MIP Based System Flexible Capacity Requirements Determination

Technical Conference:

Increasing Real-Time and Day-Ahead Market Efficiency through Improved Software

Federal Energy Regulatory Commission

Washington DC, June 25, 2013

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Outline

- Problem Definition & Current Needs
- Anatomy of a “Duck”
- Software Capability Requirements
- Expected Flexibility Deficiency Definition
- Problem Formulation
- Transmission Modeling
- Flexibility Mitigation Strategies
- Monte Carlo Simulation Modeling
- Modeling Simulation Results & Metrics
- Conclusions

The Problem

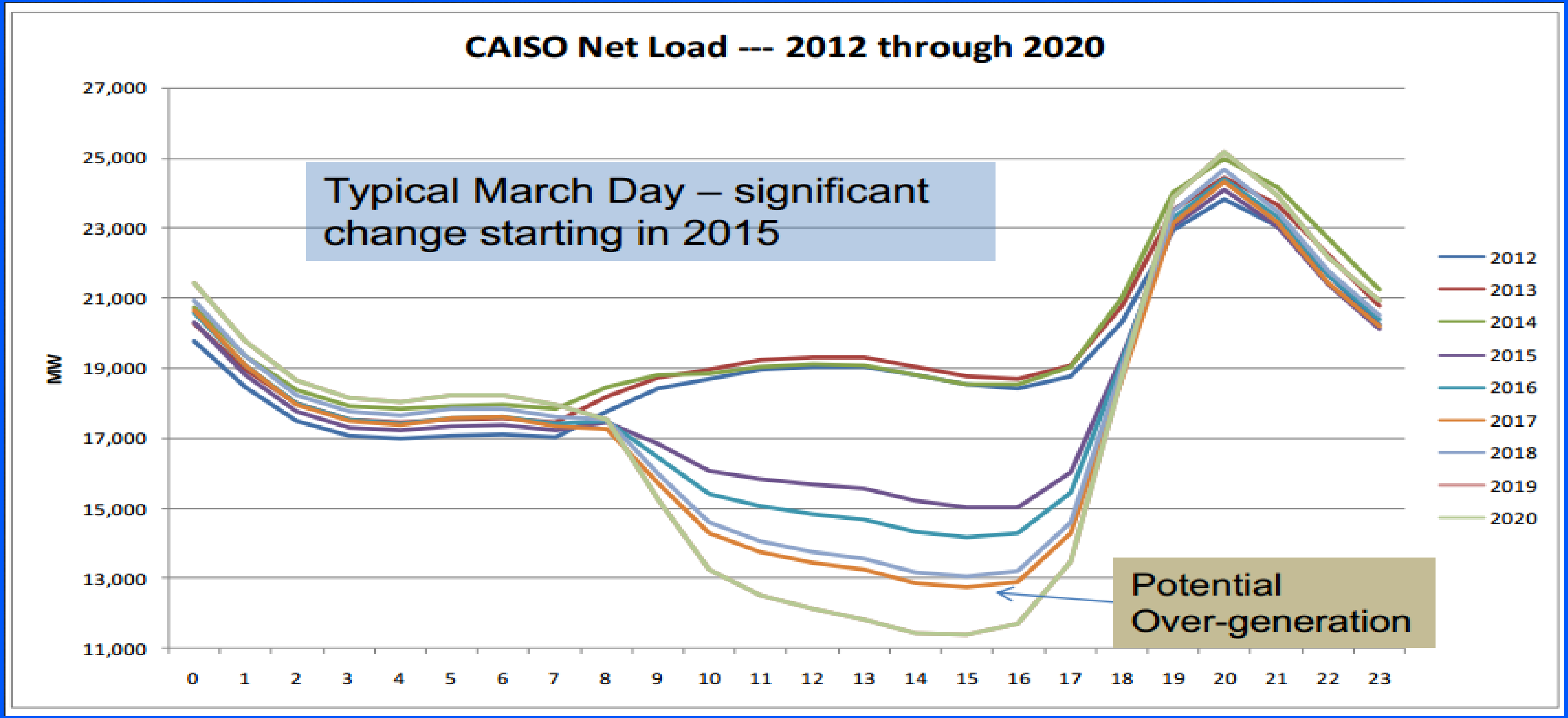
- Major changes are now occurring on the supply-side of the power balance equation
  - The supply-profile of new technology is more complex – intermittent with less predictability
  - Changes are both politically and economically driven
- Reliability is still JOB #1
  - With economics playing a larger-role than ever before
- How can entities, like ISOs, account for reliable supply that is "optimally" committed?
- How can "Flexibility" be determined over various time horizons
  - Next day or out 10-years?

The Problem - Continued

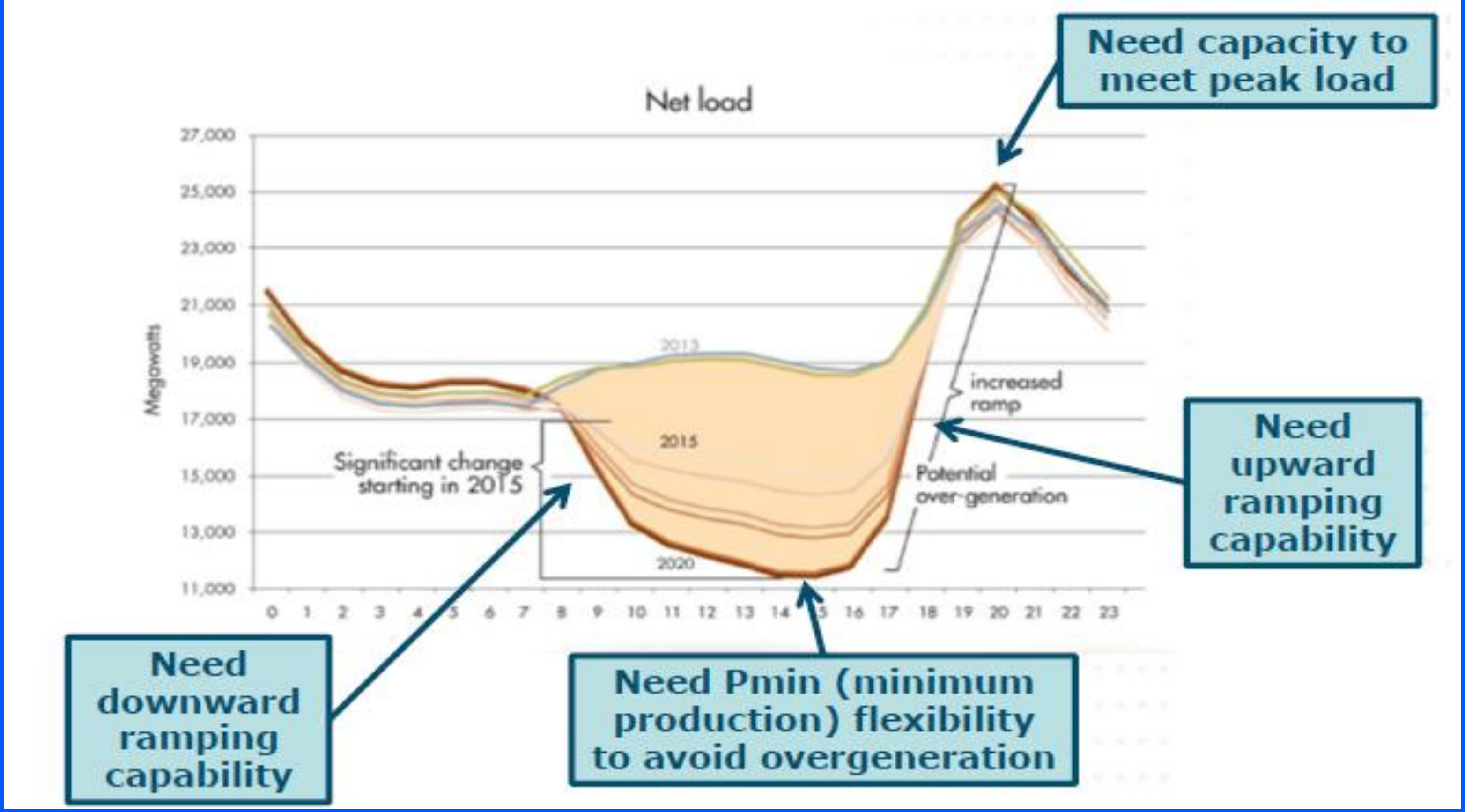
- Load is stochastic, variable and uncertain
  - Often characterized as "1-in-5" or "1-in-10"
  - Subject to forecast error
- Renewable output is also stochastic, variable and uncertain
- Supplies can also be stochastic
  - Hydro endowment varies from year to year
  - Generator forced outages are random
- Need to know size, probability and duration of any shortfalls in both capacity and ramping capability

The Problem - Continued

- The penetration of renewables will continue to increase as more states adopt Renewable Portfolio Standards (RPS) and continue to enforce more stringent targets



Potential flexibility challenges: Anatomy of a 'Duck'

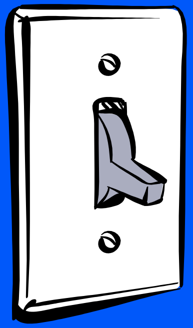


Software Capability Requirements

- Determine the optimal “mix” of resources to meet flexible response over various time horizons
- Ensure reliable system operation
  - Capacity Requirements – according to traditional metrics for capacity planning
  - Flexibility Requirements – accounting for the limitations of the fleet in time sequential operations
- Solution should result in:
  - The least-cost array of portfolio and/or operational changes that satisfy all the above objectives
  - The relative value of resource types over multiple time scales, e.g. energy storage can provide fast ramping response over a short-time period, while CCGTs provide load-following capacity and ramping capabilities

Need to Allow Multiple Solution Types

Flexibility violations could be solved by either:



Flipping a switch

Operational changes mitigate flexibility shortfalls

- ❑ Reserve scheduling, "pre-curtailment" of renewables

Grabbing a shovel

New construction meets both capacity and flexibility requirements

- ❑ Fast, expensive resources vs. cheaper, slower ones

A useful model can quantify the trade-offs between these options

Expected Flexibility Deficiency Definition

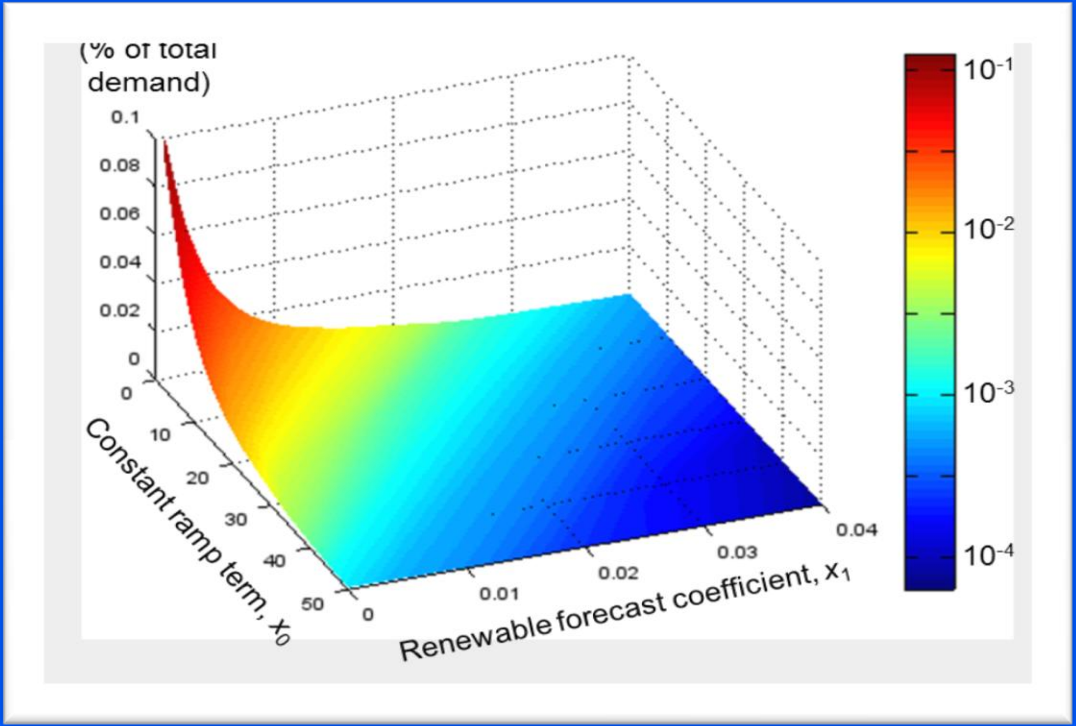
- Incorporating Flexibility Requirements
  - Introduction of an Expected Flexibility Deficiency (EFD) function
    - To determine the anticipated amount of un-served energy caused by a lack of flexibility in the generating fleet
    - The EFD is a function of the ramp and reserve policies in any given region
  - The EFD is computed <u>before</u> executing the MIP-Based Unit Commitment
    - It is derived from historical system load/renewable data, as well as the forecasts associated with a given unit commitment window
  - Ramp and reserve policies must be defined, in order to determine the EFD

Expected Flexibility Deficiency Definition

- Sample EFD calculation:
  - An example of a ramp policy is that the average ramp of the system is equal to the forecasted ramp plus some constant, x [MW/min].
  - An example reserve policy might be that y% of the forecasted net load is held in reserves
  - For these policy formulations, the EFD surface is built as a function of x and y
  - Note that the x and y variables are optimized within the MIP-Based Unit Commitment problem

Expected Flexibility Deficiency Definition

- Sample EFD calculation



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Day-Ahead Market Formulation: Mixed Integer Linear Programming Objective Function

minimize { overall variable as bid costs + overall fixed costs }

Fixed cost coefficients

Next slide

$$\min \sum_{i,t} Fuel_i(A_i n_{it} + B_i x_{it}) + C^{hydro} x_t^{hydro} + C^{import} x_t^{import} + \ldots$$

i: generation unit

t: time (hour)

Unit on/off (binary variable)

Unit MW output (continuous variable)

System hydro MW output (aggregated, continuous)

Net MW imports (continuous)

Day-Ahead Market Formulation: Additional Objective Function Terms…

Unserved energy (undergen) penalty

Unserved Spinning Reserve penalty

Unserved Reg Down penalty

$$\ldots + C^{\overline{u}}\overline{u}_t + C^{\underline{u}}\underline{u}_t + C^{res\_u} sp\_res\_u_t + Mreg\_pen\_up_t + Mreg\_pen\_dn_t$$

Overgen penalty

Unserved Reg Up penalty

Day-Ahead Market Formulation: Standard Constraint Equations

- Equations are used to enforce numerous equality and inequality constraints, such as:
  - Energy Balance (generation = load)
  - Unit output limits
  - Spinning Reserve Requirements
  - Regulation Reserve Requirements
  - Ramp rate limits (units, hydro, imports)
  - Unit temporal constraints (min up, min down, min run, …)
  - Hydro, Imports, and Pumped Hydro Energy Limits

Add Expected Flexibility Deficiency (EFD) and Renewable Curtailment to the MIP DA Market Formulation

- Additional Objective Function components

Penalty factors ($/MWh)

$$\ldots + \sum_{j \in J} C_j^c c_{jt} + C^{EFD+}\left(efd_t^+\right) + C^{EFD-}\left(efd_t^-\right)$$

J is set of renewable curtailment types

Curtailment of renewable type j, in time period t

Expected flexibility deficiency (MWh) in time period t (upward and downward directions)

Network Constraint Modelling

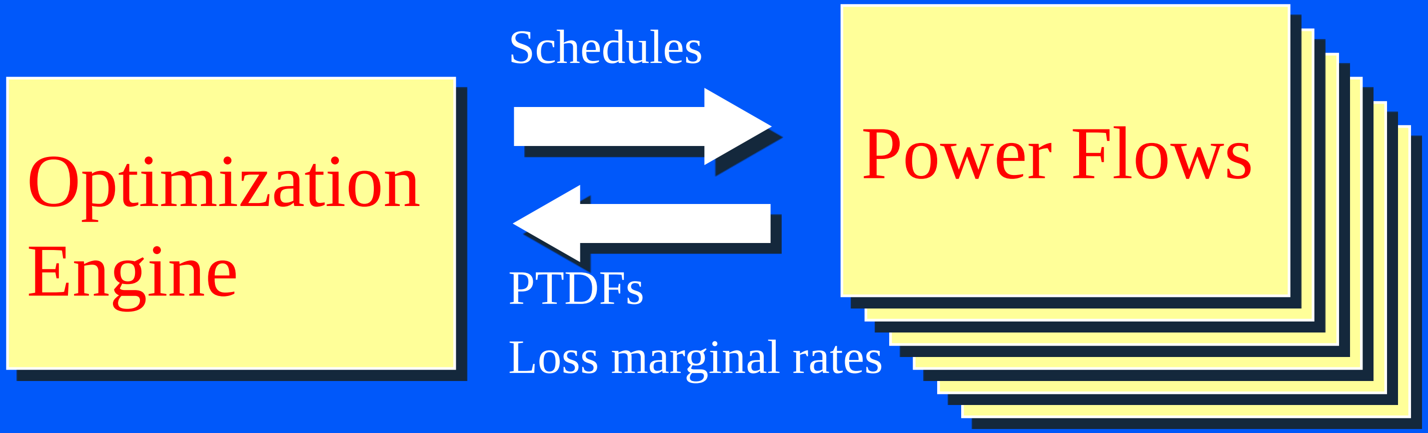
- Optionally, the network constraints may be included in the simulation
- Monte-Carlo dispatch model iterates with full power flow model (AC or DC) to enforce network constraints, including contingency constraints
- Zonal model may also be used to enforce flow constraints

Flexibility Mitigation Strategies Modelling

- Relative cost penalties impose flexibility mitigation strategy "loading order"
- Costs will depend on specific system and applicable policies
- Assuming that all renewables must be delivered is equivalent to placing an infinite penalty on curtailment and over-generation

Solution Method

- Separate power flows for each time interval
- Iterate with optimization engine that has a single power balance constraint and the active inequality constraints for each time interval



MIP-Based Flexible UC Results

- Flexibility Constraint Results
- Flexibility violations that may occur, because the penalty cost of these violations is less than the commitment of additional resources
- Optimal levels of reserves and ramp-rate capability based on ramp/reserve policy
- Economic “pre-curtailment” of renewables that avoid flexibility violations and/or commitment of excessive fast-ramping generation

Monte Carlo Simulation Modelling

We need an Expanded Monte-Carlo Simulation

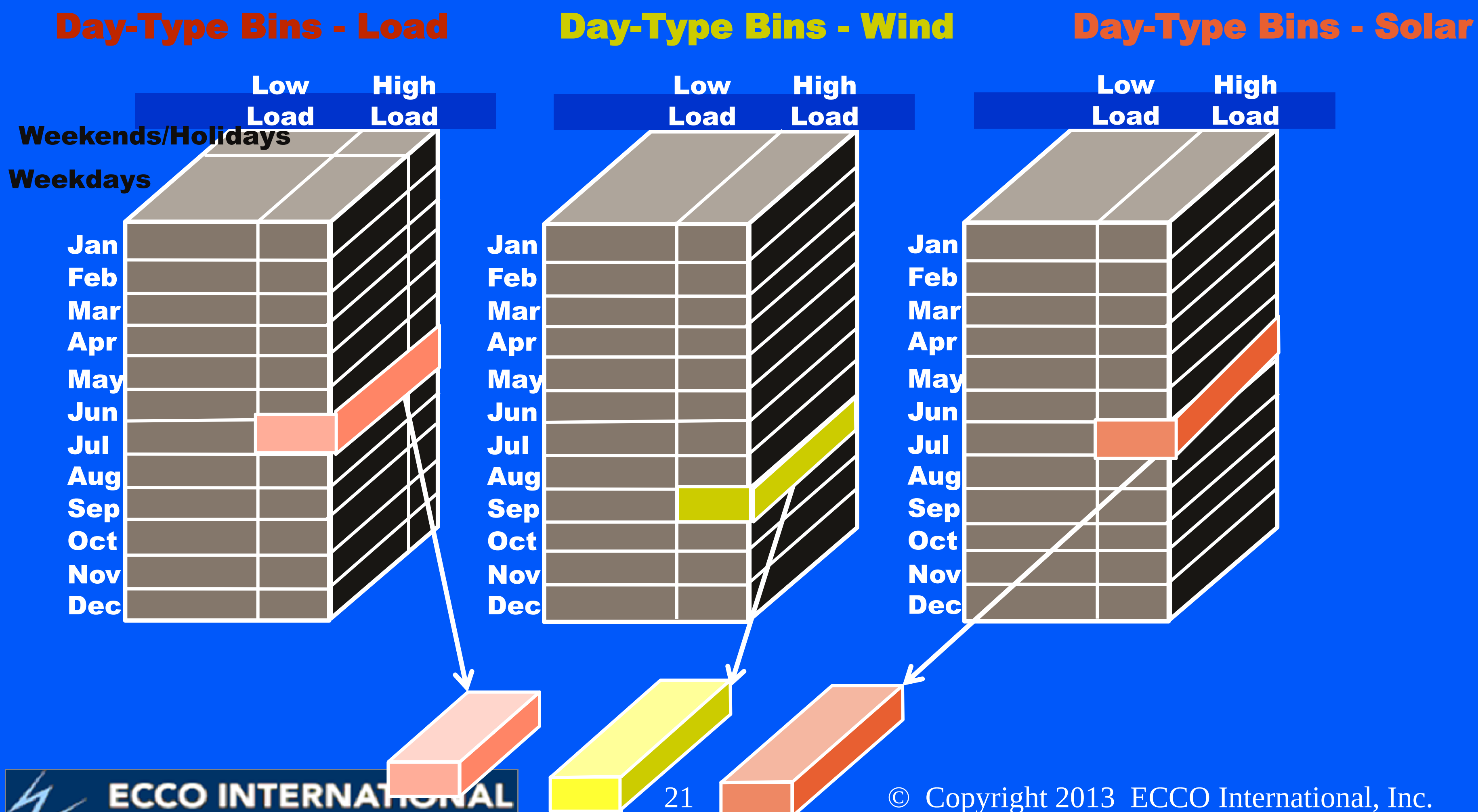
- Unit Outages are simulated using random draws of outages based on unit MTTF and MTTR

Other profiles:

- Load profiles
- Wind profiles
- Solar profiles

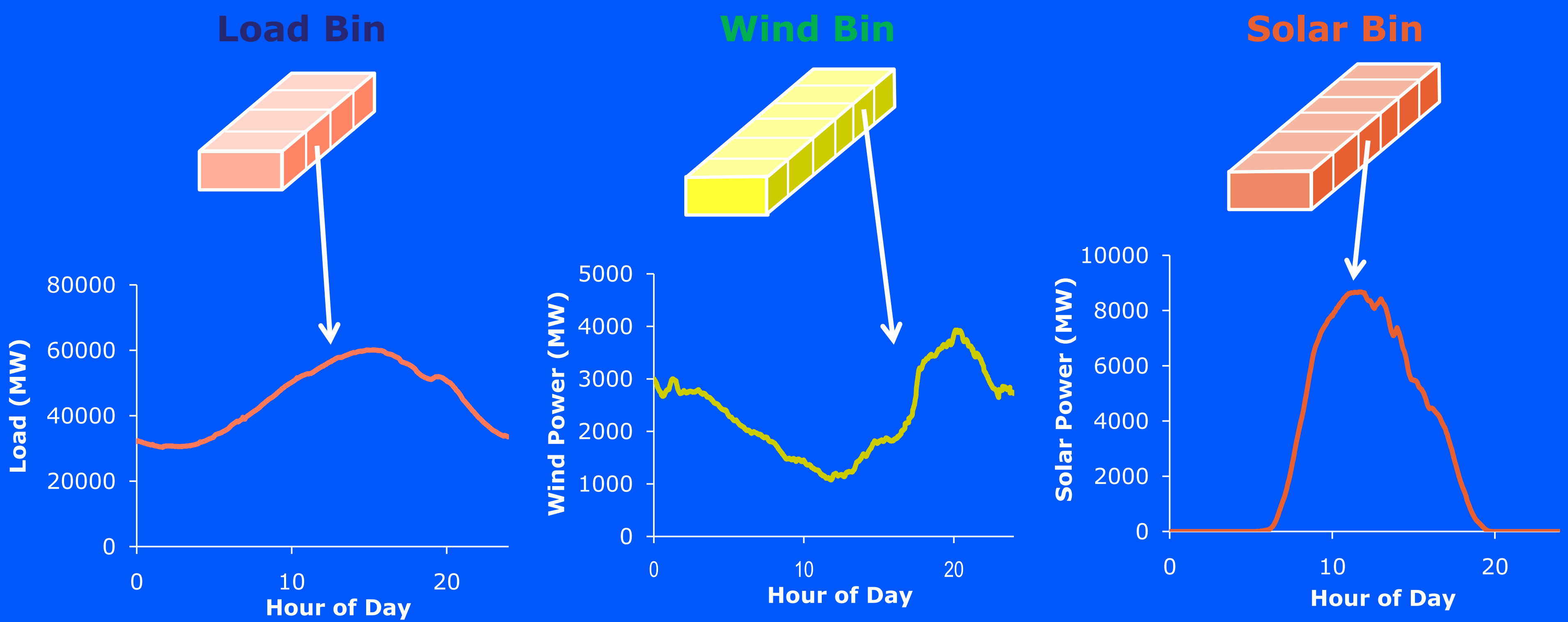
are all selected by Monte-Carlo draws from selected bins

Example Draw:
High Load Weekday in August



Example Draw: High Load Weekday in August

Within each bin, choose each (load, wind, and solar) daily profile randomly, and independent of other daily profiles



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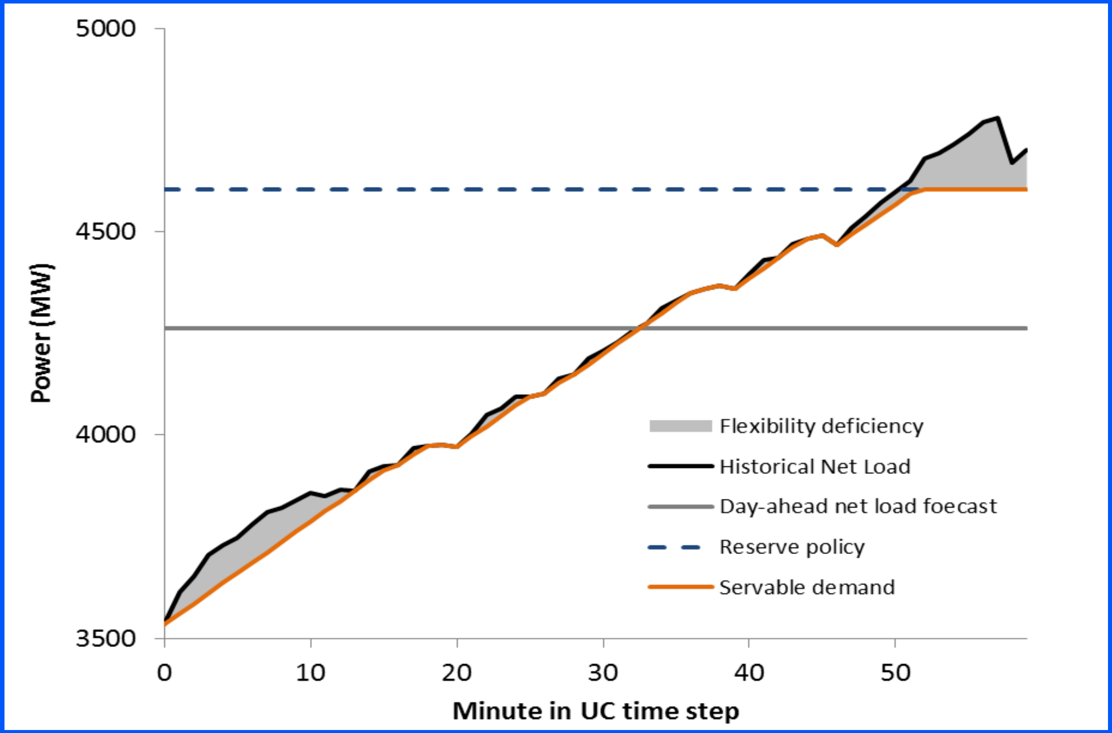
Three Market Simulations

- Day ahead, hour ahead and real-time markets are simulated sequentially
- Load forecast inaccuracy of the day ahead market vs hour ahead is also simulated via Monte-Carlo draws
- In hour ahead simulation only short start units may be committed
- In real-time simulation, only units that were on-line in the HA market may be re-dispatched

Flexible Deficiencies

- Computing Flexible Deficiencies using Historical Net Load Data



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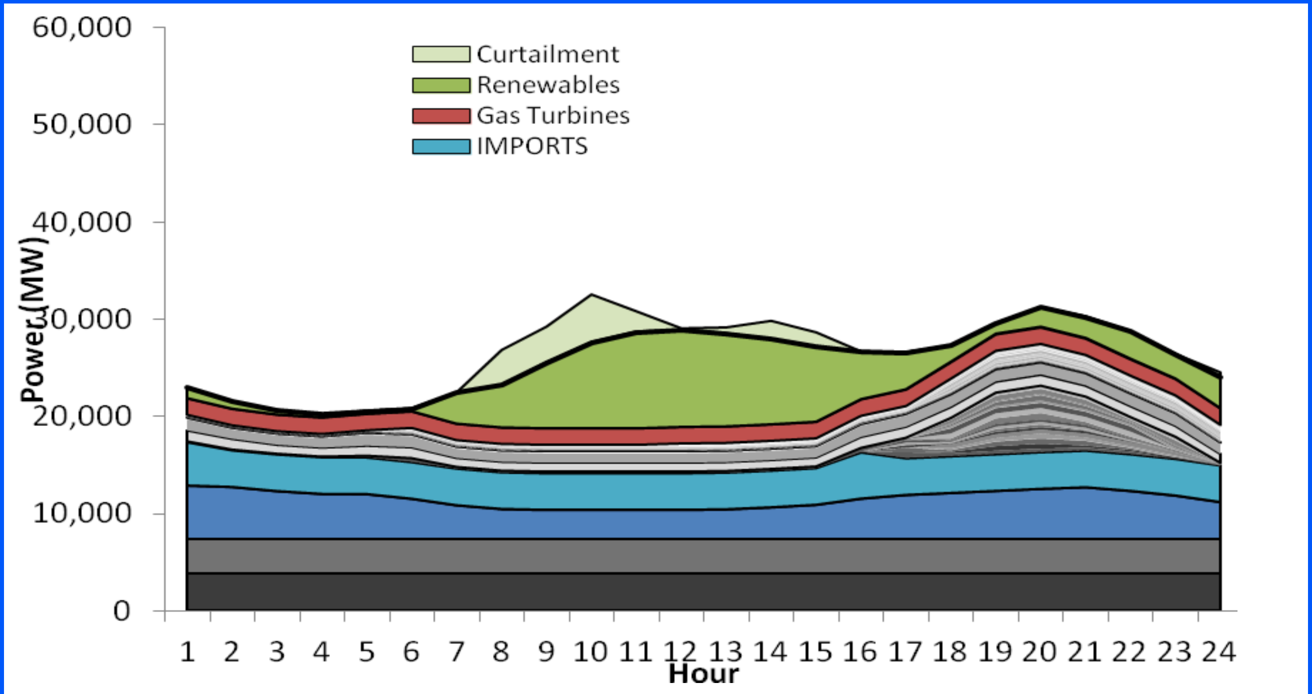
RES Curtailment

- The load forecast is plotted as the heavy black line, and the curtailment of renewables is shown above that in green



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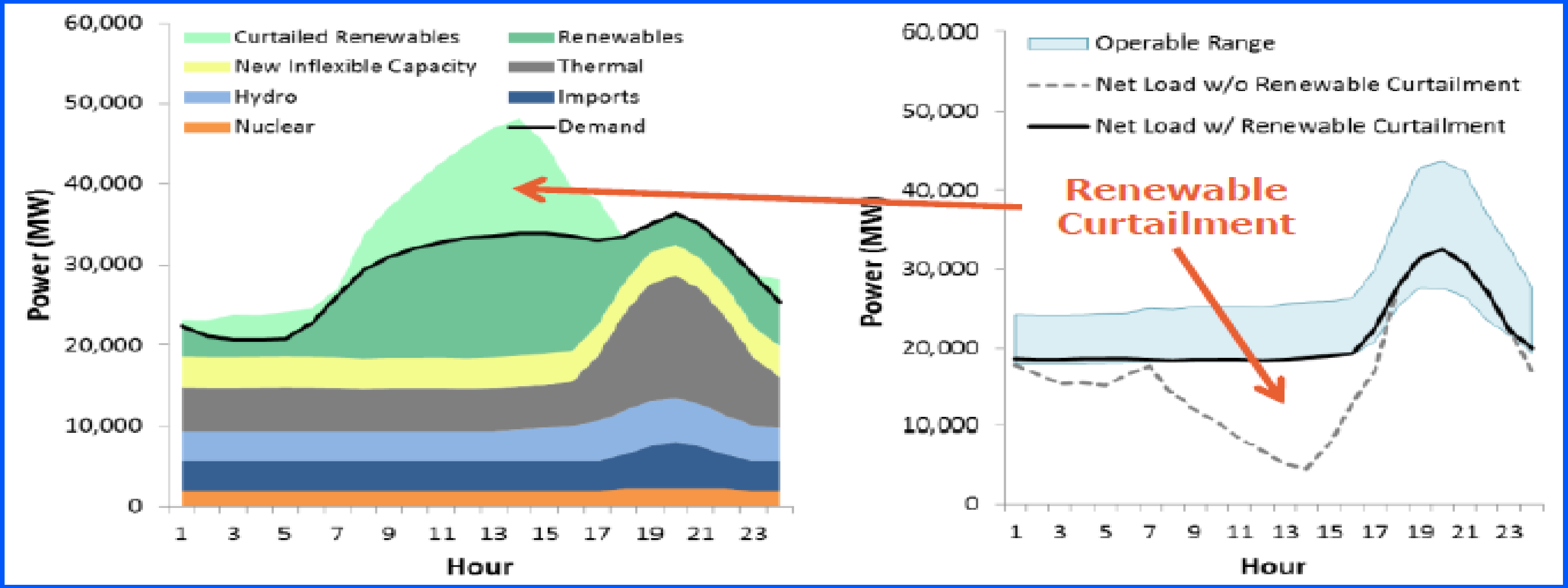
Curtailment of RES Output Could Play a Significant Role



- Scheduled curtailment of renewables can help position conventional resources to meet ramping requirements
- How does the cost of curtailment compare to the cost of procuring new flexible resources?

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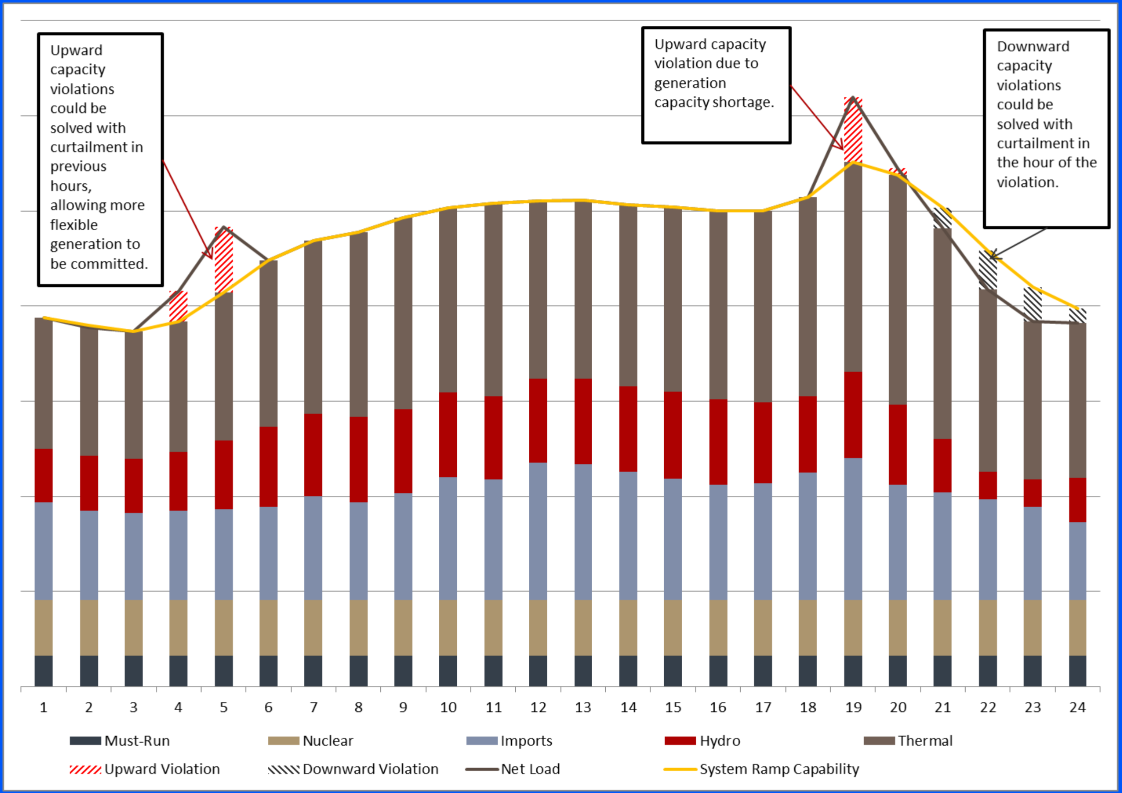
Proposed Metrics and Results

- Resource Adequacy (RA) metrics
  - LOLP, LOLE, EENS
- Flexibility deficiency metrics
  - Separated from RA metrics by isolating the impact of generator ramp constraints
  - Expected Ramp Not Served (ERNS)
  - Flexibility Shortage Induced Curtailment
- Production cost metrics
  - Proxy system cost
  - Curtailment cost
  - EENS cost

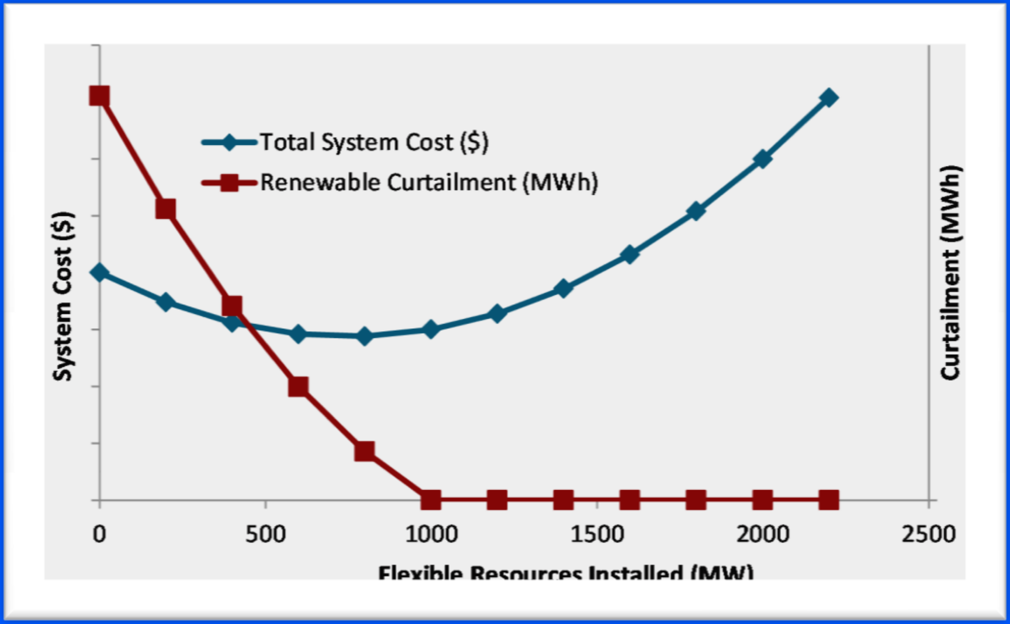
Example of potential flexibility issues caused by hourly net load ramps



Procurement Decisions

- The system operator may increase system flexibility by:
  - Investing in generation
  - Changing market structure
  - Improving forecasts
- Optimal procurement decision are found by minimizing proxy production cost
  - The large number of parameterizations necessitates fast model runtimes

Proxy System Cost vs. Investment Decision



Conclusions

- Due to rapid RES penetration, many loss of load events will be precipitated from lack of ramping flexibility rather than capacity shortage or transmission constraints
- Power systems will become ramping constrained in a substantial way as we move forward
- Special modeling of stochastic events based on renewable schedules and load forecast error is required
- A robust MIP-based UC approach is proposed based on the Expected Flexibility Deficiency Function
- The proposed methodology determines the optimal levels of reserves and ramp-rate capability based on ramp/reserve policy
- The proposed methodology also is used for optimal procurement decisions

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Thank You!

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