Impact of Forecast Errors on Expansion Planning of Power Systems with a Renewables Target

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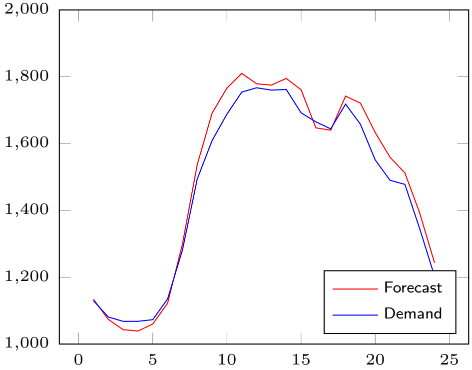
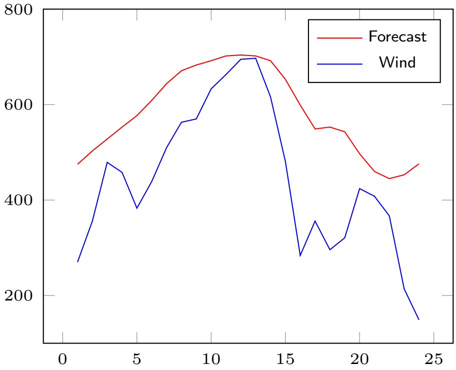
Wind power production

- Wind power production **varies** through time
- Wind power production is **hard to predict** in advance

Demand DK2 (12/08/14)



Wind DK2 (12/08/14)



We were wondering...

- How can we account for forecast errors within current generation and transmission capacity expansion models?

- What is the impact of these forecast errors on generation and transmission capacity expansion planning?

- What is the impact of the market design on generation and transmission capacity expansion planning?

Some assumptions

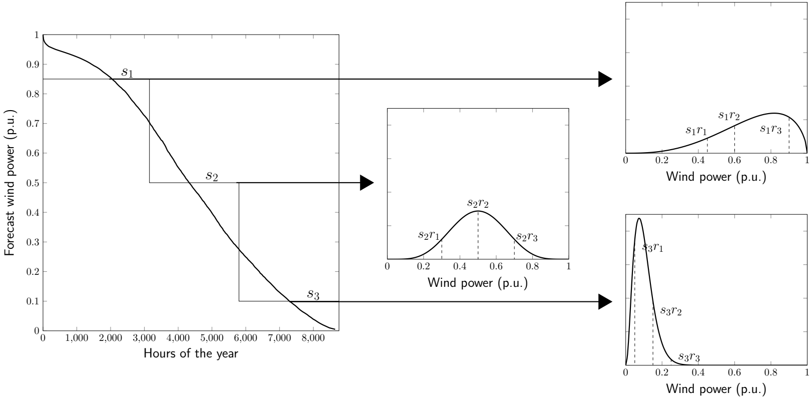
- Static expansion models (single target year)
- Focus on short-term system operation
- Unit commitment costs are internalized through balancing offers
- No inter-temporal constraints (stationary process)
- Energy-only market with marginal pricing
- Perfect competitive market (central planner approach)
- Inelastic demand
- DC representation of the network

Two markets floors

Day-ahead market
(24 hours before operation)

→

Balancing market
(30 minutes before operation)



Coordination between the two market floors

Inefficient market

Day-ahead: min $\mathcal{C}^D(\Phi^D)$

$\downarrow \Phi^D$

Balancing: min $\mathcal{C}^B(\Phi^D, \Phi^B)$

Efficient market

Day-ahead + balancing

min $\mathcal{C}^D(\Phi^D) + \sum_r \pi_r \mathcal{C}^B(\Phi^D, \Phi^B)$

- Cheapest day-ahead
- Expensive balancing
- High total cost
- Reserves after energy

- More expensive day-ahead
- Cheaper balancing
- Minimum total cost
- Simultaneous reserve and energy

We have compared three models

- G-T expansion problem **without forecast errors**
- G-T expansion problem with forecast errors under **efficient market**
- G-T expansion problem with forecast errors under **inefficient market**

G-TEP without forecast errors

$$
\begin{aligned}
\underset{\overline{p},\Phi_s^D}{\text{Min}} \quad & \sum_s \tau_s \mathcal{C}^D\left(\Phi_s^D\right) + \mathcal{C}^I\left(\overline{p}\right) \\
\text{s.t.} \quad & \psi \geqslant \psi_{\text{target}} \\
& f\left(\overline{p}\right) \leqslant 0 \\
& h^D\left(\Phi_s^D; l_s\right) = 0, \quad \forall s \\
& g^D\left(\overline{p}, \Phi_s^D; \rho_s\right) \leqslant 0, \quad \forall s.
\end{aligned}
$$

$\overline{p}$	capacity of new lines and conventional/stochastic generation
ψ	demand covered by stochastic generation (%)
Φ_s^D	dispatch decisions
ρ_s	capacity factor of stochastic units

G-TEP with forecast errors under efficient market

$$\begin{aligned}
\underset{\overline{p},\Phi_s^D,\Phi_{sr}^B}{\text{Min}} \quad & \sum_s \tau_s \left(\mathcal{C}^D \left(\Phi_s^D\right) + \sum_r \pi_{sr} \mathcal{C}^B \left(\Phi_{sr}^B\right) \right) + \mathcal{C}^I \left(\overline{p}\right) \\
\text{s.t.} \quad & \psi \geqslant \psi_{\text{target}} \\
& f\left(\overline{p}\right) \leqslant 0 \\
& h^D \left(\Phi_s^D; l_s\right) = 0, \quad \forall s \\
& g^D \left(\overline{p}, \Phi_s^D; \rho_s\right) \leqslant 0, \quad \forall s \\
& h^B \left(\Phi_{sr}^B\right) = 0, \quad \forall s, \forall r \\
& g^B \left(\overline{p}, \Phi_s^D, \Phi_{sr}^B; \rho_s, \Delta\rho_{sr}\right) \leqslant 0, \quad \forall s, \forall r.
\end{aligned}$$

Φ_{sr}^B re-dispatch decisions

$\Delta\rho_{sr}$ variation of capacity factor

G-TEP with forecast errors under inefficient market

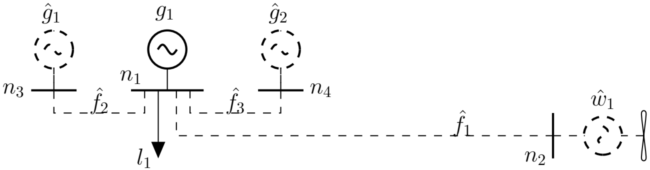
$$\underset{\overline{p},\Phi_s^D,\Phi_{sr}^B}{\text{Min}} \quad \sum_s \tau_s \left(\mathcal{C}^D\left(\Phi_s^D\right) + \sum_r \pi_{sr} \mathcal{C}^B\left(\Phi_{sr}^B\right) \right) + \mathcal{C}^I\left(\overline{p}\right)$$

$$\begin{aligned}
\text{s.t.} \quad & \psi \geqslant \psi_{\text{target}} \\
& f\left(\overline{p}\right) \leqslant 0 \\
& h^B\left(\Phi_{sr}^B\right) = 0, \quad \forall s, \forall r \\
& g^B\left(\overline{p}, \Phi_s^D, \Phi_{sr}^B; \rho_s, \Delta\rho_{sr}\right) \leqslant 0, \quad \forall s, \forall r
\end{aligned}$$

$$\Phi_s^D \in \mathsf{arg}\left\{ \begin{array}{ll} \underset{\Phi_s^D}{\text{Min}} & \mathcal{C}^D\left(\Phi_s^D\right) \\ \text{s.t.} & h^D\left(\Phi_s^D; l_s\right) = 0 \\ & g^D\left(\overline{p}, \Phi_s^D; \rho_s\right) \leqslant 0 \end{array} \right\} \forall s.$$

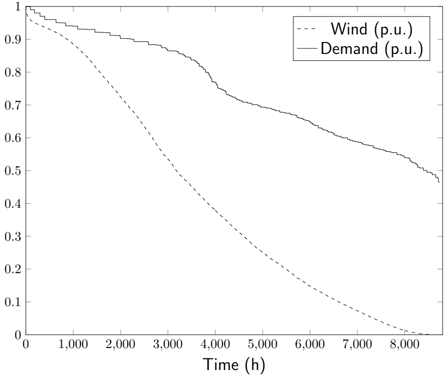
Impose cost merit-order at the day-ahead

Data of illustrative example



- Inflexible and cheap generating unit (g_1)
- Inelastic load (l_1)
- Expansion projects:
  - 1 wind farm ($\widehat{w}_1$)
  - 2 flexible but more expensive generating units ($\widehat{g}_1, \widehat{g}_2$)
  - 3 transmission lines ($\widehat{f}_1, \widehat{f}_2, \widehat{f}_3$)

Data of illustrative example



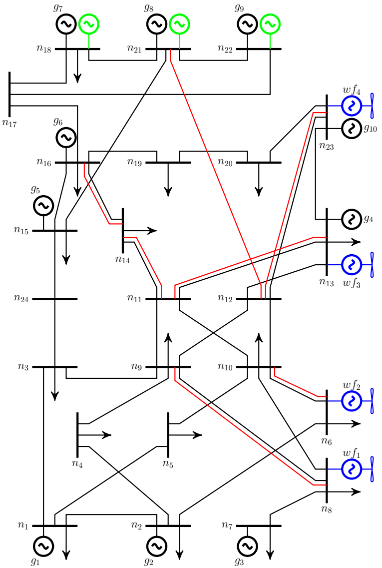
- 20 day-ahead blocks
- 30 balancing scenarios

Results of illustrative example (renewable target 40%)

	No forecast errors	Efficient market	Inefficient market
Cap. $\hat{w}_1$	392	413	441
Cap. $\hat{f}_1$	392	369	377
Cap. $\hat{g}_1/\hat{f}_2$	0	0	195
Cap. $\hat{g}_2/\hat{f}_3$	0	202	0
Inv. cost	20.69	27.15	28.52

- Forecast errors involve higher stochastic power capacity
- Without forecast errors, no investments in flexible generation
- With forecast errors, some investment in flexible generation
- Forecast errors increased the investment costs
- Investment costs are reduced under efficient market

Data of case study

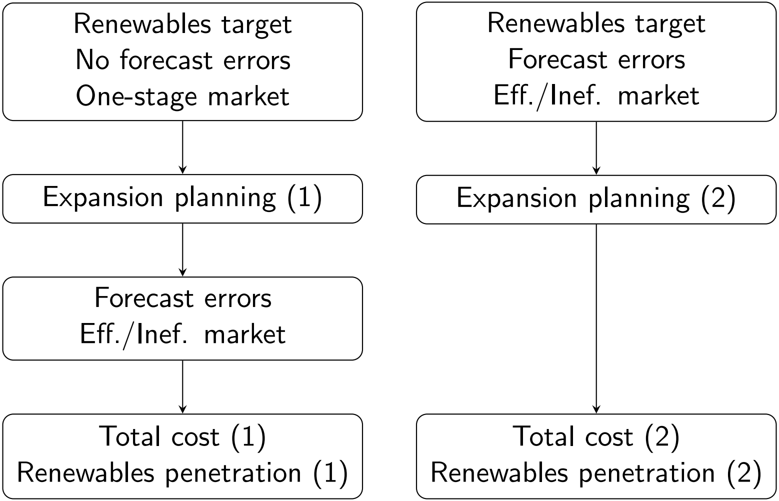


- 24-bus system (IEEE)
- 10 existing conventional units
- 3 flexible generating units
- Variable demand
- 4 projects of stochastic units
- 3 new flexible generating units
- 7 new transmission lines
- Renewable target of 20/30/40%

Expansion planning (renewable target 20%)

		No errors	Efficient	Inefficient
Wind capacity	n_6	-	-	50
	n_8	950	1000	900
	n_{13}	-	-	-
	n_{23}	400	350	450
Flexible Generation	n_{18}	-	-	-
	n_{21}	-	80	-
	n_{22}	-	-	160
Line capacity	$n_6 n_{10}$	-	-	-
	$n_8 n_9$	-	-	-
	$n_{11} n_{13}$	175	175	175
	$n_{11} n_{14}$	-	-	175
	$n_{12} n_{21}$	-	350	-
	$n_{12} n_{23}$	-	-	-
	$n_{14} n_{16}$	-	-	175
Investment cost		162.6	165.1	172.8

Impact of forecast errors



Effects of disregarding forecast errors

Market	Desired target	Cost increase	Achieved target
Efficient	20%	0.1%	19.2%
	30%	0.5%	26.5%
	40%	-0.3%	31.5%
Inefficient	20%	8.7%	19.3%
	30%	16.2%	28.7%
	40%	19.8%	36.1%

- Efficient market design
  - Similar total costs
  - Renewables penetration below the target
- Inefficient market design
  - Significant increase of total costs
  - Penetration levels closer to the desired target

Summary

- We have presented a set of generation and transmission expansion models that account for the forecast errors of stochastic production and two different market designs
- These models can be reformulated as single-level mixed-integer linear programming problems
- Considering production forecast errors impacts the generation and transmission expansion planning of a power system
- An efficient market design softens the negative effects of forecast errors and leads to cheaper expansion plans for a given target
- The consequences of an expansion plan determined under an error-free assumption highly depend on the market design

Future research

- Incorporate strategic behaviour of market players
- Modify the models to account for flexibility using unit commitment constraints (ramp rates, minimum times, etc)
- Model intermediate market designs between the paradigmatic efficient and inefficient
- Apply dedicated computational methods to improve tractability of the multi-year case

Thanks for the attention!

Questions?

Website: https://sites.google.com/site/slv2pm/