Modelling start/stop in short-term multimarket hydropower scheduling

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Background

- Mainly day-ahead trading
- Increasing share of wind production
- Increasing integration with rest of Europe
  - Cables
  - Market coupling
- Expects increasing variability and volumes in short-term markets
  - Intra day
  - Reserves
  - Balancing

- ➢ Business opportunities for hydropower producers
- ➢ Changed operating patterns

Start/stop properties

- **Binary – spinning state**
- **Minimum production rate**
- **Start-up cost**

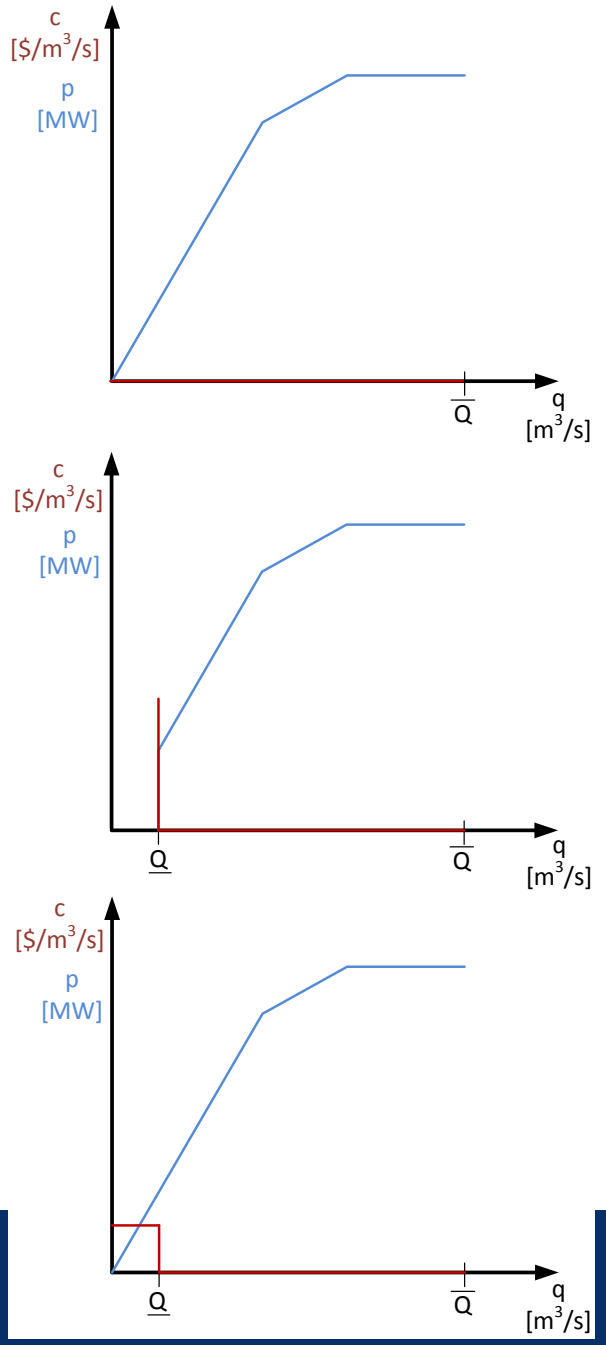
- Ramping rate
- Minimum up/down-time
- Shut-down cost
- Down-time dependent start-up cost
- Logical dependencies between generators/pumps

Start/stop modelling

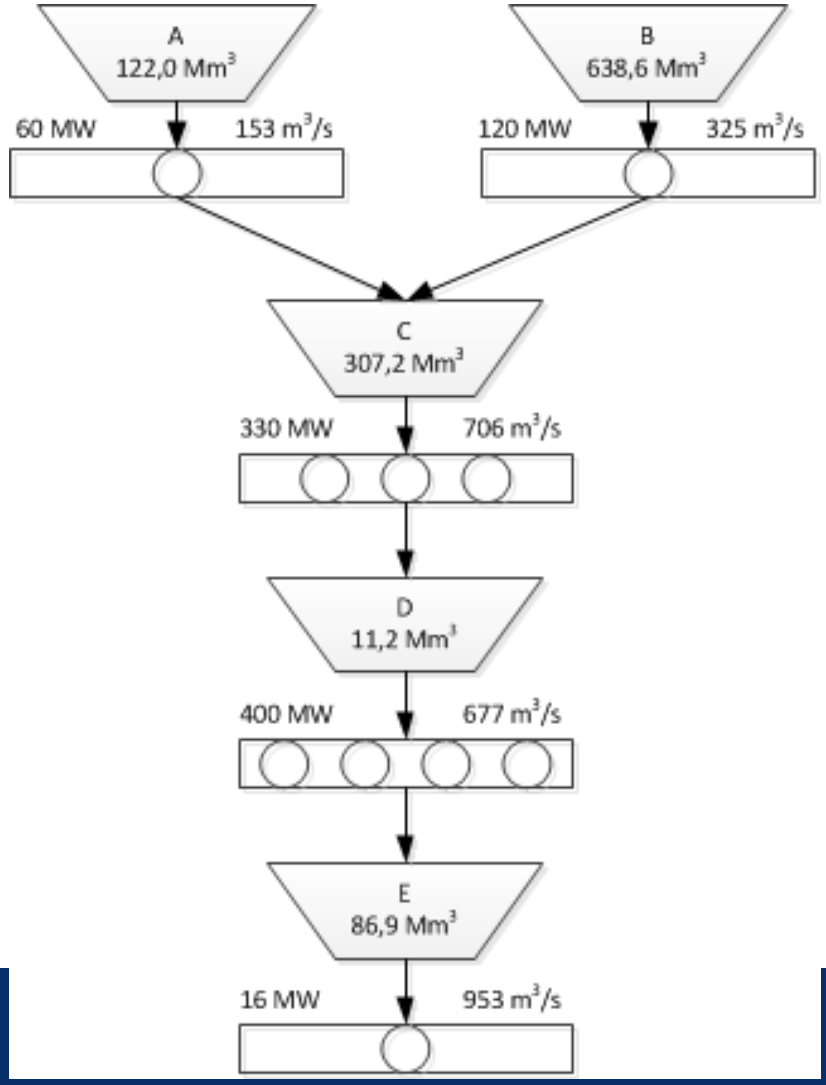
1. No start/stop ("noSS")
   - No minimum production
   - No start-up cost
2. Binary start/stop ("0/1")
3. Linear approximation ("linearSS")
   - Incentive to stay above $\underline{Q}$

$$c_t \geq C(u_t^L - u_{t-1}^L)$$
$$Qu_t^L + \left(\overline{Q} - \underline{Q}\right)u_t^H = q_t$$
$$u_t^L \geq u_t^H$$
$$0 \leq u_t^L, u_t^H \leq 1$$

Warland&Huuse, 2008

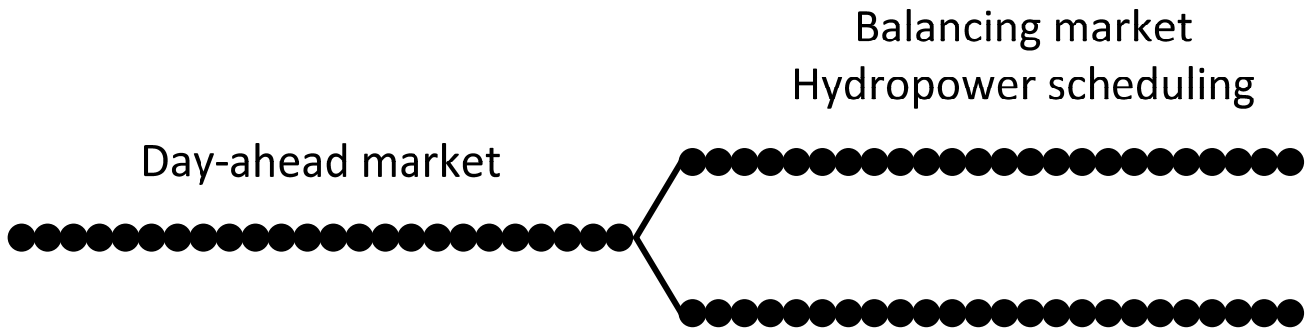


Test case – a Norwegian water couse



Trade and market modelling

- Day-ahead (DA) and balancing market (BM) by price
- Balancing market
  - Activation given by price difference
    - Day-ahead price > balancing market price => down regulation
    - Day-ahead price < balancing market price => up regulation
- Allocation, no bidding
  - Increasing allocation with increasing price



Scenario tree generation

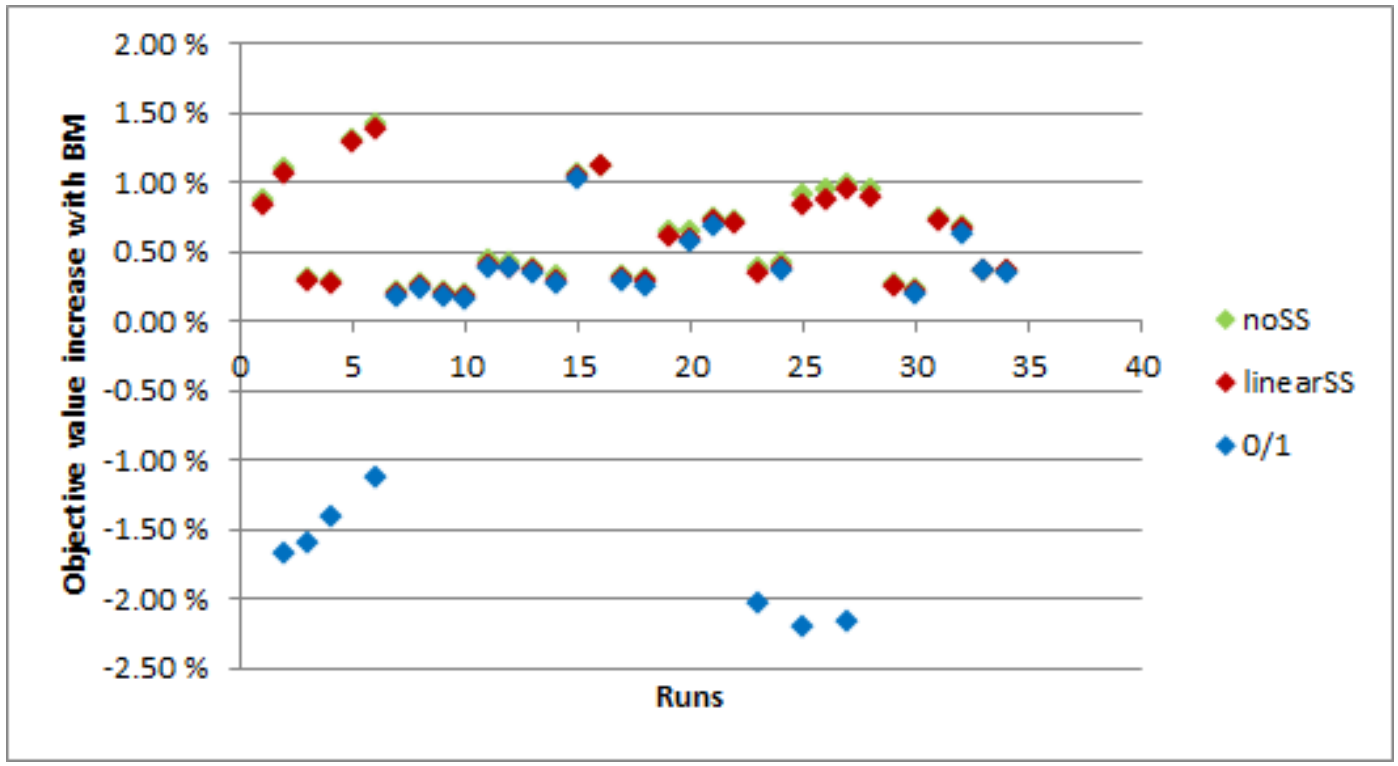
- Highly inspired by Boomsma, Juul & Fleten (2014) in EJOR
- Prices from Nord Pool Spot, 2013-2014, Southern Norway (NO2)
- Time series model
  - Day-ahead price: SARIMA
  - Balancing price: SARIMAX
  - Joint trend and seasonality correction
- Procedure:
  - Sample day-ahead
  - Scenario reduction day-ahead
  - Sample balancing market
  - Scenario reduction balancing market
  - Remove arbitrage possibilities

Test setup

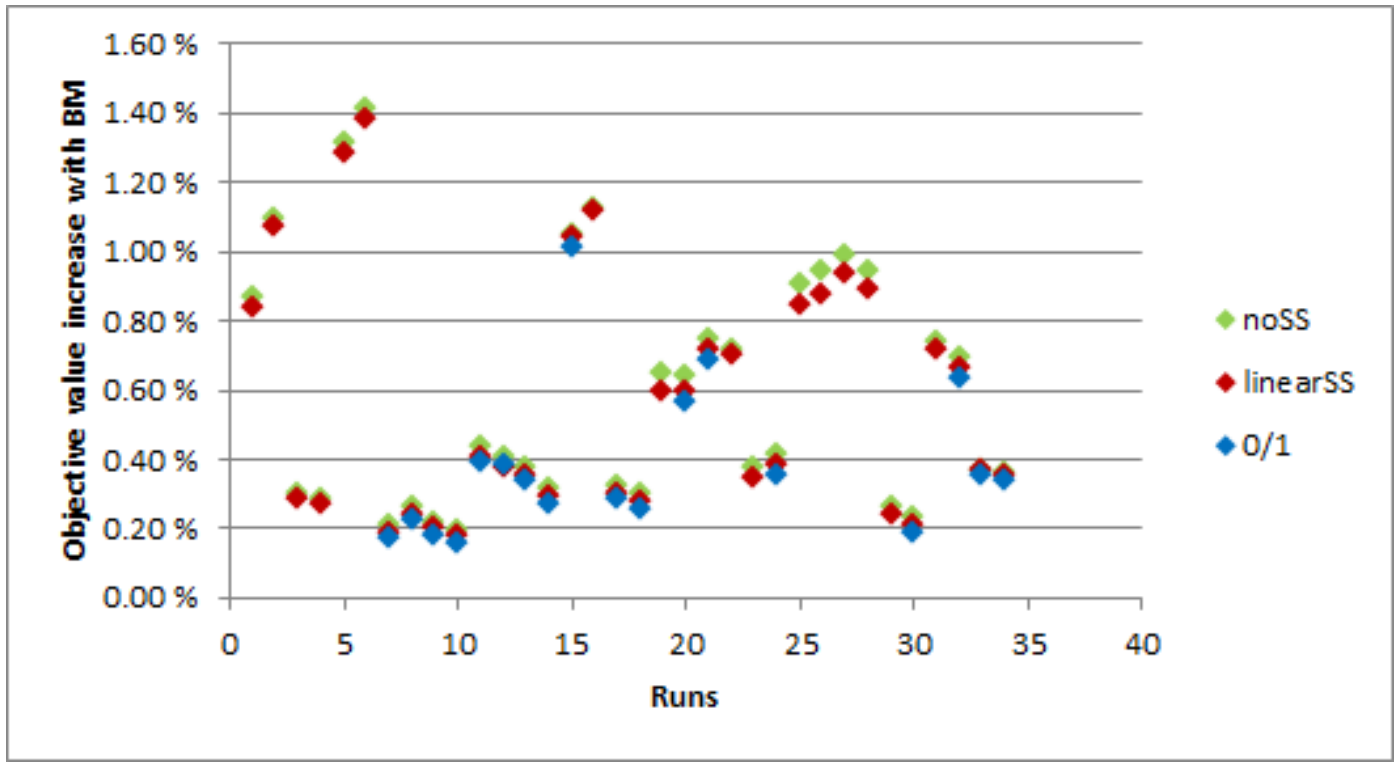
- 34 one-day scenario trees generated
  - 225 scenarios (15 day-ahead x 15 balancing market)
- September/October
- Initial reservoir level: 90%

- Compares model run
  - with and without balancing market (+BM vs -BM)
  - with different start/stop modelling

Value of Balancing Market (BM)



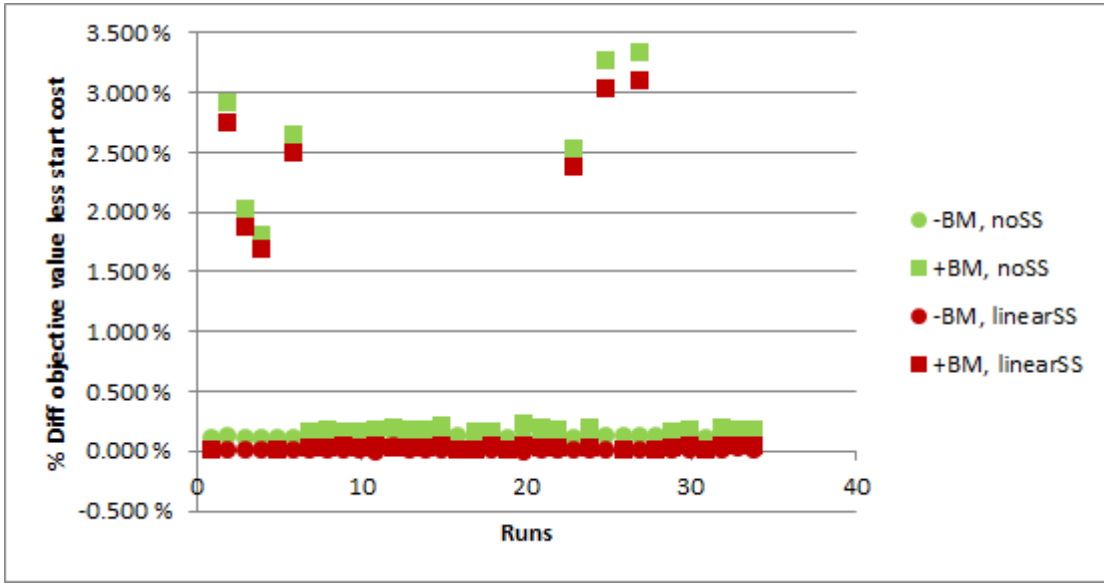
Value of Balancing Market (BM)

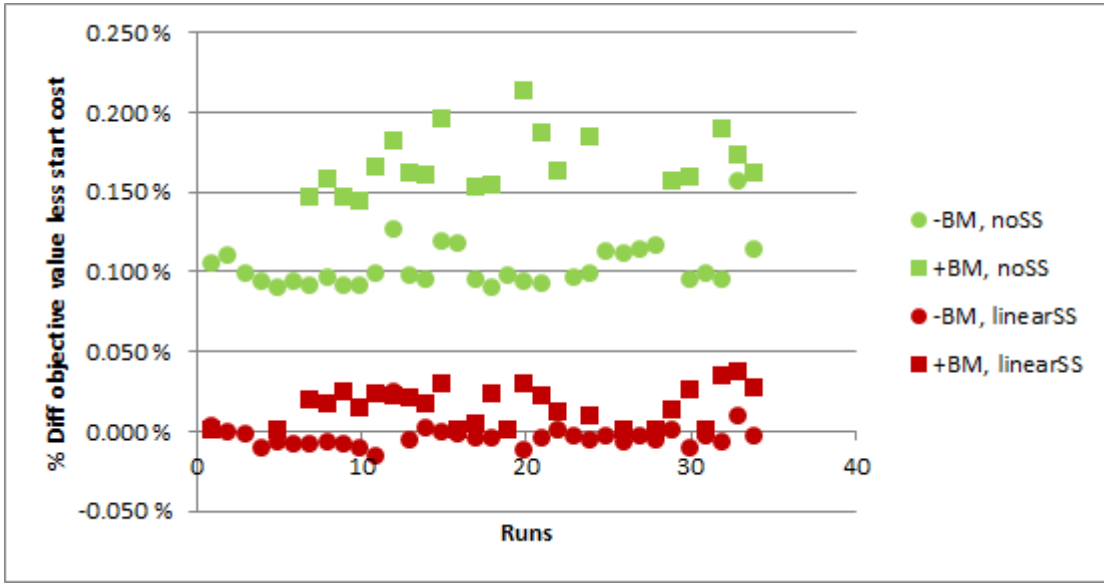


Comparison of start/stop models

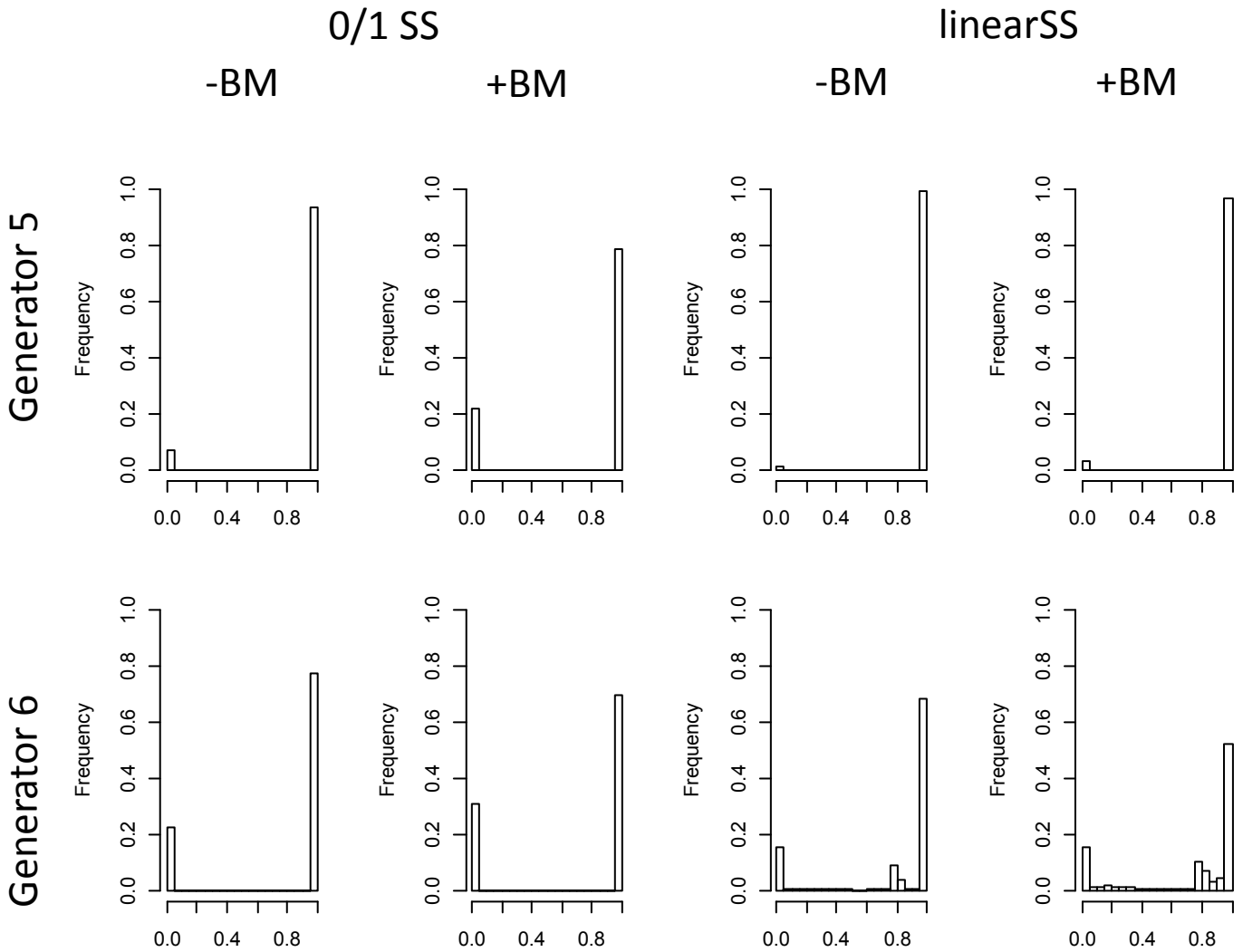
Observations

- Linear better than noSS (red vs green)
- Without BM better than with (circles vs squares)
- Introduction of BM reduces approximation quality





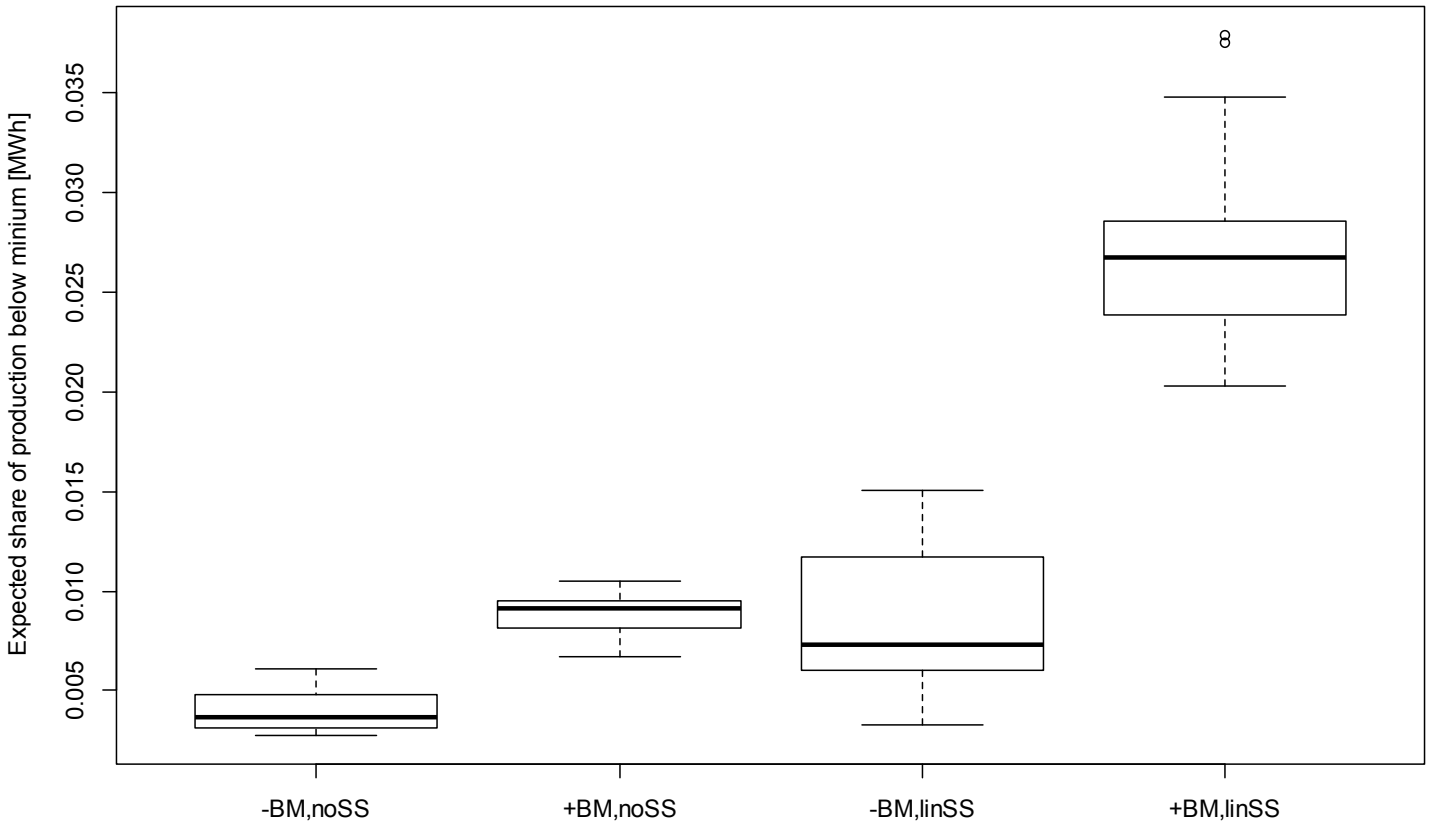
Spinning states



Observations:

- More non-spinning with BM
- More non-spinning with 0/1
- More fractional spinning variables with BM
  - 19% vs 29%

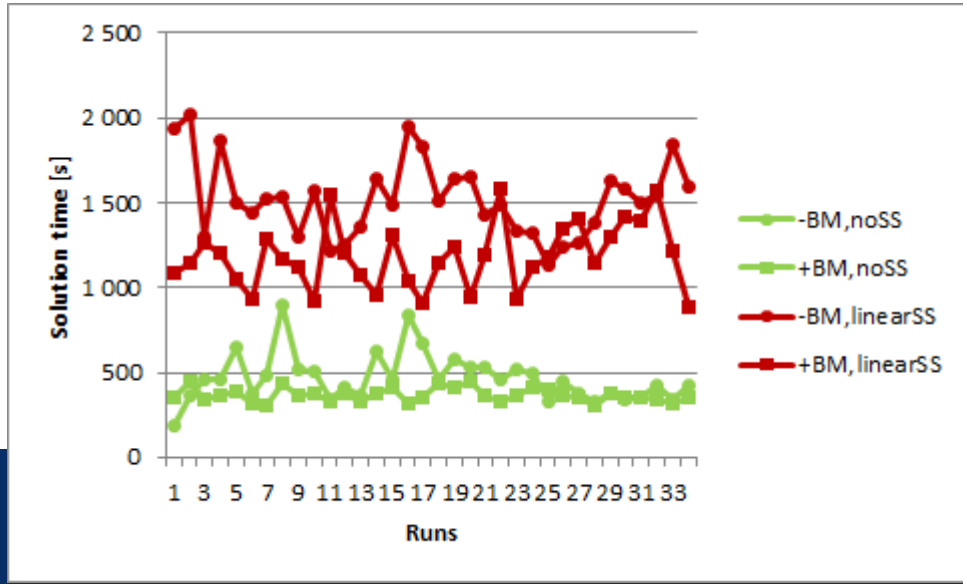
Operation below minimum production



Solution times

- Standard solver (CPLEX) without any tuning or algorithmic efforts
- 204 instances
  - 9 instances removed due to failure (out of memory)
  - Most 0/1 time limited [24 h]

- Binary start/stop slow and memory consuming
  - Even harder with BM
- LinearSS 3-4 times slower than noSS



Conclusion and further work

- Preliminary "conclusions"
  - Linear ok for valuation, but worse with BM
    - Objective function value good
    - Solution time ok
    - Operating decisions not ok for scheduling
  - BM currently limited value

- Further work
  - Sensitivity to start cost
  - Different seasons

Thank you!

References

- Warland, G., Huuse, E. S., "Including thermal unit start-up costs in a long-term hydro-thermal scheduling model", 16th PSCC, Glasgov, Scotland, July 14-18, 2008