The Impact of Short-term Variability and Uncertainty on Long-term Power Planning Problems

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Motivation

- More RES → more variability and uncertainty

Wind production in DK1

Wind production and forecast error 2014

Wind production and forecast error January 2014
Motivation

- More RES → more variability and uncertainty → dynamic and stochastic optimization → computational problems

Wind production in DK1

Wind production and forecast error 2014

Wind production and forecast error January 2014
Research questions

- Quantify the trade-off between including uncertainty and variability of renewable production in terms of performance and computational times.
- How to include short-term uncertainty and variations in the best way.
Short-term effects

Two short-term effects that call for flexible generation:

- Inter-temporal variation.
- Uncertainty balancing.

They overlap but we try to analyse them separately - inter-temporal variations through ramping limits and uncertainty balancing market.
### Short-term effects

Two short-term effects that call for flexible generation:
- Inter-temporal variation.
- Uncertainty balancing.

They overlap but we try to analyse them separately - inter-temporal variations through ramping limits and uncertainty balancing market.

### Investment model

Static central planner investment model:
- Central planner minimizes investment and operating cost
- No existing generating capacity
- Minimum wind penetration constraint

For simplicity, disregard unit commitment decisions and network constraints.
Models

Model overview (LP)

\[
\begin{align*}
\text{Min}_{p_g, p_{gt}, \bar{p}_{gts}} & \quad \sum_g \left[ C^I(\bar{p}_g) + \sum_t (C^{DA}(p_{gt}) + \sum_s \pi_s C^B(\tilde{p}_{gts})) \right] \\
\text{s.t.} & \quad p_{gt} \leq \bar{p}_g \quad \forall g \\
& \quad \sum_g p_{gt} = d_t \\
& \quad -r_g \leq p_{gt} - p_{g(t-1)} \leq r_g \quad \forall g \\
& \quad \sum_g \bar{p}_{gts} = 0 \\
& \quad 0 \leq p_{gt} + \bar{p}_{gts} \leq \bar{p}_g \quad \forall g \\
& \quad -r_g \leq p_{gt} + \bar{p}_{gts} - p_{g(t-1)} - \bar{p}_{g(t-1)s} \leq r_g \quad \forall g
\end{align*}
\]

Objective

Day-ahead

Balancing

Additional

- Load shedding (with cost)
- Wind curtailment (with cost)
## Models

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<th>Approaches</th>
<th>Daily approach With ramping</th>
<th>Hourly approach Without ramping</th>
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<td>HS</td>
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<td>With balancing market</td>
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Example

Illustrative Example

Illustrative example with a time horizon of 6 days
Illustrative Example

Illustrative example with a time horizon of 6 days

Demand and wind

Each day consists of two time periods.

Variation over time

- Day 1
- Day 2 (average)
- Day 3

δ_d

Stochastic variation

- δ_w
- s_1
- s_2

Demand and wind
Units

In order to pinpoint the different effects, units are assumed very specialized (and unrealistic).

The considered units are: wind, inflex, flexDA, flexBal and flex.

Evaluation

The investment decisions from each approach is fixed in the full (DS-6) model in order to evaluate the impact of investments in terms of total system costs.

For each approach, the procedure is:

1. Solve the problem.
2. Fix the investment decision in the full approach.
3. Solve the full approach for day-ahead and balancing production variables.
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Introduction

Short-term effect

Models

Example

Case Study

Conclusion

Example

Results

Analysis:

• Uncertainty and variations effects

• In this example, uncertainty is dominant.
Case Study

Data and approach

- Data from region DK1: Demand, Wind forecast and Wind production.
- Uncertainty in forecast error - modelled as an AR(2) process and scenarios sampled from this.
- Realistic investment data (annualized)
- Representative days/hours from clustering.
- Official 2020 target: 30% RES.
- No initial installed capacity.

Figure: Source: nordpoolspot.com
Case Study

Units

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Table: Generation unit data for the case study. Sources: [1],[2],[3]

Balancing costs $c_g^+, c_g^-$ are assumed as 20% of the linear production cost $c_g$. 
Case Study

Full model results

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Table: Investment decisions and runtimes for the different approaches. Total costs (TC), investment costs (IC), operating costs (OC) and load shedding costs (LSC) all in M€

Analysis

- W/ ramping: nuclear is substituted by coal.
- W/ uncertainty: increase in coal and gas.
- Stochastic model increases runtime.
Case Study

Varying no. of days/hours

- Low impact from no. of hours.
- For more than 40 days, uncertainty is irrelevant.

Figure: Total costs difference in % between aggregated approaches and DS-365.
Case Study

Investment decisions

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Legend:
- HC
- HS
- DC
- DS
- DS-365
Sensitivity Analysis

Balancing costs reflects ramping \( c_g^+ = M \frac{c_g}{p_g} \)

- Balancing costs have an effect.
- Hard to get realistic estimate.
- In this model, ramping is still more important.
Conclusion

- Including short-term uncertainty in generation expansion models yields a high computational burden but no significant better solution.
- Including inter-temporal constraints is crucial to capture flexibility needs.
- The coupling of flexibility in a realistic setup regarding short-term variability and uncertainty means including variability needs also serves the uncertainty needs.
Conclusion

• Including short-term uncertainty in generation expansion models yields a high computational burden but no significant better solution.

• Including inter-temporal constraints is crucial to capture flexibility needs.

• The coupling of flexibility in a realistic setup regarding short-term variability and uncertainty means including variability needs also serves the uncertainty needs.

Further research

• Include network, unit commitment constraints, market power etc.

• Clustering days/hours more efficiently.
Thank you for your attention.

Any questions?


## Appendix

### Unit Data

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Evaluation steps

In order to evaluate the investment decisions resulting from the different approaches, the following procedure is incorporated:

1. Solve each of the approaches: DC-6, DS-6, DC-2, DS-2, HC-4, HS-4.

2. Fix the investment decision made by each approach and solve the generation expansion problem using the DS-6 approach (without minimum wind constraints).

3. Evaluate the investment decisions of each approach by simulating the real system operation that includes both time variability and short-term uncertainties.
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Bylling, Pineda, Boomsma

References

Appendix

Appendix

<table>
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<th>Approach</th>
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Table: Investment decisions and runtimes for the different approaches.
Sensitivity Analysis

Increased wind uncertainty

![Graph showing increased wind uncertainty](image1)

Analysis on balancing costs

![Graph showing analysis on balancing costs](image2)

Sensitivity Analysis

- Stochastic approaches outperform the deterministic approaches as uncertainty increases.
- Daily approaches still outperform hourly approaches.
- No effect from balancing costs.
## Appendix

### Computer statistics

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