NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Market Design Simulations with Variable Energy Resources (VERs)

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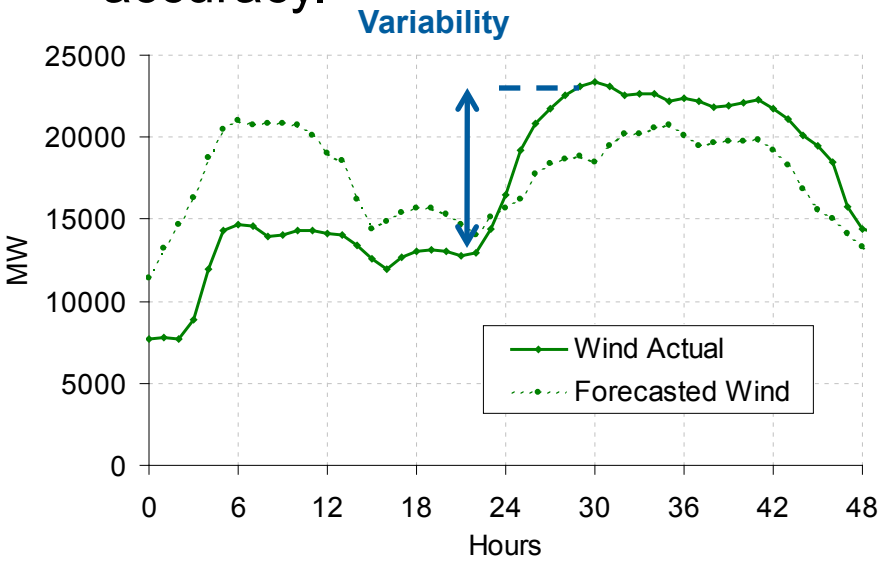
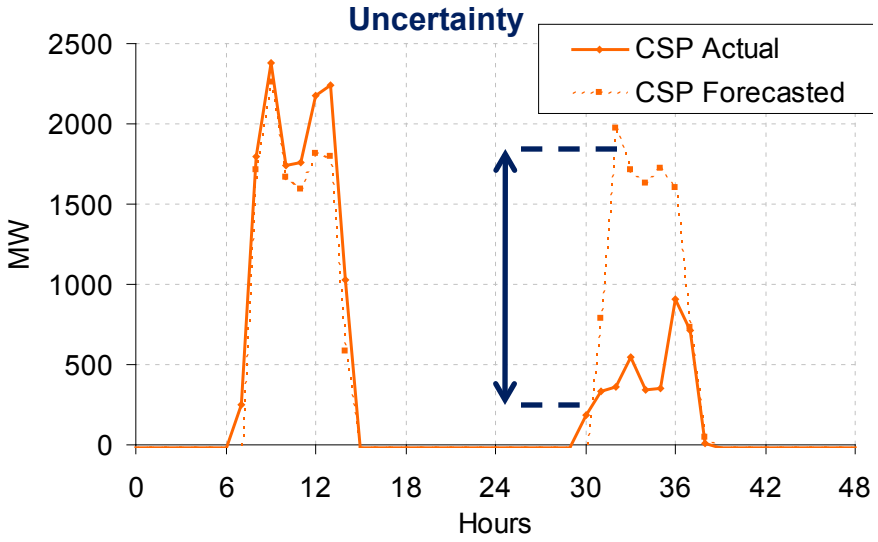
Variability and Uncertainty

Variability: Wind and solar generator outputs vary on different time scales as the intensity of their energy sources (wind and sun).

Uncertainty: Wind and solar generation cannot be predicted with perfect accuracy.





Variability: load varies throughout the day, conventional generation can often stray from schedules.

Uncertainty: Contingencies are unexpected, load forecast errors are unexpected.

Operating Reserves

- Why do we need operating reserves?
  - Real and reactive power balance (frequency and voltage control);
    - Focus on real power for this presentation.
  - Scenarios happen that we do not explicitly plan for. (e.g., uncertainty)
  - Things happen that we may expect but at time resolutions we are not prepared for. (e.g., variability)
- Question: What would unit commitment and economic dispatch look like with infinite computing power (and with infinite data)?
  - Stochastic programs capturing every possible scenario that can happen on the power system at the highest time resolution.
  - Think of a stochastic SCUC/ED program where every possible contingency, load, and variable generation outcome was analyzed, at 1 second intervals and updated/repeated every 1 second looking at extremely long optimization horizons.
  - Program inherently schedules all the reserves that are needed, no need to think about explicit requirements.
- We don't have infinite computing power. How can we walk back from that ideal scenario to what is feasible?

How to Model Uncertainty and Variability?

Type of Model	Mathematical	Explicit Secure	Full Optimal
Uncertainty	Operating reserve	Security constrained	Stochastic optimization
Variability	Operating reserve	Maximum movement ramp constrained	Faster interval resolution

Computation time and complexity.

Efficiency.

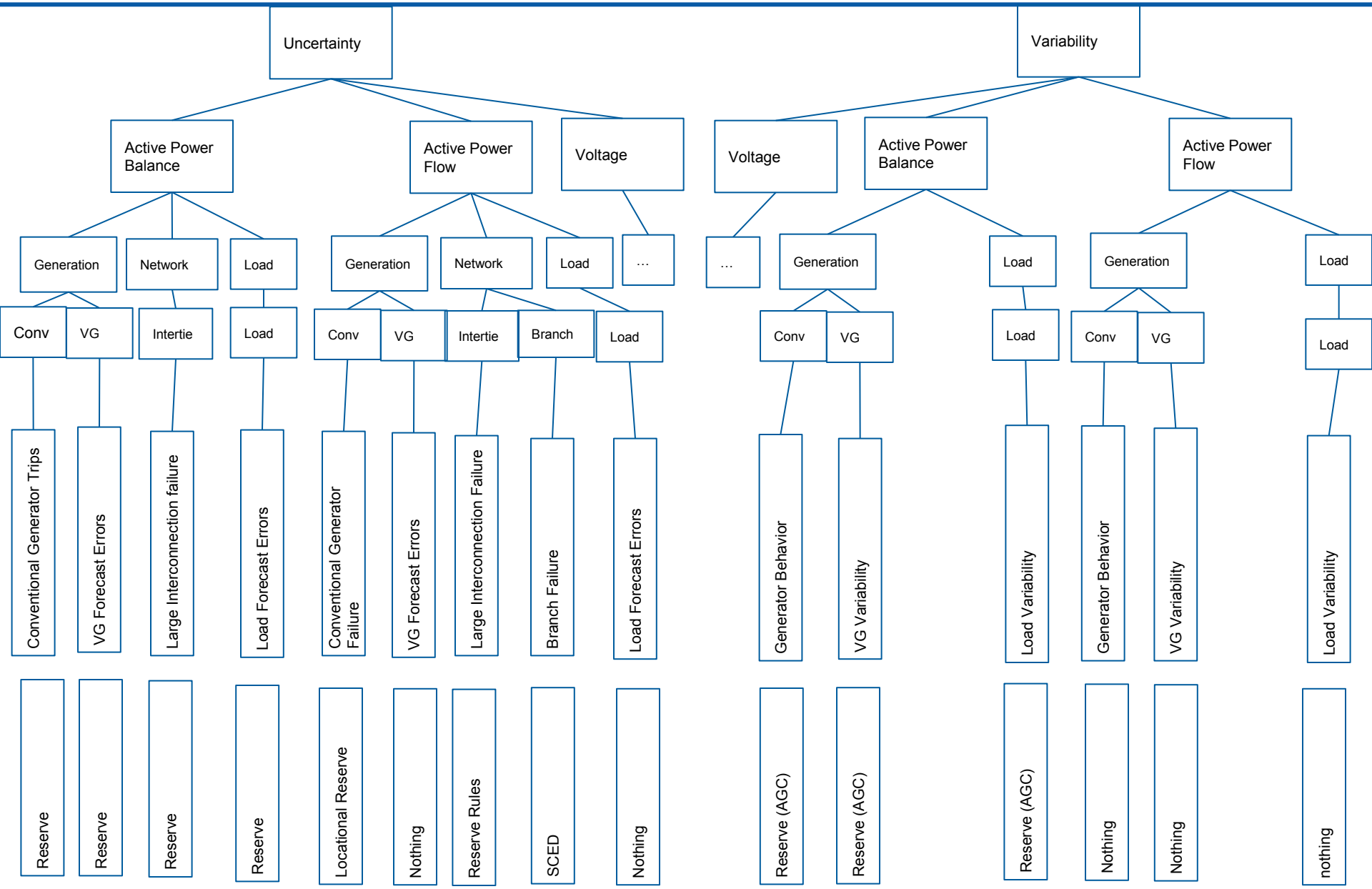
How to Model Uncertainty Variability?

Mathematical: Deterministic, Estimation, Currently based on rules of thumb, easiest to solve.

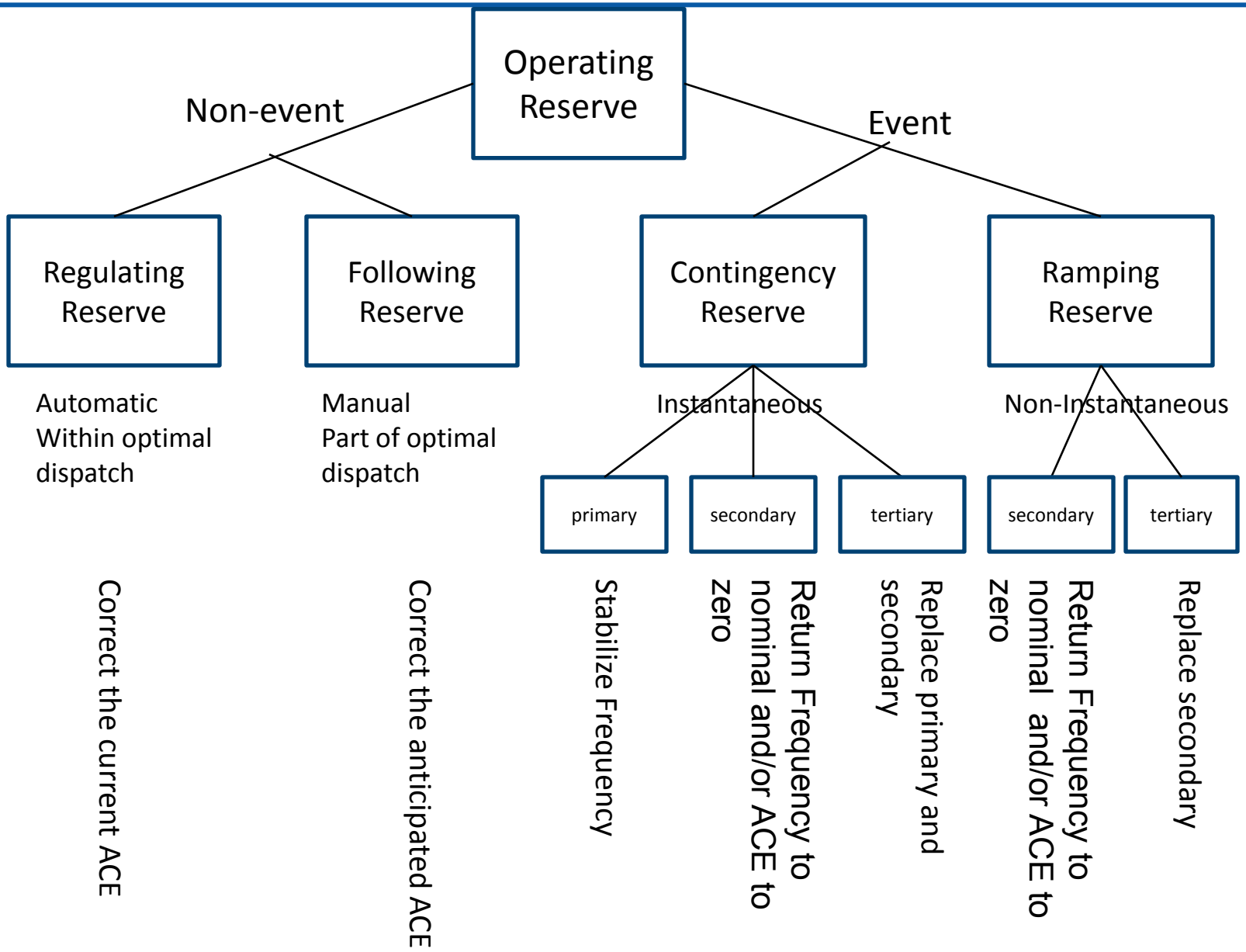
Explicit Secure: Reliable, not cost optimal, estimation of risk.

Optimal: Reliable, cost optimal, risk can be explicitly modeled with cost tradeoff or threshold (VOLL or max ENS), highest computational effort.

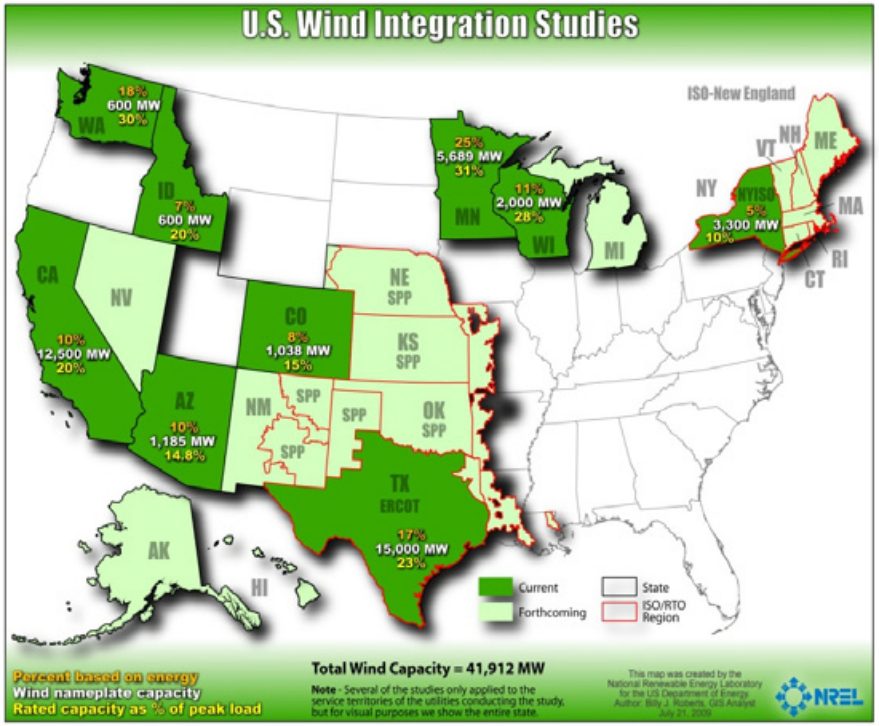
Where does each fit?

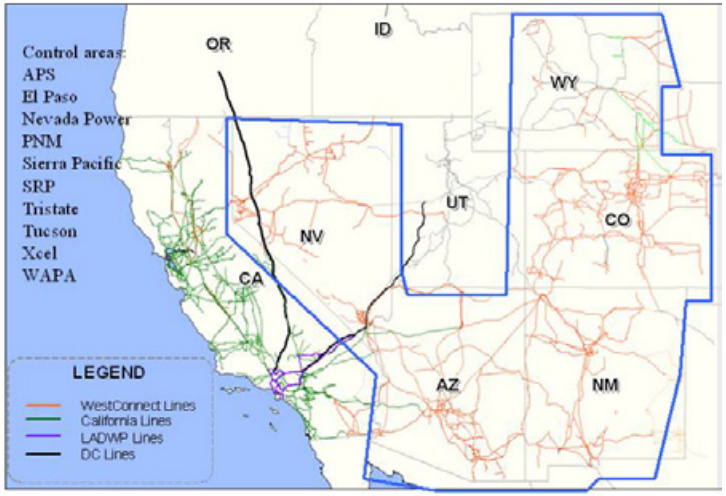

Uncertainty
Variability
Active Power Balance
Active Power Flow
Voltage
Voltage
Active Power Balance
Active Power Flow
Generation
Network
Load
Generation
Network
Load
…
…
Generation
Load
Generation
Load
Conv
VG
Intertie
Load
Conv
VG
Intertie
Branch
Load
Conv
VG
Load
Conv
VG
Load
Conventional Generator Trips
VG Forecast Errors
Large Interconnection failure
Load Forecast Errors
Conventional Generator Failure
VG Forecast Errors
Large Interconnection Failure
Branch Failure
Load Forecast Errors
Generator Behavior
VG Variability
Load Variability
Generator Behavior
VG Variability
Load Variability
Reserve
Reserve
Reserve
Reserve
Locational Reserve
Nothing
Reserve Rules
SCED
Nothing
Reserve (AGC)
Reserve (AGC)
Reserve (AGC)
Nothing
Nothing
nothing

Operating Reserve Categorization

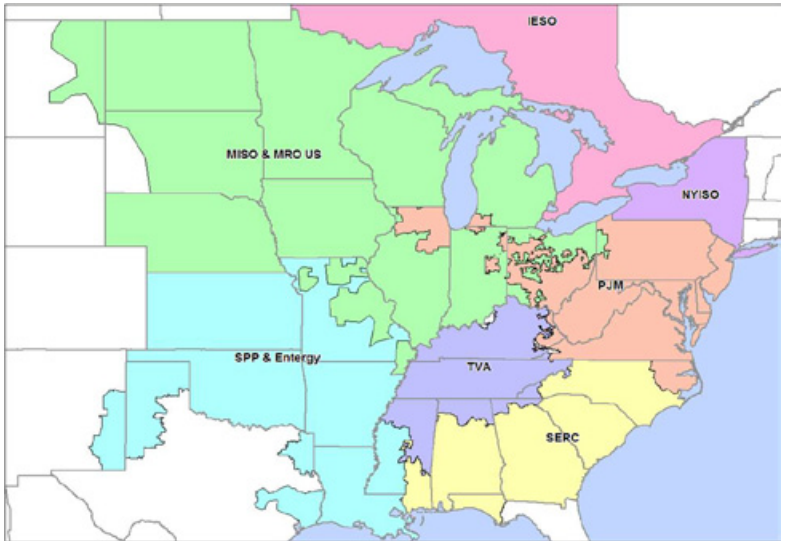


Wind Power Integration Studies





WWSIS



EWITS

Studying the Integration of VER

- These are generally considered planning studies;
- Generally study some of the following:
  - Capacity contribution of VER to system adequacy;
  - Integration costs of VER;
  - Operational cost impact;
  - Transmission flow impact;
  - Generation production impact;
  - Emission impact;
  - Reserve requirements (more on this).
- The common metric of comparison is the sum of hourly production costs for the year.

Studying the Integration of VER

- What these studies generally have not done:
  - Intra-hourly impact;
  - Do the reserves work;
  - Impact on control performance;
  - Impact on frequency;
  - Emission impact;
  - Reserve requirements (more on this).

Current SS Modeling Status

- Hourly resolution for the most part:
  - All ISOs in the U.S. run 5-minute economic dispatch;
  - Impacts of following ACE.
- 1-stage or 2-stage:
  - Miss impact of multiple real-time forecast updates.
- Flexibility toward different market structures;
- No operator action or reserve deployment:
  - Reserves are held but not deployed.

FESTIV

- Flexible Energy Scheduling Tool for Integration of VG/Variable Generation (FESTIV);
- SCUC, SCED, and AGC sub-models;
- Models at high resolution:
  - Typically AGC, the highest resolution at 2-6 seconds;
  - All metrics are calculated at this resolution: ACE, Line flow exceedance, production costs.
- Models multiple time frames with communication between sub-models:
  - Multiple chances of forecast error and forecast correction;
  - Interval length, interval update frequency, and optimization horizon configurable.

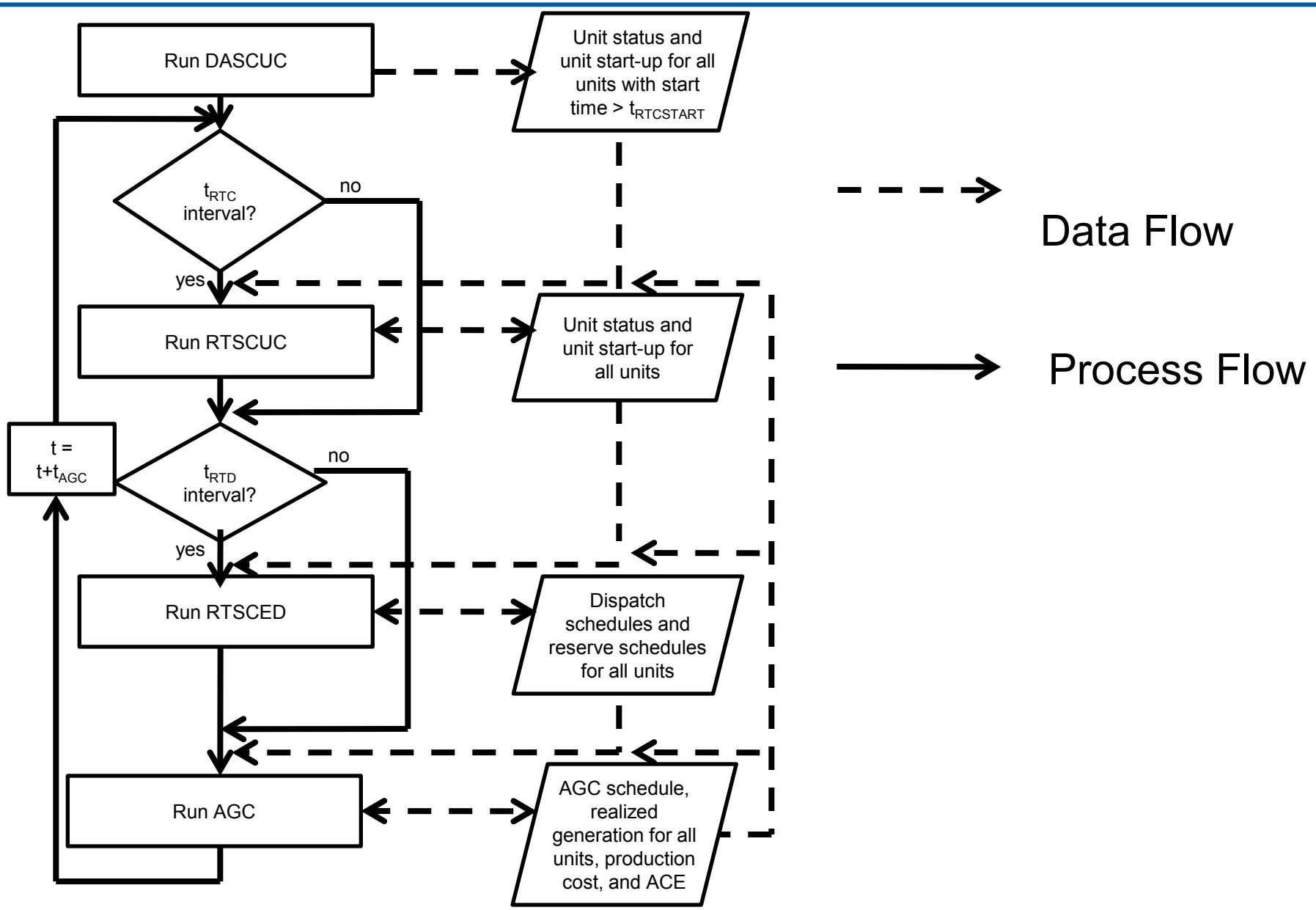
FESTIV

- Flexible operating structures:
  - Dispatch frequency, how reserves are used, stochastic vs. deterministic, AGC mode of operation, etc.
- Deployment of operating reserves modeled:
  - User defined meaning of operating reserve;
  - Reserves are held in one sub-model and used in another.

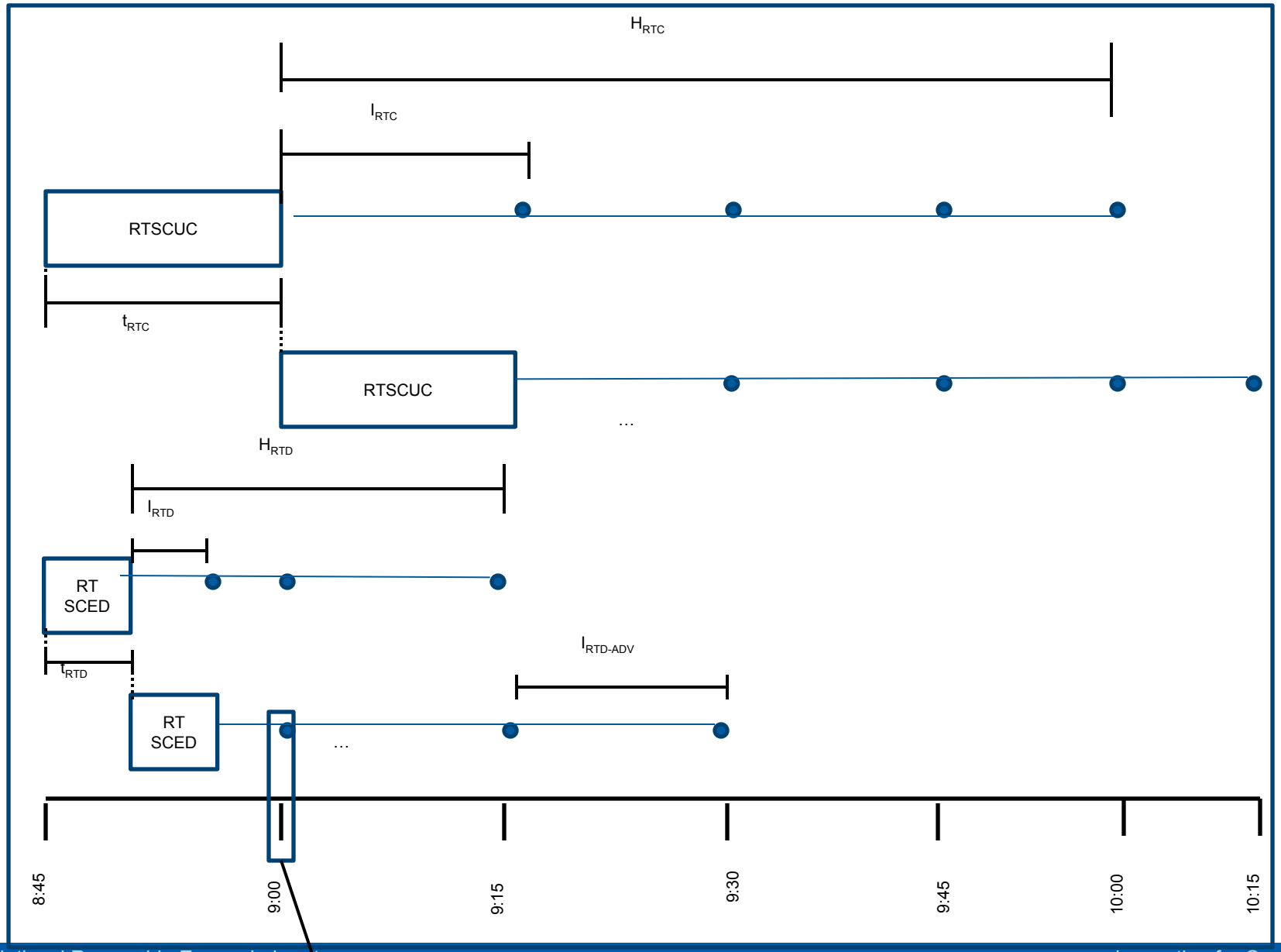
Sub-model Descriptions

- SCUC: unit commitment subject to system, generator, and transmission constraints. (MILP)
- SCED: economic dispatch subject to system, generator, and transmission constraints. (LP)
- AGC: generation control based on ramp rates and ACE (rule-based);
- 4 AGC modes: Blind, Fast, Smooth, Lazy.
- RPU: reserve pick-up, unit commitment triggered by event or large ACE/transmission flow exceedance.

FESTIV Flow Diagram

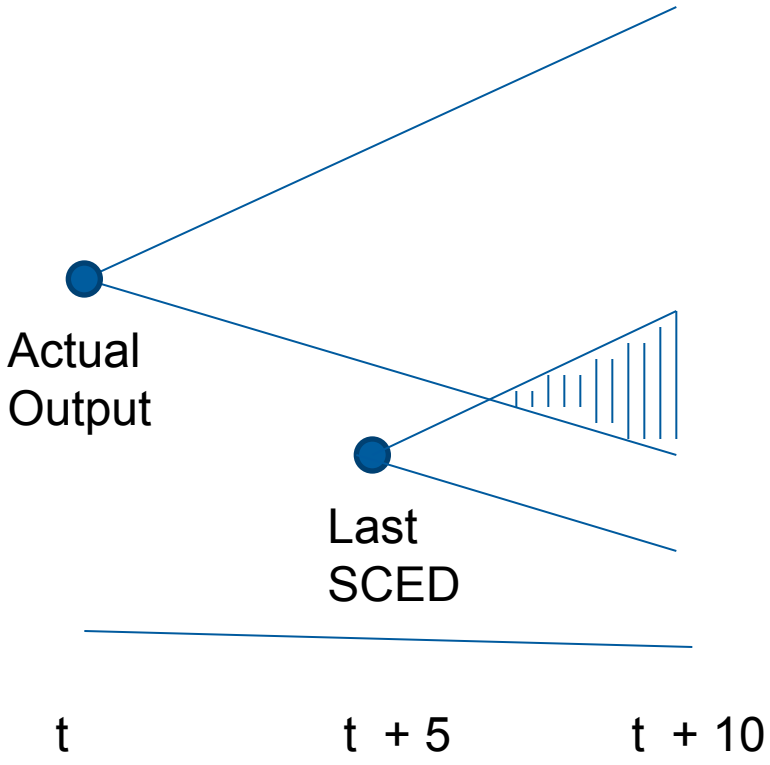


RT SCUC/SCED Parameters



Ramp Constraints

Ramp Constraints that model feasibility if the AGC gives a different direction than the SCED or if the generator is not following schedule.

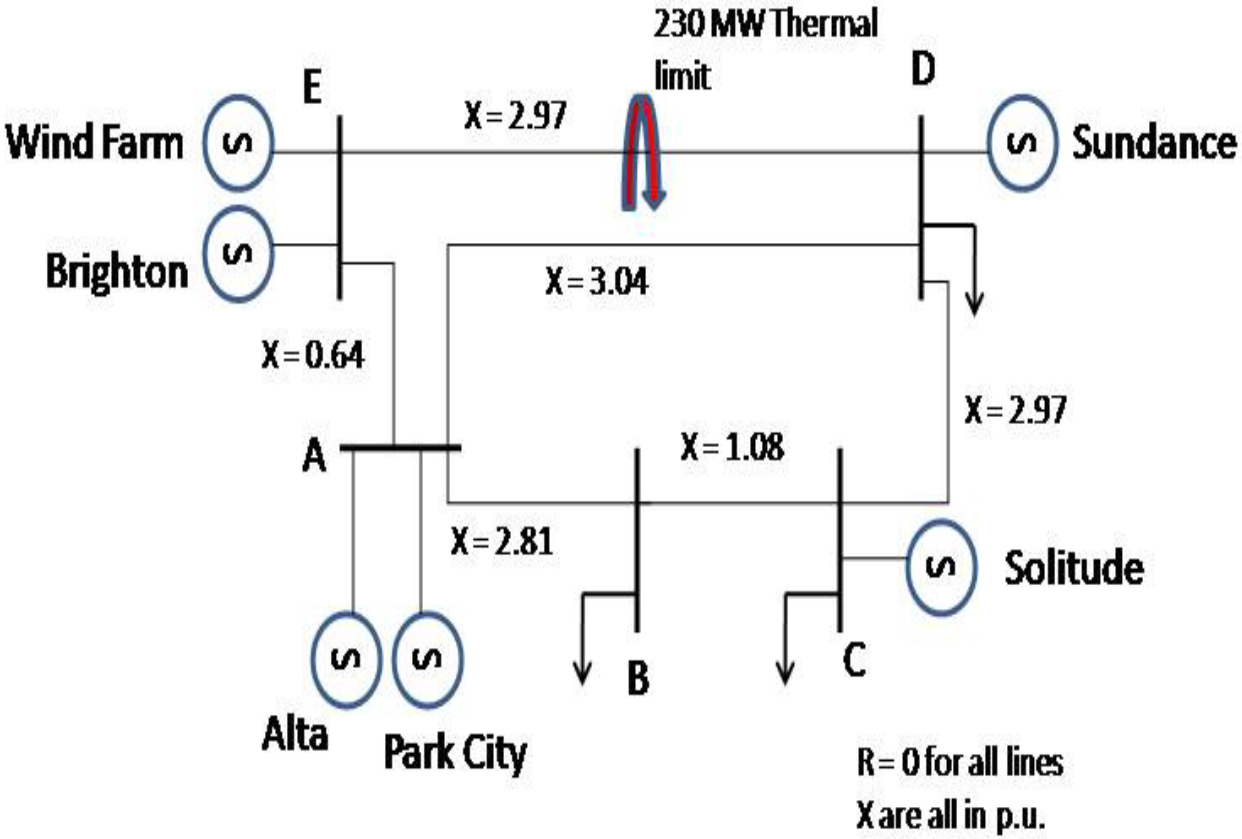


Metrics

- The model focuses on short-term reliability impacts (i.e. 1 day);
- It can be used to compare inputs (e.g. VG penetrations) as well as scheduling strategies (e.g. dispatch frequency);
- Metrics:
  - Extreme imbalances - CPS2 violations (with configurable L10 and CPS interval);
  - Total imbalances - Absolute ACE Energy (AACEE);
  - Variability of imbalances – $\sigma_{ACE;}$
  - Similar metrics can be made for line flow, voltage, etc.
    - e.g. Absolute Line Flow Exceedance in Energy (ALFEE).

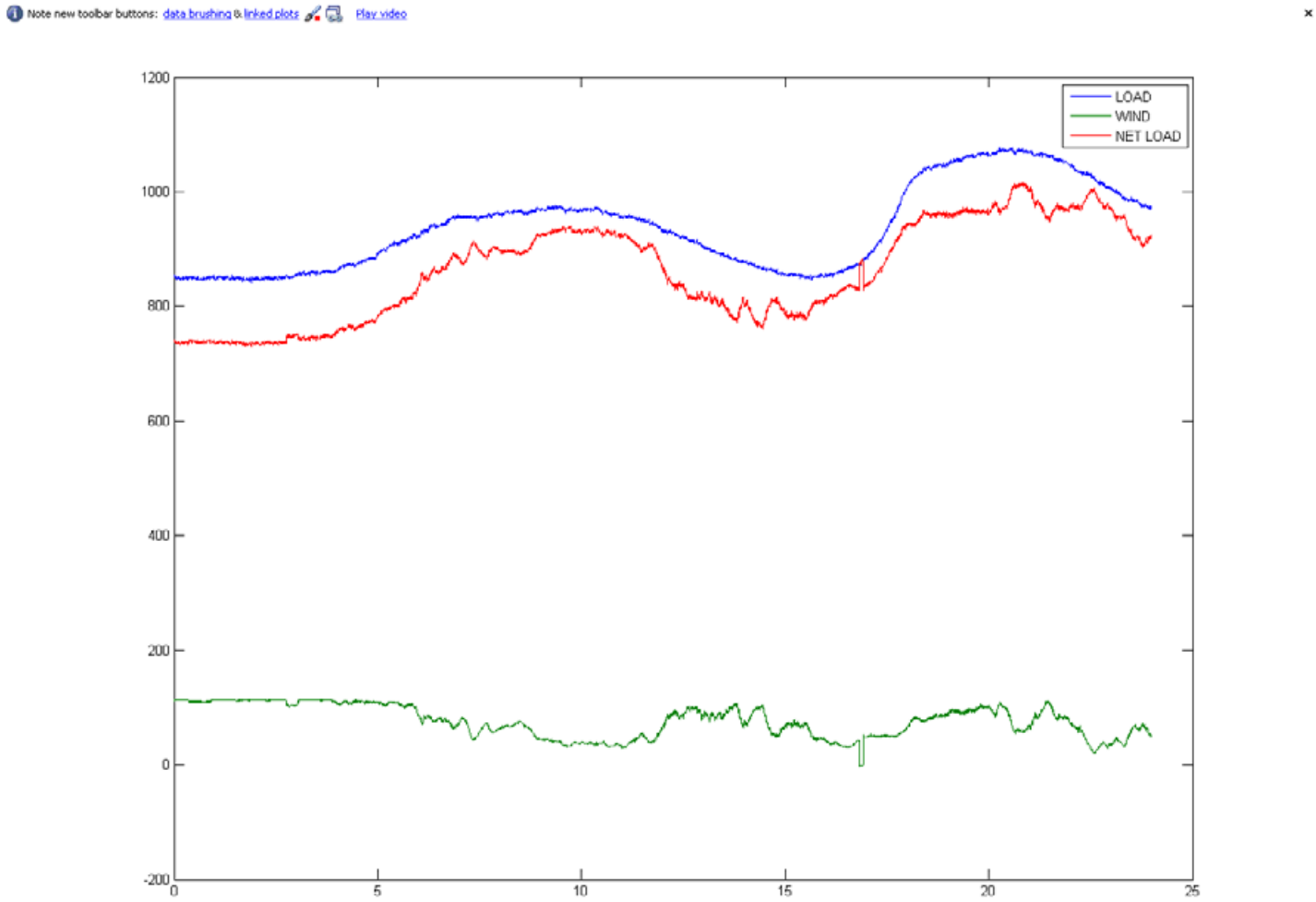
Wind Integration Case Study

PJM 5-bus

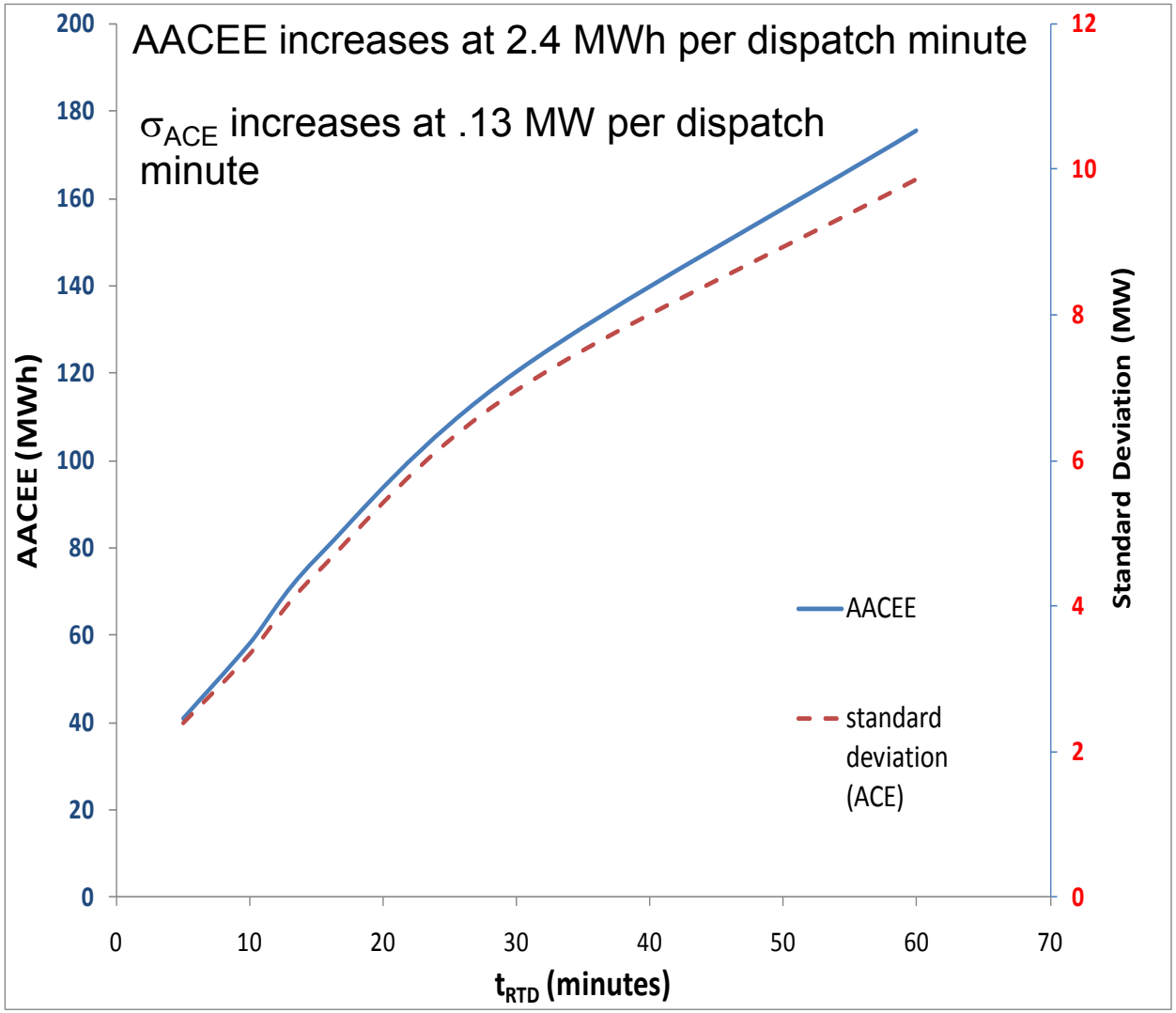

230 MW Thermal limit
E
D
Wind Farm
X = 2.97
Sundance
Brighton
X = 3.04
X = 0.64
X = 2.97
A
X = 1.08
X = 2.81
Solitude
B
C
Alta
Park City
R = 0 for all lines
X are all in p.u.

Load and Wind

Every simulation uses this data

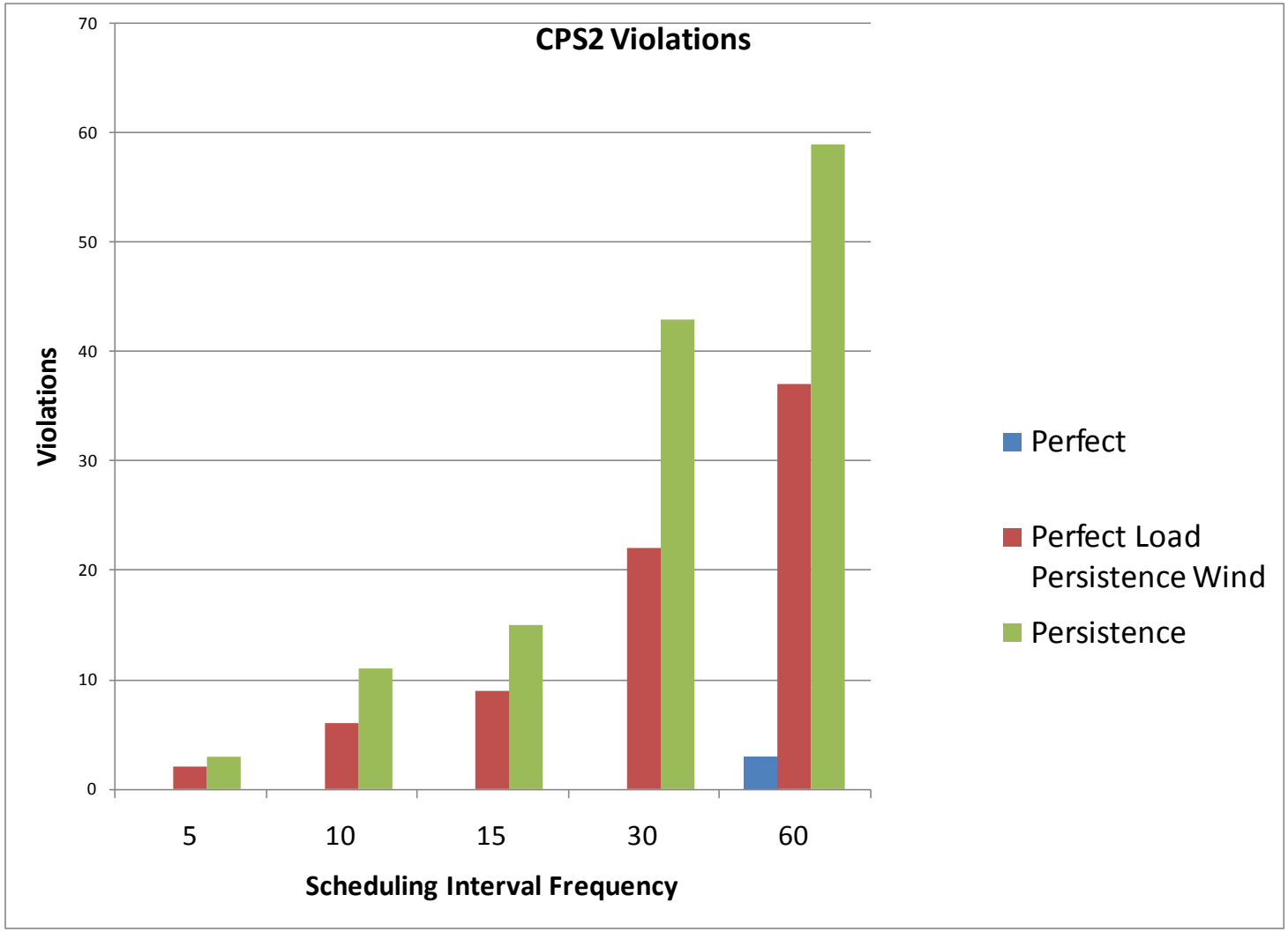


Impact of Variability (Blind AGC)



Impact of Uncertainty (Blind AGC)

5-minute SCED would have 288 SCED forecasts



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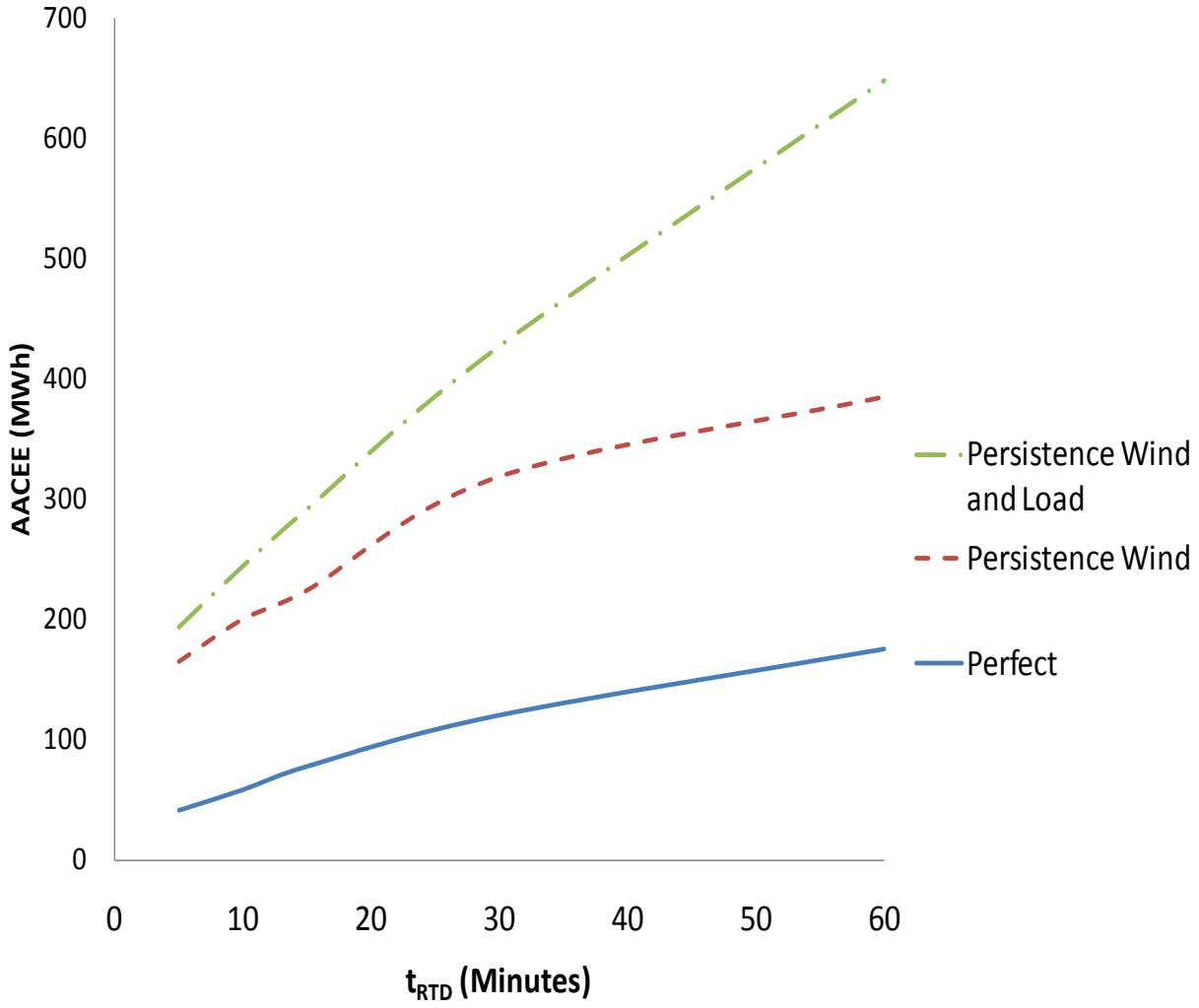
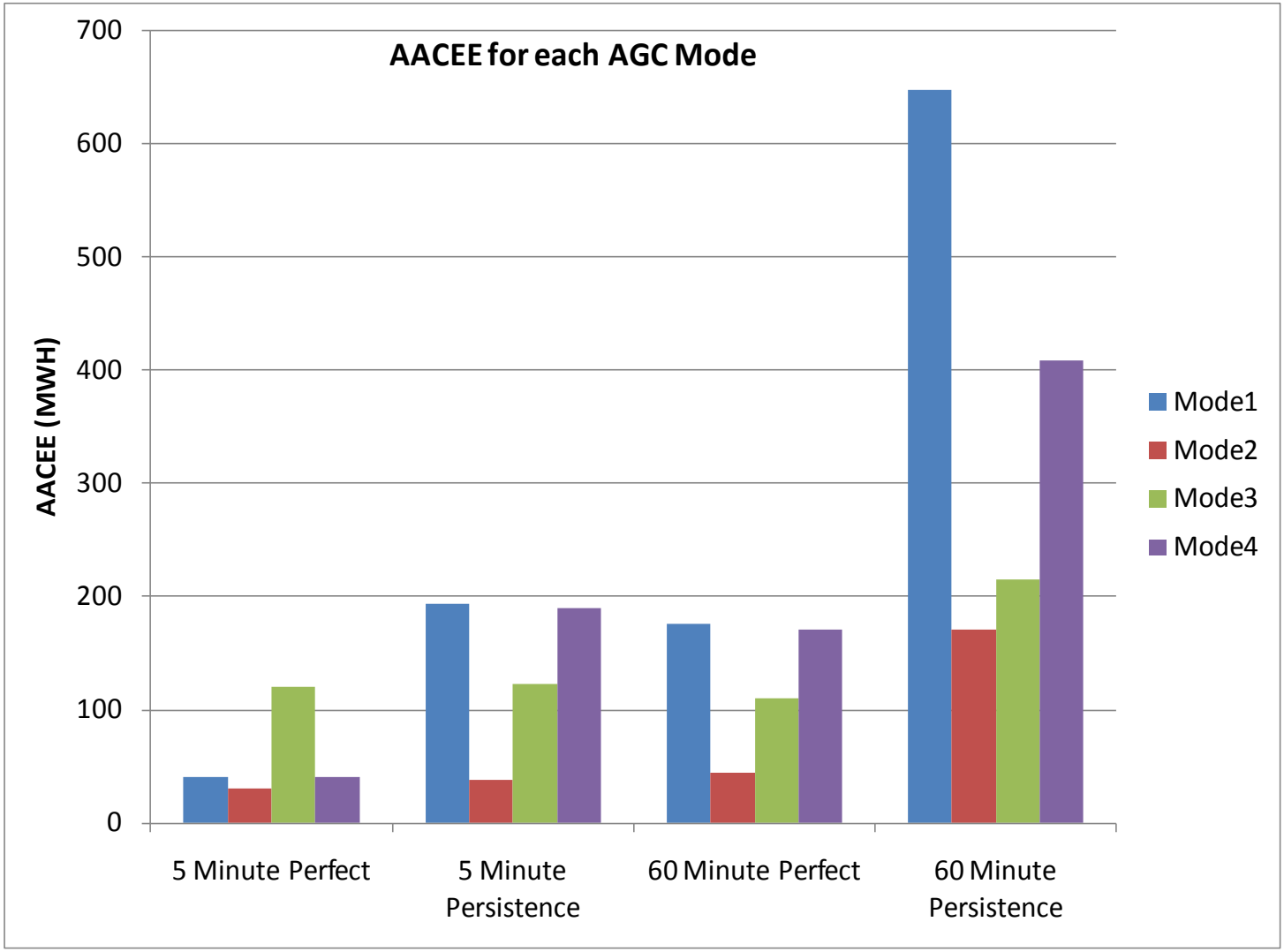


Impact of V and U with AGC Operation

1:Blind
2:Fast
3:Smooth
4:Lazy



Where to Next?

- How can this model be used to understand VER impact on different categories of operating reserve?
- How can this model be used to understand how sources of variability and sources of uncertainty should be modeled?
  - Mathematical (reserve) vs. explicit secure vs. full optimal.
- What different market strategies can be tested to see what works best for high penetration of VER?
- What are the true reliability (imbalance) impacts?

Questions

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