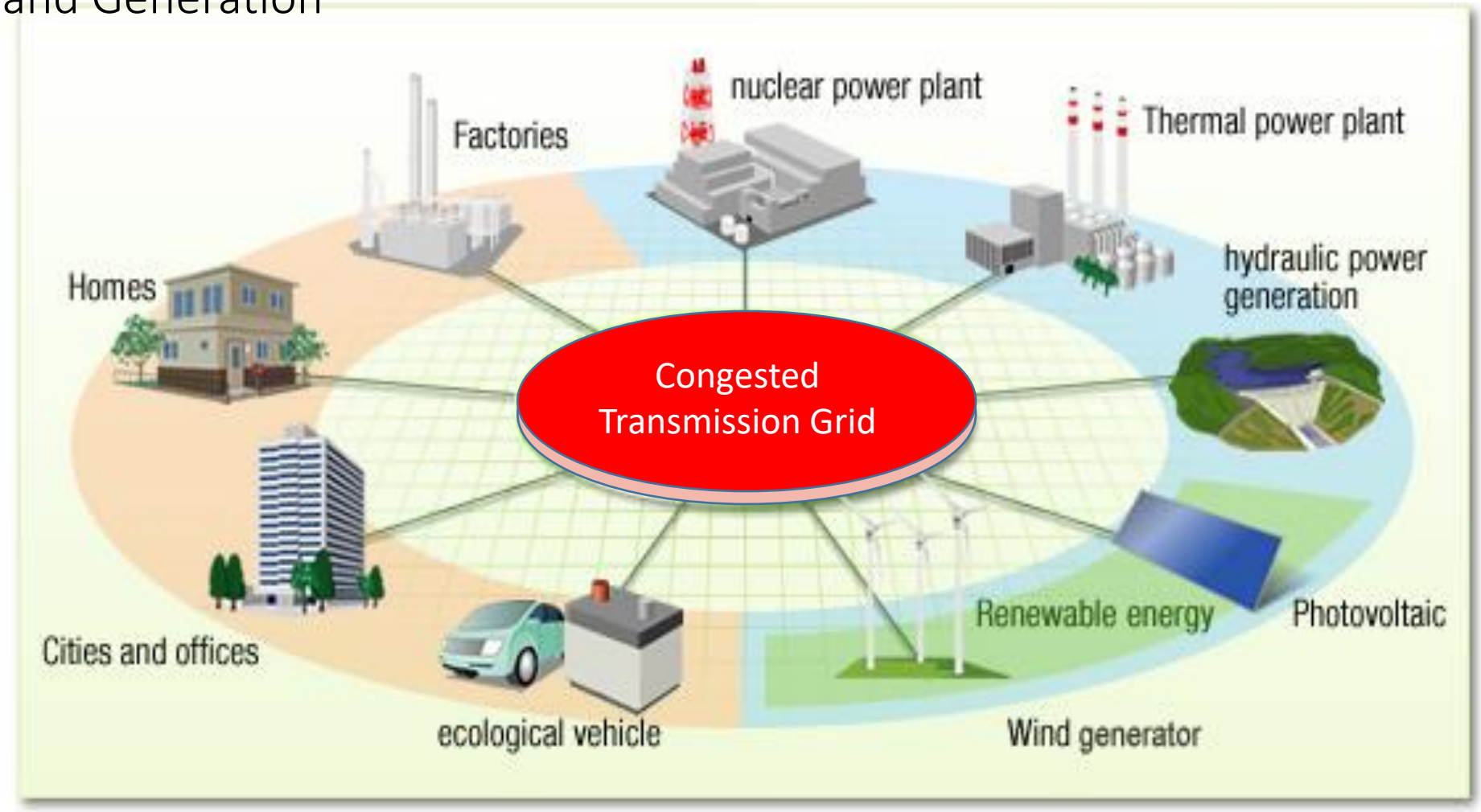
Why do you think these curves are different? What causes these shapes?

What will these curves look like when everyone comes home to charge their electric vehicle?



Power System Basics

Loads and Generation



Power moves from generator to load across the transmission grid

Transmission Congestion

- What might cause a transmission system to be congested?
- What happens if Transmission Constraints don’t allow enough power to flow to loads?
- How do you know if the system becomes congested?

Power System Control

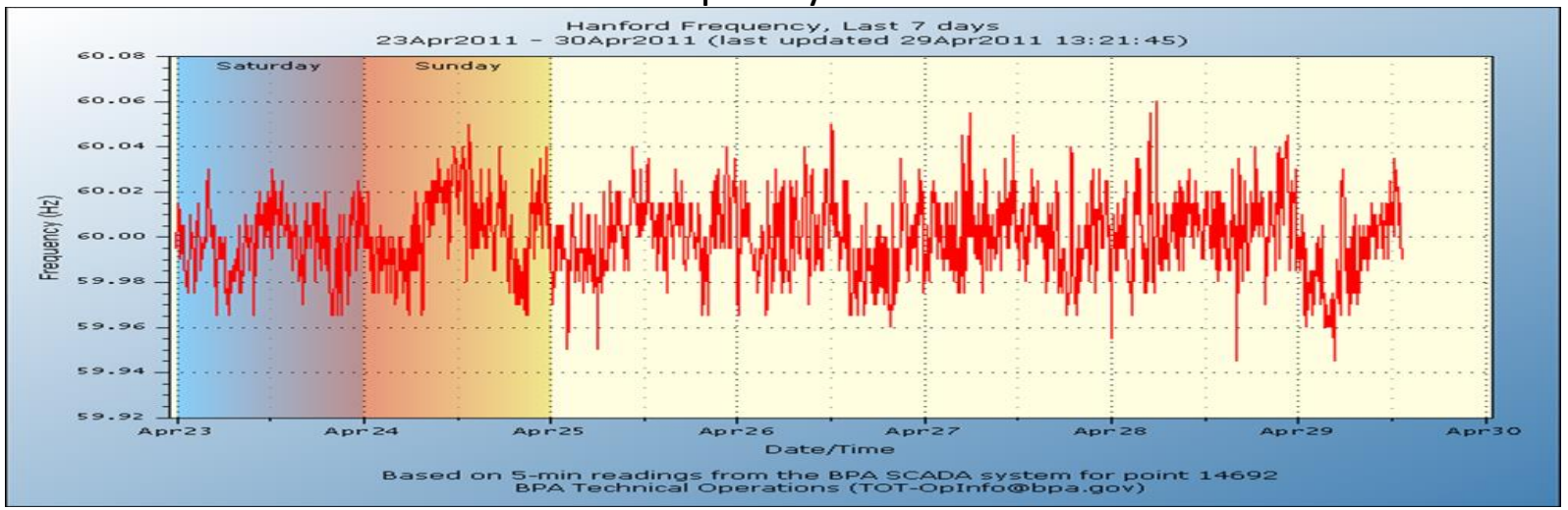
2 Basic Control Parameters

- Frequency
  - Agreed upon value (60Hz in NA, 50Hz in EU)
    - Frequency Response at unit (governor action)
    - AGC Response (f_{error} term in ACE Equation)
- Voltage
  - Set by Transmission Operator
    - Voltage Schedule
    - Reactive Power Schedule

Power System Control

[FNET/GridEye Server Map Gradient Display (utk.edu)]

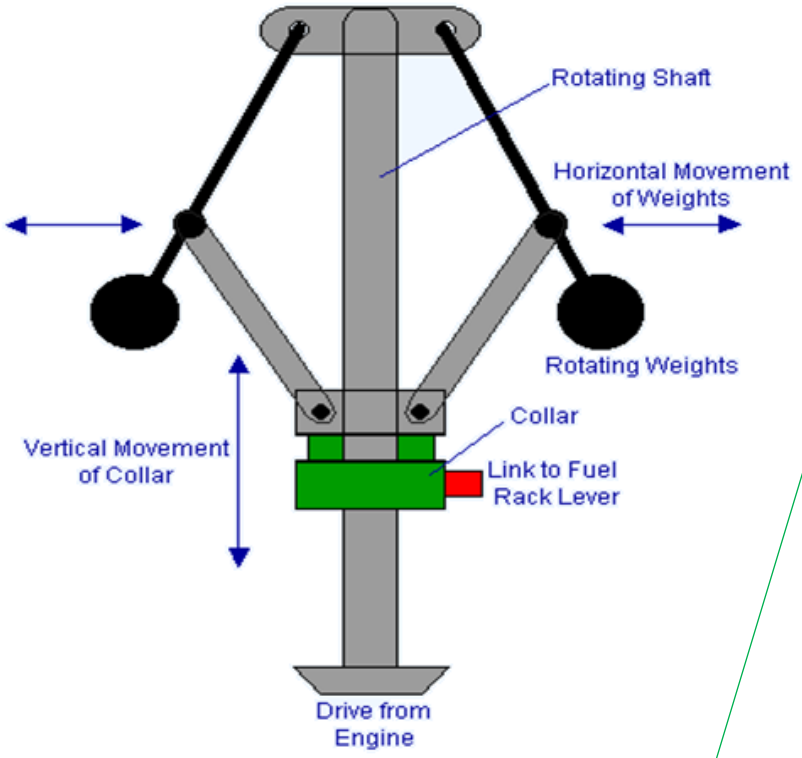
Frequency



Voltage

Balancing Power Systems
Real Power Balance

Unit Control



Governor Control

BA Level Control
(Balancing Authority)

Automatic Generation Control (AGC)

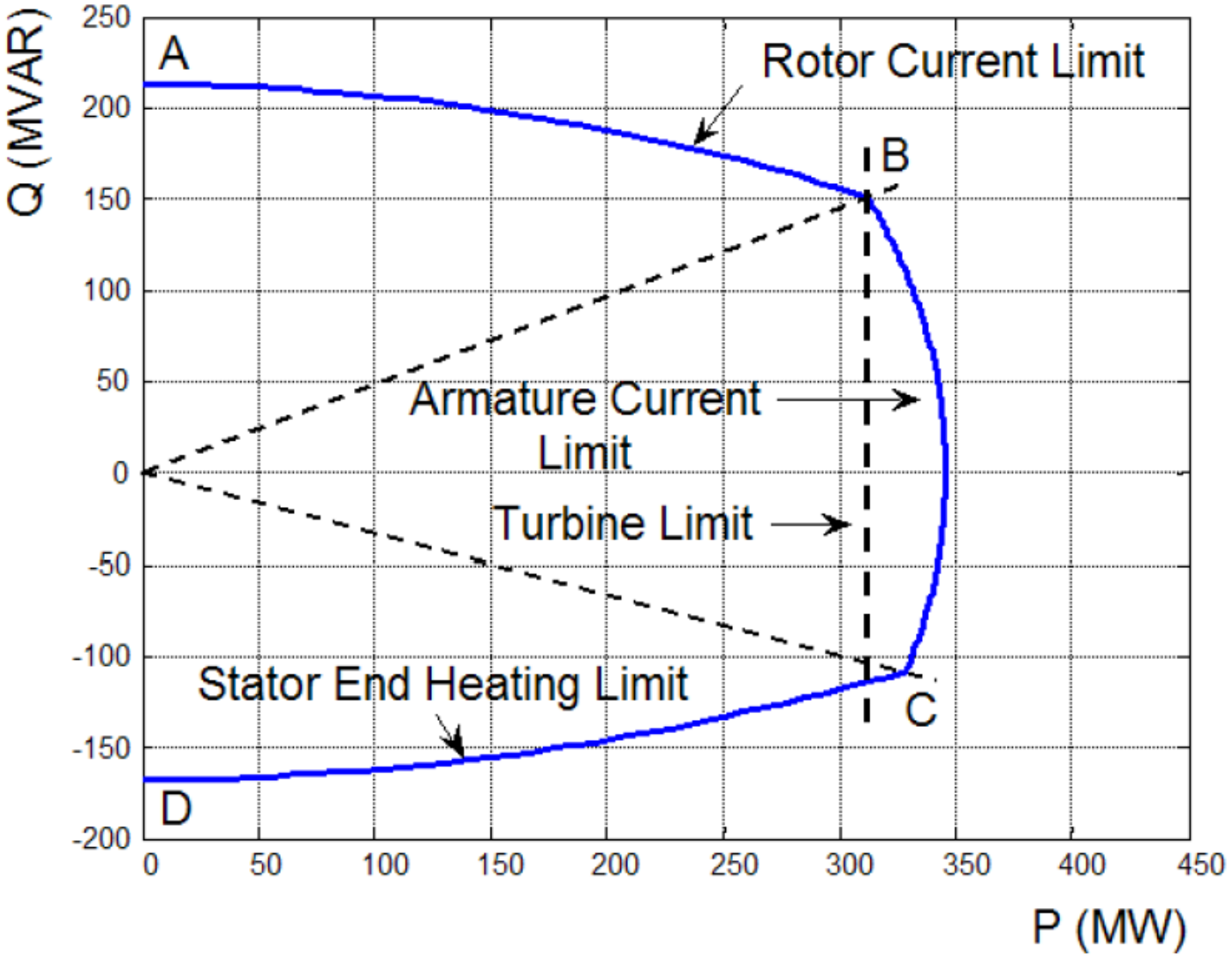
Area Control Error (ACE)

ACE is a function of:

Interchange Error
and
BA share of Frequency Error

Balancing Power Systems

Voltage Controlled by Reactive Power



Balancing Power Systems
Reactive Power Balance - Some Transmission Reactive

Interconnected System Operation

Benefits include

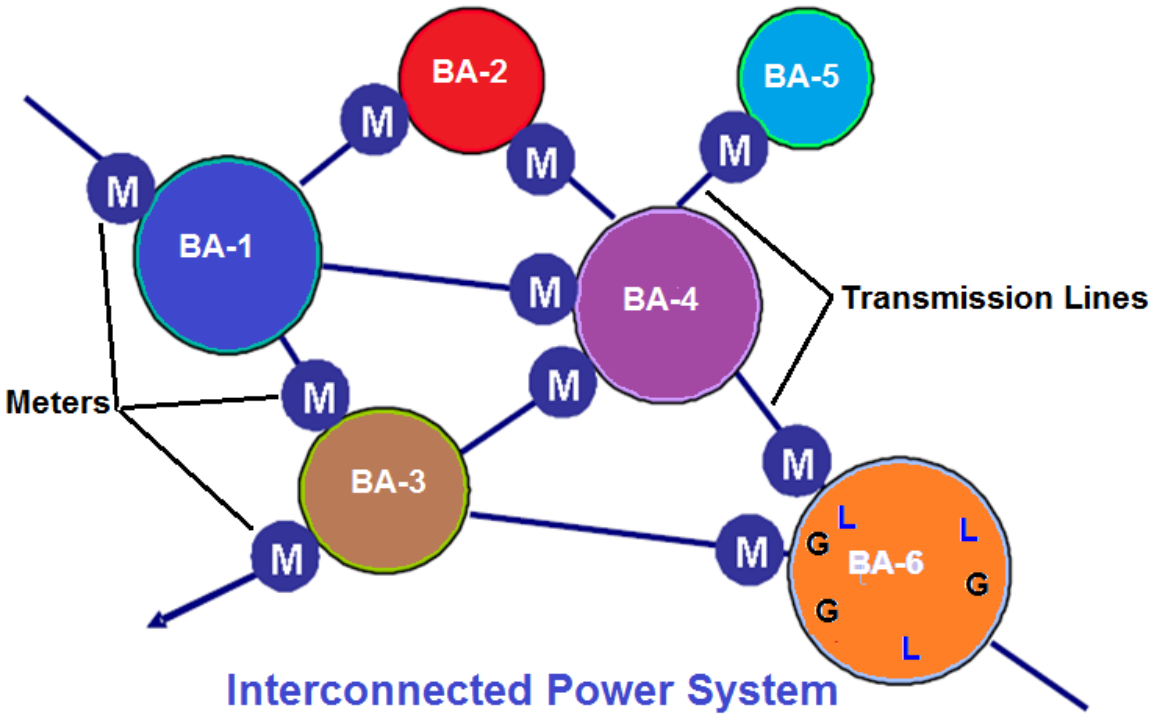
- Reserve sharing (Contingency, Frequency, Regulation)
- Diversity in transmission paths
- Sharing frequency error
- Access to wholesale energy markets
  - Economic Purchases or Sales

Disadvantages

- All systems “see” disturbances
- Other generation suppliers can sell to your customers

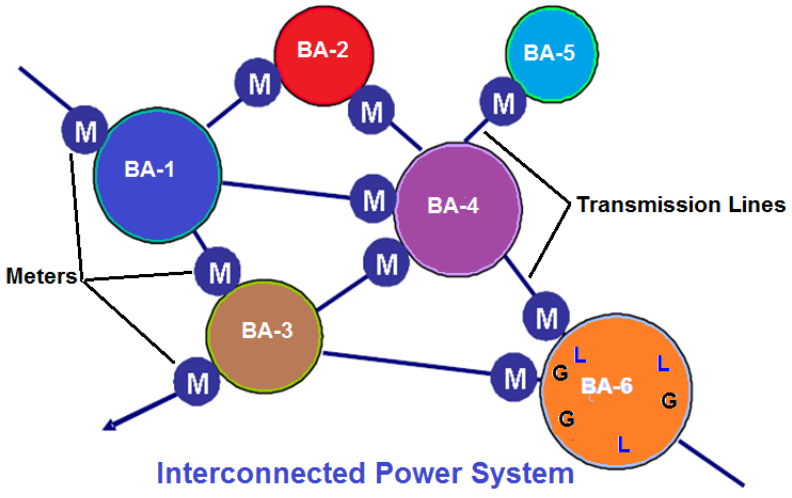
Makes Retail Power Markets possible

- Customers have choices



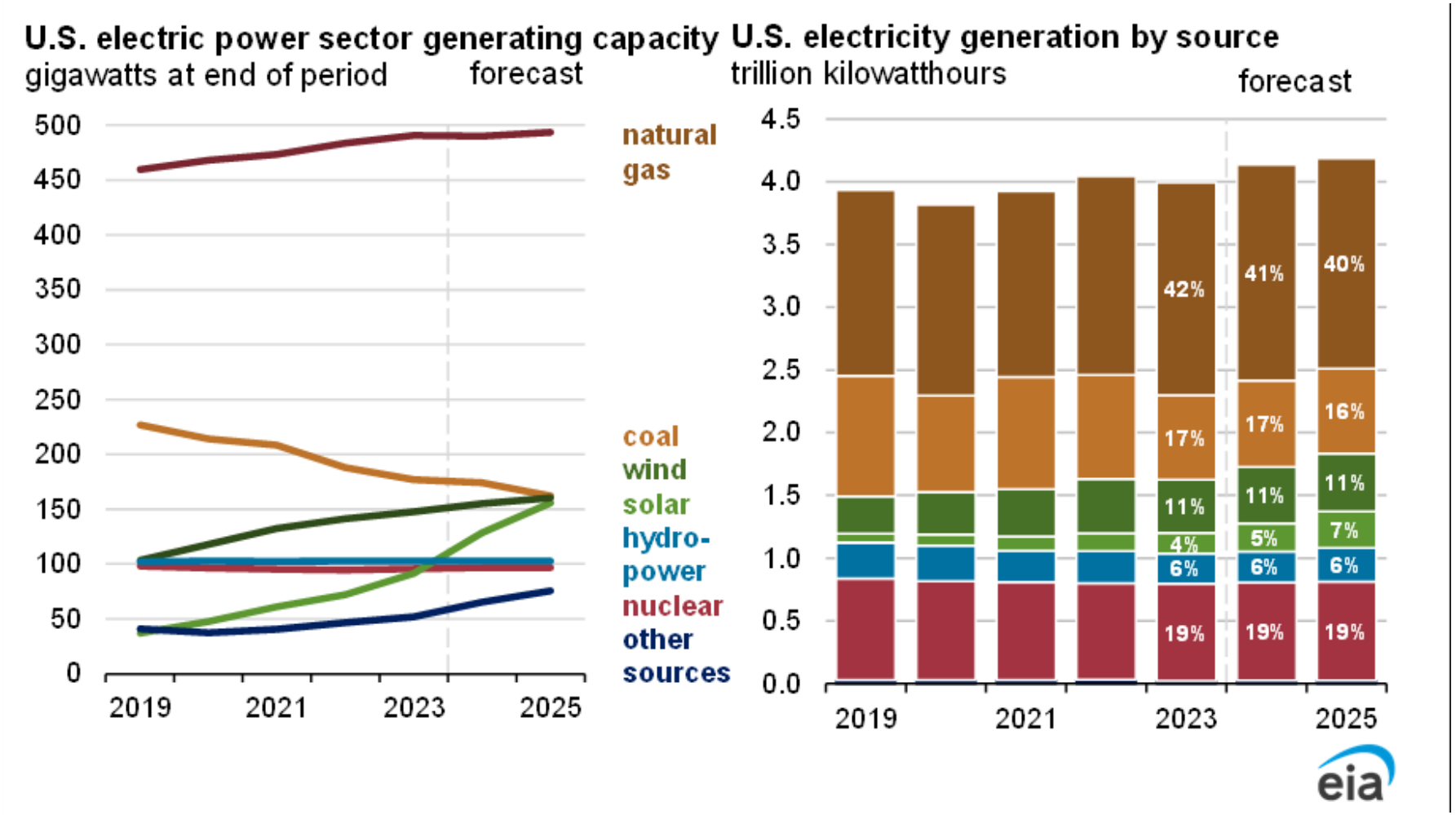
Energy Interchange

- Excess generation can be sold to other entities, or
- Energy can be purchased from other suppliers
  - Neighboring (or distant) utilities
  - Power marketers
  - Independent generators



- Purchases are just another resource you use to meet your load demand.

National Electric Resource Mix



Source: U.S. Energy Information Administration, Short-Term Energy Outlook, June 2023

Generation Dispatching

Meet Real Time Load Demand at Minimum Cost

Costs whether I run or not

Costs only when I run

Fixed Operations Cost

Fixed Maintenance Cost

Debt Service

Variable O&M Cost

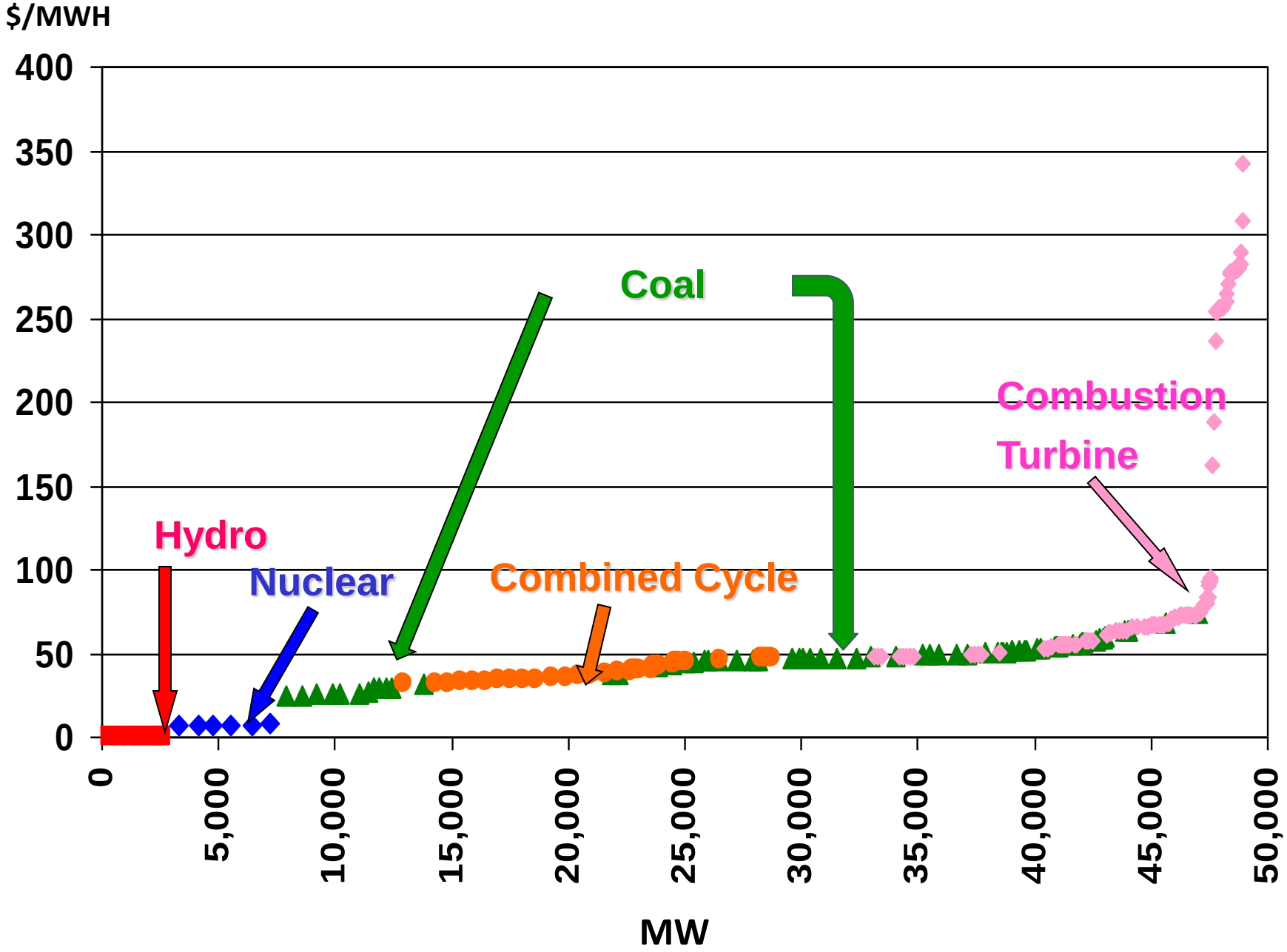
Fuel Cost

Start Up Cost

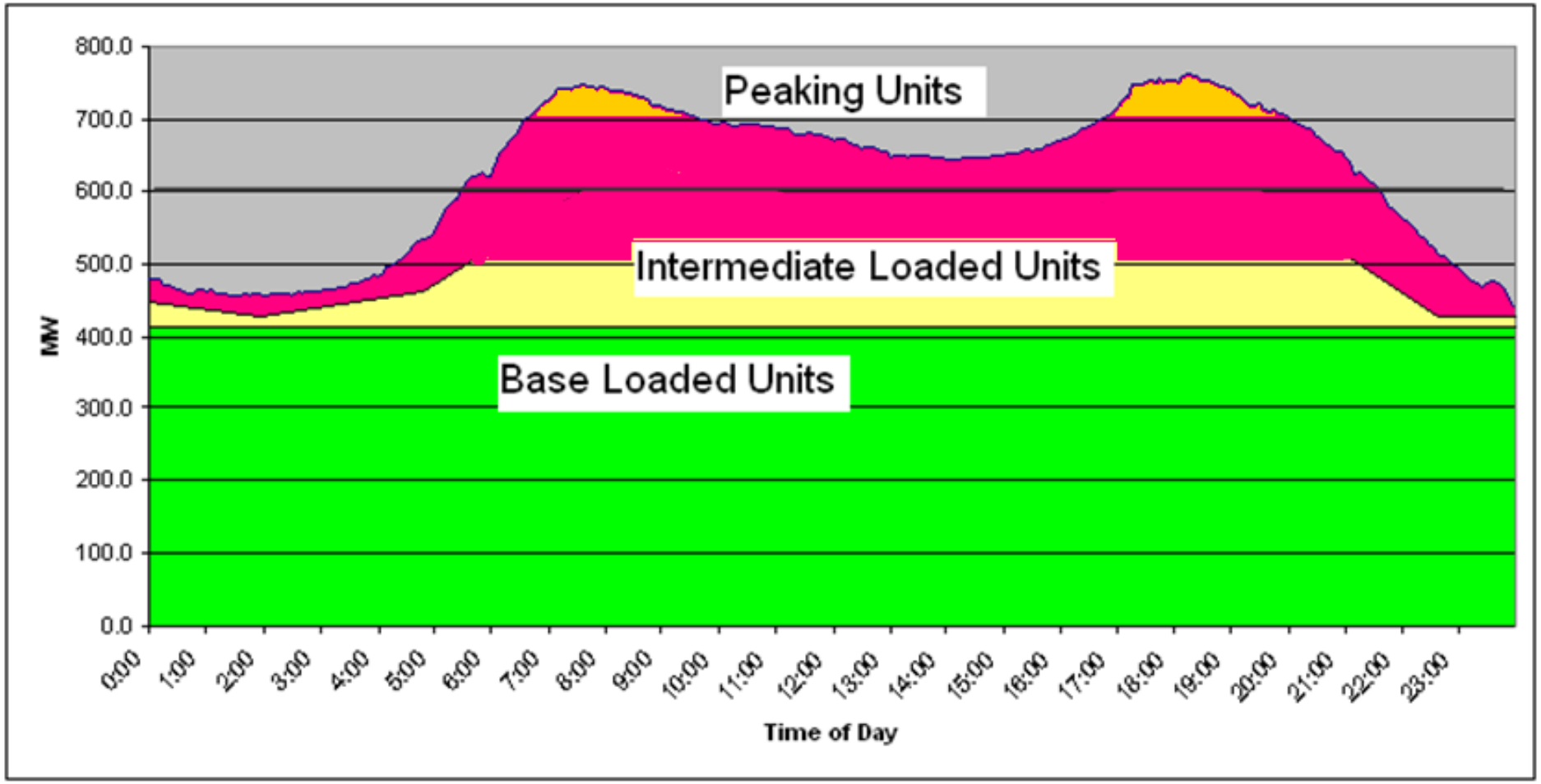
For Utilities, these are “Rate Based”

Total cost per MWh

Generation Cost Curve

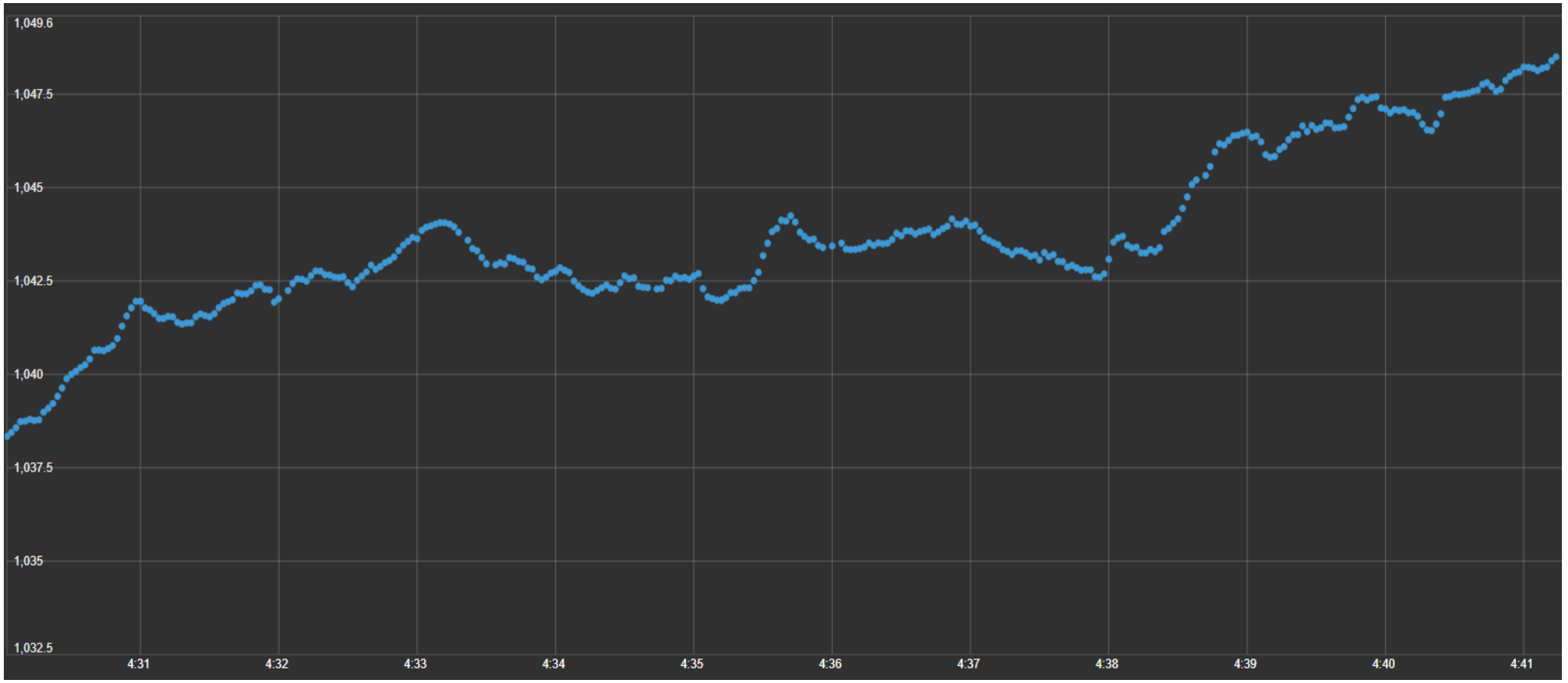


Generation Dispatch



Deep Dive into Load Curve

Load Increment is 2.5 MW

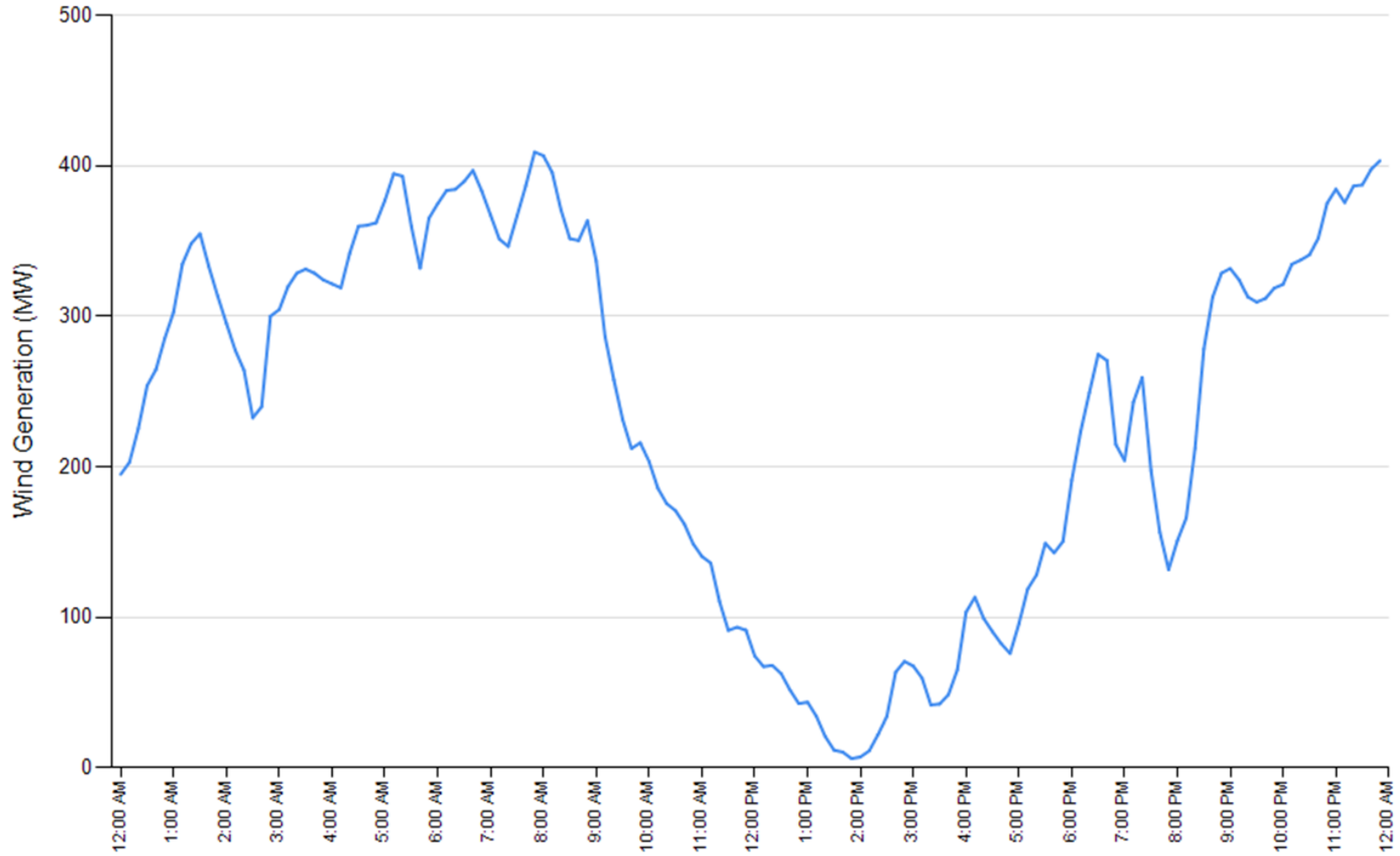


Time Increment is One Minute

New Additions to the Power System

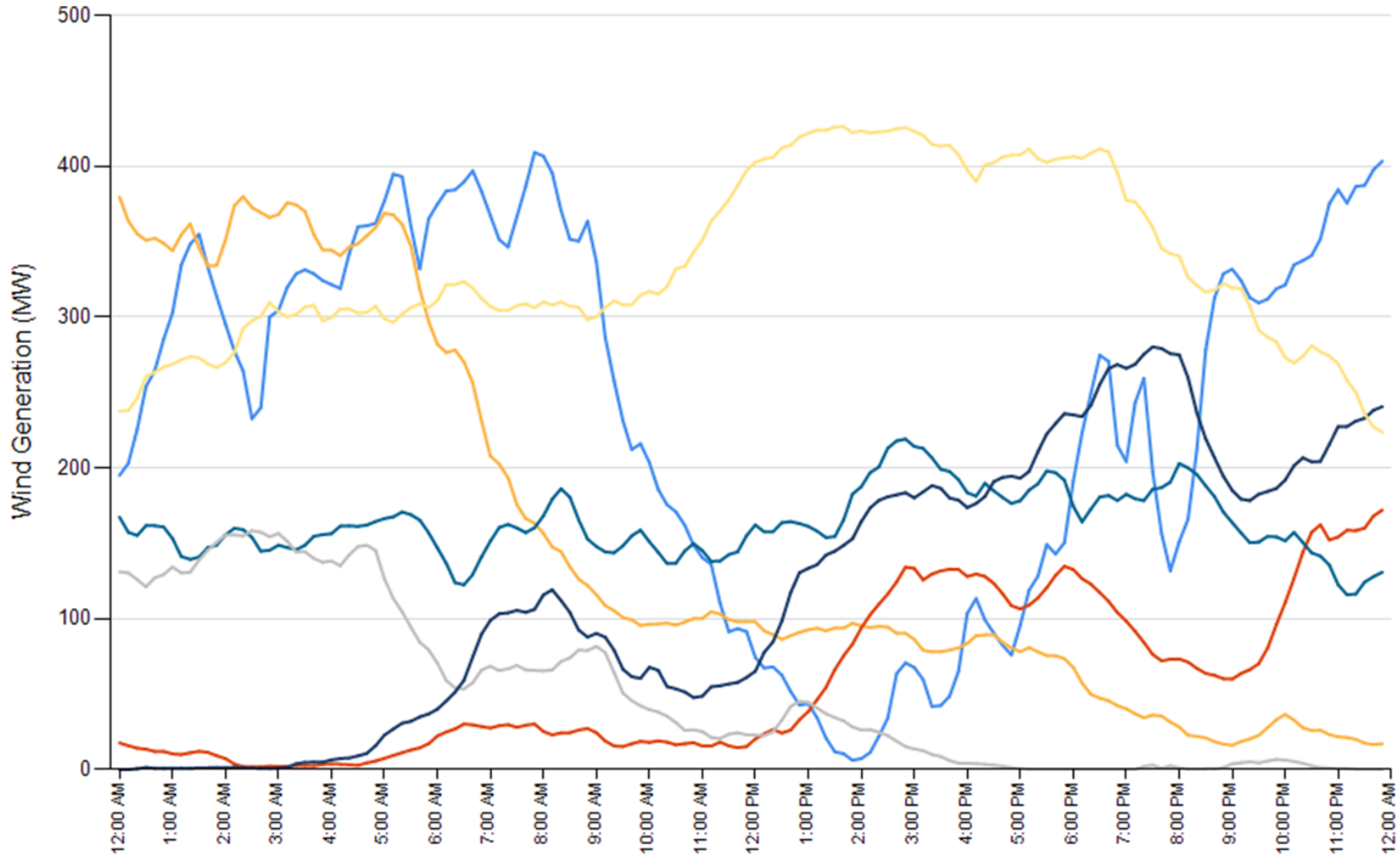
February 2012 – 1 day

Wind Generation



February 2012 – 7 days

Wind Generation



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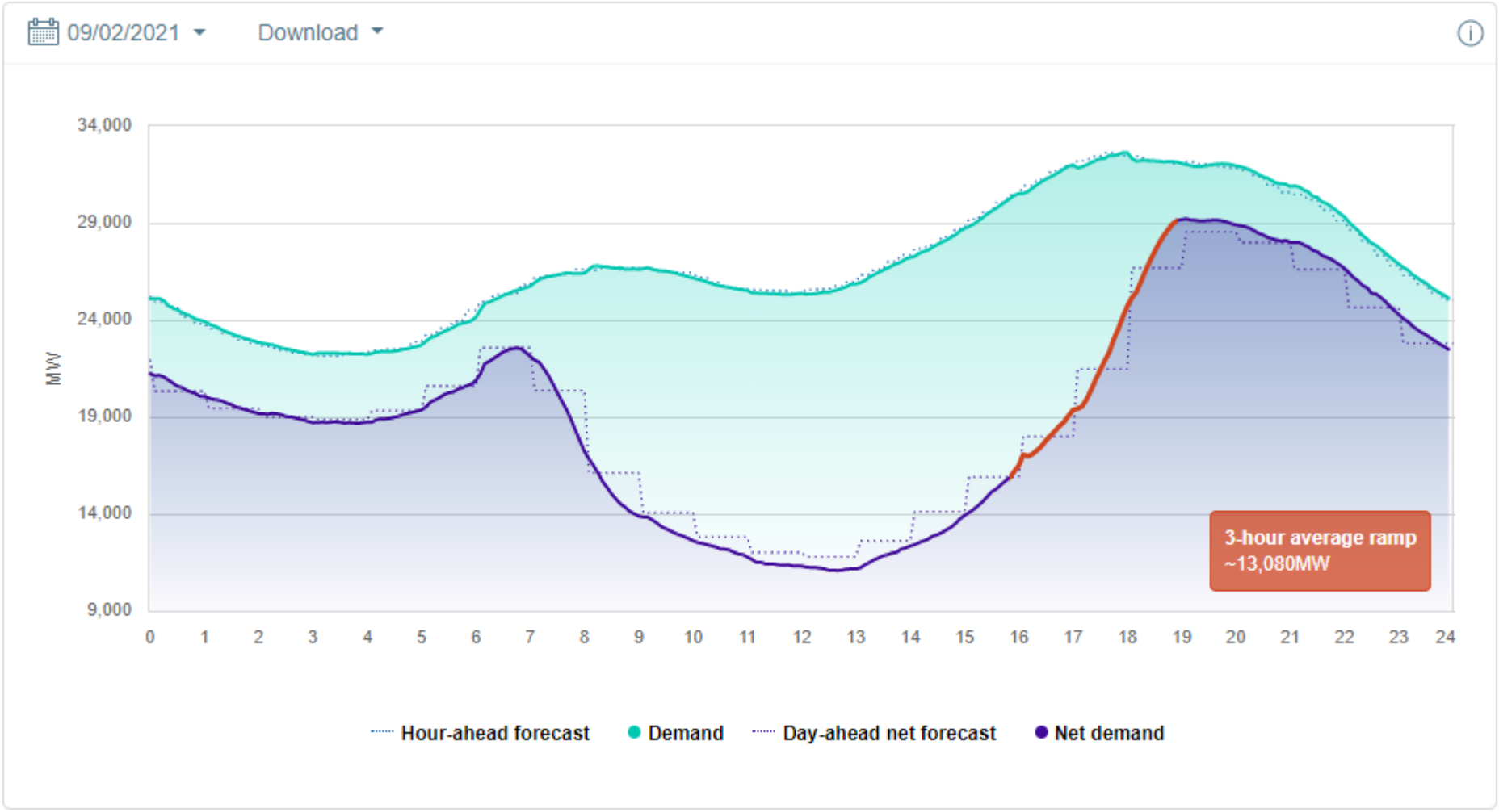
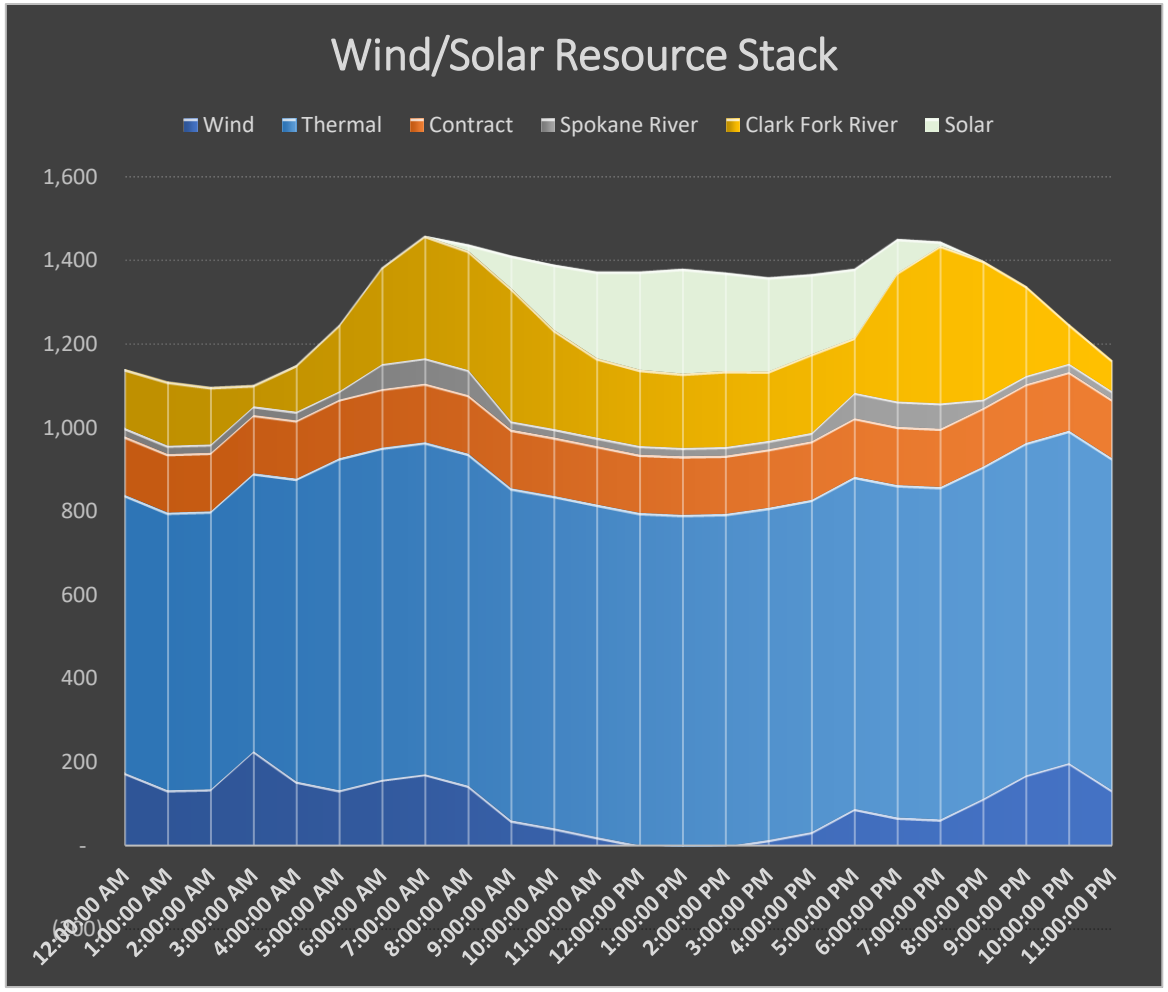
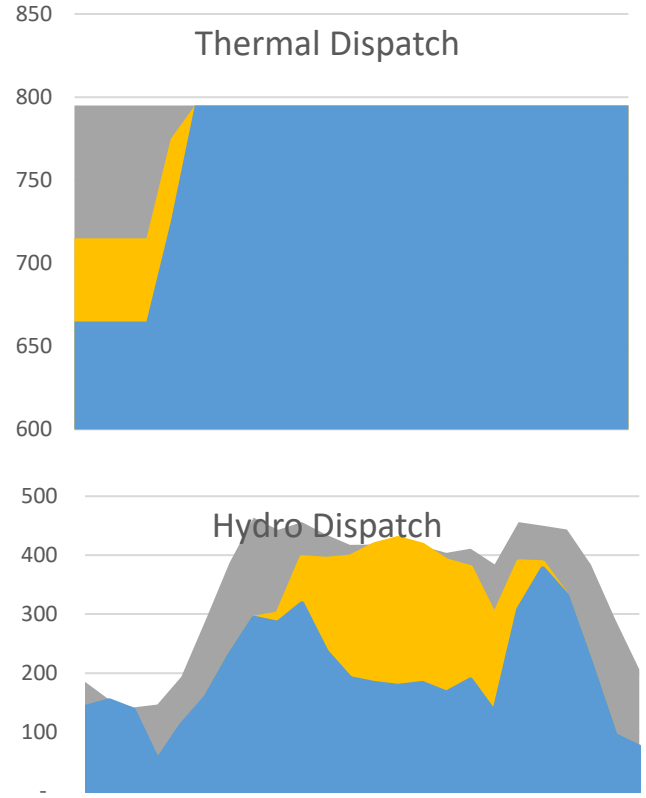
Flexibility for Short-Term Uncertainty

Generation Dispatch



Impacts of Wind and Solar Penetration - Scenario





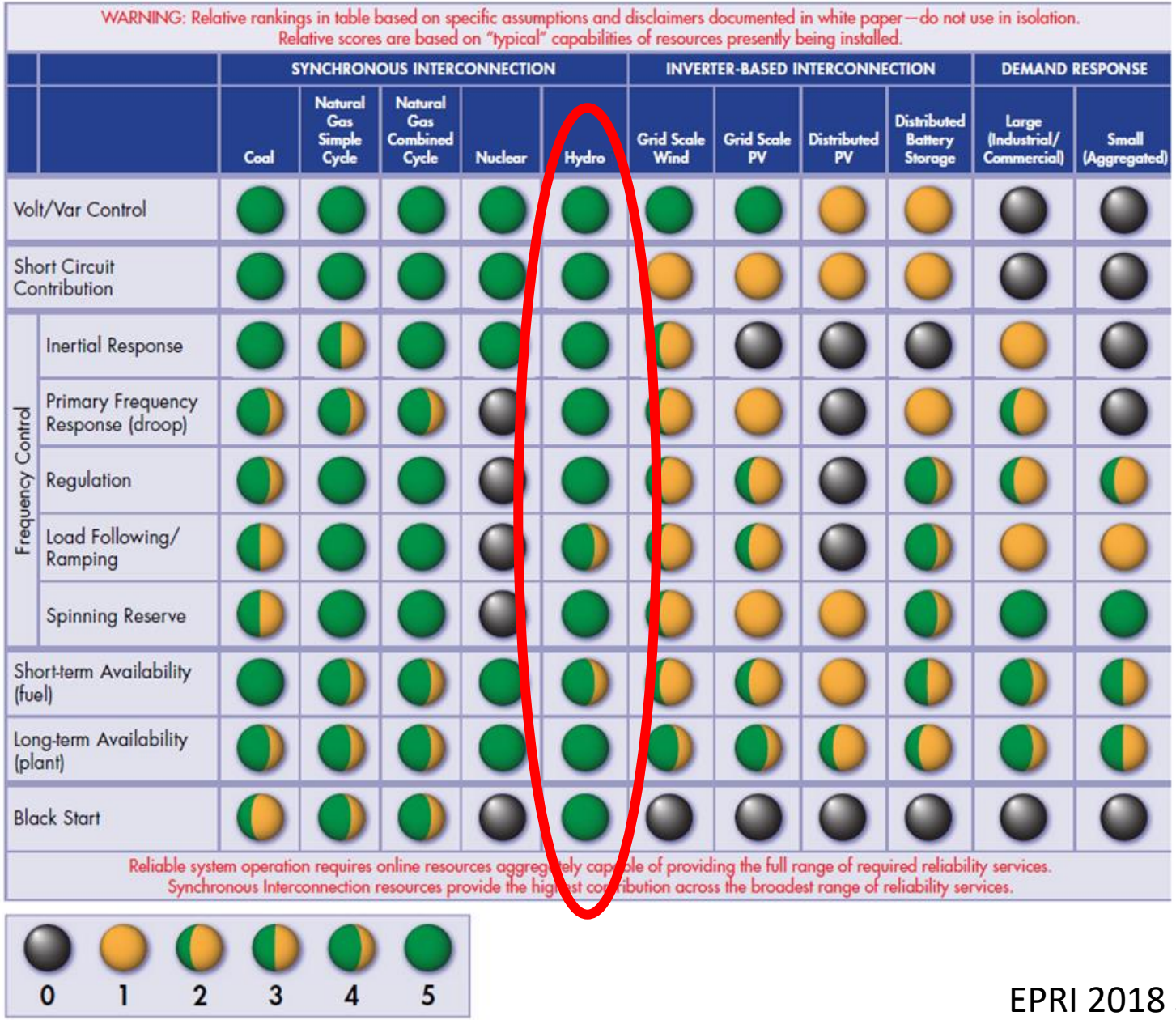
Other Considerations

Do you think a battery is a good thing or a problem thing?

Ancillary Services

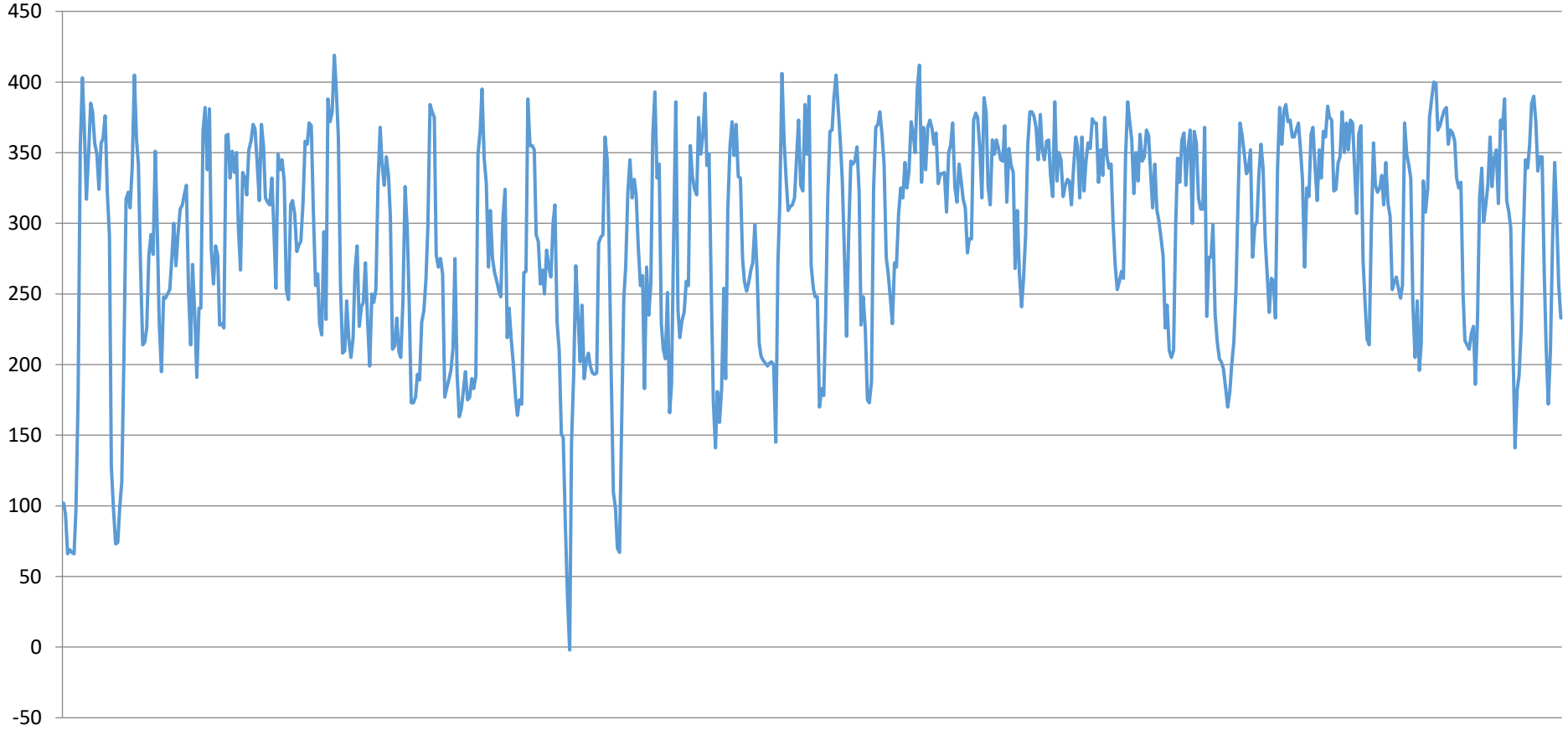
- Non-energy services required to operate power system
- Six types as defined by FERC Order 888
  - Scheduling, system control, and dispatch
  - Reactive power supply and voltage control
  - Regulation and frequency response
  - Energy imbalance service
  - Spinning reserve service
  - Supplemental reserve service

Ancillary Services

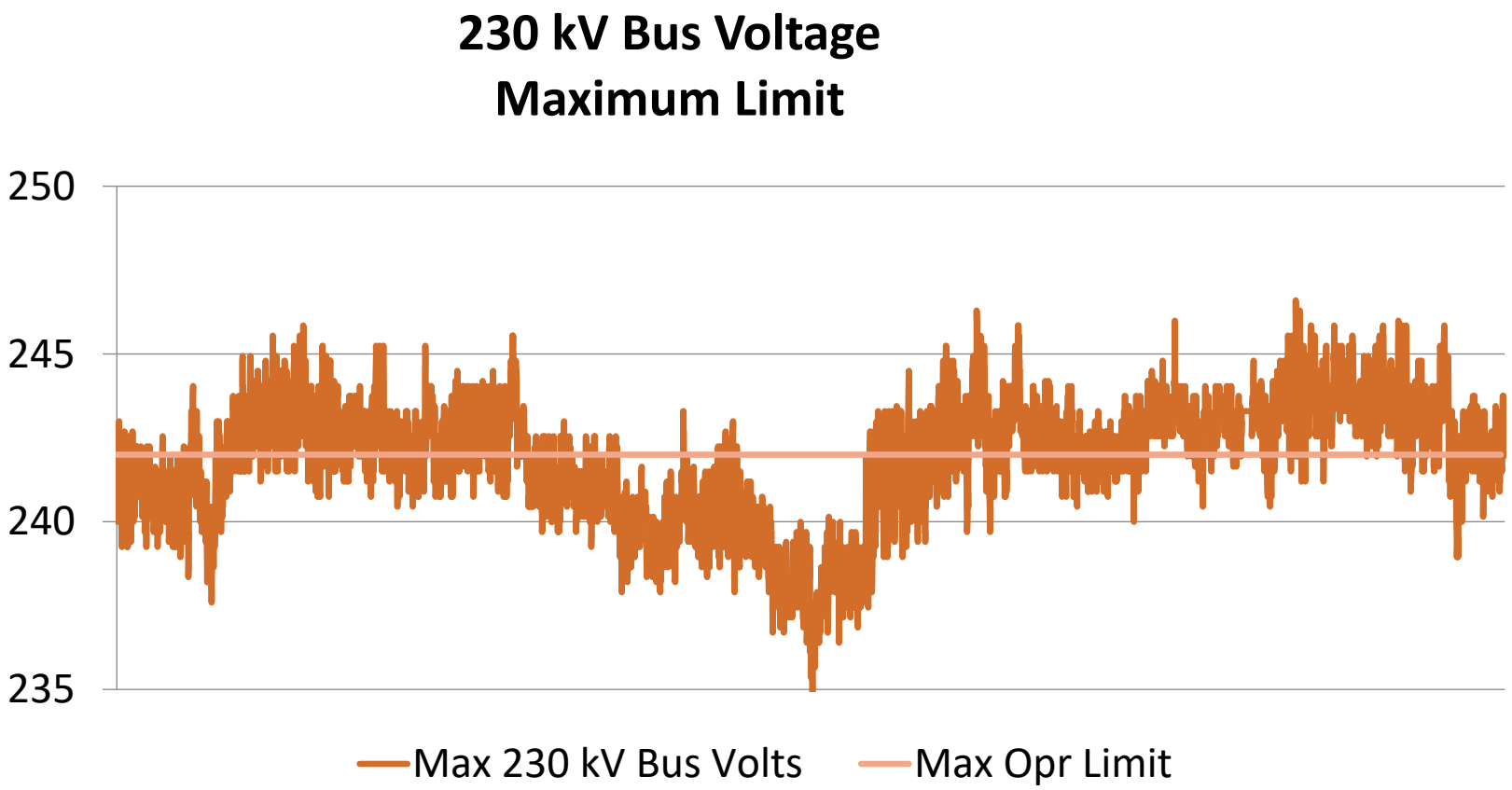


EPRI 2018 System Reliability Services

Plant Regulation



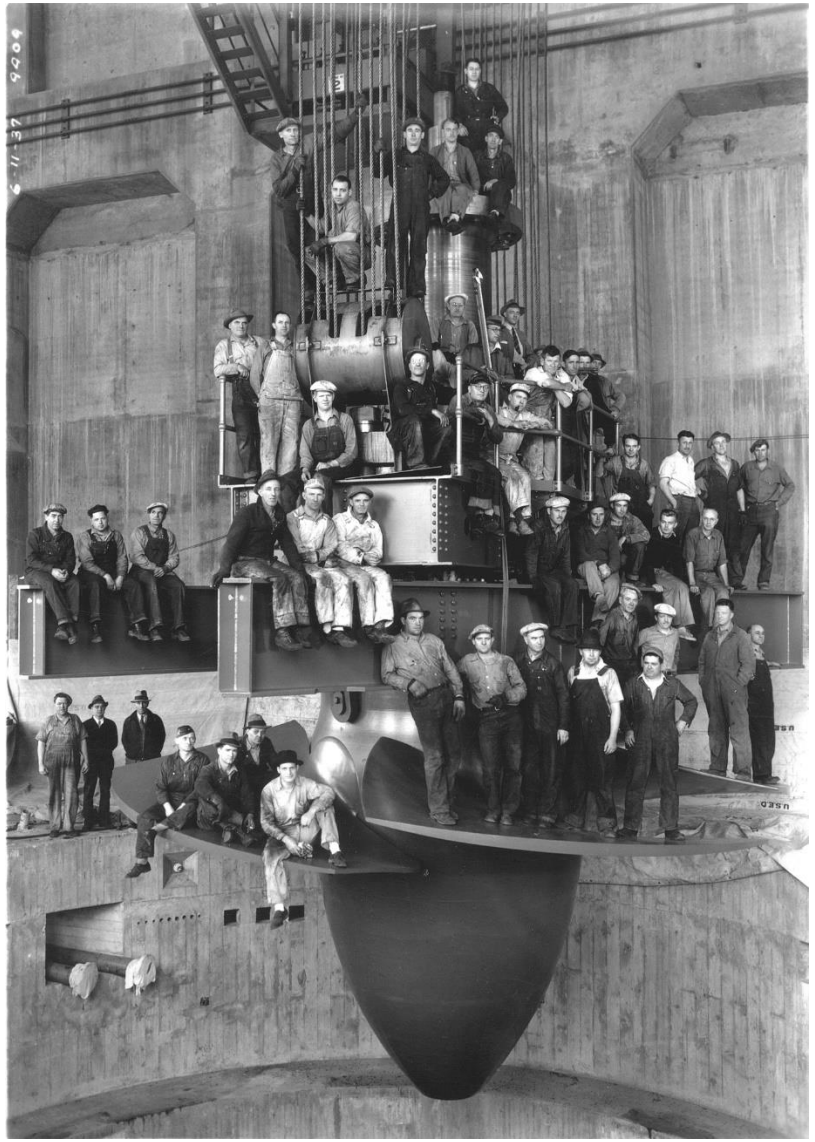
Voltage Support



Another reliability benefit: Inertial Response

Hydro turbines are massive and resist frequency change

Turbo Units create inertia with their speed



Plan for Contingencies

- You must leave room for unexpected events
- Types of contingencies
  - unplanned Unit outages
  - Loss of “fuel” (wind)
  - Loss of transmission lines (when power sales or purchases are being transmitted)
- BA’s Must have Reserve Generation (Operating Reserves) to reliably serve their load

What are some other contingencies that you might need to plan for?

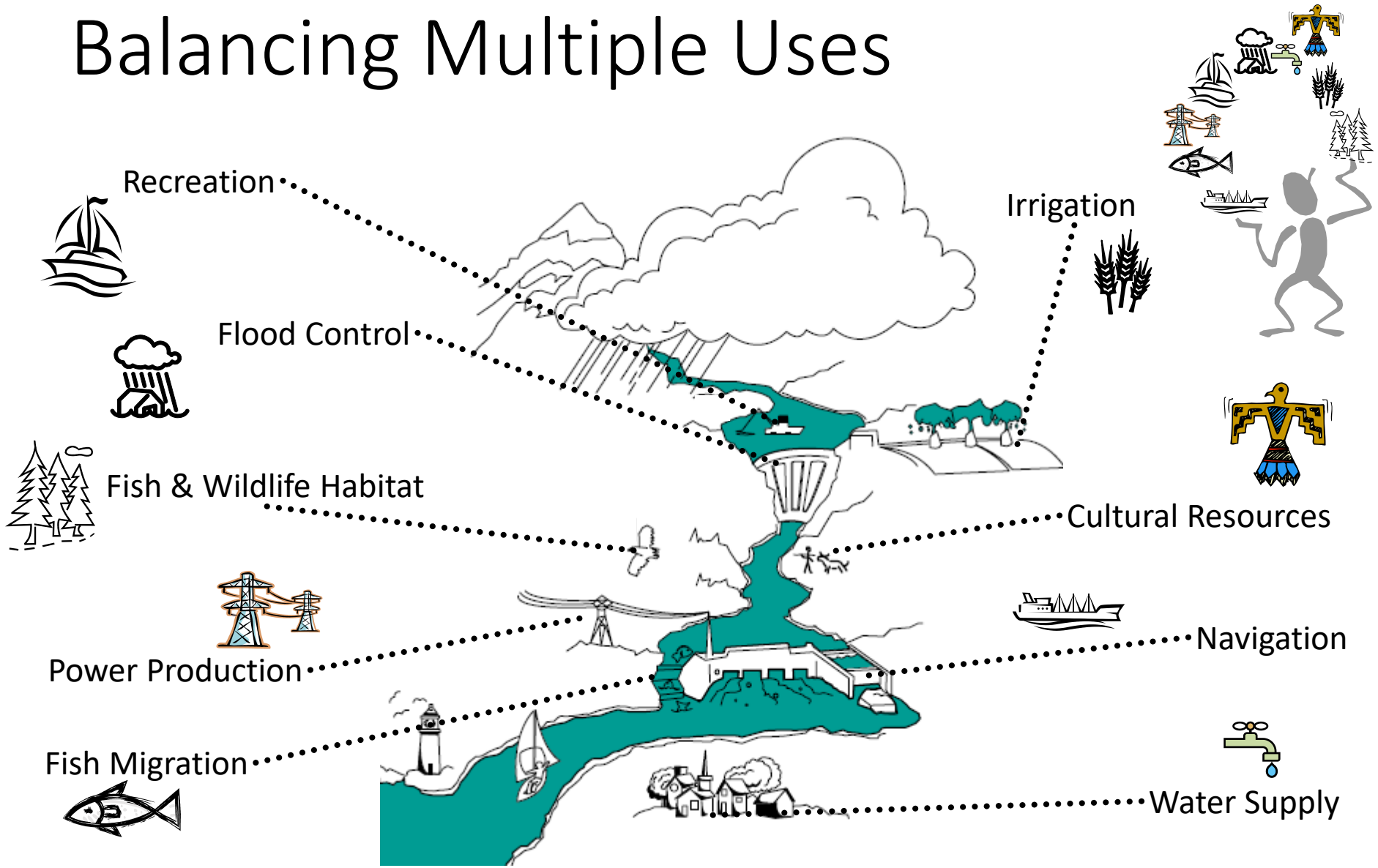
Operating Reserves

- Increase generation – INC Reserve
  - Spinning reserves (already on-line but loaded at less than full capacity)
  - Supplemental (must start and load up in 10 minutes)
- Short term purchases
  - Buy on spot market for replacement power
  - Reserve sharing with connected utilities
- Reduce loads (Demand Response)
  - Drop interruptible loads
  - Drop other loads
- Reduce Generation – DEC Reserve
  - New problem introduced by wind and solar. If they unexpectedly come up something needs to back off to maintain a balanced system

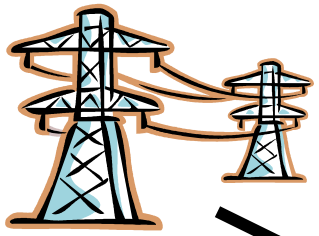
Generation Reserves
NERC Reliability Standards

- BAL 001 – Control Performance Standard
  - How well does a BA maintain frequency, follow load, and minimize Area Control Error (ACE)
- BAL 002 – Disturbance Control Standard
  - Must recover ACE within 15 minutes of a contingency event.
  - Must restore reserves before end of the Disturbance Recovery Period (60 – 105 min)
- BAL 003 – Frequency Response Standard
  - How well does a BA respond to large frequency, frequency deviations.

Balancing Multiple Uses



Transmission Constraints



Environmental Constraints

- NOx requirements, fish flows
- Thermal discharge limitations

Fuel Constraints/Markets

- Hydro
- Coal
- Natural Gas
- Oil

- Coal planned burn requirements for inventory management
- Gas curtailments
- Oil supply limitations
- Hydro – Drought, flood control, recreational, transportation

Weather

Load Forecast

Streamflow forecast

Reliability Requirements
- Long Term &Daily Must-Run Units

Generation Availability, Operating Characteristics & Costs

- Unit Status
- Operating Limits
- Thermal Efficiency
- Variable O&M
- Fuel Handling
- Minimum Up & Down Times
- Start-Up Costs
- Emissions Costs
- Operating Reserves

Day-Ahead Unit Commitment

Real-time Operations

Other Contract Obligations

Contract Resources Availability & Cost

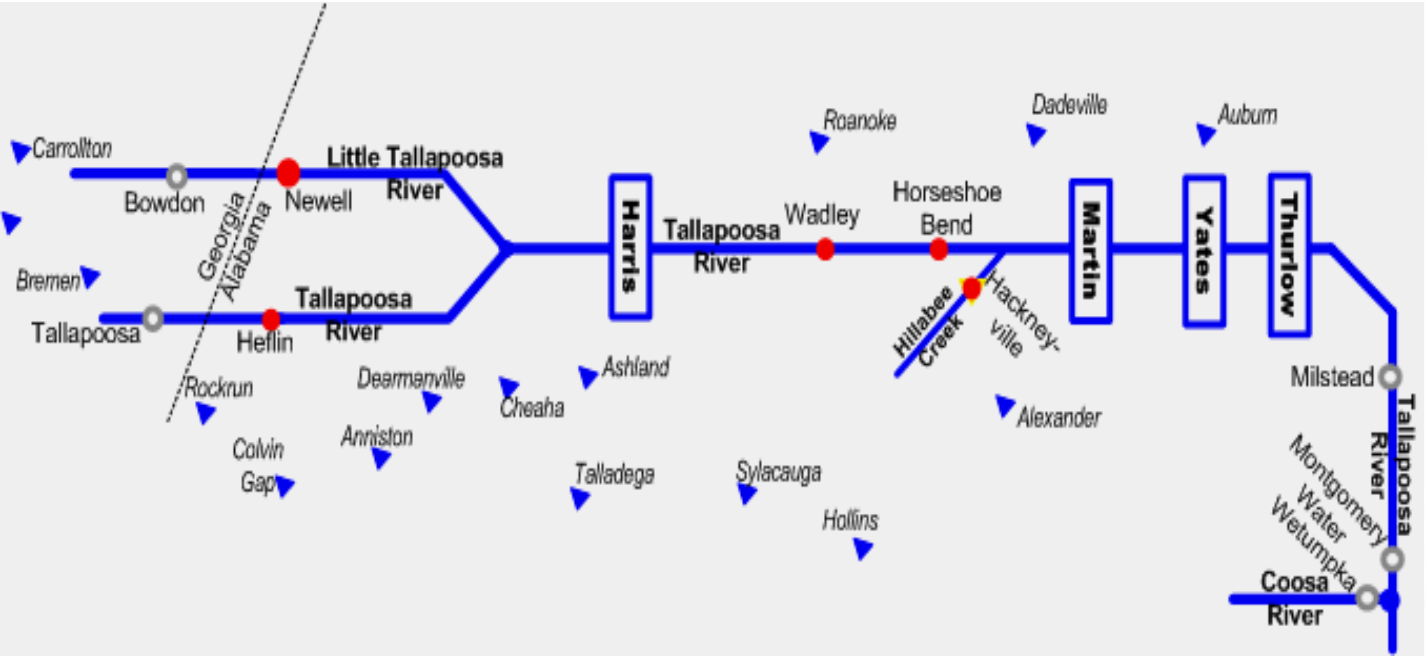
Wholesale Electricity Market Assumptions

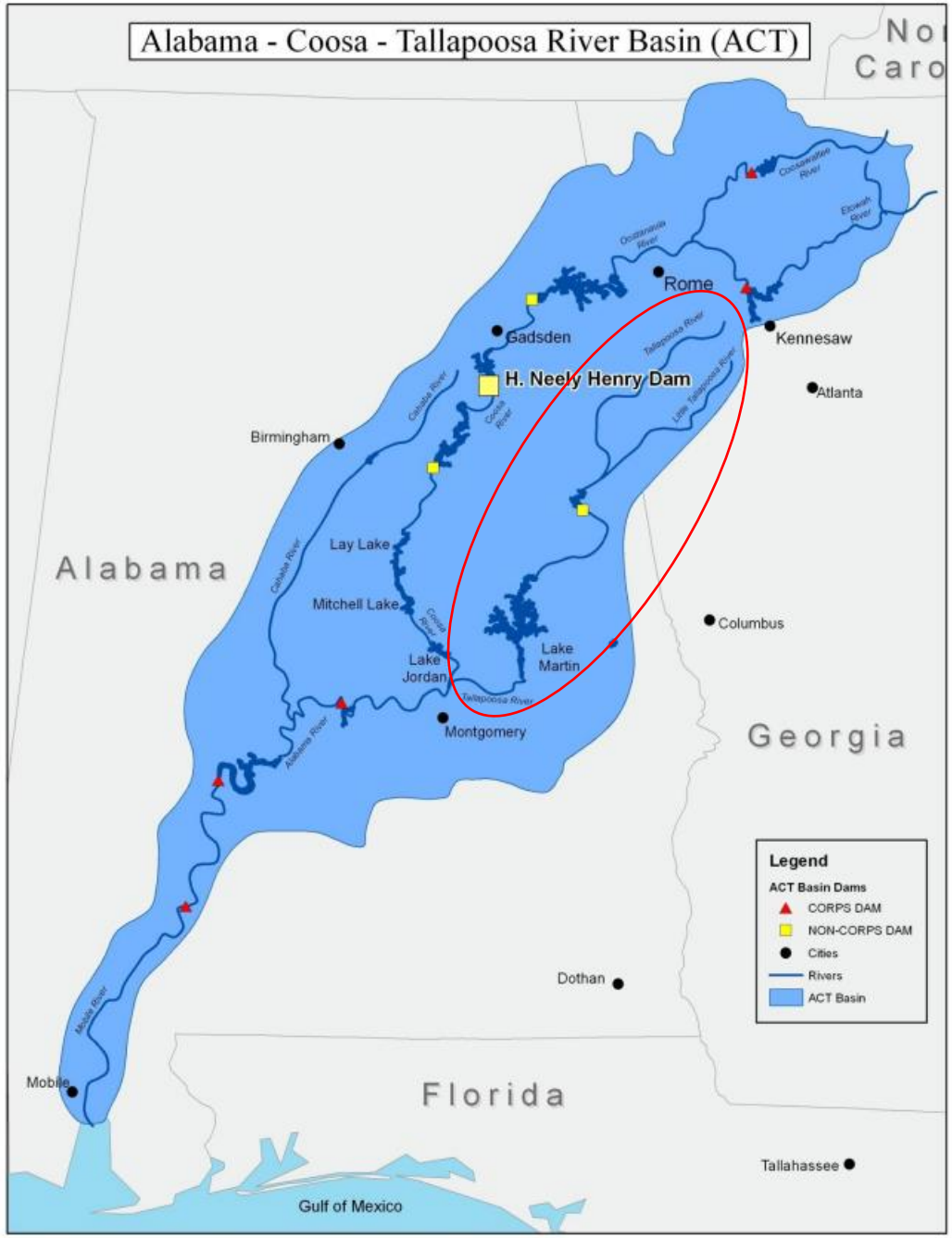
Planning for Operations

- Fuel Supply
  - Thermals
    - Purchase your gas, coal oil, uranium
    - Consume in real time
  - Wind and Solar
    - Hope for windy sunny days
    - Wait until real time to see how it unfolds
  - Hydro
    - Use Historic Hydrology Records
    - Statistical Analysis
    - Hope for lots of rainy days and a little luck

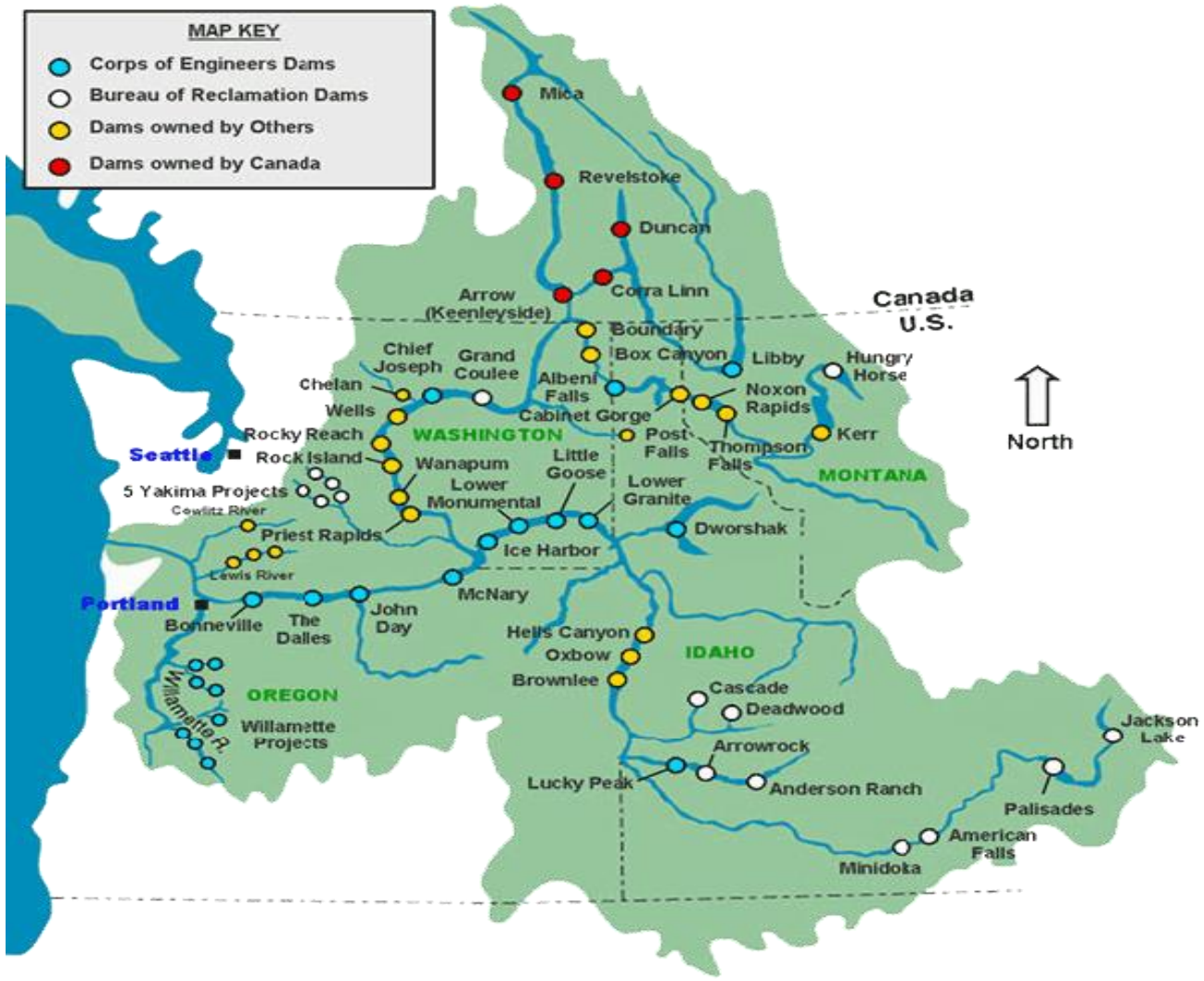
Drainage area of Alabama River, Coosa River, Tallapoosa River

Tallapoosa River Schematic





Hydro plants have a Dynamic Fuel Supply



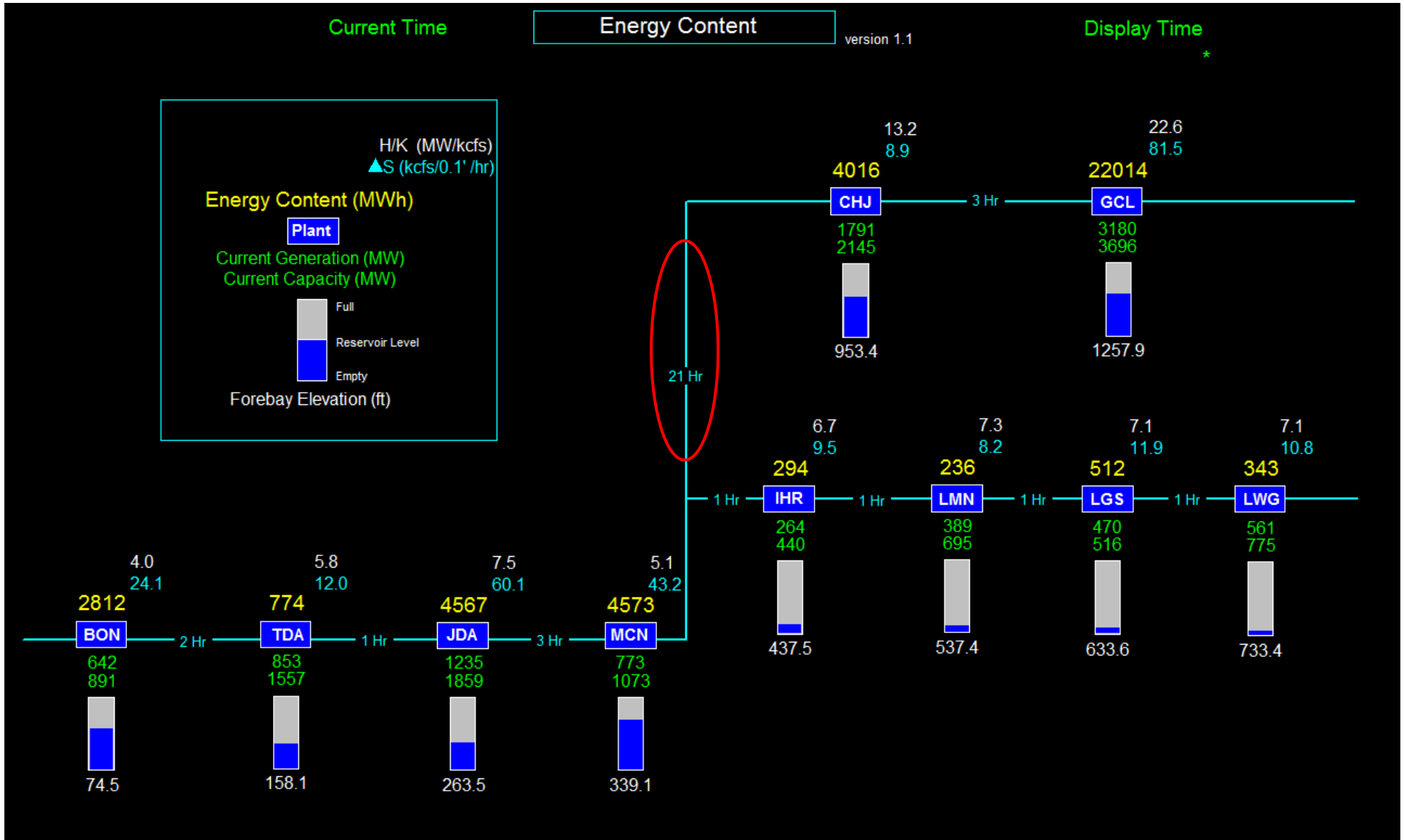
Upstream outflow = downstream inflow

Lots of planning and coordination is required for reliable operations

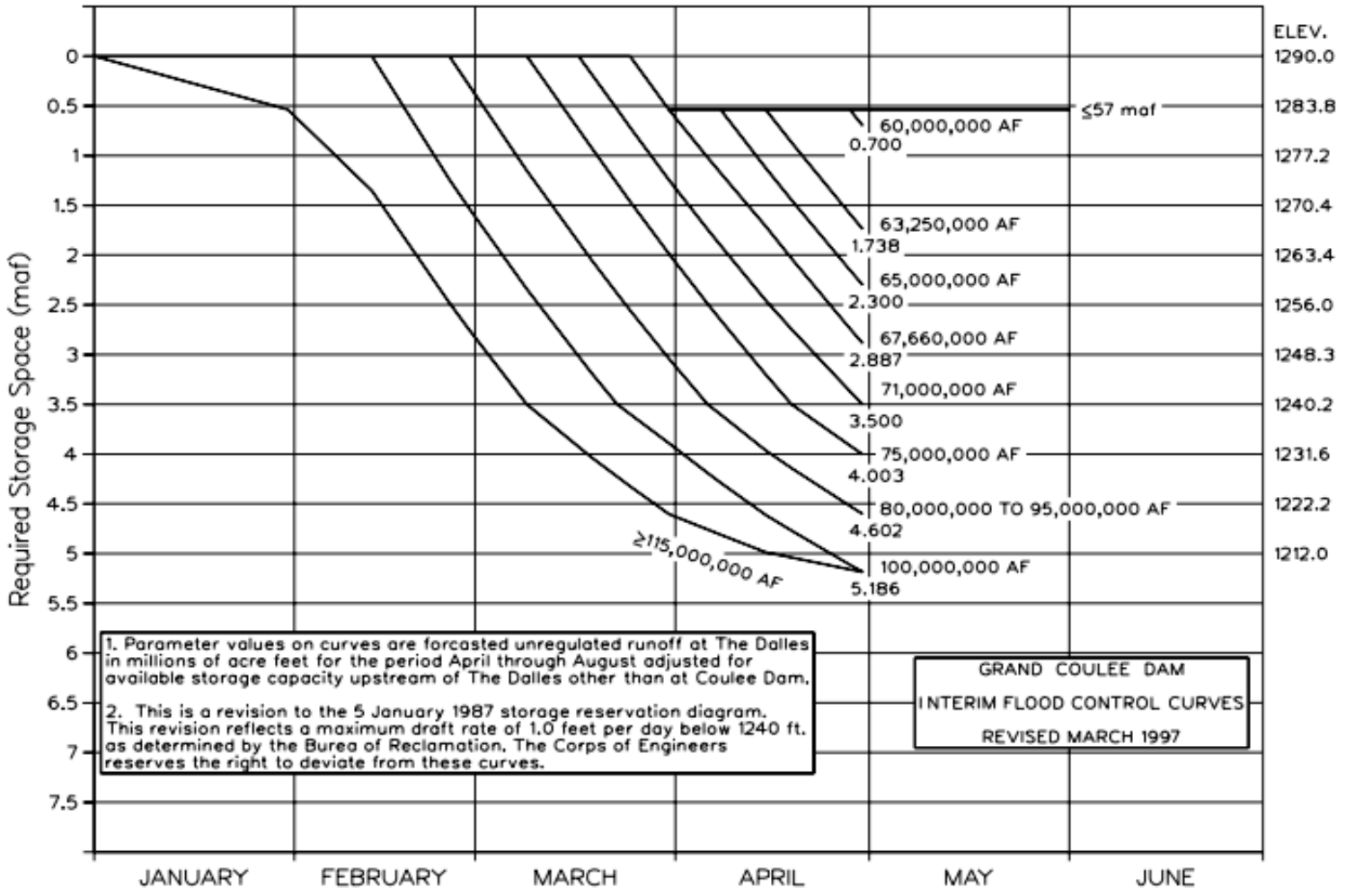
Real Time Considerations

10 kcfs increase at LWG

Generate or Store Today?? Sell ??? What about tomorrow?



Rule Curves



Rule Curves force operations for flood control

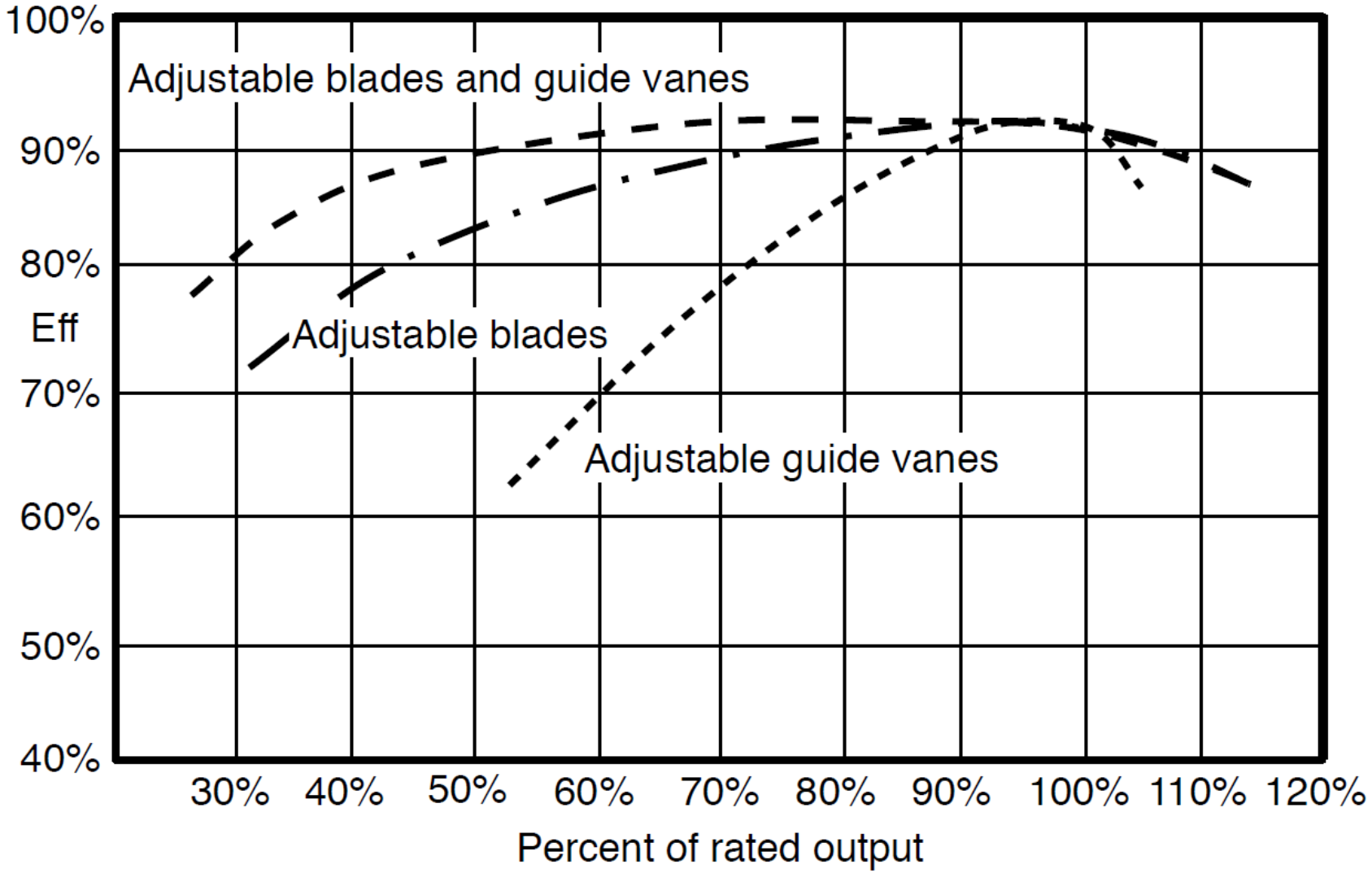
Unique Capabilities of Hydro

- Black start (start without off-site power)
  - Simple auxiliaries can be started by engine-generator set, or even batteries
- Energize dead lines
  - Salient pole rotor construction results in higher line charging limits
- Ride-through disturbances
  - Hydro turbine and generators relatively insensitive to frequency deviations

Unique Capabilities of Hydro

- Spinning Reserves
  - Capacity above current operating point due to max Efficiency below full capacity
- Regulation
  - Kaplans are best because of flat Efficiency curves
- Dec Reserve
  - Kaplans again are best
  - Short term storage utilized to prevent spill
- Inc Reserve

Efficient Hydro Operations
= Operating Reserves



Impacts to Hydro Units Due to Integrating Alternative Sources

- Increase in start stop cycles can accelerate aging of generator
  - Cyclical loading and heating
- More frequent maintenance may be needed to minimize effects
  - Possibly more wear in wicket gates, bearings, actuators, other moving parts

Hydro’s Role in the Future

- Continues to be very flexible resource in generation mix (provided there’s water)
- Capable of marketable ancillary service and reserves support
- Expanded need for pumped-storage hydro to “store” or shift timing of output from alternative variable energy sources

The Shift in Fundamentals

- Traditionally, energy has been stored in the fuel (i.e. the coal pile, the gas pipeline, the reservoir)
- Traditionally, energy has been delivered “just in time”
  - If more energy was needed, we just added more fuel.
- Now with intermittent renewables, the energy being created is only available for consumption when it is created
  - This has increased the value of storage

What other factors might be different in the future?

CONCLUSIONS

- Hydro generation provides easily controllable and flexible source of real and reactive power
- Fast startup and ramp rates
- Low operating costs
- Few moving parts means greater reliability
- Proven technology and a renewable fuel
- Lots of uncertainty but still well suited to meet the anticipated needs of the future.