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High Resolution Generation Expansion Planning Considering Flexibility Needs: The Case of Switzerland in 2030

Elena Raycheva, Jared Garrison, Christian Schaffner, Gabriela Hug
ETH Zurich

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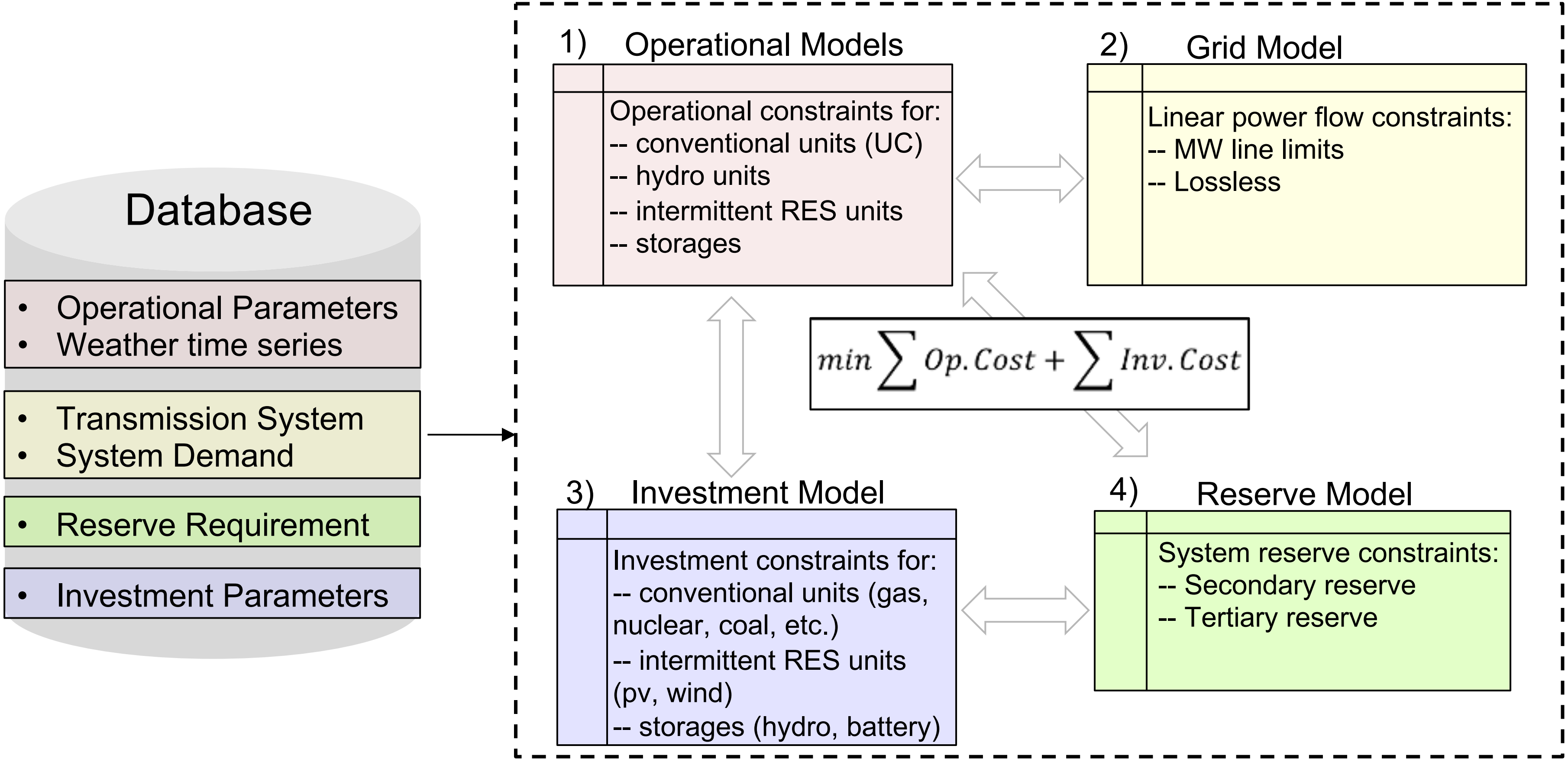
Outline

- Motivation and Objective
- Problem Formulation
- Solution Process
- Case Study
  - Validation of Operation in Switzerland
  - 2030 Generation Expansion Planning in Switzerland
- Conclusion and Outlook

Motivation and Objective

- Motivation
  - The integration of large shares of RES impacts power systems planning
  - Increased need for operational flexibility from new and existing units
- Objective
  - Present a formulation which co-optimizes operational and capacity investment decisions of generators/storages on the transmission system level considering flexibility needs
  - Demonstrate the functionality of the formulation on a real-size power system

Problem Formulation



Operational Models

Operational constraints for:
-- conventional units (UC)
-- hydro units
-- RES units
-- storages

- Unit commitment constraints for conventional units based on [1]
- Three binary variables for on/off status, start-up and shut-down + one continuous variable for power output above minimum + four continuous variables for reserve provision (per unit per time period)

Generator limits

1) 2)

$$p_{j,t}^{min} + (\boxed{r_{j,t}^{SCR\uparrow}} + \boxed{r_{j,t}^{TCR\uparrow}}) \leq (P_j^{max} - P_j^{min})u_{j,t} - (P_j^{max} - SU_j)v_{j,t}, \forall t, \forall j \in M_j^{ut} = 1$$

$$p_{j,t}^{min} + (r_{j,t}^{SCR\uparrow} + r_{j,t}^{TCR\uparrow}) \leq (P_j^{max} - P_j^{min})u_{j,t} - (P_j^{max} - SD_j)w_{j,t+1}, \forall t, \forall j \in M_j^{ut} = 1$$

$$0 \leq p_{j,t}^{min} - (\boxed{r_{j,t}^{SCR\downarrow}} + \boxed{r_{j,t}^{TCR\downarrow}}), \forall j, t$$

3) 4)

- Constraints for generator limits, ramping limits, min up/down time + maintenance
- Fully linear constraints for all other technologies

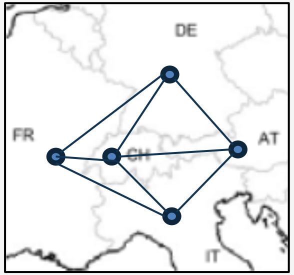
[1] Van der Bergh, K., et. al: 'Lusym: a unit commitment model formulated as a mixed- integer linear program', KU Leuven, TME Working Paper, Jul. 2015.

Grid Model

Linear power flow constraints:
-- MW line limits
-- Lossless

Modelled Power System

- CH in full detail
  - 298 lines
  - 165 nodes
  - 313 gens
- DE, FR, IT, AT aggregated (one border node plus country node)



	Full Detail	# Gens	Capacity [GW] in 2015
DE	✗	12	187
FR	✗	11	110
IT	✗	10	122
AT	✗	9	22
CH	✓	313	19

- Nodal balance:

$$p_{n,t} = P^{D}_{n,t} - ls_{n,t} + \sum_{s \in S_{n,t}} p^{ch}_{s,t} - \sum_{j \in J_{n,t}} p_{j,t} - \sum_{s \in S_{n,t}} p^{dis}_{s,t} - \sum_{r \in R_{n,t}} p_{r,t}, \quad \forall n, \forall t$$

- Line Limits:

$$p_{n,t} = \sum_{i \in l(n,i)} p_{l(n,i),t}, \forall n, \forall t$$

$$-P^{max}_{l} \leq p_{l(n,i),t} \leq P^{max}_{l}, \forall l(n,i), \forall t$$

- By modelling the grid, we facilitate the allocation of candidate units to system nodes of interest

Investment Model

Investment constraints for:
-- conventional units
-- intermittent RES units
-- storages

- For conventional thermal generators (UC), the investment decision variable is binary (investments in discrete units)
- We only dispatch units that have been built by linking investment and operational decisions (on/off status of each candidate unit in each time period)

$$u_{c,t} \leq \boxed{u_c^{inv}}, \quad u_c^{inv} \in [0,1], \forall t, \forall c \in \mathcal{C}^{thermal}$$

$$min \underbrace{\sum_{j \in J} \sum_{t \in T} (C_j^{prod} p_{j,t} + C_j^{su} v_{j,t})}_{\text{i)}} + \underbrace{\sum_{s \in S} \sum_{t \in T} C_s^{prod} p_{s,t}^{dis}}_{\text{ii)}} + \underbrace{\sum_{r \in R} \sum_{t \in T} C_r^{prod} p_{r,t}}_{\text{iii)}} + \underbrace{\sum_{n \in N} \sum_{t \in T} C^{ls} ls_{n,t}}_{\text{iv)}} + \underbrace{\sum_{c \in C} \boxed{u_c^{inv}} I_c}_{\text{v)}}$$

Op. cost of conventional units	Op. cost of storages	Op. cost of RES	Load shedding costs	Inv. costs

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Reserves Model

	System Reserve constraints: -- Secondary -- Tertiary

- Controllable units (thermal and storages) can provide reserve
- The reserves provided by the units must satisfy the system-wide needs for up/down balancing capacity in each time period, for tertiary control reserve (TCR):

$$\sum_{j \in J} r_{j,t}^{TCR\uparrow} + \sum_{s \in S^{hydro}} r_{s,t}^{TCR\uparrow} \geq TCR_t^{\uparrow,sys} + r^{TCR\uparrow,RES}, \forall t$$

$$\sum_{j \in J} r_{j,t}^{TCR\downarrow} + \sum_{s \in S^{hydro}} r_{s,t}^{TCR\downarrow} \geq TCR_t^{\downarrow,sys} + r^{TCR\downarrow,RES}, \forall t$$

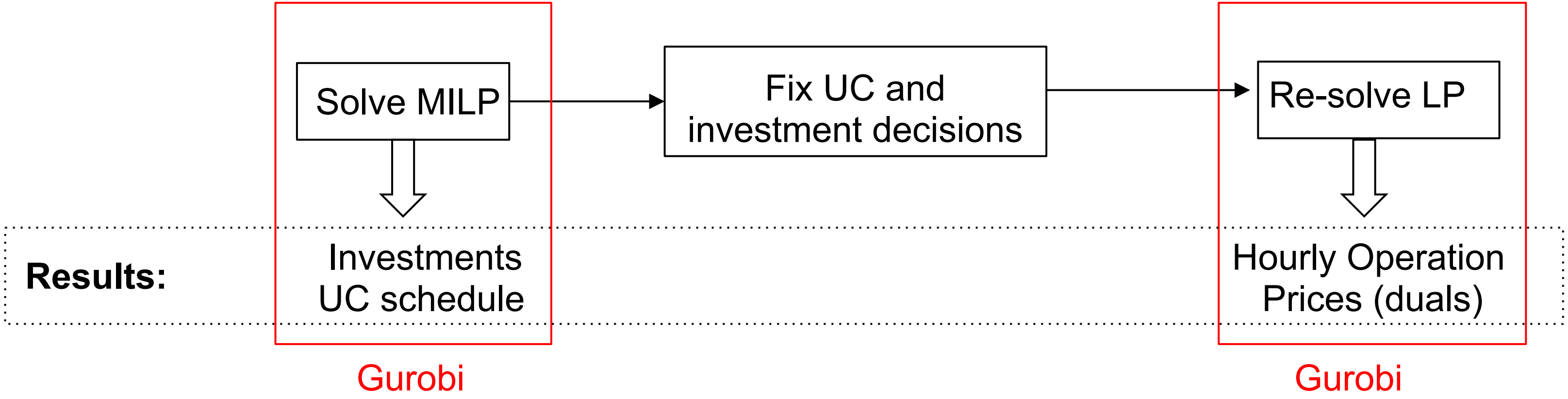
- Depending on the investments in intermittent RES, the tertiary reserve requirement is updated:

$$r^{TCR\uparrow\downarrow,RES} = A_{wind}^{\uparrow\downarrow} \sum_{c \in C_{wind}^{RES}} u_c^{inv} + A_{pv}^{\uparrow\downarrow} \sum_{c \in C_{pv}^{RES}} u_c^{inv}$$

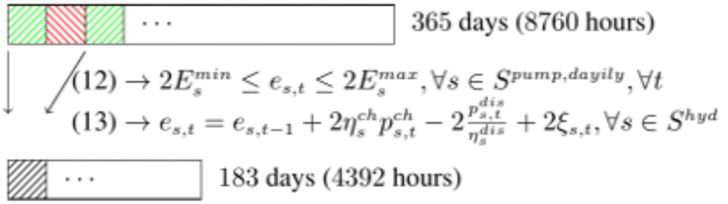
Operational, grid, investment and reserve constraints are deeply connected and must be co-optimized.

Solution Process

- Use Pyomo to formulate the problem and Gurobi to solve it



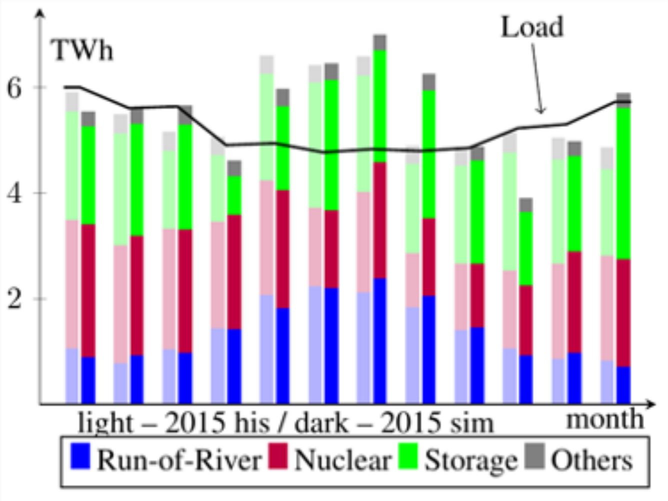
- Computationally challenging even without investments
- Our solution: duplicate simulation days
  - Use simple heuristics to adjust hydro storage levels and decrease the problem size by simulating every other day of the year



Case Study - Validation of Operation in Switzerland (2015)

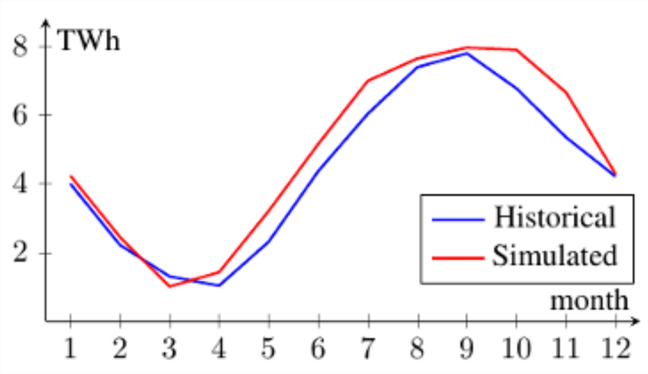
Result 1:
Monthly dispatch per technology type in 2015 (hist. data from [1])

- Good agreement
- Most notable difference is generation of hydro storages in period August – December
- Simulation has perfect foresight about demand, inflows, RES production, etc.



[1] Gesamte Erzeugung und Abgabe Elektrischer Energie in der Schweiz 2015, BFE

Result 2:
Comparison of end-of-month hydro storage levels (hist. data from [1])



Result 3:
Net cross-border exchange in 2015

Net Export (From - To)	Hist. [TWh]	Sim. [TWh]
AT - CH	6.7	4.9
DE - CH	13.1	9.0
FR - CH	5.3	4.3
CH - IT	25.4	21.0

Case Study - Swiss Generation Expansion Planning (2030)

- 50-year nuclear decommissioning plan: only 36% (1220 MW) of the 2015 installed nuclear capacity operational in 2030
- Two scenarios: 1) Business-as-Usual (BaU) and 2) Renewable Target (RES)
  - In 2) we set a production target of 9 TWh from non-hydro RES generators incl. existing generators

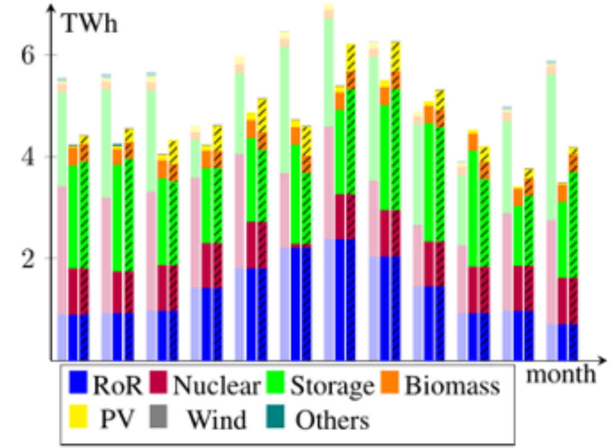
Result 1:
New Investments in 2030

Scen.	Techn.	Built [MW]	Gen. [TWh]	+ TCR↑ [MW]	+ TCR↓ [MW]
BaU	Biomass	240	2.0	✗	✗
RES	Biomass	240	2.0	✗	✗
	PV	3254	3.64	26	28

Result 2:
Change in net generation and average electricity price

Scen.	Tot. net gen. [% 2015]	Av. el. price [% 2015]
BaU	-19%	+51%
RES	-14%	+47%

Result 3:
Monthly simulated dispatch in 2030 vs. 2015



light – 2015 / normal - 2030 BaU / striped – 2030 RES

Conclusion and Outlook

- Generation Expansion Planning formulation which provides the 1) location, 2) size and 3) type of new generators/storages considering flexibility needs
- Results with high level of detail (both spatial and temporal)
- Useful to TSOs, policy makers and asset owners alike
- Future work will investigate a coordinated approach to investments on the transmission and distribution system levels

Thank you for watching

Any questions?

Highlights

- Detailed operational constraints of different flexibility providers
- DC Power Flow constraints including market-based tie line flow constraints with neighbouring zones
- Reserve provision capabilities of existing and new units
- High temporal and spatial resolution
- Extensive validation of the problem formulation