Assessment of operation reserves in a hydrothermal electric system with high wind generation

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1 Introduction

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Short-term system operation

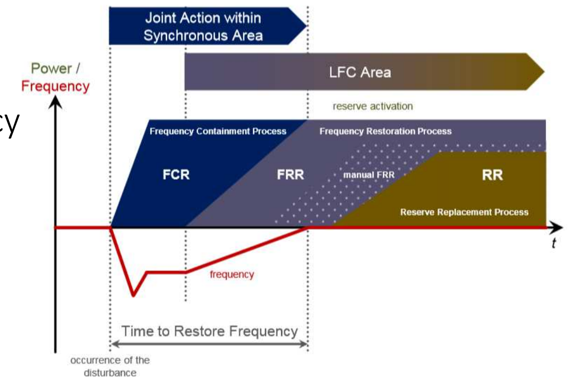
- Unit Commitment (UC): essential tool for day(week)-ahead planning
- Decide the generating units' operation (e.g., on-off) at minimum cost
- UC is a (non-convex) computationally demanding problem
- Wind power introduces uncertainty → more difficult planning
  - Reserve-based deterministic UC
  - Stochastic UC
  - Robust UC
- Optimal amount of operation reserves must be scheduled in advance
  - Providing flexibility in the real-time operation
  - Allowing the system to face real-time uncertainty

How much operation reserve?

- Too low operation reserve levels increase the costs
  - risks system security
  - startup of expensive fast-start units
  - significant load shedding
- Too high operation reserve levels increase the costs
  - facilities not fully exploited
  - reserves are an expensive commodity
- To achieve an optimal economic operation
  - All predictable events must be scheduled in advance (e.g., satisfying demand)
  - Only unforeseen events must be addressed using reserves (e.g., outages, wind forecast error)

ENTSO-e operating reserves

- Frequency Containment Reserves (FCR) (Primary Control)
  - Reserves activated to contain System Frequency after the occurrence of an imbalance
- Frequency Restoration Reserves (FRR)
  - Active Power Reserves activated to restore System Frequency to the Nominal Frequency and for Synchronous Area consisting of more than one LFC Area power balance to the scheduled value
  - Automatic (aFRR) (Secondary Control) or Manual (mFRR) (Tertiary Control)
- Replacement Reserves (RR) (Tertiary Control)
  - Reserves used to restore/support the required level of FRR to be prepared for additional system imbalances. This category includes operating reserves with activation time from Time to Restore Frequency up to hours



Operating reserves in the Iberian market

- Secondary reserve
  - Offered and cleared one day in advance (at 16 h D-1)
  - Can be asked for at any time
  - Has to be deployed in less than 15 min
- Tertiary reserve
  - Offered one day in advance (at 23 h D-1) and updated continuously
  - Asked with 10 min in advance

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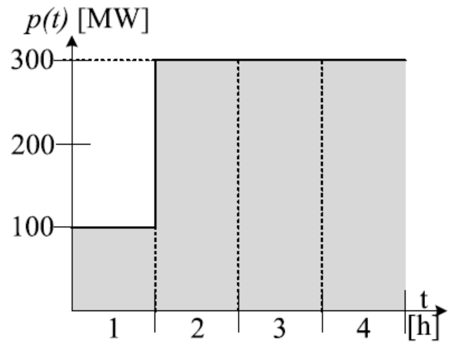
System Representation

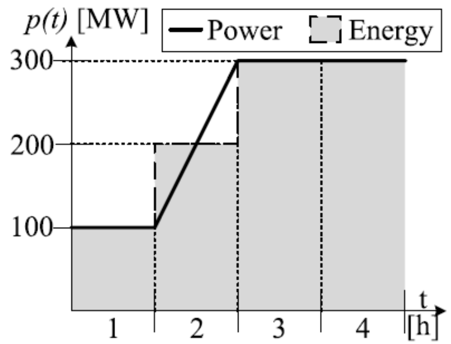
Energy vs. Power Scheduling

- Energy scheduling (stepwise, power constant for 1 hour)
- Power scheduling (piecewise linear, straight line in every hour)

Traditional UC



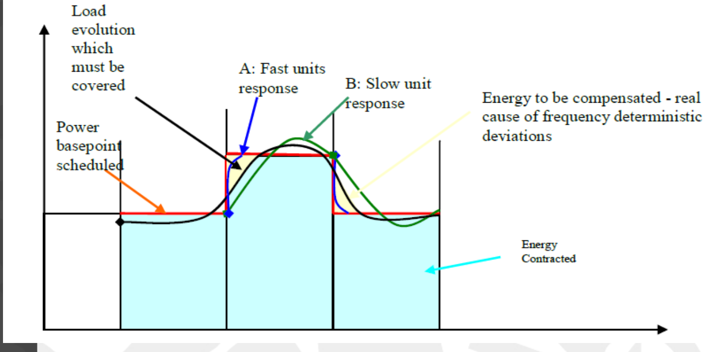
Feasible energy profile

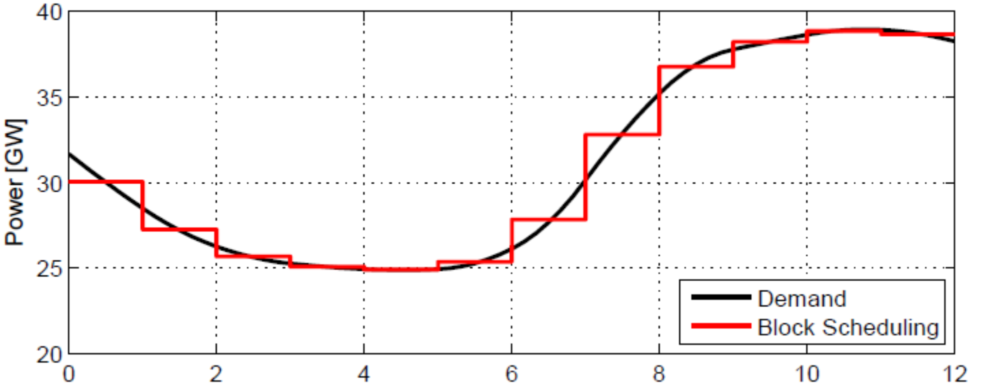


G. Morales-España, A. Ramos, and J. Garcia-Gonzalez [An MIP Formulation for Joint Market-Clearing of Energy and Reserves Based on Ramp Scheduling](#) IEEE Transactions on Power Systems 29 (1): 476-488, Jan 2014 10.1109/TPWRS.2013.2259601

Energy-Based Scheduling

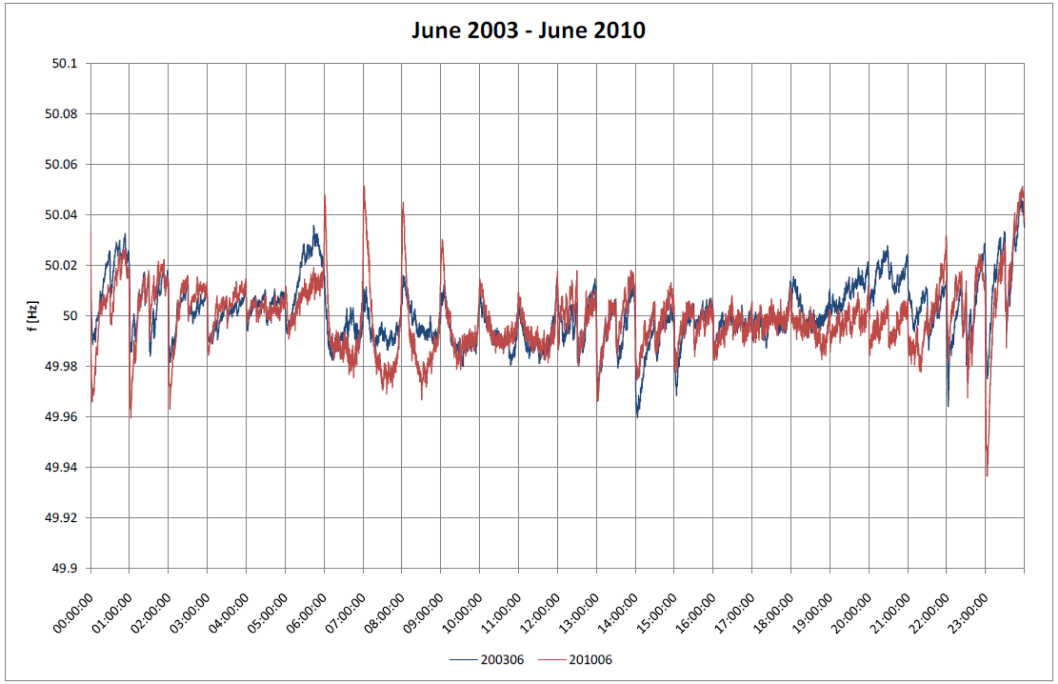
- Generators try to follow the stepwise energy profile
- Generation-Demand balance is needed in real time
  - Operation reserves provide the difference





EURELECTRIC – ENTSO-E "Deterministic frequency deviations – root causes and proposals for potential solutions" December 2011

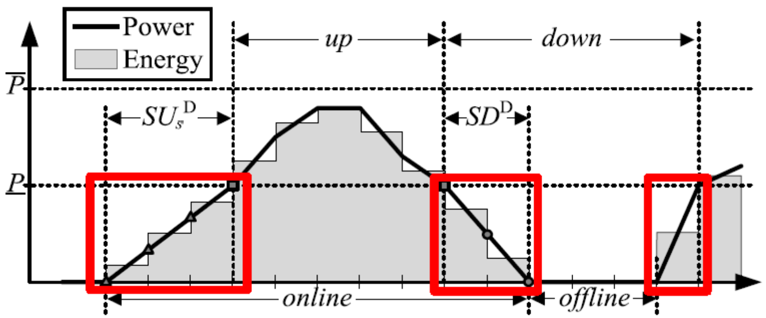
Impact on frequency



EURELECTRIC – ENTSO-E “Deterministic frequency deviations – root causes and proposals for potential solutions”
December 2011

Thermal subsystem (i)

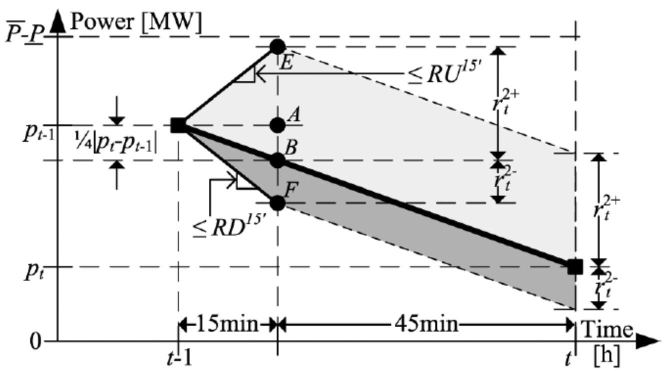
- Startup and shutdown power trajectories



G. Morales-España, J.M. Latorre, and A. Ramos [Tight and Compact MILP Formulation for the Thermal Unit Commitment Problem] IEEE Transactions on Power Systems 28 (4): 4897-4908, Nov 2013 10.1109/TPWRS.2013.2251373

Thermal subsystem (i)

- Operating-reserve (secondary and tertiary) constraints

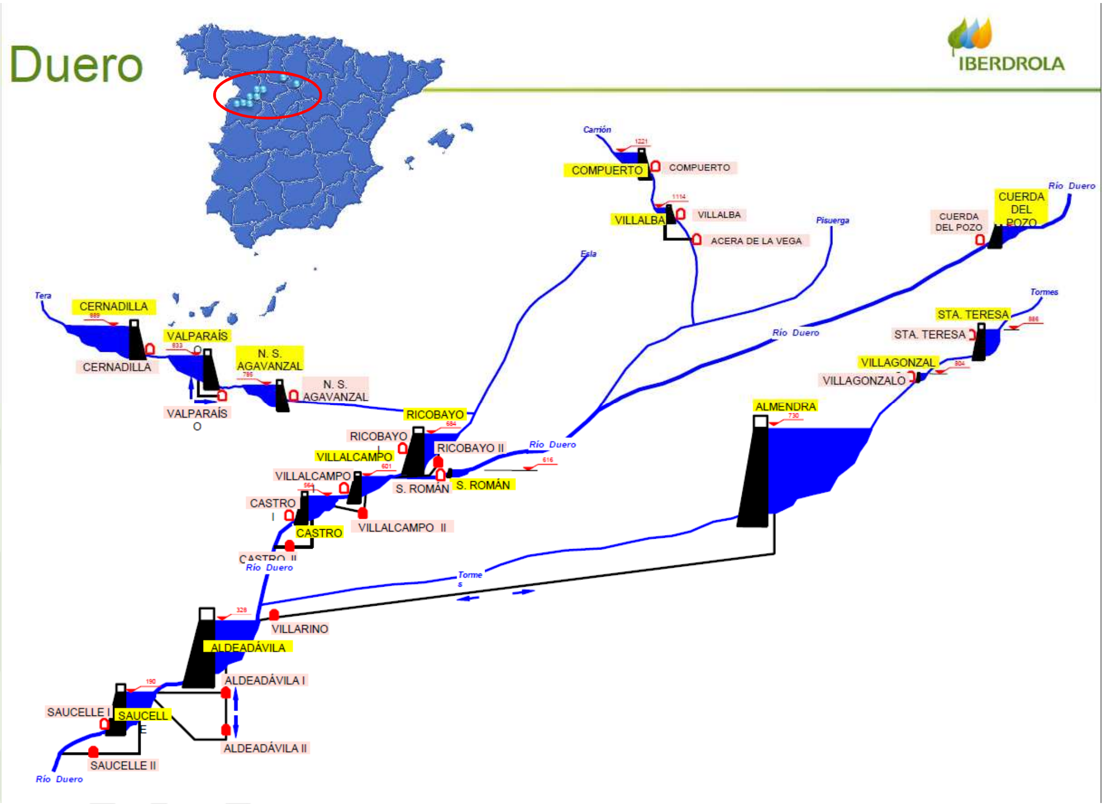


G. Morales-España, A. Ramos, and J. Garcia-Gonzalez *An MIP Formulation for Joint Market-Clearing of Energy and Reserves Based on Ramp Scheduling* IEEE Transactions on Power Systems 29 (1): 476-488, Jan 2014 10.1109/TPWRS.2013.2259601

Hydro subsystem

- Representation is relevantly conditioned by the data availability.
- A detailed hydraulic model, with time-space connections and individual physical unit representation. Very accurate and detailed solutions are obtained with this type of modeling. However, in very complex system such as the one considered in this report, it is in general not possible to use this type of modeling due to the enormous computational burden involved.
- An aggregated model for the different hydrological basins of the system. Although the computational burden is significantly reduced, lot of details are lost in the process.
- The market programming units because the market and system operation is recorded based on these units. These units represent either one hydro unit or a group of hydro units belonging to the same generation company, which are geographically linked.

Example of hydro programming unit



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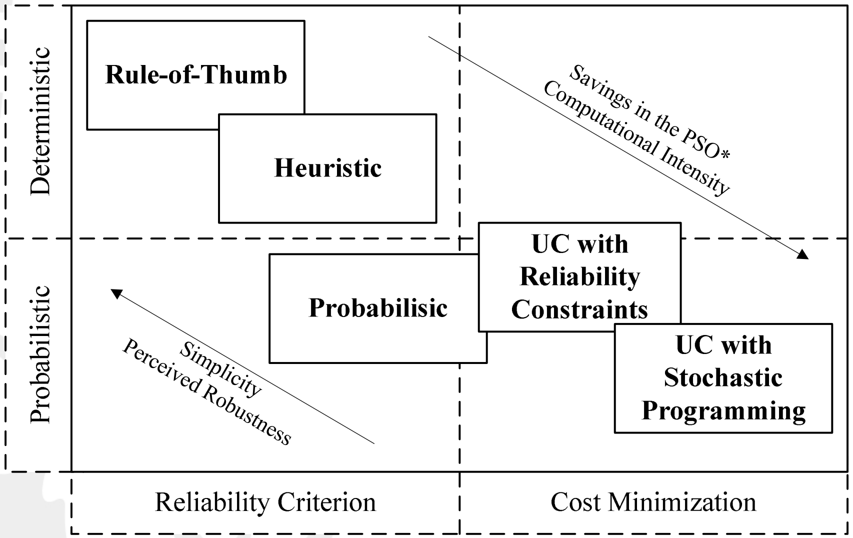
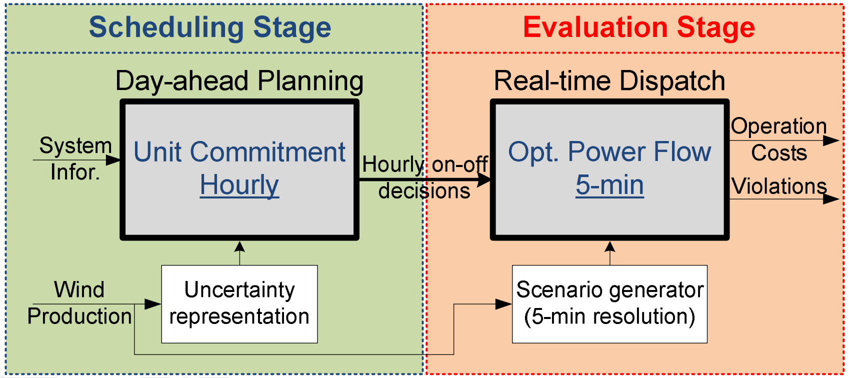
System Operation

Operation Reserve Assessment



Planning decision validation

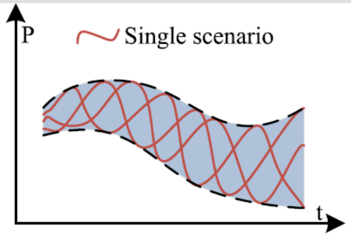


- Scheduling stage: planning of day-ahead hourly UC of the hydro and thermal units
- Evaluation stage: simulation of real-time system operation (ED for different time periods from 5 to 60 minutes) once the commitment of thermal units is already decided for all the scenarios

G. Morales-España, R. Baldick, J. García-González, A. Ramos *Power-Capacity and Ramp-Capability Reserves for Wind Integration in Power-Based UC* IEEE Transactions on Sustainable Energy 10.1109/TSTE.2015.2498399

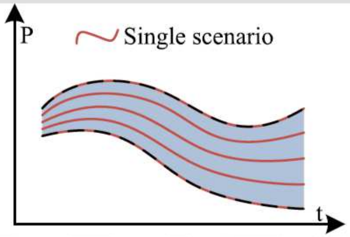
Stochastic and robust UC models

Stochastic

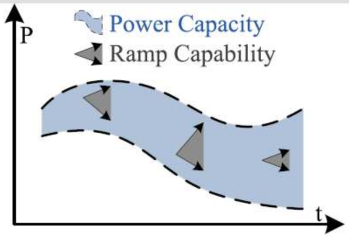


Feasible for a discrete (finite) number of scenarios

Stochastic



Robust



Feasible for a continuous (infinite) uncertainty region

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Case Study

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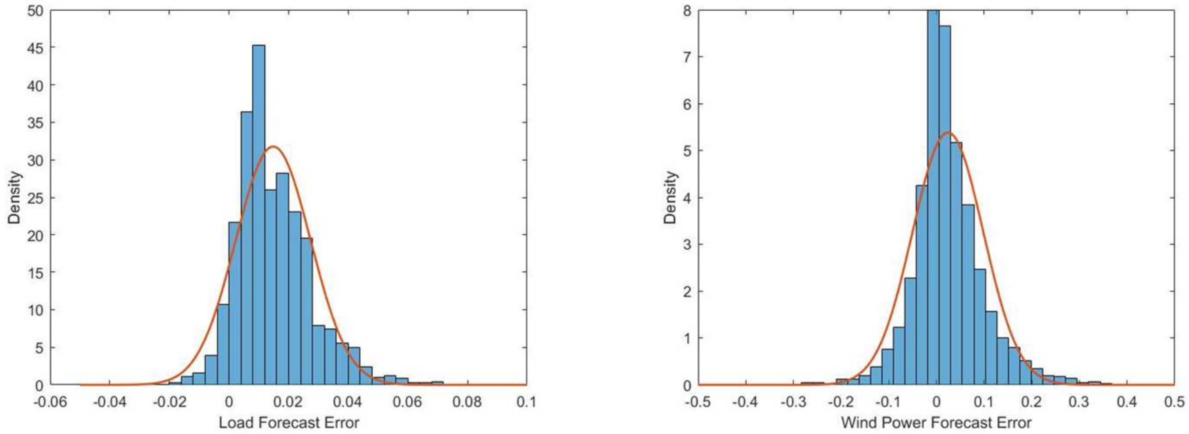
Spanish Case Study

- Thermal and hydro unit characteristics obtained by analyzing (several) historical electricity market data
  - Thermal units considered individually
  - Hydro units considered aggregated in programming units

Estimation of uncertainty



μ=0.0148, σ=0.0126, γ=0.8711, κ= 4.4142 μ=0.0241, σ=0.0741, γ=0.4118, κ=6.1605

- Not the point of view of the TSO but of any generation agent
- Time series of the demand and wind power forecast errors obtained by approximating with an ARIMA model the historical forecast errors

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Results

Case study

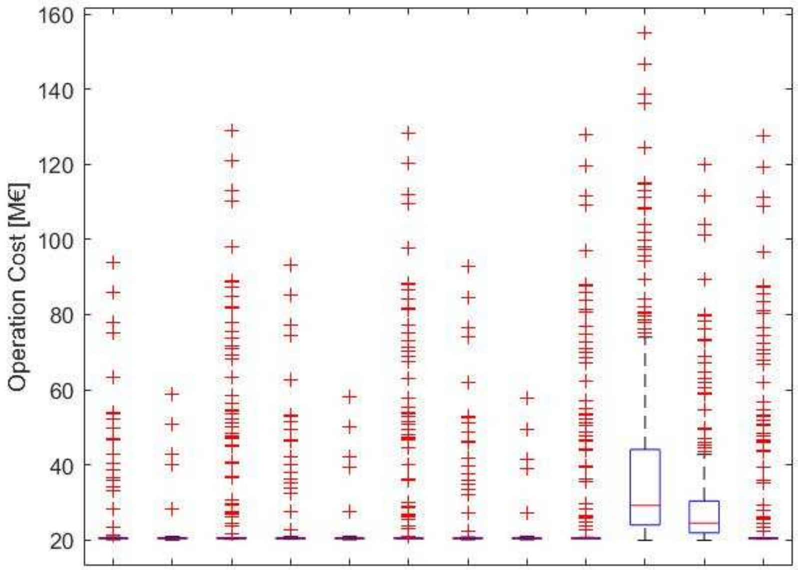
- A single day is analyzed
- Commitment of thermal units decided at scheduling stage with hourly time period and with a pre-defined operation reserve level
- 200 scenarios are generated to simulate the ED with plausible future outcomes of the forecast errors.
- Sensitivity to shorter time periods (5, 15, 30 and 60 minutes)
- Sensitivity to larger or smaller operation reserves provision (120 and 80 %)
- Infeasibilities valued as energy not served

Operation costs and violations in p.u. of the different cases

	60 min	60 min	60 min	30 min	30 min	30 min	15 min	15 min	15 min	5 min	5 min	5 min
Dispatch Cost	100 %	120 %	80 %	100 %	120 %	80 %	100 %	120 %	80 %	100 %	120 %	80 %
Mean	100%	90%	126%	100%	90%	126%	100%	90%	125%	177%	133%	125%
Std	100%	37%	194%	98%	36%	192%	97%	36%	191%	260%	161%	190%
Best	100%	100%	101%	100%	100%	101%	100%	100%	101%	99%	99%	101%
Worst	100%	63%	137%	99%	62%	137%	99%	62%	136%	165%	128%	136%
Violations	100%	19%	363%	77%	34%	193%	60%	11%	160%	2408%	1447%	134%

- Impact of the amount of upward and downward secondary reserve is very high
- Violations measured by number of hours with ENS
- In real operation the system operator will resort to tertiary reserve many times because no enough secondary reserve has been provided.

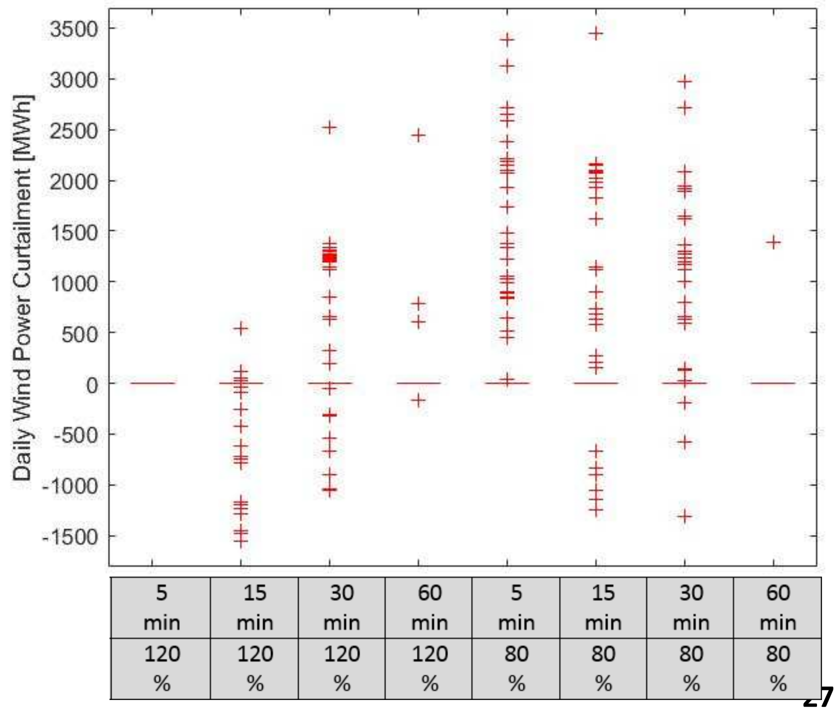
Uncertainty in Operation Costs



60 min	60 min	60 min	30 min	30 min	30 min	15 min	15 min	15 min	5 min	5 min	5 min
100 %	120 %	80 %	100 %	120 %	80 %	100 %	120 %	80 %	100 %	120 %	80 %

Daily Wind Curtailment

- Sensitivity of daily wind curtailment for larger or smaller values of operation reserve



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Conclusions

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Conclusions

- Wind curtailment decreases when decreasing the ED unit time period.
- Reducing the unit time period in the UC also diminishes the mean value of system production cost.
- High volatility of the operation costs due to forecast errors
- In a market environment the reduction of the unit market clearing period would reduce the operation reserve requirement/usage. This effect has an important consequence on the electric system frequency.

Challenges

- Data capture and data analysis: specially for hydro subsystem characteristics and forecast errors
- Separate the understanding of the impacts and the weight of the different uncertainties
- Extend to many varied days
- Improve real-time operation representation by introducing additional operational reserves (e.g., tertiary)

Thank you for your attention

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