Stochastic Models for Generation Unit Commitment

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Agenda

▷ Motivation
▷ Day-Ahead and Intraday Stochastic Models
▷ Forecast & Scenario Simulation
▷ Rolling Horizon Evaluation
▷ The GB Model
▷ Results
▷ Conclusions
Our Motivation - Wind Power Uncertainty

- Increasing supply from volatile renewable sources → predictability problem
- Installed Wind in UK 2012: 6.5GW → predicted 2020: 28GW
- In this context, how does day-ahead UC compare to intraday UC?
- What is the added value of stochastic models over deterministic ones?
Deterministic Unit Commitment Problem

- Minimum cost on/off (binary) and power output decisions (24h)
- Constraints: load balance, spinning reserve, generator bounds, up/downtimes, ramp rates
- Large MIP, solved e.g. by B&C
Wind forecast error is captured by including a variety of scenarios.

Multiple wind scenarios result in different residual loads – “spread” increases over time, as forecast uncertainty increases.

Additional constr.: non-anticipativity, startup notification time.
Day-Ahead vs. Intraday Planning: Overview

- UC procedures vary from one operator to another
- Day-ahead example: prepare a 24h schedule between noon and 4pm, schedule becomes active at midnight
- Intraday example: make 24h schedules, update them every 1-3 hours
- Different types of stochastic models: two-stage and multi-stage
Stochastic Day-Ahead Model

- Two-stage stochastic model with 12 wind scenarios
- Forecasts are made well in advance (here: 8h)
- Scenarios are independent, i.e. don’t form a tree
- Non-Anticipativity: common commitments in all scenarios, except OCGT and pumped storage
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Stochastic Intraday Model

- Multistage stochastic model with 12 wind scenarios
- Forecasts are made shortly beforehand (here: 1h)
- Scenarios are organised in a tree structure
- Non-Anticipativity: identical solutions in scenario bundles, identical commitments on first stage, respect startup notification times
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Forecast & Scenario Simulation: Overview

- **Required:**
  - historic wind data
  - historic point forecasts
  - scenarios

- **Available:**
  - historic regional wind speeds [3]
  - scenario generation techniques for forecast errors [6, 2]

- Point forecasts need to be synthesized
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Synthesizing Point Forecasts

- State of the art wind power forecasts combine NWP and TS models [4]
- Synthesized forecasts should match their error statistics [1]
- Step 1: Synthesize forecasts by matching average past wind patterns
- Step 2: Pattern forecasts are unreliable $\geq 6h$ ahead $\rightarrow$ use weighted average of pattern forecast and shifted real wind as final forecast

Forecast error statistics of synthesized forecasts for the year 2010.
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Scenario Simulation and Selection

1. Once point forecasts are available, fit correlated $ARMA(1, 1)$ models to regional error time series [6]
2. Simulate 500+ error scenarios
3. Add errors to point forecasts, translate wind speeds to load factors
4. Select scenarios and merge into a tree if required [2]

Example selecting six scenarios in the region North Wales.
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Example selecting six scenarios in the region North Wales.
Rolling Horizon Evaluation: Overview

- Compare deterministic vs. stochastic models in both, the day-ahead and intraday UC context
- Long term rolling horizon evaluation: define the procedure
Rolling Evaluation: The Intraday Procedure

- Use the wind forecast from one hour ago, solve deterministic model
- ... or a stochastic model. Fix first stage commitments.
- Realize three hours of real wind, adapt OCGT, PS, shed load, remaining reserve. Beyond three hours use the next forecast.
- Roll three hours forward and repeat.
Rolling Evaluation: The Intraday Procedure

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Rolling Evaluation: The Day-Ahead Procedure

- Use wind forecast from eight hours ago, solve det./stoch. model
- Fix all commitments, roll 24h, use exp. initial system state, solve
- Evaluation: Realize three hours of real wind, adapt OCGT, PS, shed load, remaining reserve. Beyond three hours use next forecast.
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![Wind Prediction Graph](image-url)
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![Chart showing wind forecast over time]
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![Wind Forecast Chart](chart.png)
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Rolling Evaluation: Expected Loss Cost Function for Reserve

- Evaluation: after realizing wind, treat reserve as soft constraint – derive a cost function to penalize for keeping too little reserve
  - Besides wind, major uncertainty are failures (assume independent)
  - Expected loss based cost, assuming generators fail every 1.5 years
  - Planning: Stochastic models treat reserve as soft constraint
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![Graph showing expected loss cost function]

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![Graph showing the expected loss cost function for reserve availability. The x-axis represents reserve available for failures in MW, and the y-axis represents expected loss in $/h. The curve indicates a decreasing trend as reserve availability increases, illustrating the cost savings associated with higher reserve levels.](image-url)
The British Model: Overview

- Centrally planned optimal social welfare model of the expected 2020 British National Grid
- Minimize fuel & carbon cost, using estimated generator efficiencies
- 130 conventional generators $\approx 64\text{GW}$ total capacity
- 160 wind farms $\approx 28\text{GW}$ total capacity (30% penetration)
- Pump storage: 2 Scotland, 2 Wales
- Interconnectors: Ireland, France, Netherlands
The British Model: Transmission

- 17 nodes, corresponding to National Grid study zones
- 27 transmission links, only real power variables, no losses, no phase angles
- Transmission limits: single line and boundary import/export constraints
- Local generation/demand, but global reserve with 47% min. conventional reserve
The British Model: LMPs & PS

- An example with very high wind
- Transmission limits split the system in price zones: north-south export pressure
- Pumped storage helps cope with the wind where possible

![Graph showing demand and wind over hours]

Z1
Z2
Z3
Z4
Z5
Z6
Z7
Z10
Z11
Z12
Z16
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Z14
Z15
Z8
Z9
NI
IE
FR NL
B5
B6
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The British Model: Cost Drivers

- A breakdown of cost drivers
- Costs associated with binary decisions are small, thereby reducing the scope of optimization
- Besides good MIP cuts [5], this is a reason for small MIP gaps

![Pie chart with cost drivers](chart.png)
Rolling Evaluation Results

- Focus of the study is performance of the different planning techniques in presence of wind forecast uncertainty
- One year long rolling horizon evaluation of deterministic and stochastic intraday and day-ahead models
- Utilized data: GB 2020 system, wind from 2010 (ARMA model fit to 2009 data), demand and HVDC profiles from 2013, but scaled to meet National Grid’s expectations for 2020
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Conclusions

- Intraday is superior to day-ahead, stochastic intraday models can respect startup notification times (0.9% $\approx$ $0.5M$ daily)
  - Intraday UC requires less spare capacity (lower forecast uncertainty)
  - Stochastic models choose spare capacity levels close to "right" amount
  - Stochastic models have better awareness of the location where spare capacity is required (transmission restrictions)
  - Intraday: stochastic solutions are slightly more cost efficient than deterministic ones (between 0.5% and 0.05% $\approx$ $230k$ and $30k$ daily)
  - Day-ahead: stochastic solutions are much better if deterministic models have too small reserve margin, but similar if they have large reserve margin (max. difference: 3.6% $\approx$ $2.7M$ daily)
- Figures to be interpreted in context: only 2.7% of total cost depend directly on binary decisions, remaining scope of optimization depends on variance of generation cost. This variance may be higher in a market environment.
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G. Giebel, P. Sorensen, and H. Holttinen. 
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Scenario reduction and scenario tree construction for power management problems. 

S. L. Hawkins. 
*A High Resolution Reanalysis of Wind Speeds over the British Isles for Wind Energy Integration.* 
G. Kariniotakis, P. Pinson, N. Siebert, G. Giebel, and R. Barthelmie.
The state of the art in short-term prediction of wind power – from an offshore perspective.

D. Rajan and S. Takriti.
Minimum up/down polytopes of the unit commitment problem with start-up costs.

L. Söder.
Simulation of wind speed forecast errors for operation planning of multi-area power systems.
Backup: More Rolling Evaluation Results

- Variability of reserve levels in the evaluation step
- Left: average and standard deviation of reserve levels in evaluation of deterministic intraday and day-ahead planning
- Right: even perfect foresight plan uses the essential part of reserve (at associated cost). Not more than the essential 1.52GW is ever allocated (same in all other evaluations).
Backup: Dantzig-Wolfe Scenario Decomposition

- Multiple scenarios with different residual loads
- Non-anticipativity constraints bundle the commitments in different scenarios. Here: multi-stage stochastic model.
- How to exploit the structure imposed by bundles?

Tree with four wind power scenarios.
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Four independent wind power scenarios.
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- An overview of the column generation procedure
  - RMP initialization: initial primal and dual guess
  - Dually stabilized: perturb RMP and initial LP relaxation
  - Heuristics: RMP initialization, repeat in the process for better bounds
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Diagram:

1. Initialize RMP
2. Add violated rows to RMP
3. New rows violated?
   - yes: Add columns with negative reduced cost to RMP
   - no: Solve RMP
4. Solve RMP
5. Solve pricing
6. Columns
7. All reduced costs ≥ 0?
   - no: Go back to 2
   - yes: Terminate
Backup: Dantzig-Wolfe Scenario Decomposition

- Performance results: B&C on det. equivalent vs. decomposition
- The decomposition outperforms direct B&C on large problems
- When opt. primal solution is found, MIP formulation is tight enough for CPLEX to terminate at root node (Heuristic+CPLEX)
- 16 threads, Linux 64bit 128GB RAM, Dual 8 Core Intel Xeon