SMART-ISO: Modeling Uncertainty in the Electricity Markets

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  - Christine Feng (ORFE)
  - Joe Yang (ORFE)
  - Austin Wang (ORFE)

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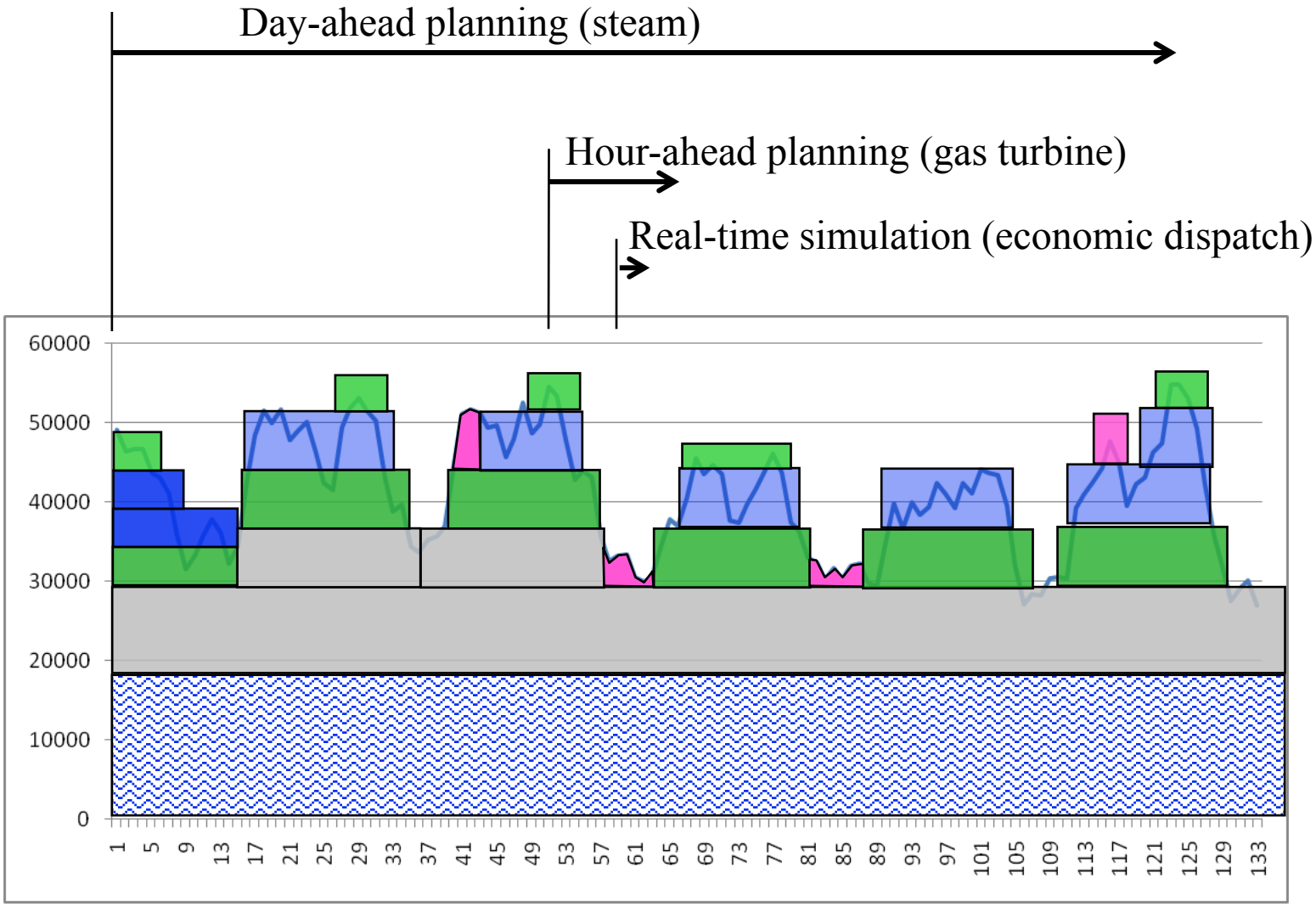
The stochastic unit commitment problem



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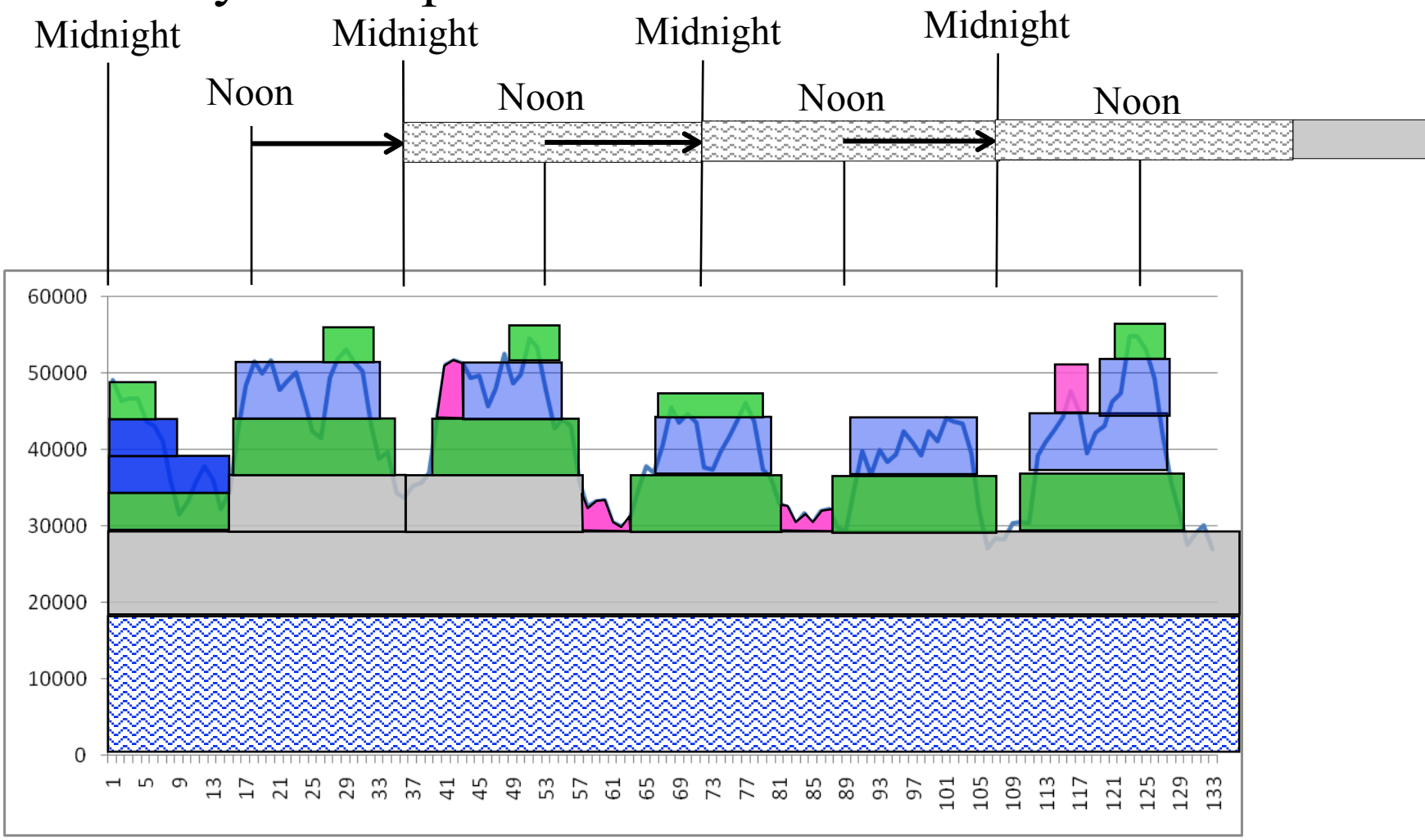
The timing of decisions

- The day-ahead problem



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The timing of decisions

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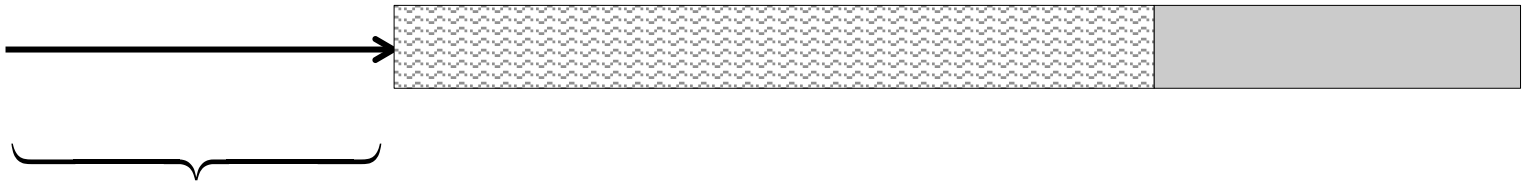

Noon to midnight:

Steam (1) on/off decisions determined the day before
Optimize within spinning reserve margins
Optimize on/off operation of gas turbines (2)
Constrained by aggregate DC power flow

(1) Includes also most combined cycle and some gas turbine generators (the so-called *slow* generators)
(2) Includes all hydro and some combined cycle generators (*fast*)

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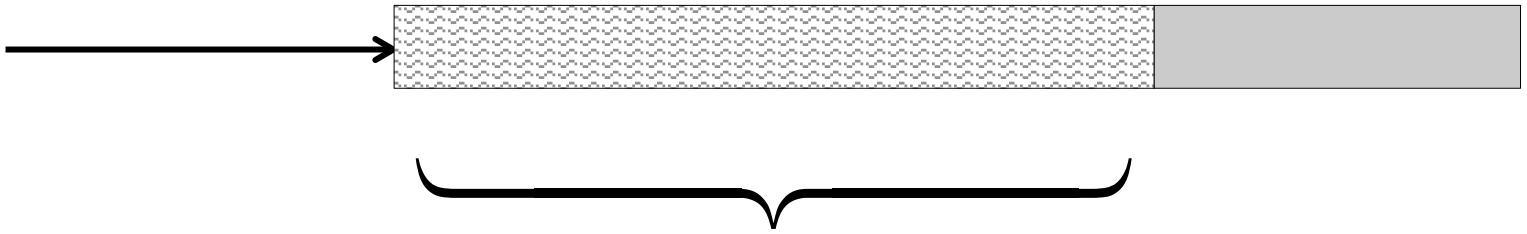
The timing of decisions

- The day-ahead problem



Midnight to midnight:

Optimize steam on/off decisions

Optimize within spinning reserve margins

Optimize on/off operation of gas turbines

Constrained by aggregate DC power flow

Steam on/off decisions are stored and implemented

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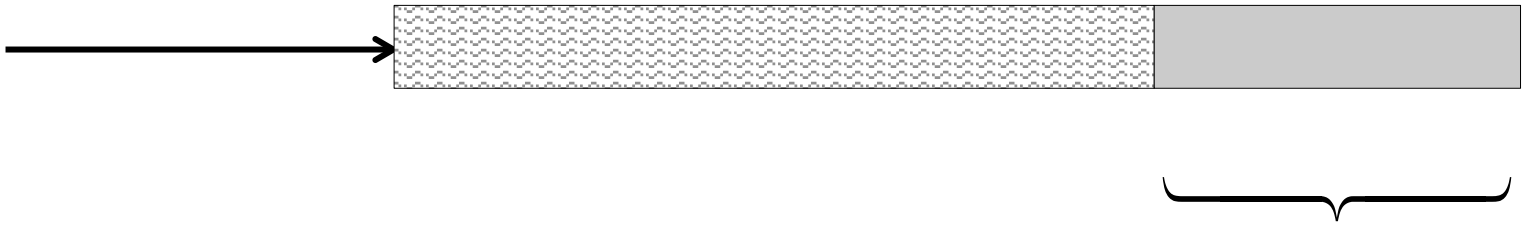
The timing of decisions

- The day-ahead problem



Midnight to, say, 4am the next day

Optimize steam on/off decisions
Optimize within spinning reserve margins
Optimize on/off operation of gas turbines
Constrained by aggregate DC power flow

No decisions are implemented. These are solved only to minimize end-of-day truncation error.

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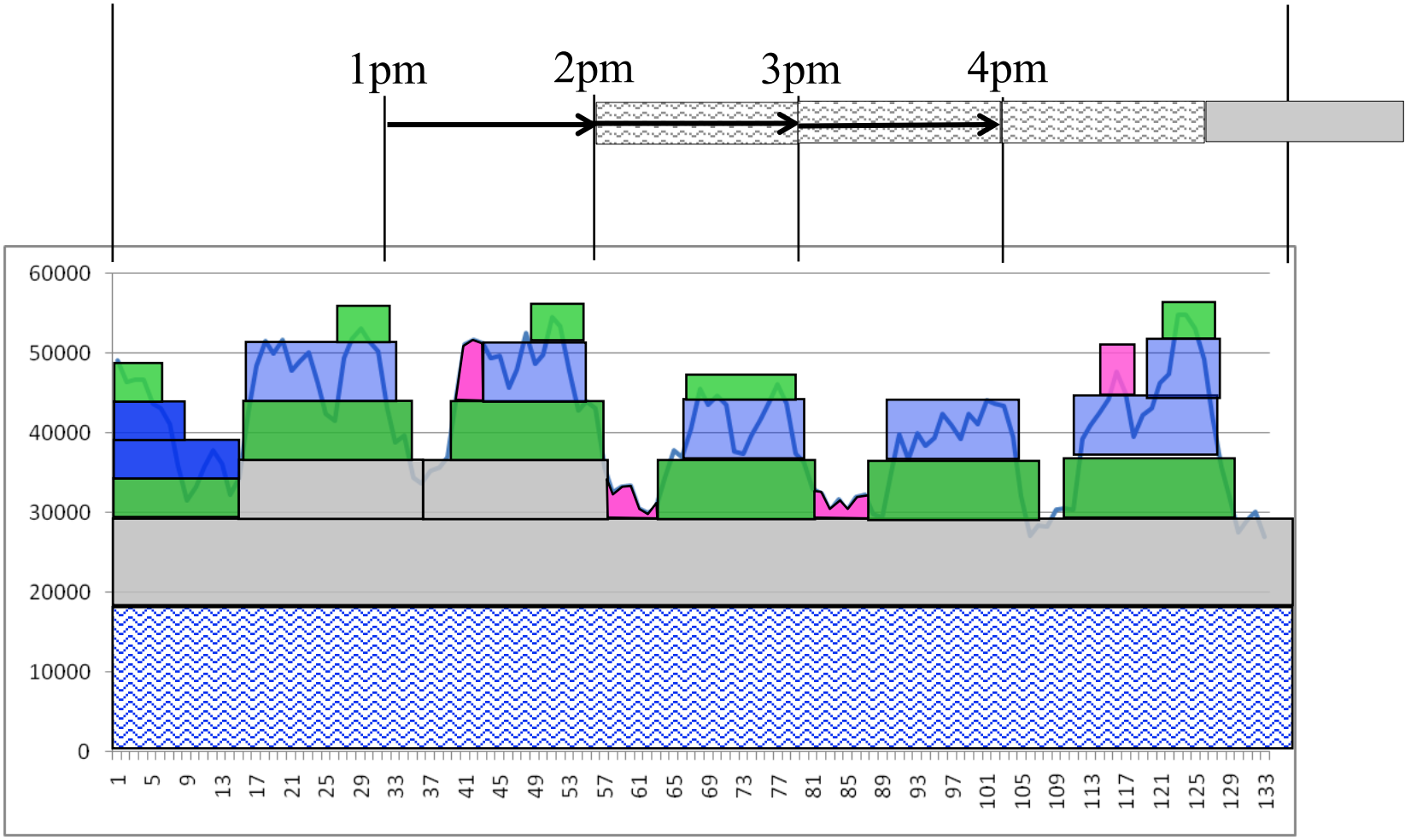
The timing of decisions

- The hour-ahead problem



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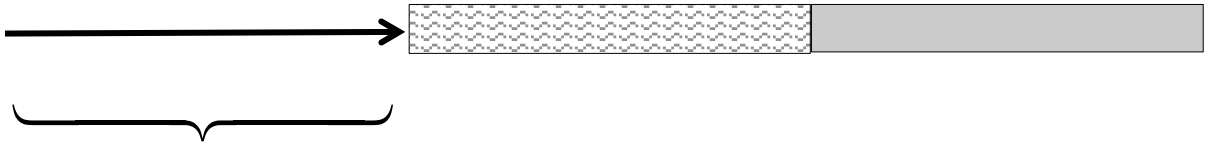
The timing of decisions

- The hour-ahead problem



1pm to 2pm:

Steam on/off decisions determined the day before

Optimize within spinning reserve margins

On/off operation of gas turbines determined the hour before

Constrained by aggregate DC power flow

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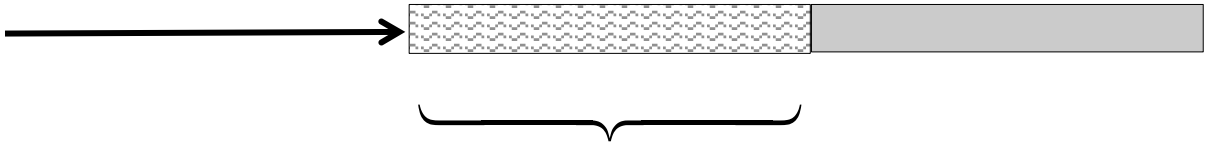
The timing of decisions

- The hour-ahead problem



2pm to 3pm:

Steam on/off decisions determined the day before
Optimize within spinning reserve margins
Optimize on/off operation of gas turbines
Constrained by aggregate DC power flow

On/off decisions for gas turbines are stored and implemented

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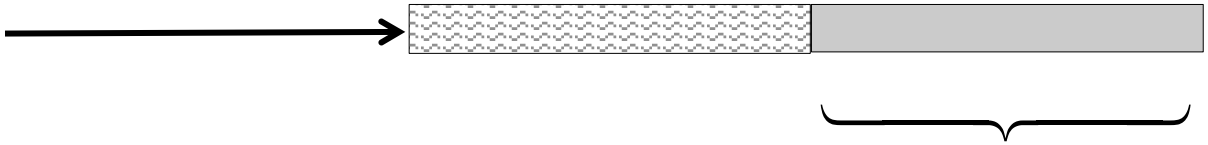
The timing of decisions

- The hour-ahead problem



3pm to, say, 3:10pm:

Steam on/off decisions determined the day before
Optimize within spinning reserve margins
Optimize on/off operation of gas turbines
Constrained by aggregate DC power flow

No decisions are stored or implemented.

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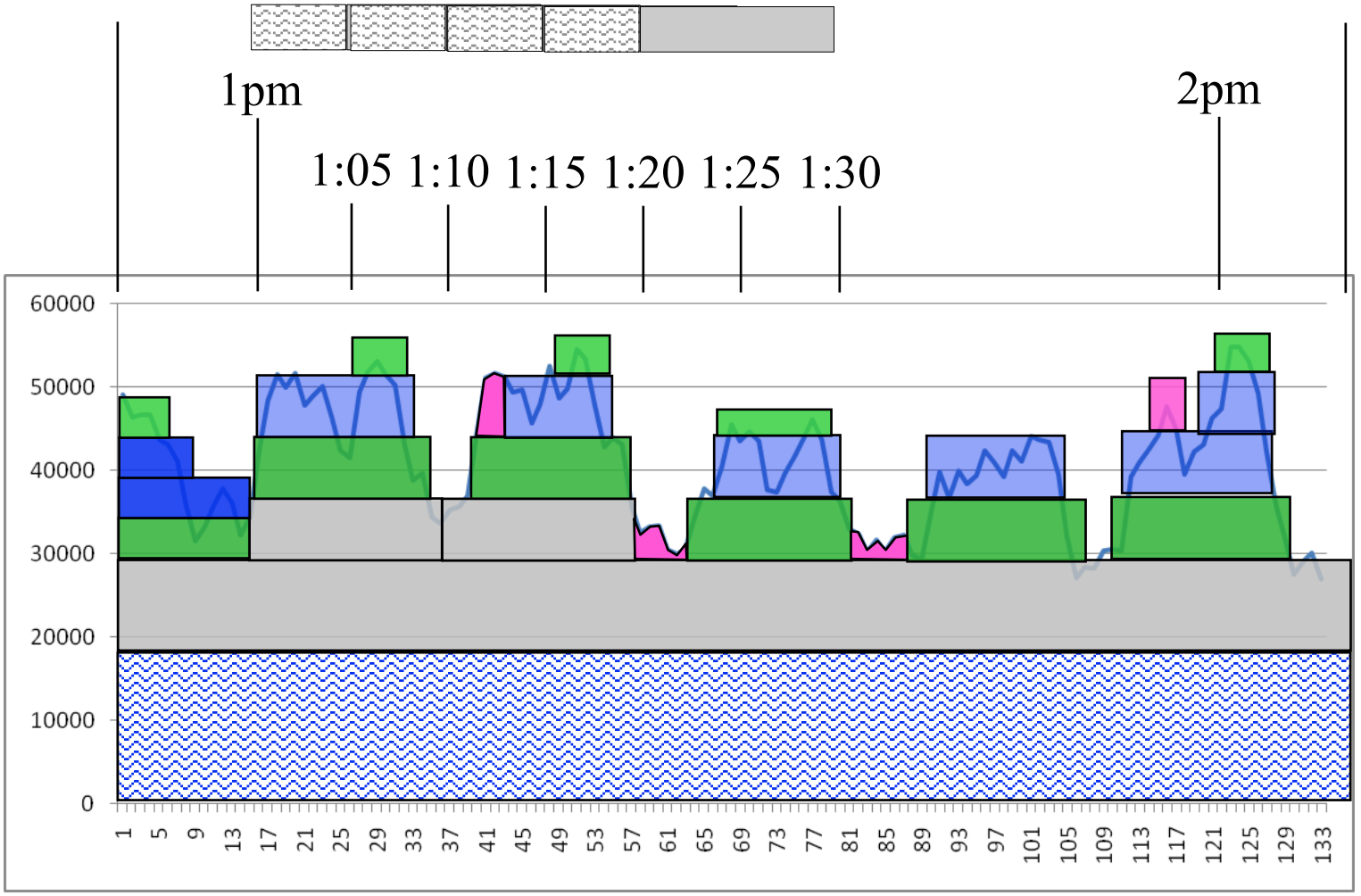
The timing of decisions

- The real-time (economic dispatch) problem



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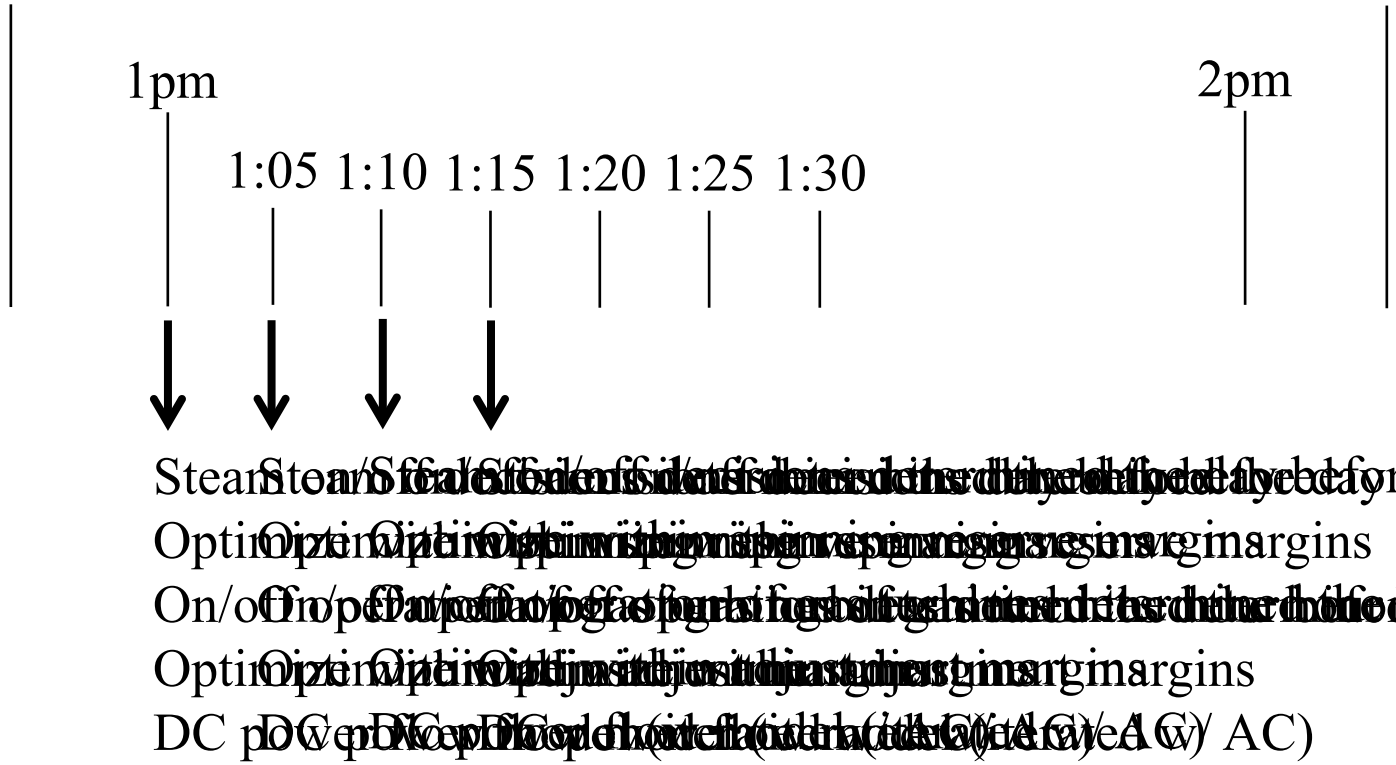
The timing of decisions

- The real-time problem



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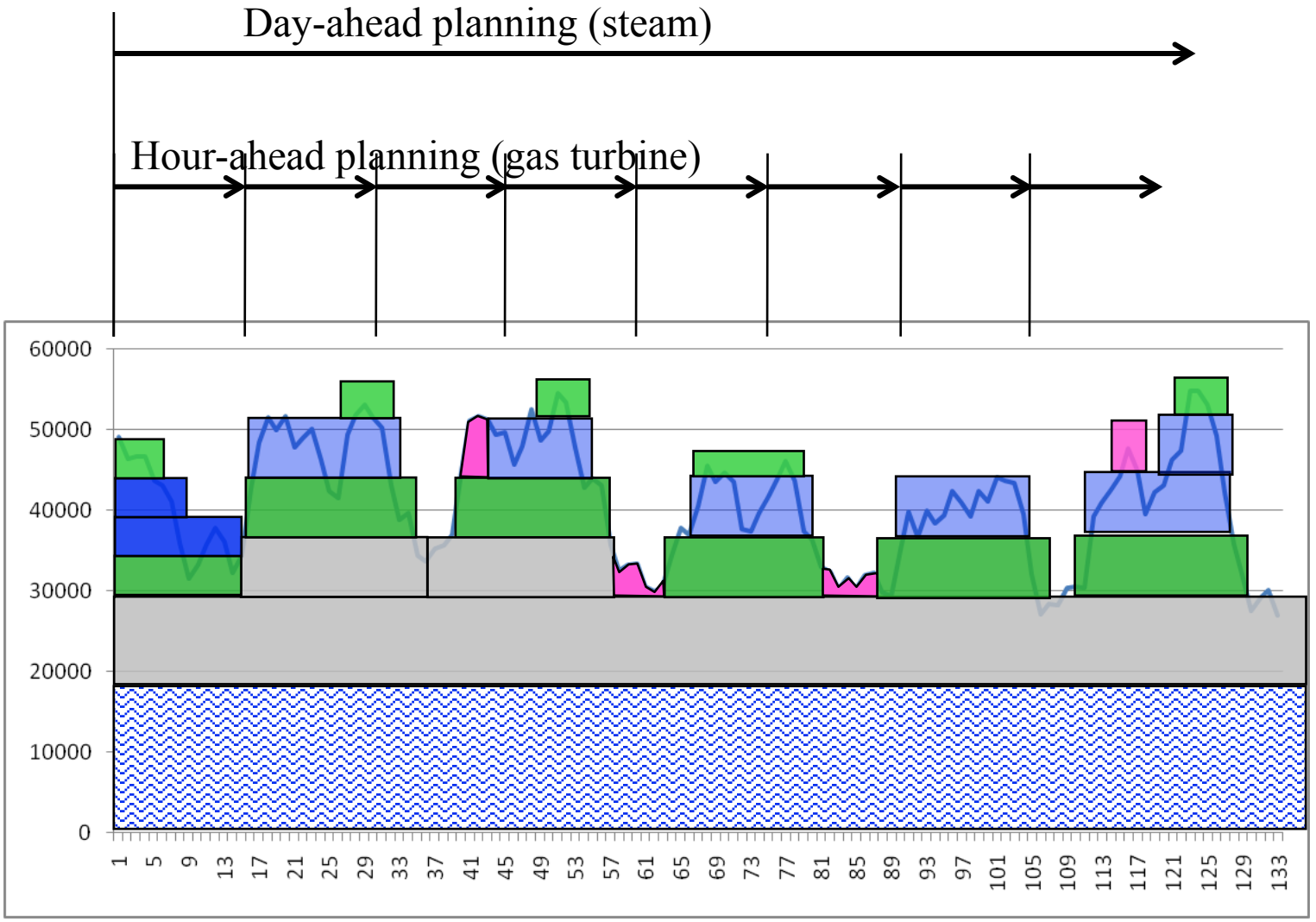
The nesting of decisions



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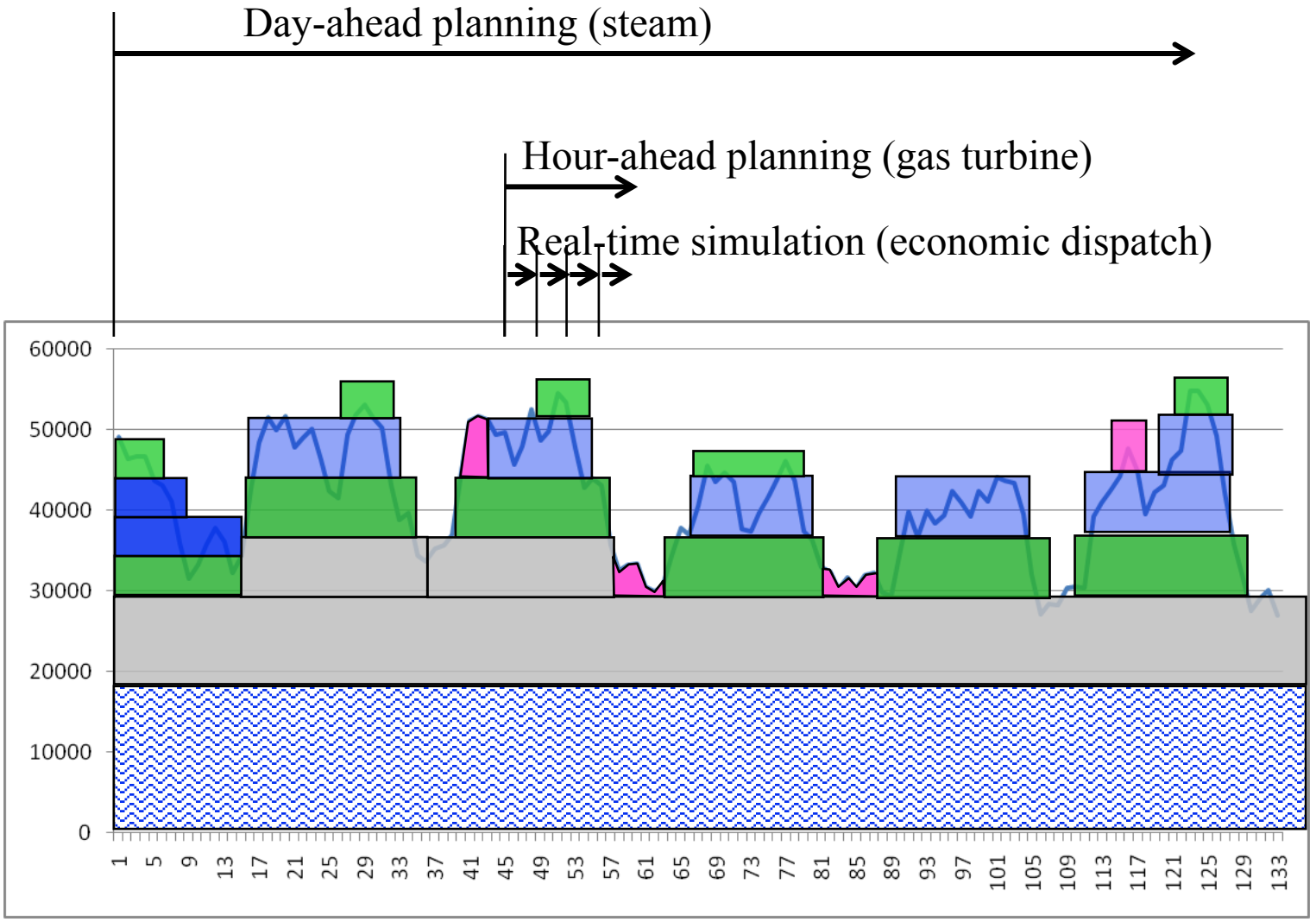
The nesting of decisions



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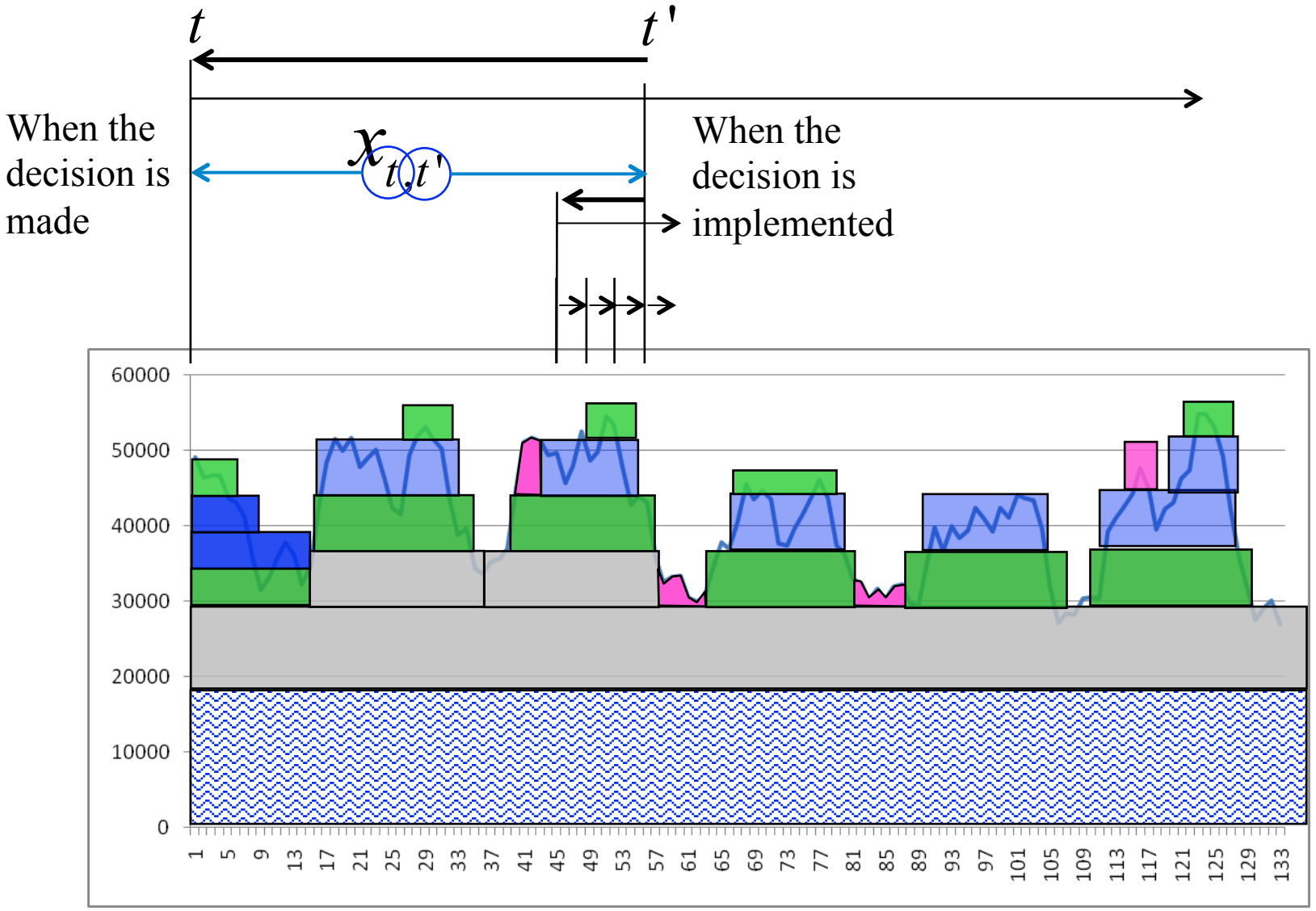
The nesting of decisions



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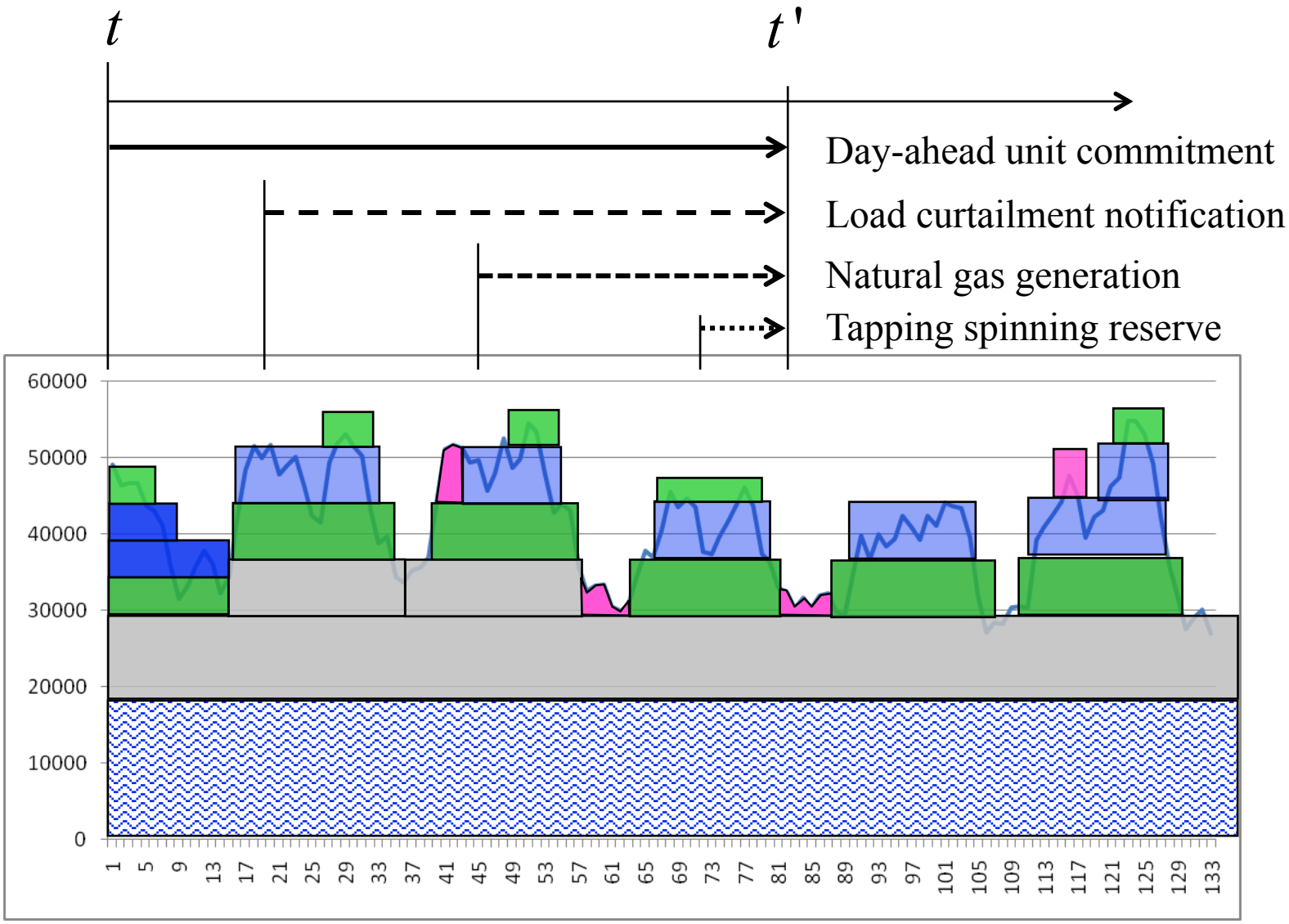
The nesting of decisions



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Four classes of policies

1) Cost function approximation

» $X^{CFA}(S_t \mid \theta) = \arg\min_{x_t} \bar{C}^{\pi}(S_t, x_t \mid \theta)$

2) Lookahead policies

» ***Deterministic lookahead:***

$$X_t^{LA-D}(S_t) = \arg\min_{\tilde{x}_{tt}, \tilde{x}_{t,t+1}, \ldots, \tilde{x}_{t,t+T}} C(\tilde{S}_{tt}, \tilde{x}_{tt}) + \sum_{t'=t+1}^{T} \gamma^{t'-t} C(\tilde{S}_{tt'}, \tilde{x}_{tt'})$$

» ***Stochastic lookahead ("stochastic programming")***

$$X_t^{LA-S}(S_t) = \arg\min C(\tilde{S}_{tt}, \tilde{x}_{tt}) + \sum_{\omega \in \tilde{\Omega}_t} p(\omega) \sum_{t'=t+1}^{T} \gamma^{t'-t} C(\tilde{S}_{tt'}(\omega), \tilde{x}_{tt'}(\omega))$$

3) Policy function approximations

» Lookup tables, rules, parametric functions

4) Policies based on value function approximations

» $X_t^{VFA}(S_t) = \arg\min_{x_t} \left(C(S_t, x_t) + \gamma \bar{V}_t^{x} \left(S_t^{x}(S_t, x_t) \right) \right)$

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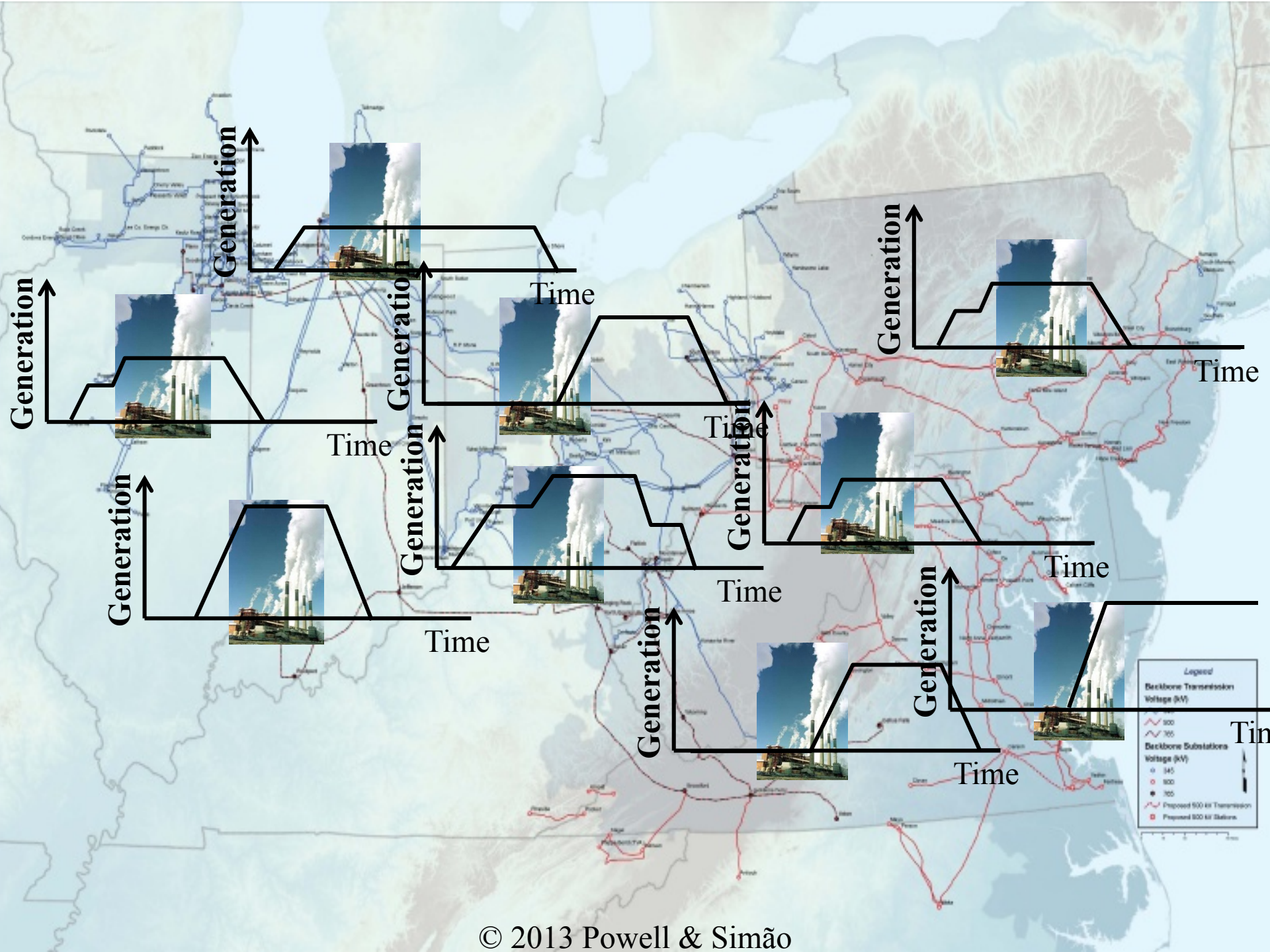

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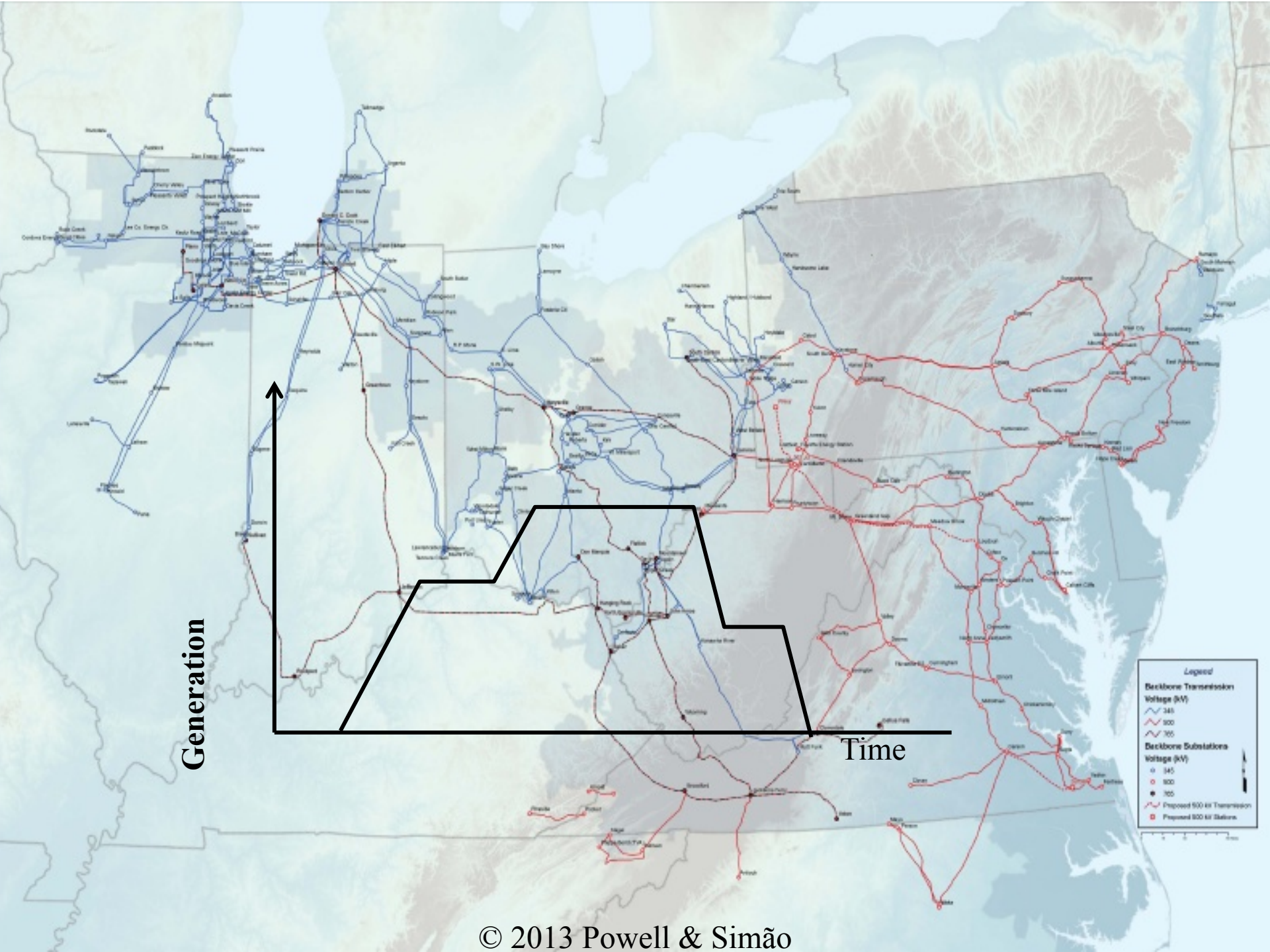

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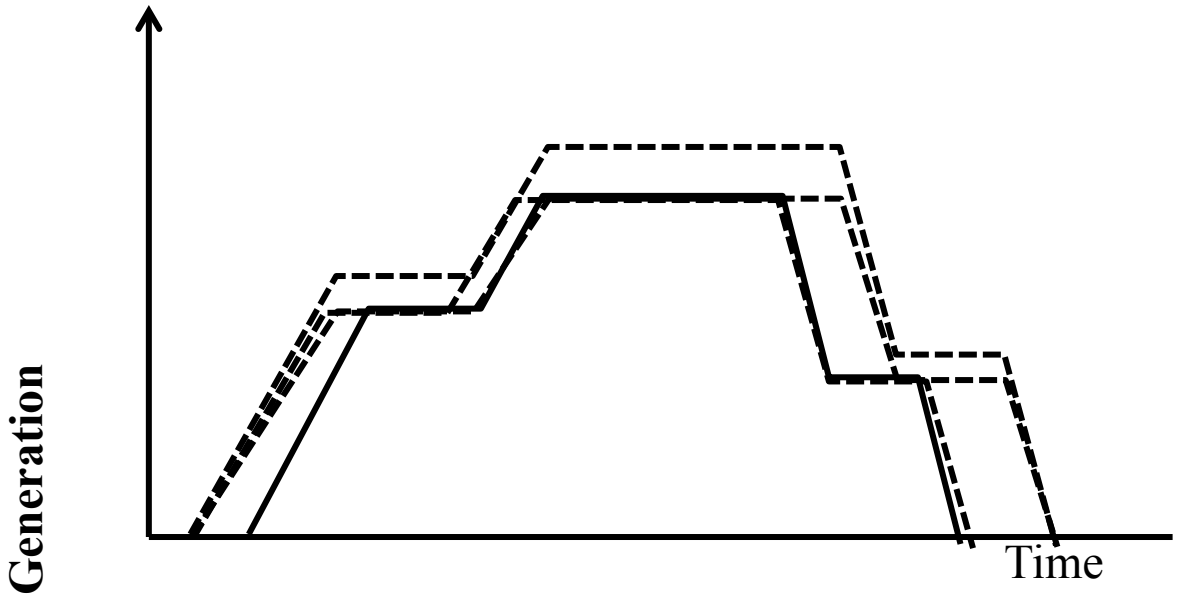
Robust unit commitment

- We need to achieve a robust schedule:



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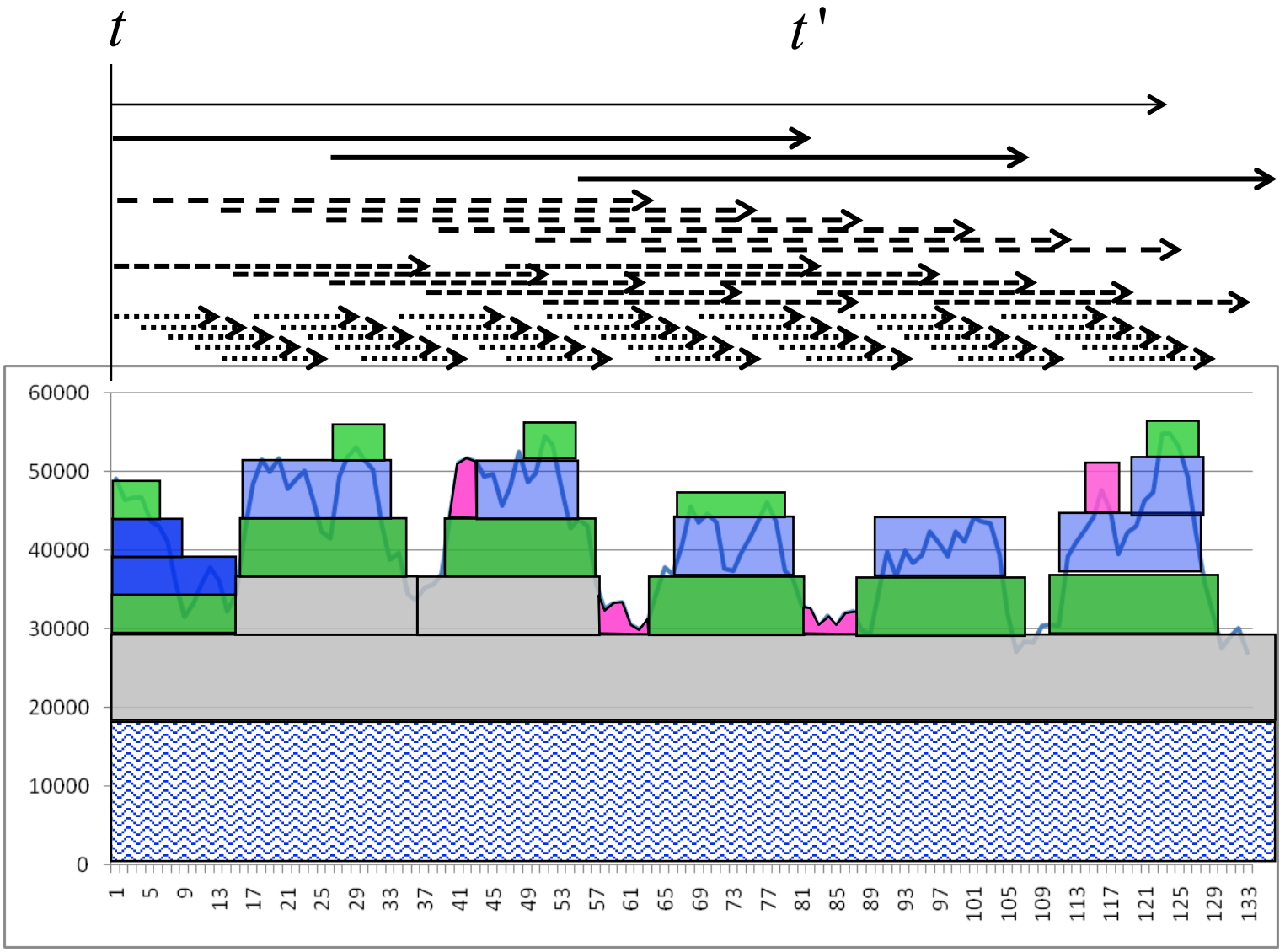
A nested, adaptive policy



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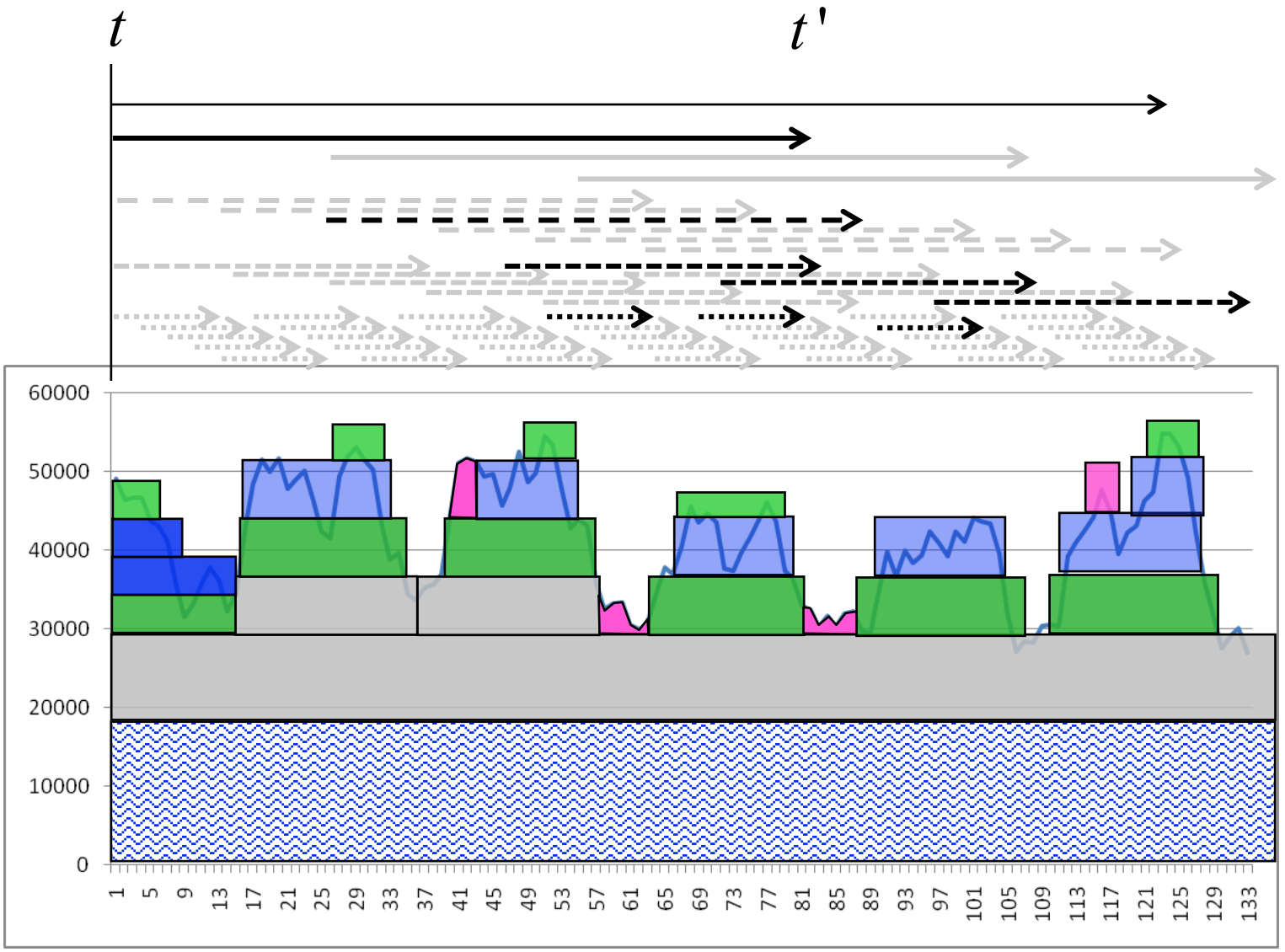
A nested, adaptive policy



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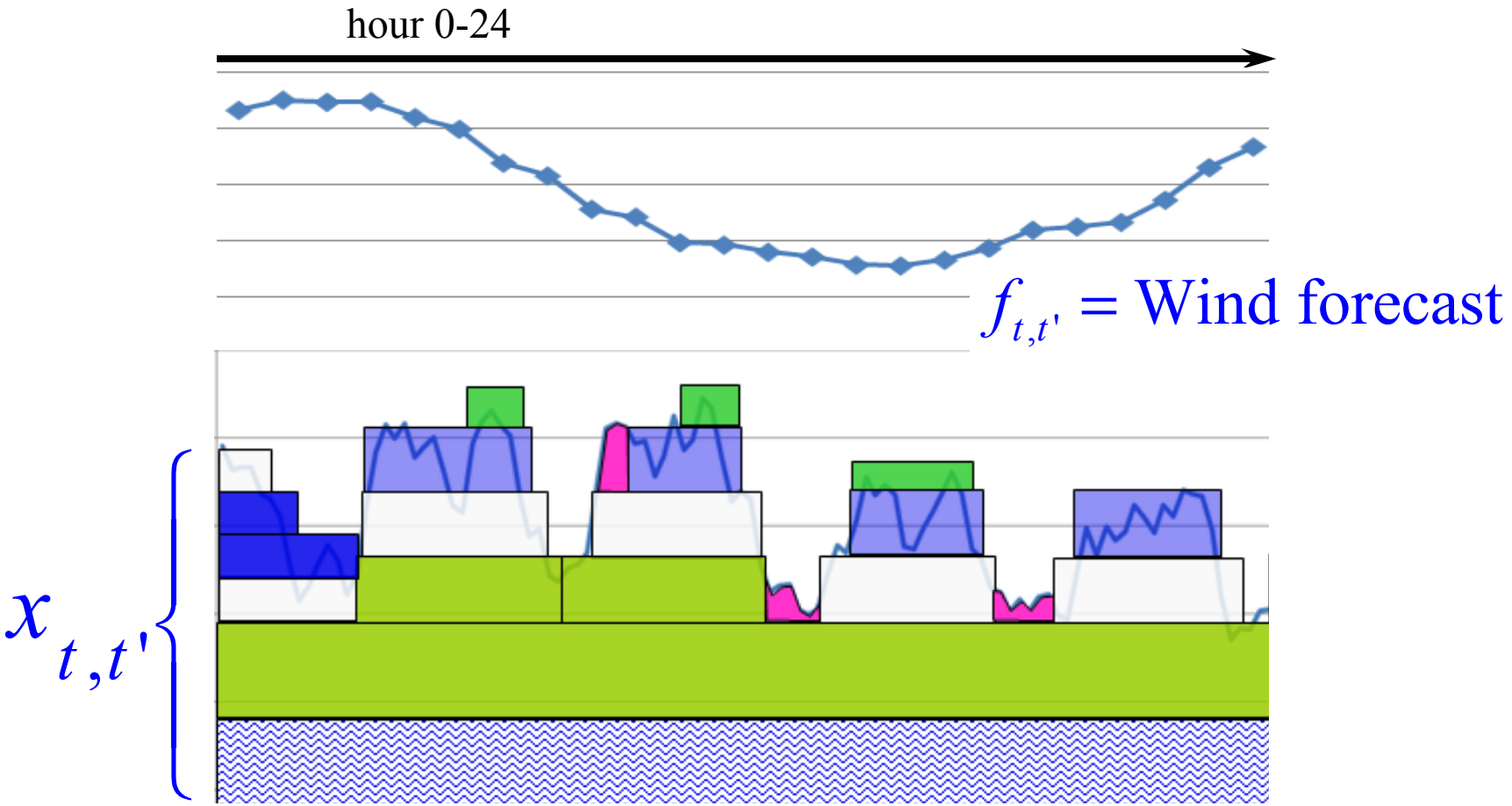
The stochastic unit commitment problem

- When planning, we have to use a *forecast* of energy from wind, then live with what *actually* happens (in the simulation)



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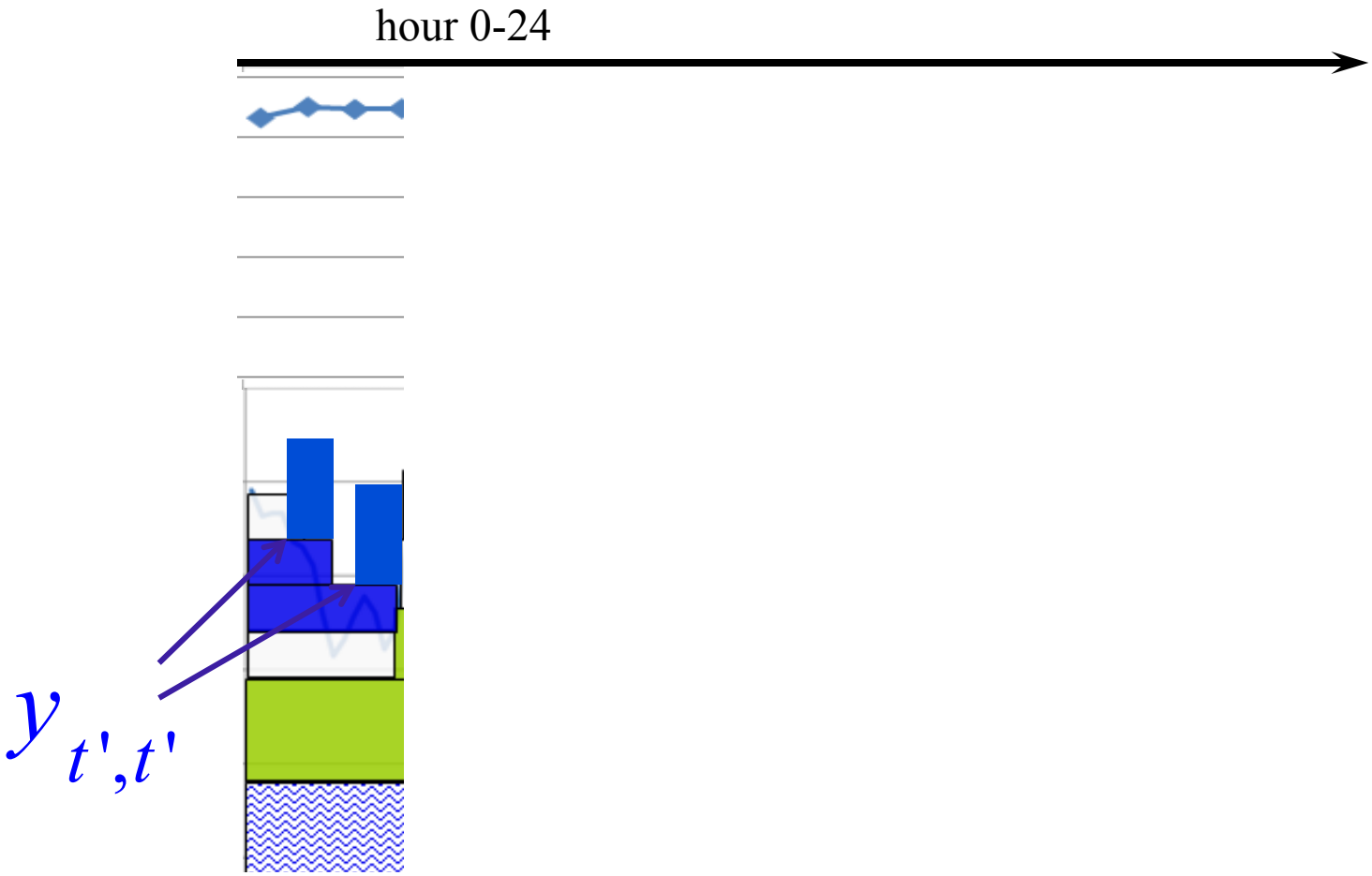
The stochastic unit commitment problem

- The unit commitment problem
  - » Stepping forward observing actual wind, making small adjustments



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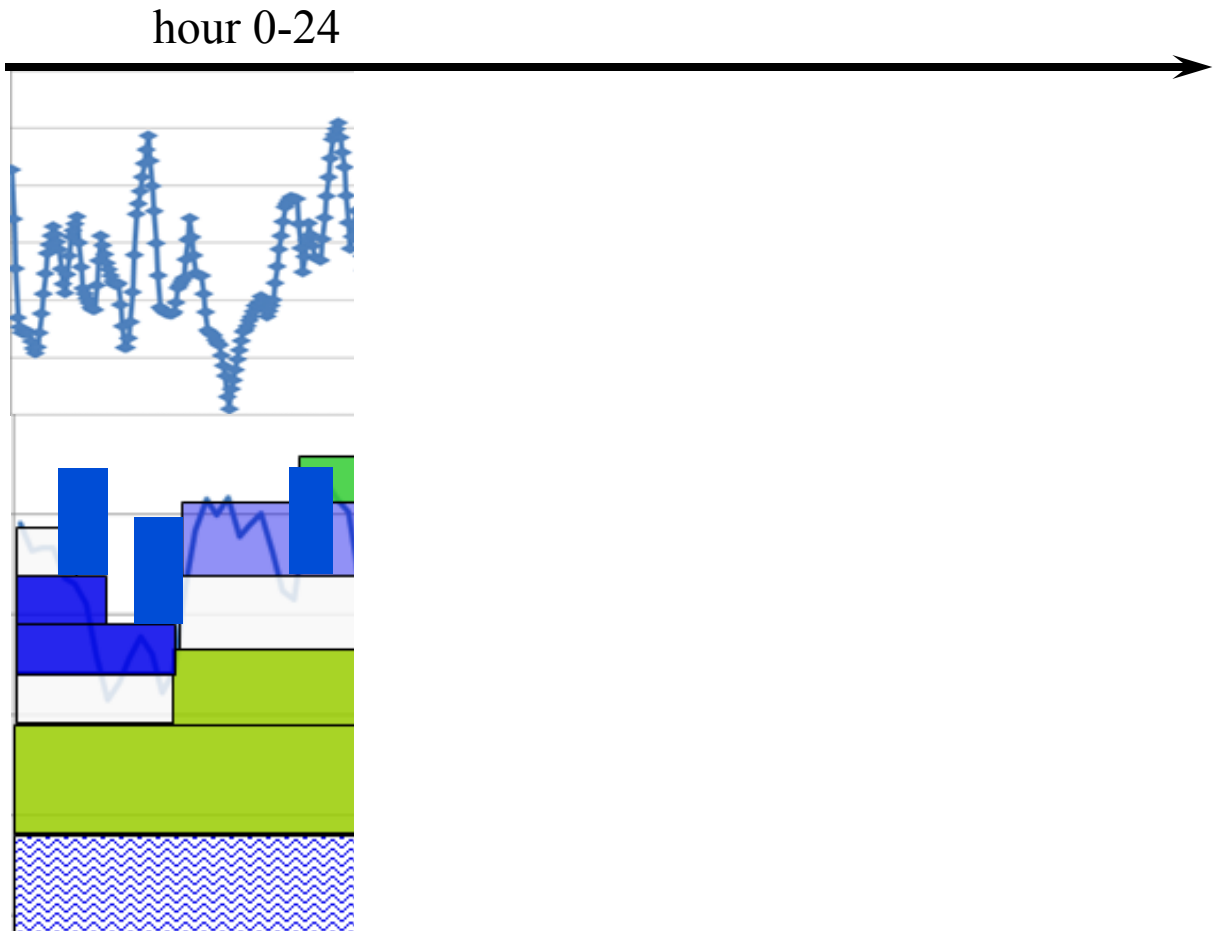

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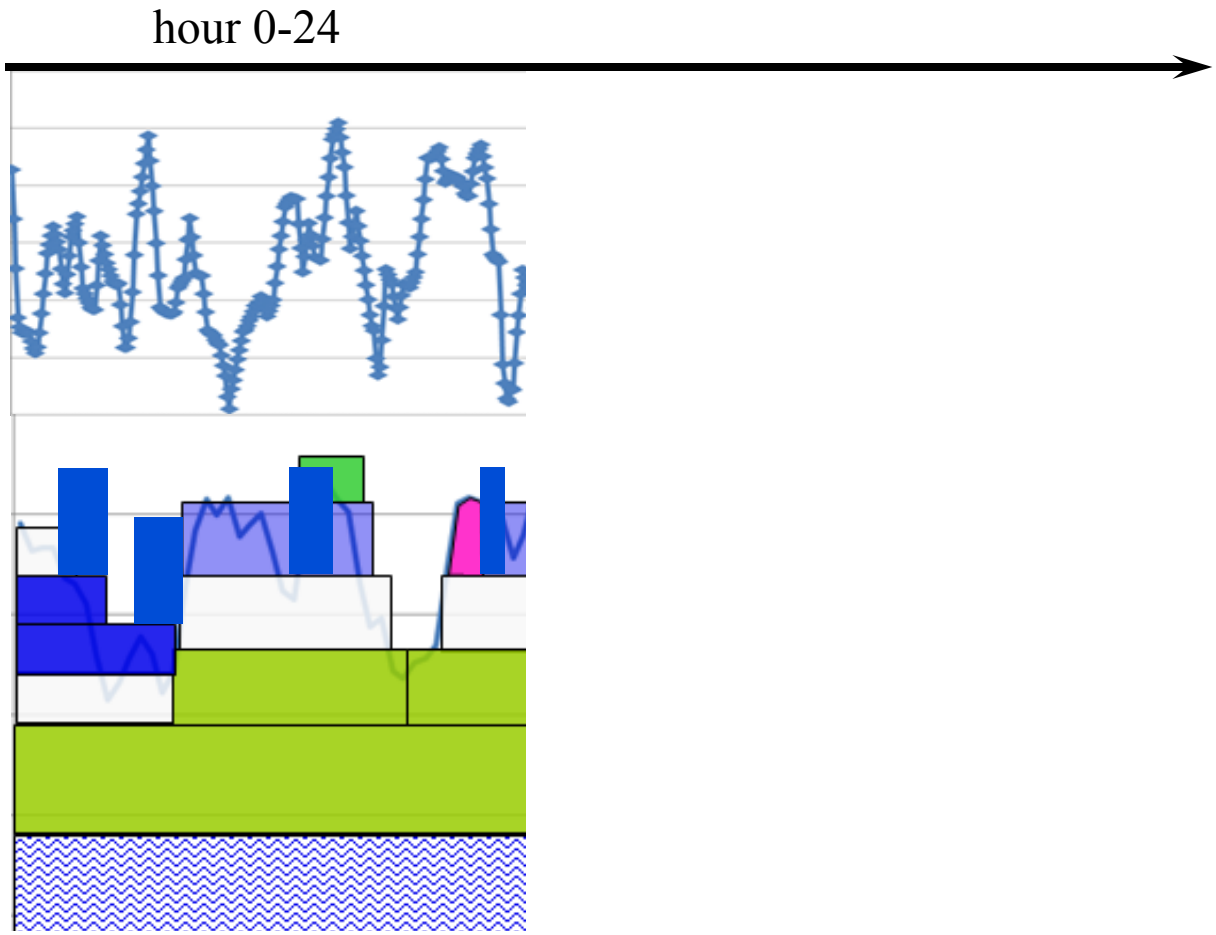

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The stochastic unit commitment problem

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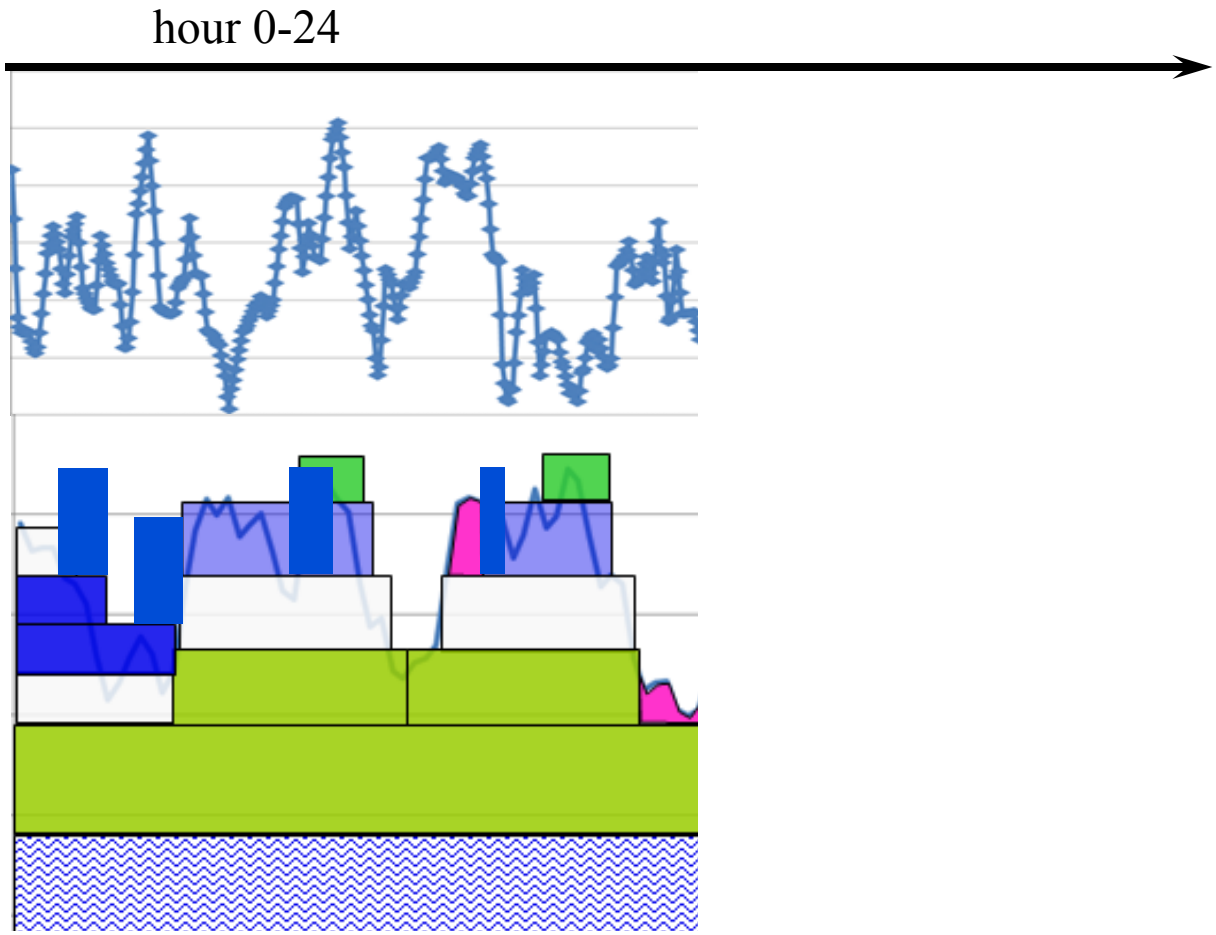

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The stochastic unit commitment problem

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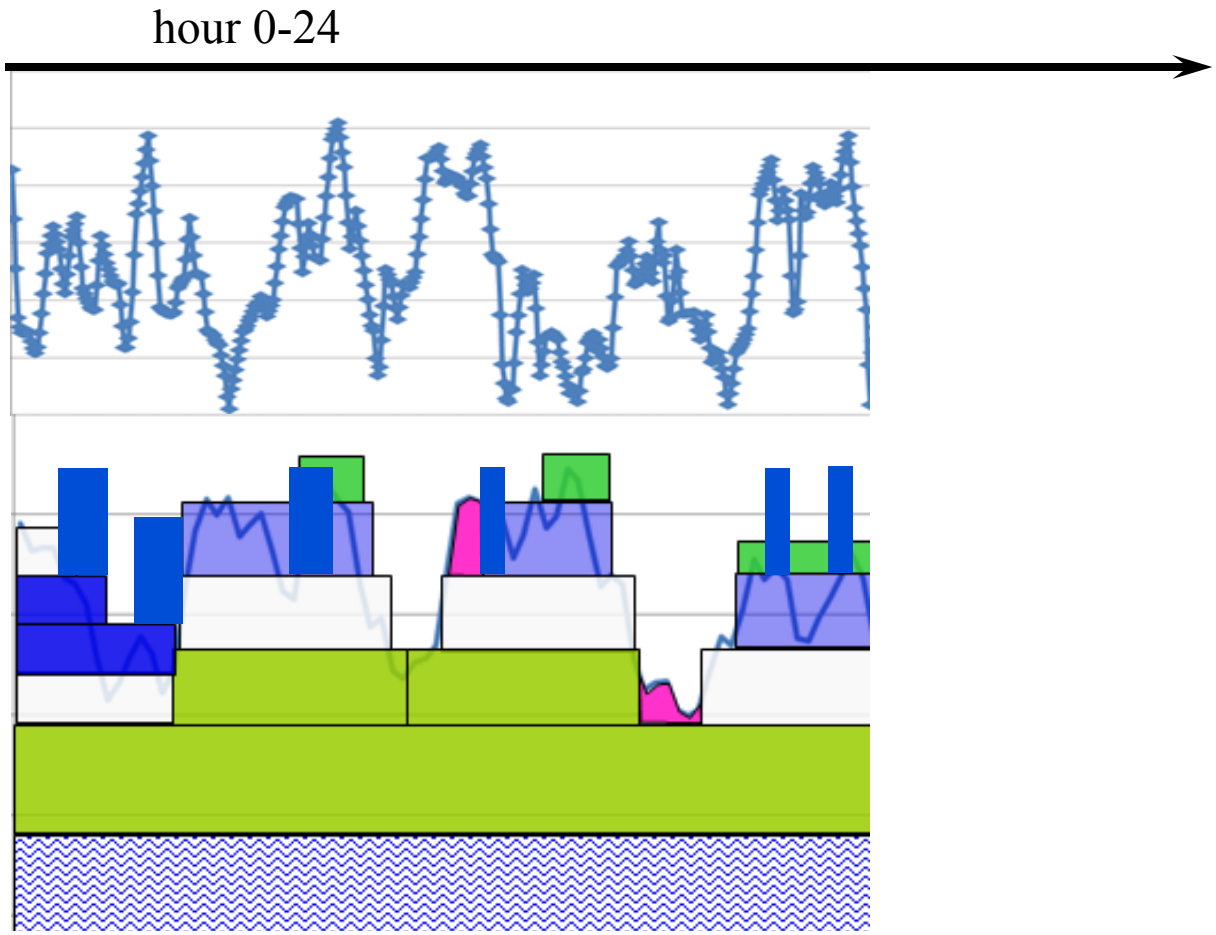

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The stochastic unit commitment problem

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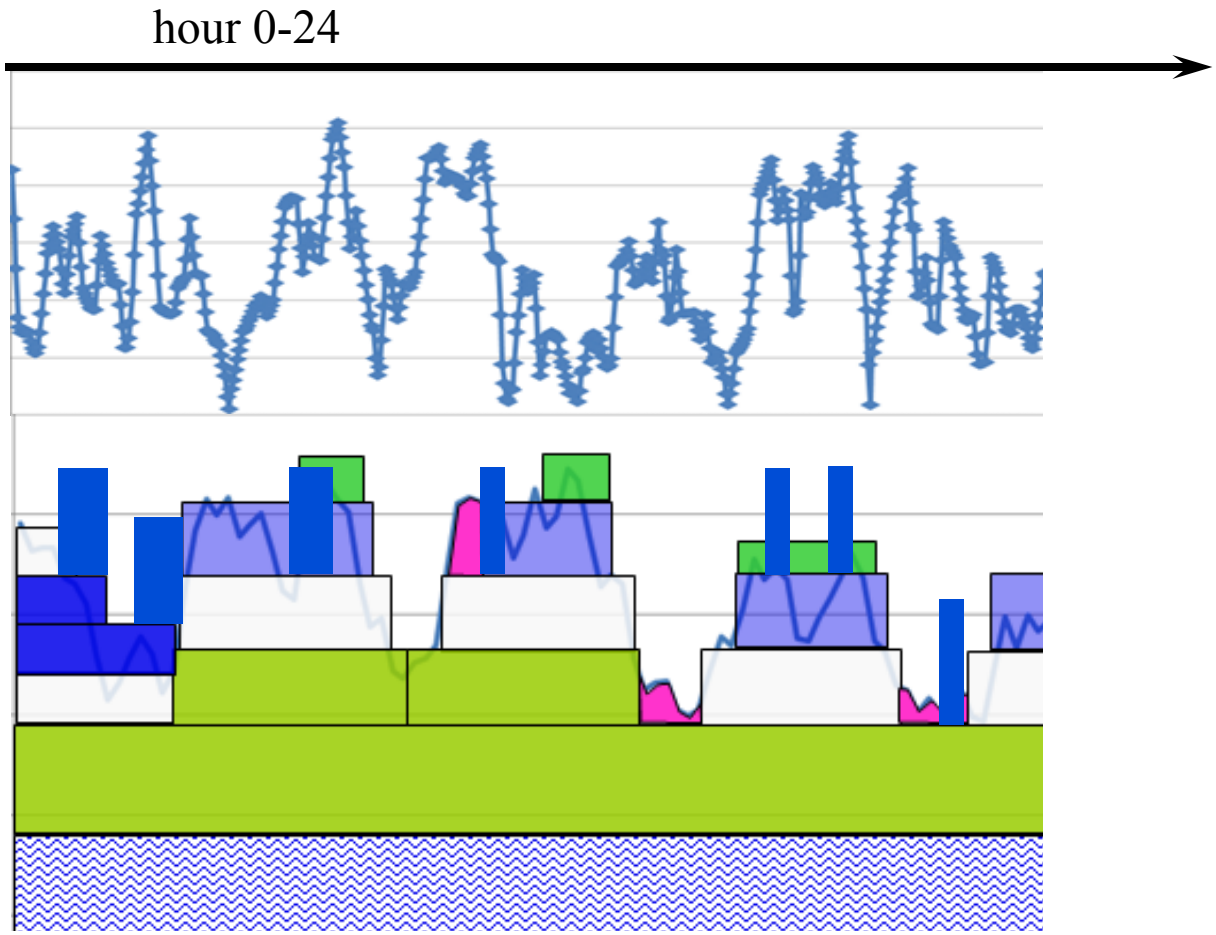

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The stochastic unit commitment problem

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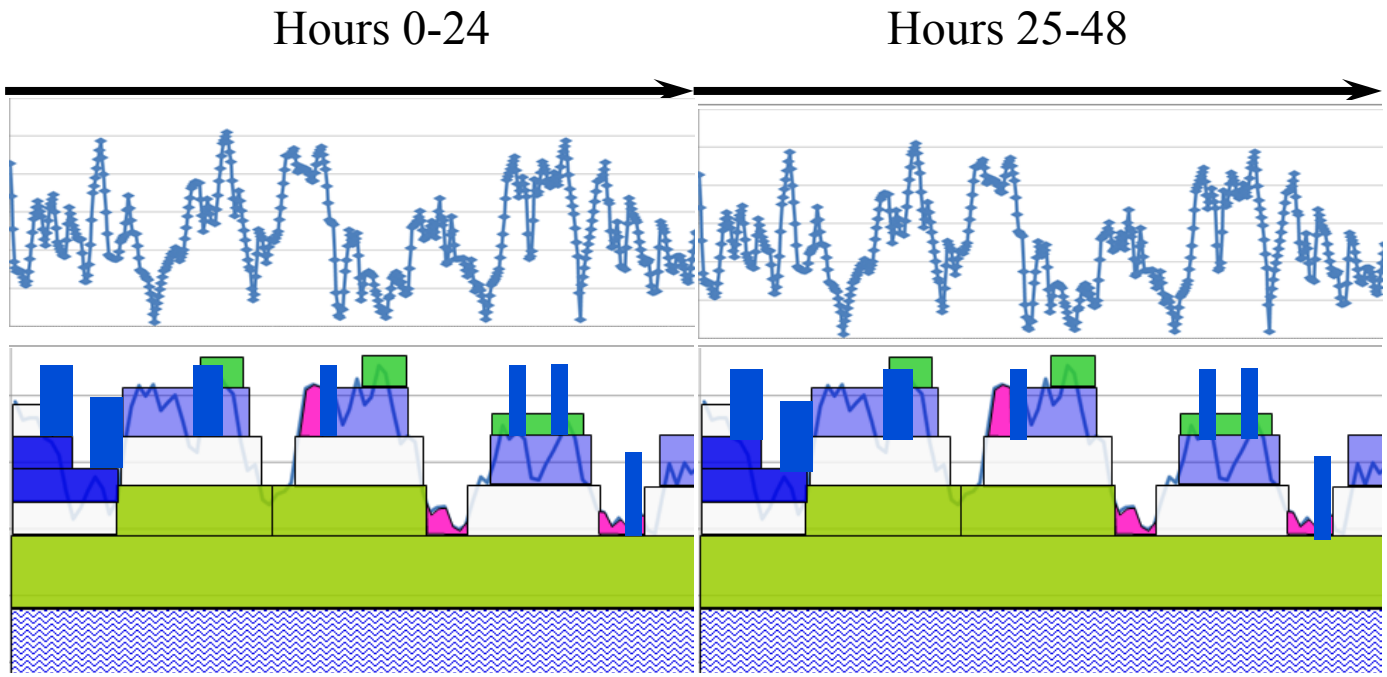

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SMART-ISO:

- Currently implemented and in testing for the PJM market:
  - » 830 generators w/ installed capacity of 164 GW (including 7 GW of pumped storage and hydro)

Mover	Slow GW	Fast GW
Nuclear	32	
Steam	73	2
Combined Cycle	18	6
Gas Turbines	2	24

  - » Historical load data for 2010, in 5-min intervals
  - » Transmission grid aggregated to different levels of kV

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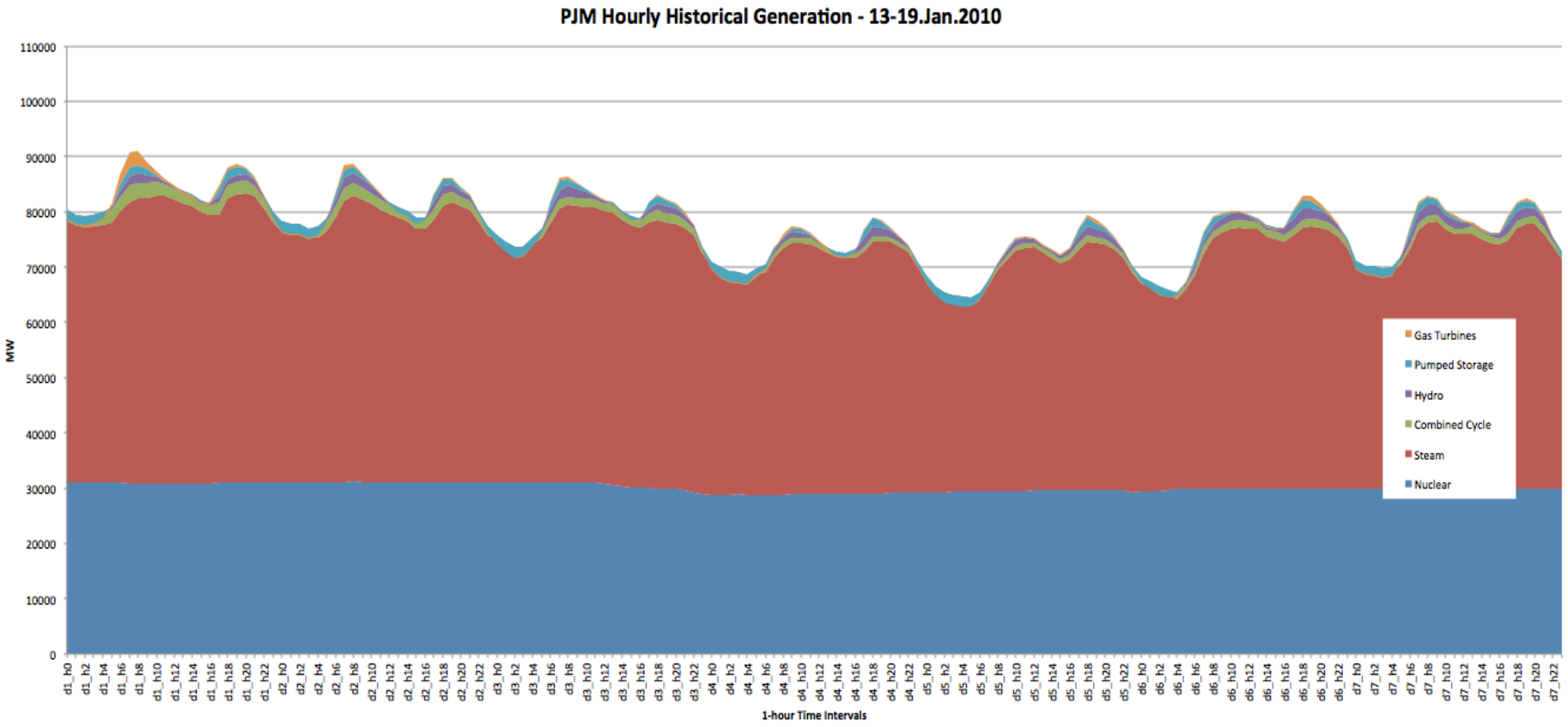
SMART-ISO: Calibration

- Historical power generation during 13-19 Jan 2010



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SMART-ISO: Calibration

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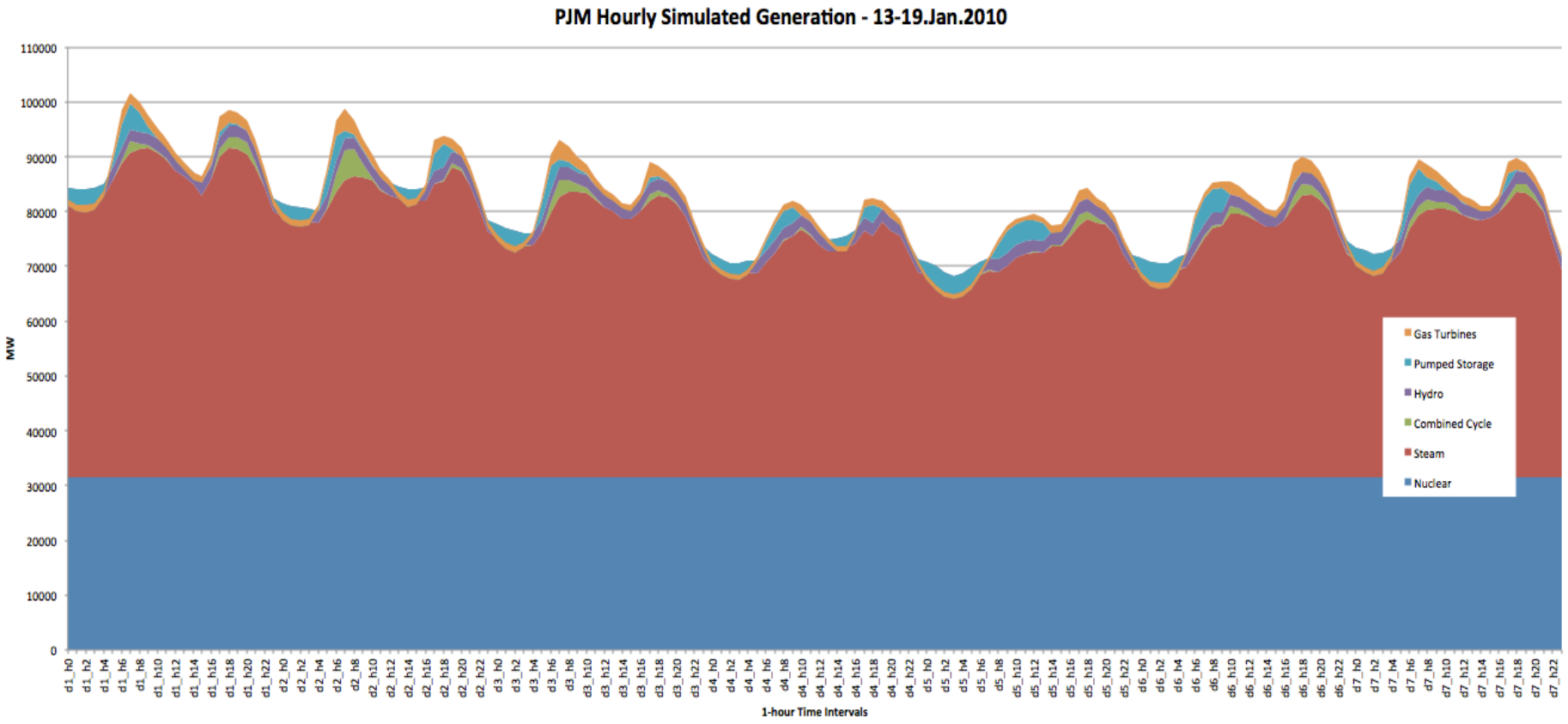

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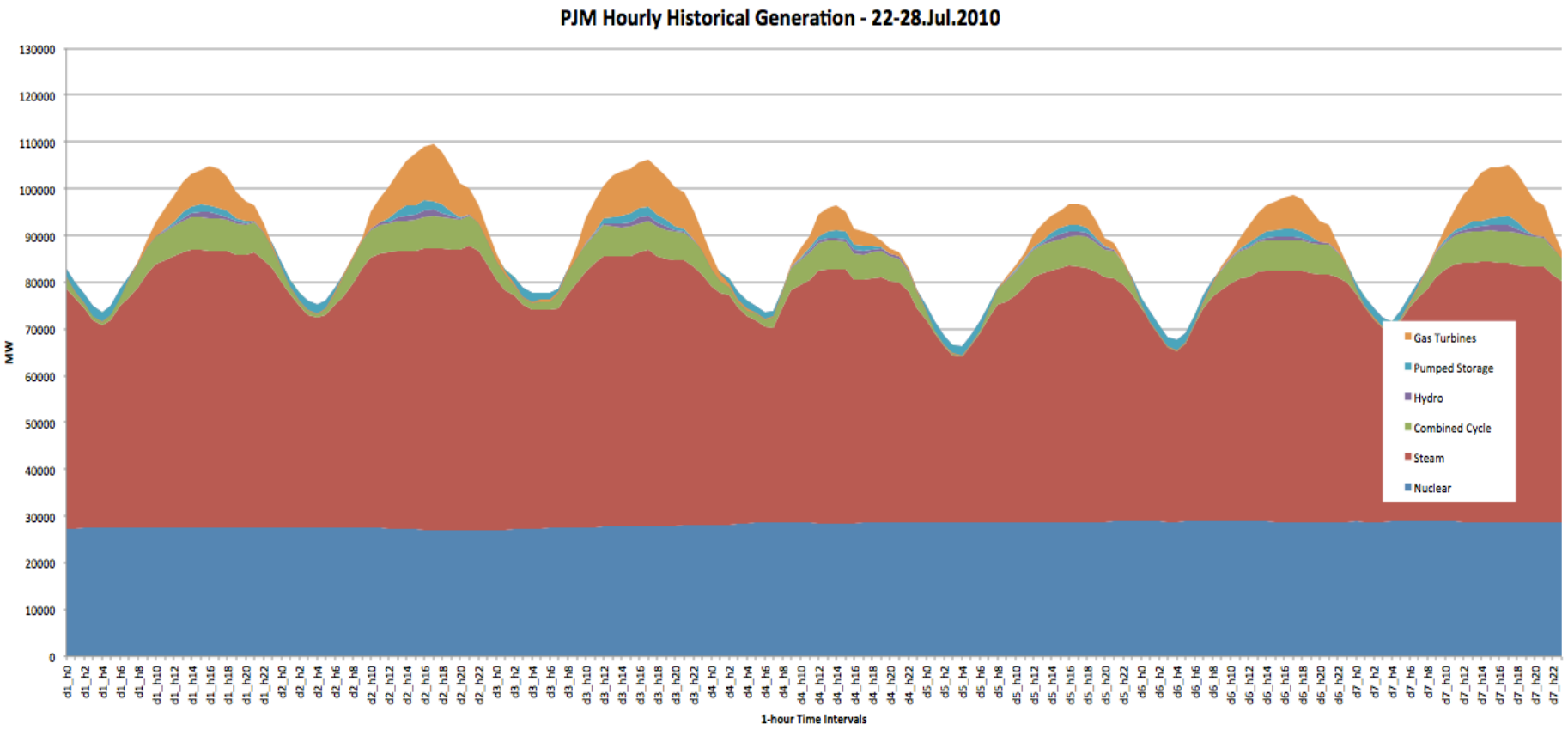
SMART-ISO: Calibration

- Historical power generation during 22-28 Jul 2010



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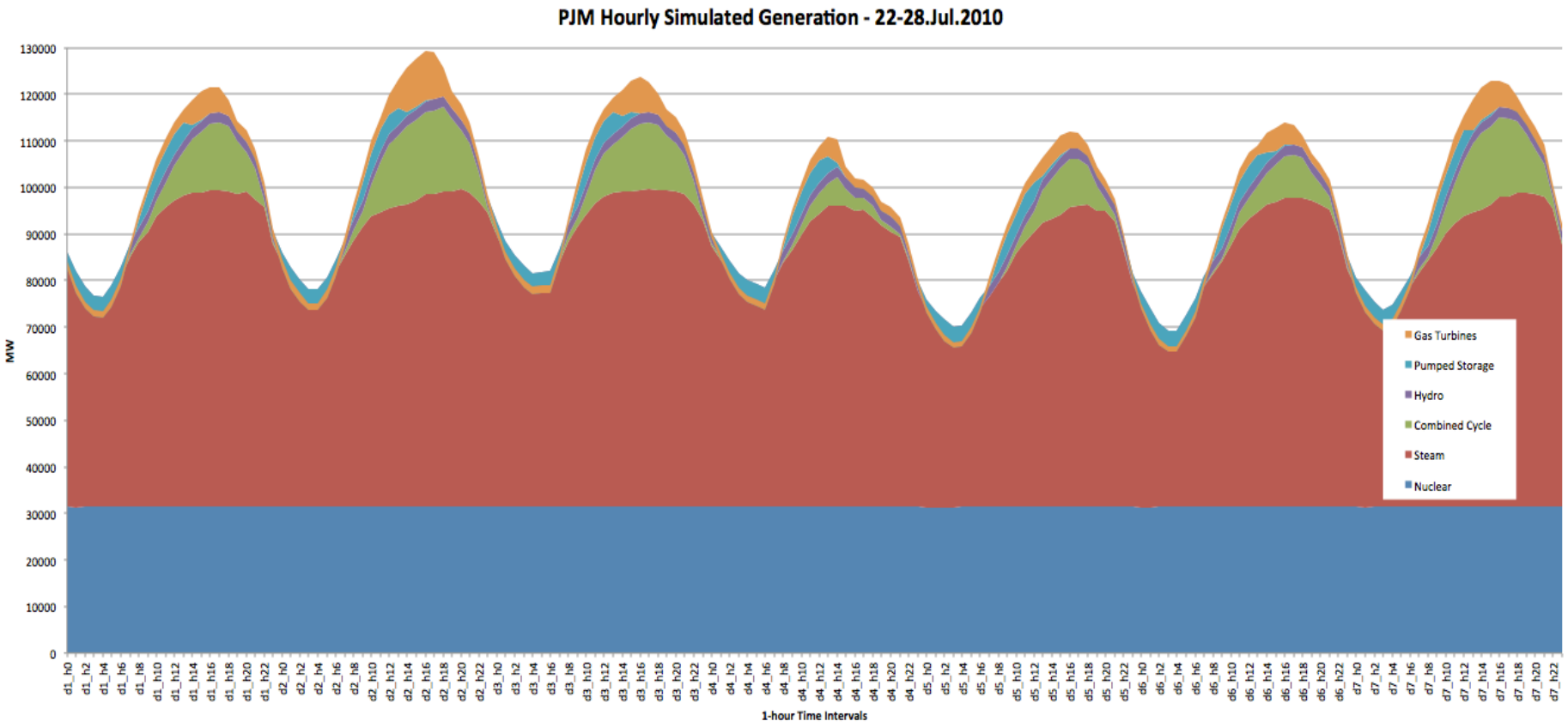
SMART-ISO: Calibration

- Simulated power generation during 22-28 Jul 2010



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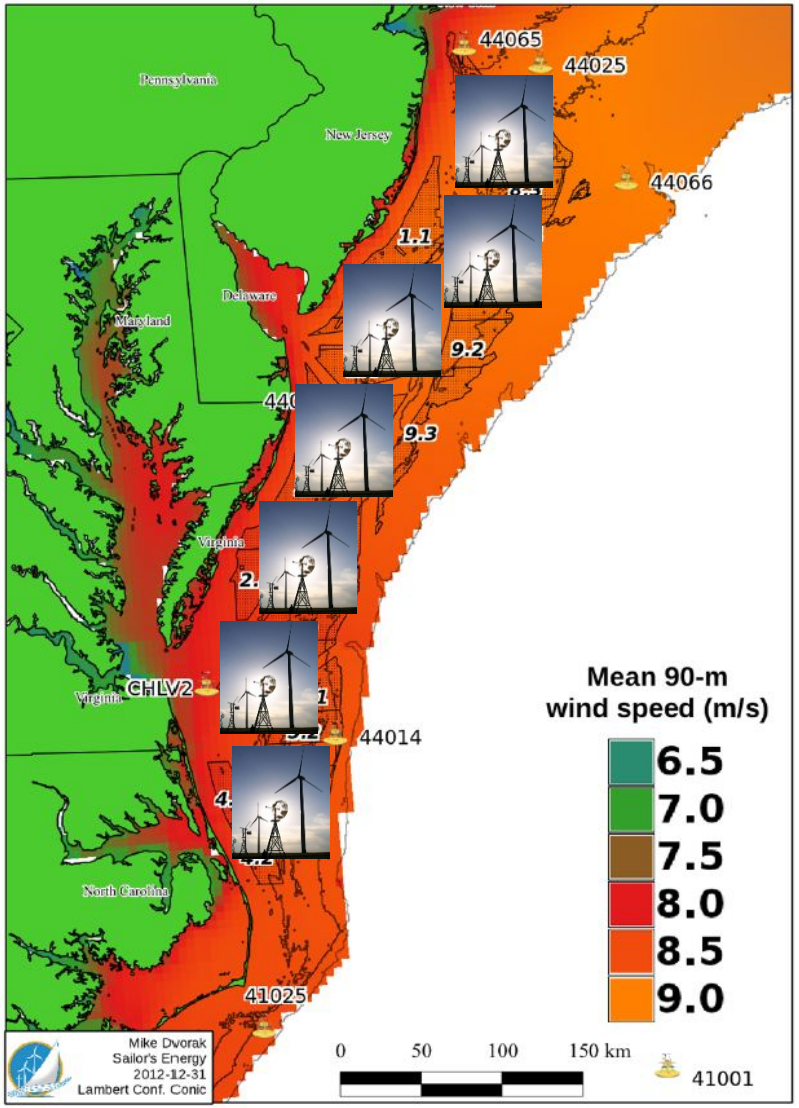
SMART-ISO: Illustrative application

- Mid-Atlantic Offshore Wind Integration and Transmission Study (UD & partners, funded by DOE)
- 29 offshore sub-blocks in 5 build-out scenarios:
  - » 1: 8 GW
  - » 2: 28 GW
  - » 3: 40 GW
  - » 4: 55 GW
  - » 5: 78 GW



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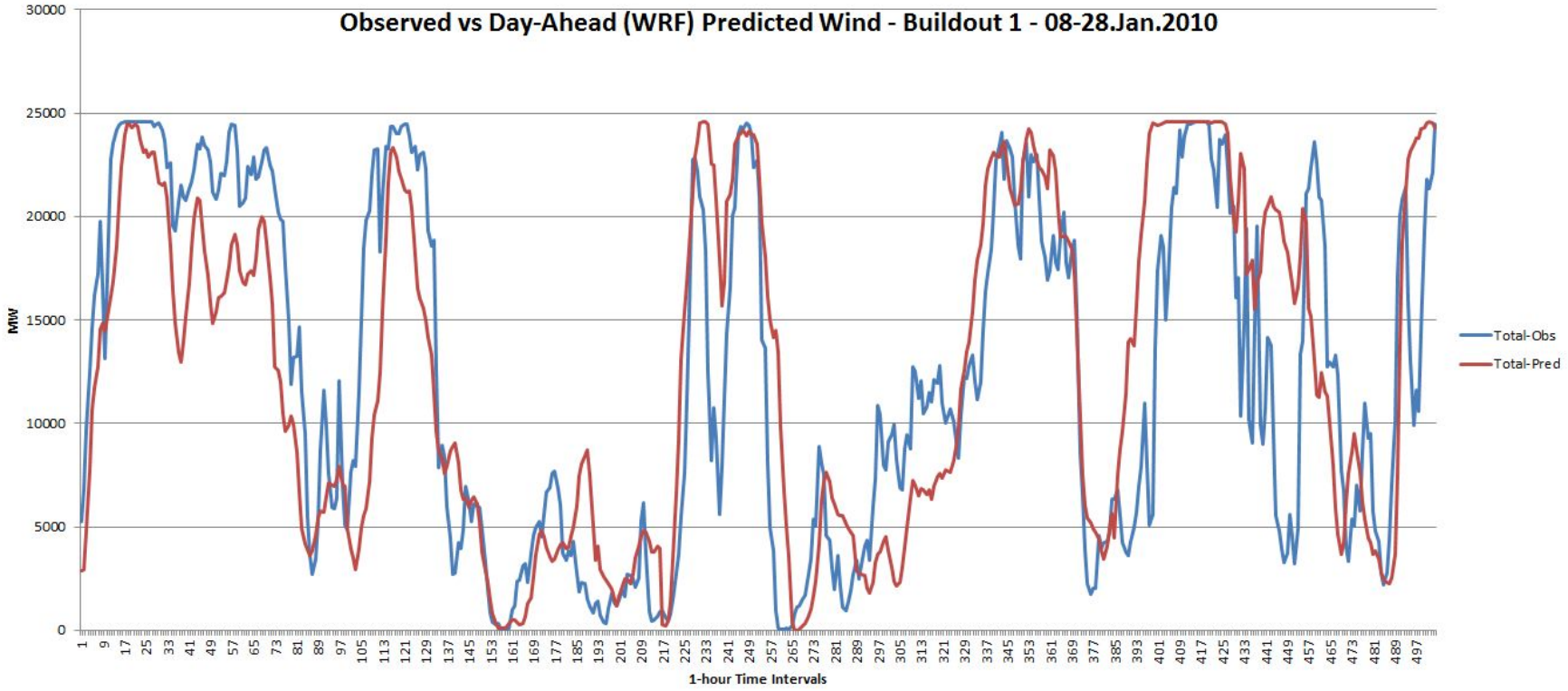
SMART-ISO: Illustrative application

- Observed vs WRF predicted wind on Jan 8-28, 2010



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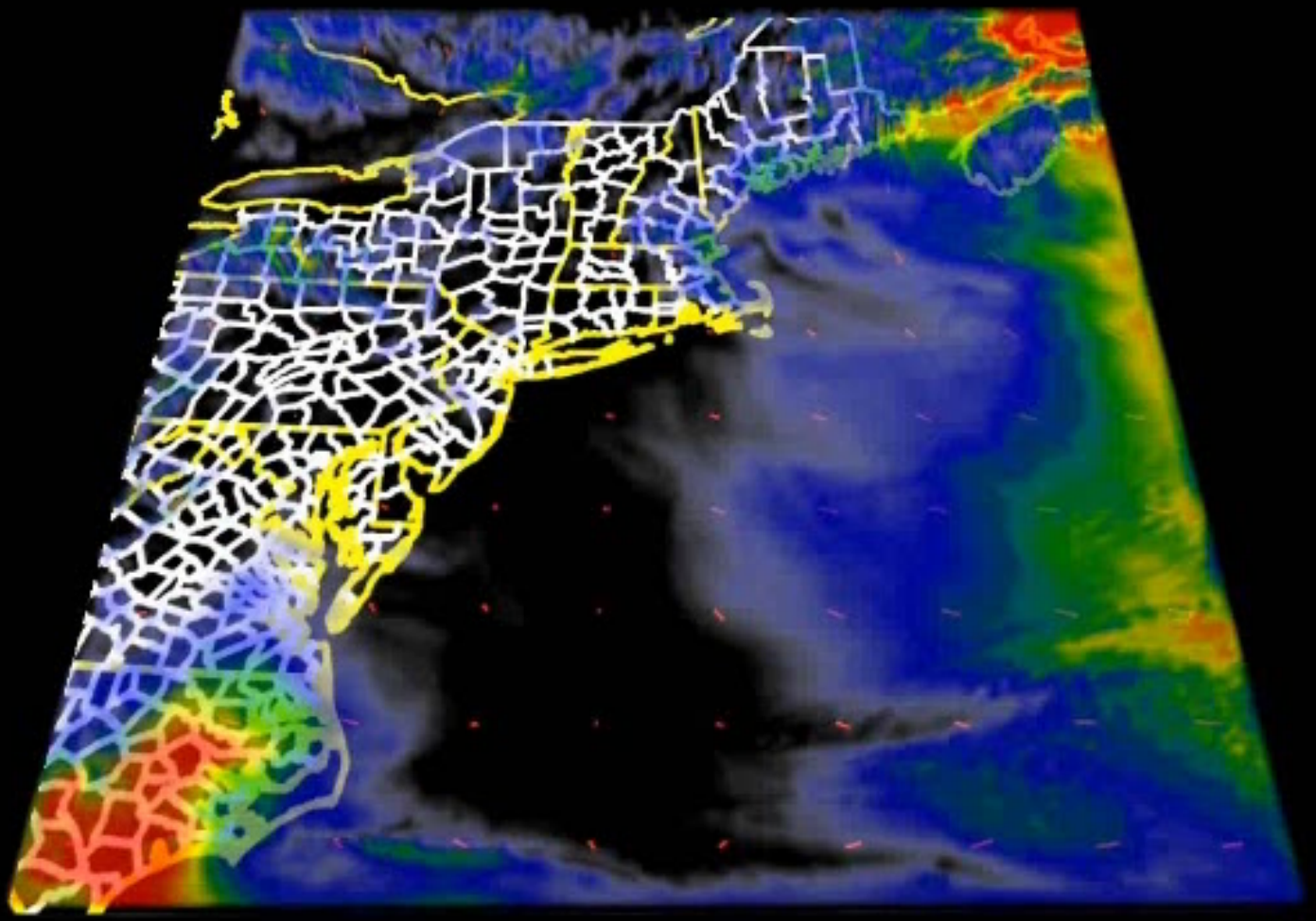

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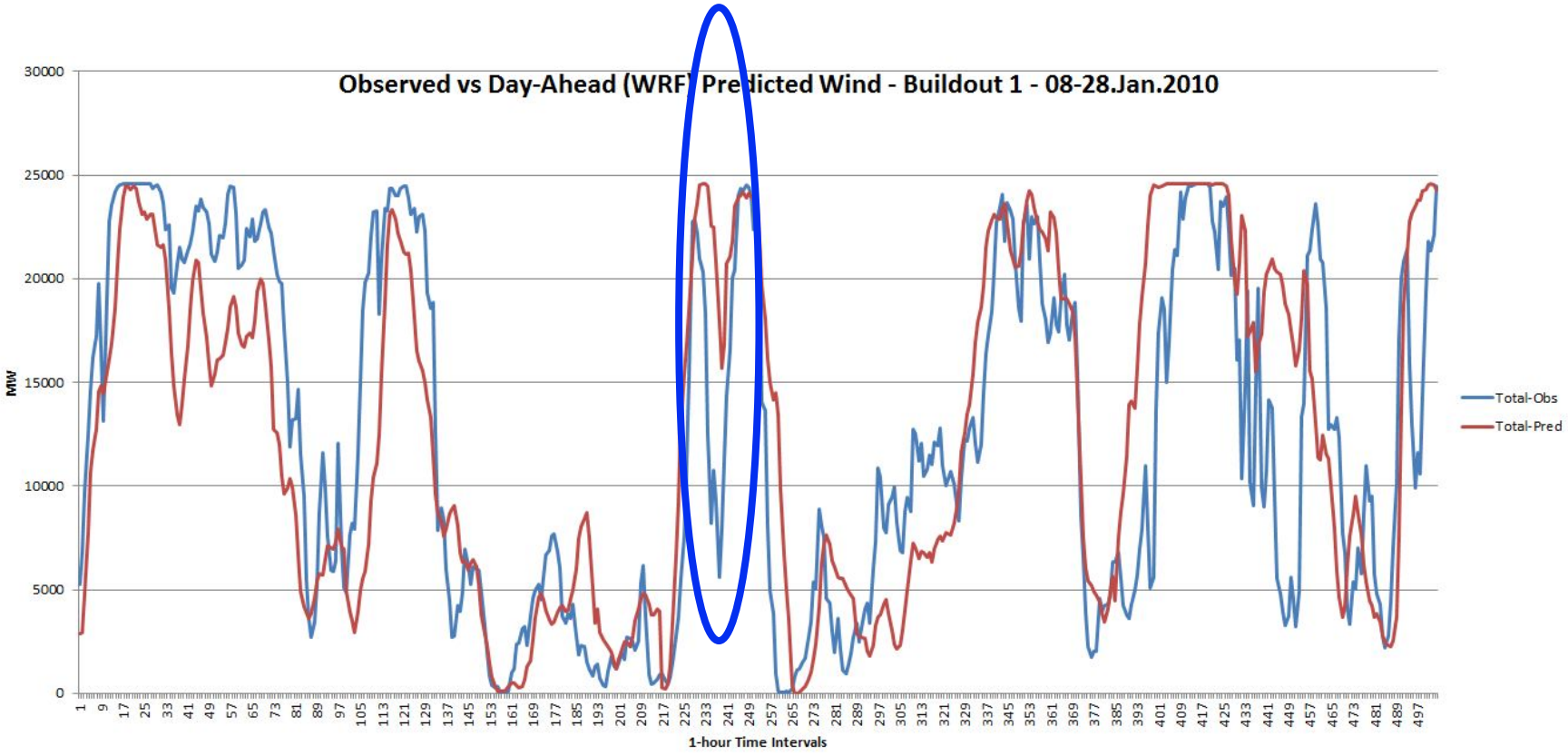
SAILOR'S ENERGY

SMART-ISO: Illustrative application

- Observed vs WRF predicted wind on Jan 8-28, 2010



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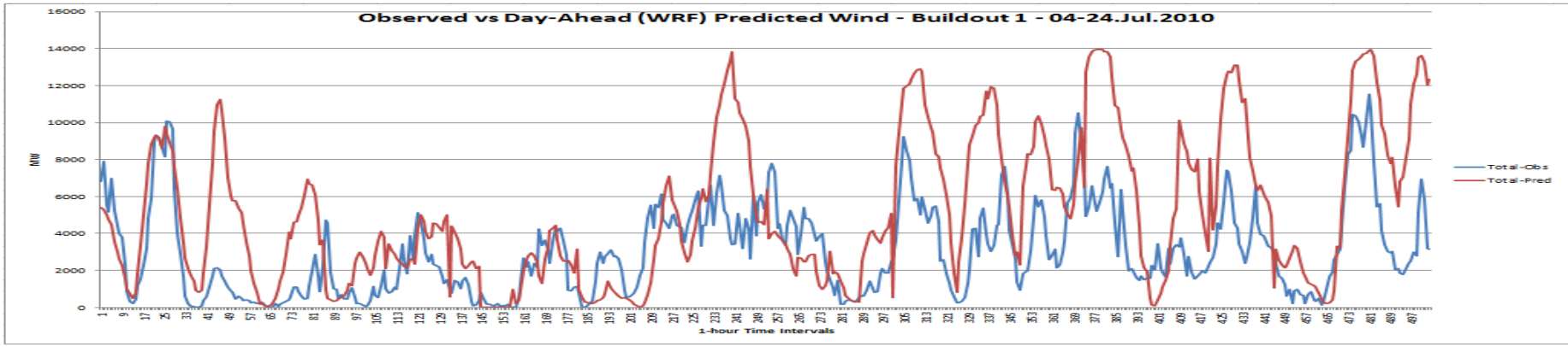
SMART-ISO: Illustrative application

- Observed vs WRF predicted wind on Jul 4-24, 2010
  - » Plotted same scale as January data



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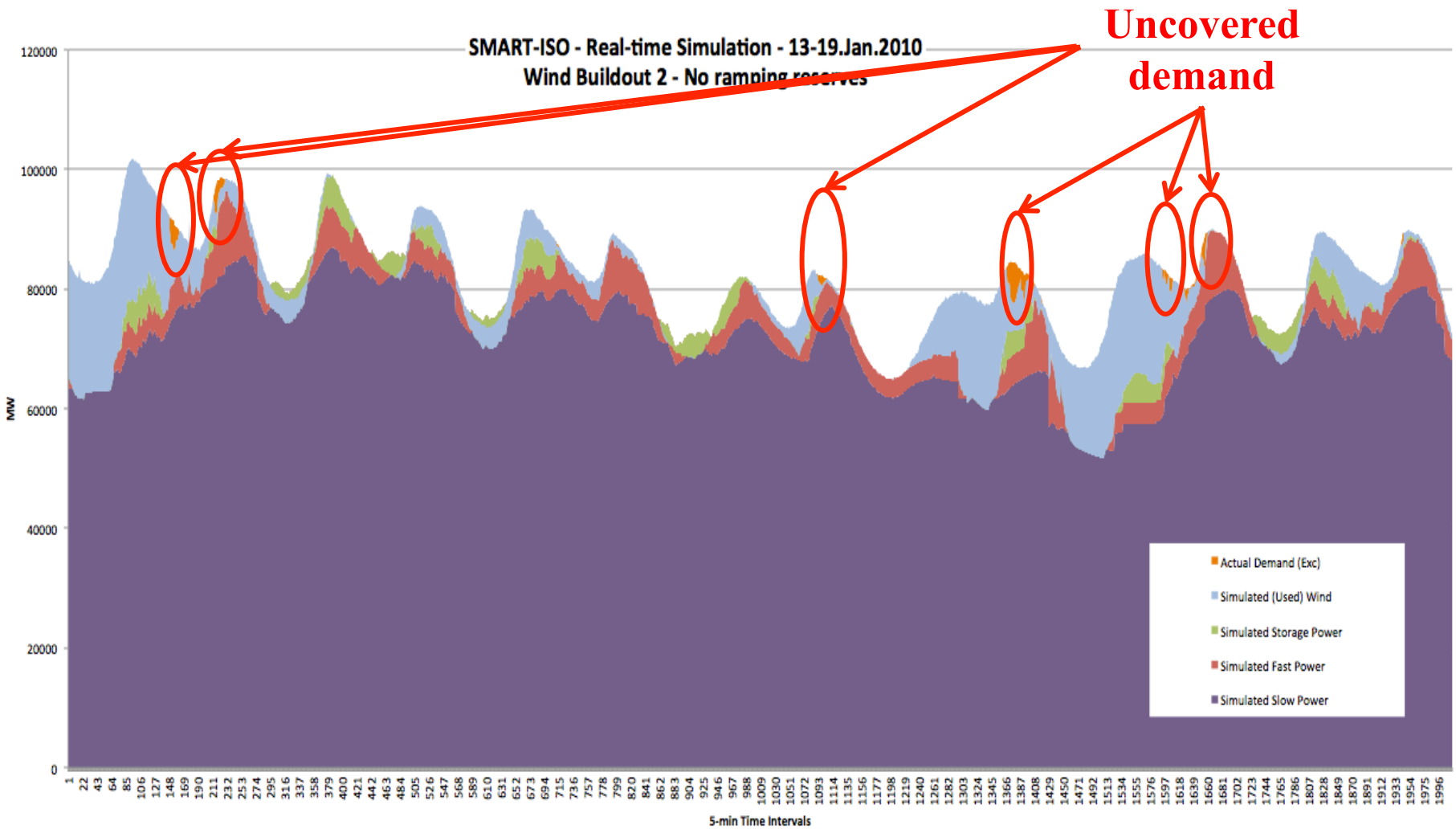
SMART-ISO: Illustrative application



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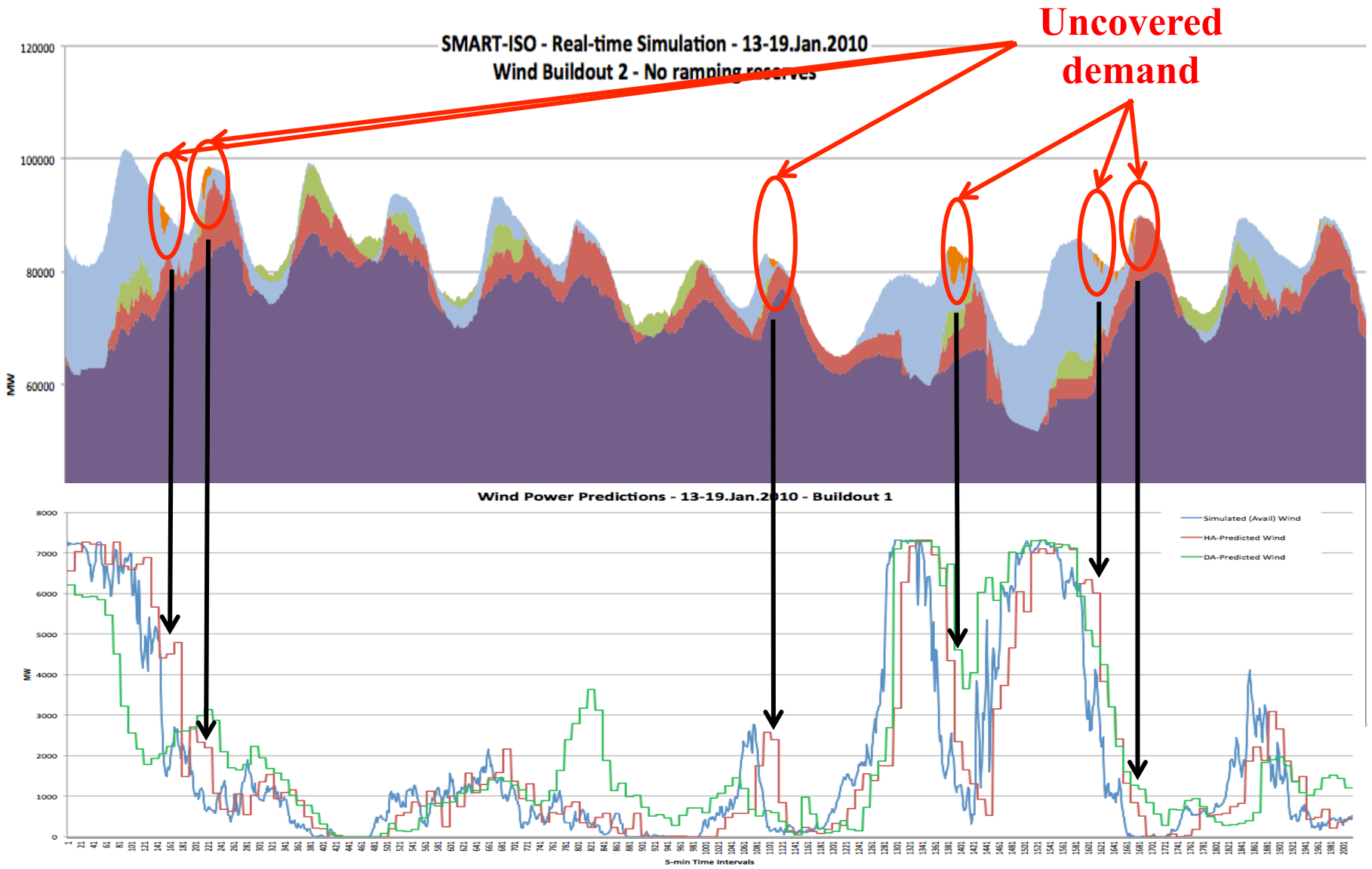
SMART-ISO: Illustrative application



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SMART-ISO: Illustrative application

- Issue: difficulty to forecast precipitous drops in wind in the hour-ahead time frame
- Possible solutions:
  - » Better short-term forecasting models
  - » Require additional spinning reserves, namely, the ability to ramp up (or down) a significant amount of (fast) generation within a relatively short period of time (say, 10 min)

Challenge!

We added the requirement to ramp up (or down) a percentage of the daily peak forecast of VER (in this case, wind).

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SMART-ISO: Illustrative application

- But what should the percentage be?

% of daily peak VER forecast	% Steam	% Nuclear	% Combined Cycle	% Gas Turbines	% Hydro-Pumped Storage	% External (Offshore Wind)	Average Generation Cost ($/MWhr)	Total Demand Shortage (MWhr)	Maximum Demand Shortage (MWhr)
0	49.4	38.1	0.3	1.7	3.8	6.6	16.75	23978	10794
5	48.6	38.0	0.3	2.9	3.8	6.4	17.60	5732	2725
10	47.7	38.0	0.2	4.4	3.7	5.9	18.83	151	86
15	47.3	38.0	0.2	5.0	3.7	5.8	19.69	134	123
20	47.0	38.0	0.2	5.3	3.7	5.8	19.90	0	0
30	46.5	38.0	0.1	6.0	3.7	5.7	20.40	0	0

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SMART-ISO: Illustrative application

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% of daily peak VER forecast	% Steam	% Nuclear	% Combined Cycle	% Gas Turbines	% Hydro-Pumped Storage	% External (Offshore Wind)	Average Generation Cost ($/MWhr)	Total Demand Shortage (MWhr)	Maximum Demand Shortage (MWhr)
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5	48.6	38.0	0.3	2.9	3.8	6.4	17.60	5732	2725
10	47.7	38.0	0.2	4.4	3.7	5.9	18.83	151	86
15	47.3	38.0	0.2	5.0	3.7	5.8	19.69	134	123
20	47.0	38.0	0.2	5.3	3.7	5.8	19.90	0	0
30	46.5	38.0	0.1	6.0	3.7	5.7	20.40	0	0
No Wind	56.8	38.1	0.2	1.3	3.7	0.0	17.90	29	17

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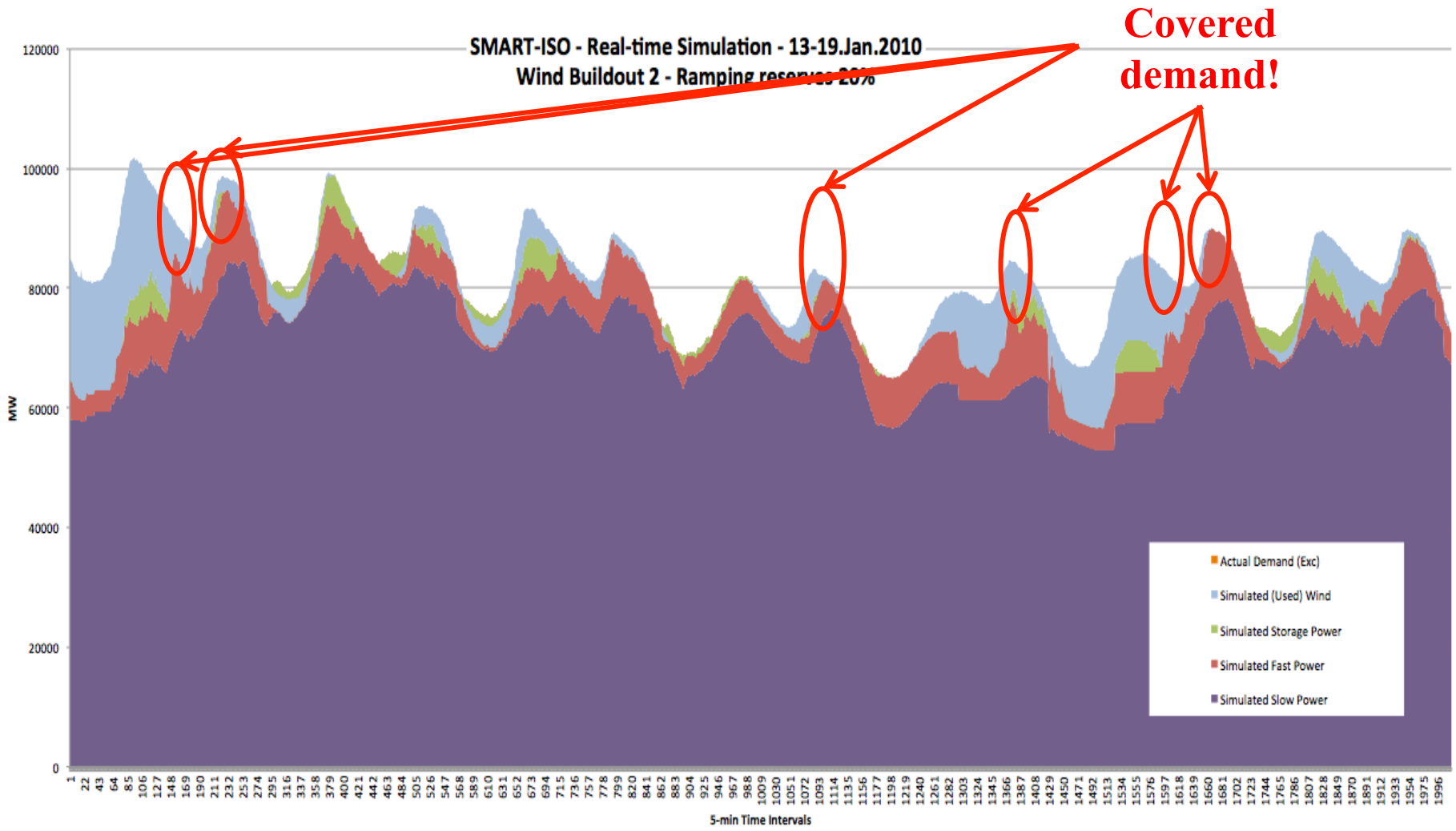
SMART-ISO: Illustrative application



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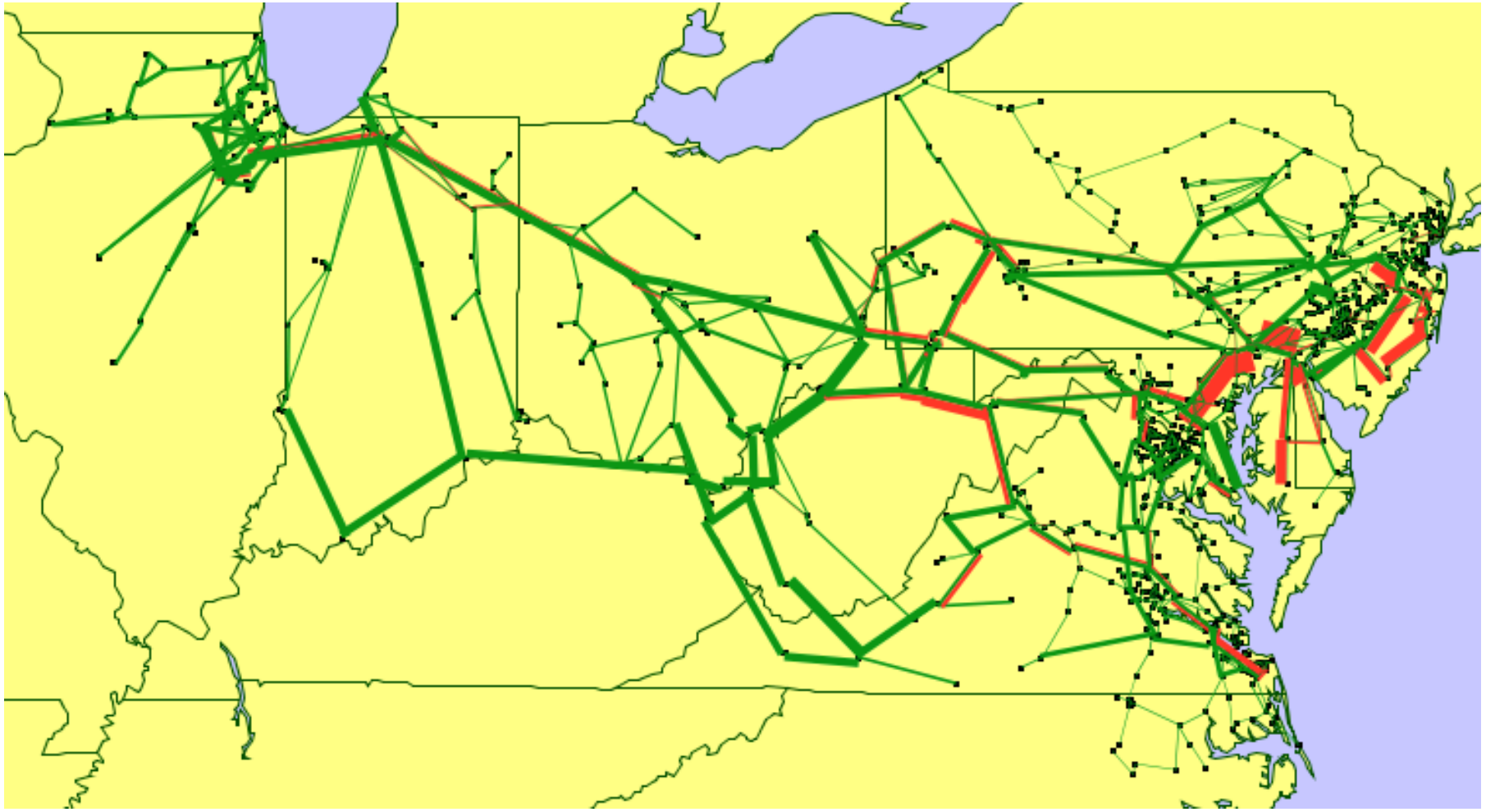
SMART-ISO: Illustrative application

- Possible transmission bottlenecks (220kV):



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Next Steps

- Incorporating an iterative AC power flow logic
- Incorporating demand response strategies (load curtailment and dynamic pricing)
- Developing a Web interface to allow others to run the simulator and perform studies
- Expansion to larger and/or other geographies (MISO, Eastern Interconnect, WECC)

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SMART-ISO website

http://energysystems.princeton.edu/smartiso.htm

SMART-ISO

SMART-ISO is a stochastic, multiscale model of grid operations under development at PENSA, which is currently being built around the full PJM grid. The purpose of this website is to provide ongoing documentation of what we have accomplished, what we are working on and features that we hope to develop in the near future. (If you have been to this website before, be sure to hit your refresh button to ensure you have the latest version.)

When the model settles down, we will begin providing indications of "what is new." For now (summer, 2012) the model is going through rapid evolution and we ask for everyone's patience.

A video of SMART-ISO (new! August 28, 2012)

Overview of SMART-ISO

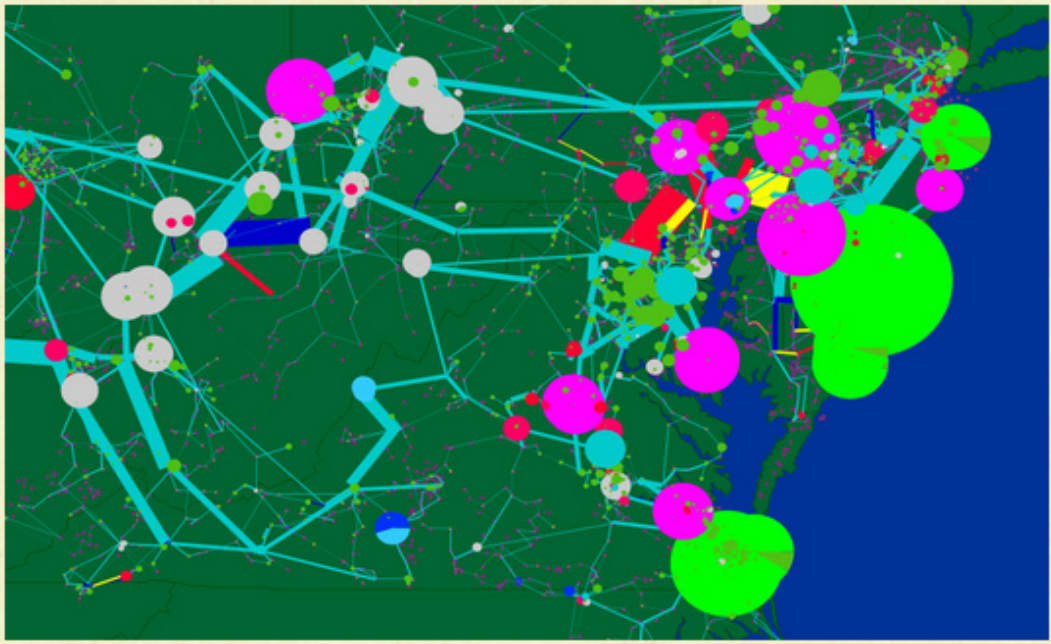
Studies (ongoing and anticipated)

Features (current and planned) (updated August 28, 2012)

Supporting data (updated August 28, 2012)

System components (updated August 28, 2012)

Handling uncertainty

Documentation

The SMART-ISO development team