Impact of topology control on zonal electricity market operations

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Outline

Zonal electricity markets

- In Europe, the market is organized as a zonal market
  - Unique price per zone
  - Intra-zonal transmission constraints ignored
  - Transmission constraints defined at the zonal level
- Two models of market coupling in Europe :
  1. Available-Transfer-Capacity (ATC): Limit on the power exchanged between two zones
  2. Flow-Based (FBMC): Polyhedral constraints on zonal net injections which can capture constraints that the ATC model cannot
- FBMC went live in Central Western Europe (CWE) in May 2015
- Recent analysis (Aravena *et al*, 2018) shows that ATC and FBMC attain comparable performance and are outperformed by nodal pricing in terms of short-run operational efficiency
- Difference comes from inefficiency of zonal pricing in terms of day-ahead **unit commitment**

Transmission switching in zonal markets

- Transmission switching can significantly help with congestion management in zonal markets
- Questions:
  1. To what extent can transmission switching improve the efficiency of zonal markets?
  2. How does the resulting performance compare to nodal?

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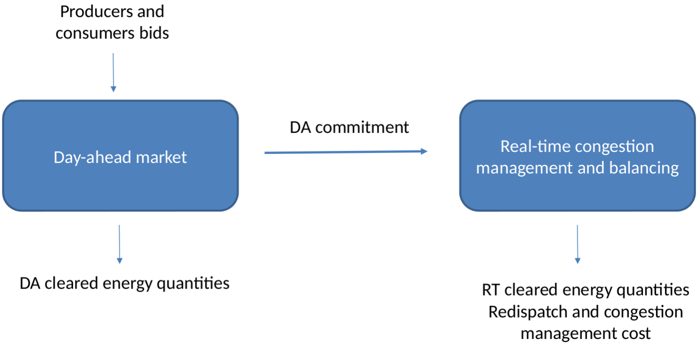
Day-ahead and real-time model



Day-ahead market clearing with proactive switching

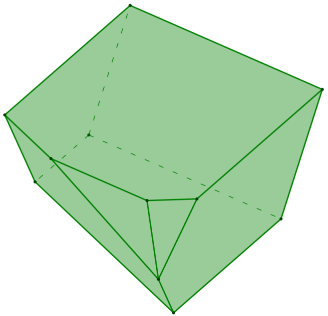
$$\begin{aligned} \min_{v\in[0,1],p,t} & \sum_{g\in G} P_g Q_g v_g \\ \text{s.t.} & \sum_{g\in G(z)} Q_g v_g - p_z = \sum_{n\in N(z)} Q_n \qquad \forall z \in Z \\ & p \in \mathcal{P}_t \end{aligned}$$

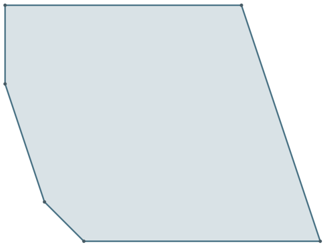
The acceptable set of net positions depends on the topology.

Acceptable set of net positions

$$p \in \mathcal{P}$$

space of nodal injections $\rightarrow$ space of zonal net positions

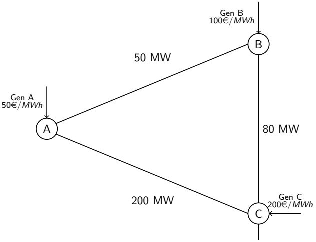




$$\mathcal{R} := \left\{ r \in \mathbb{R}^{|N|} : r \text{ is feasible for the real network} \right\}$$

$$\mathcal{P} := \left\{ p \in \mathbb{R}^{|Z|} : \exists r \in \mathcal{R} : p_z = \sum_{n \in N(z)} r_n \;\; \forall z \in Z \right\}$$

Acceptable set of net positions with switching

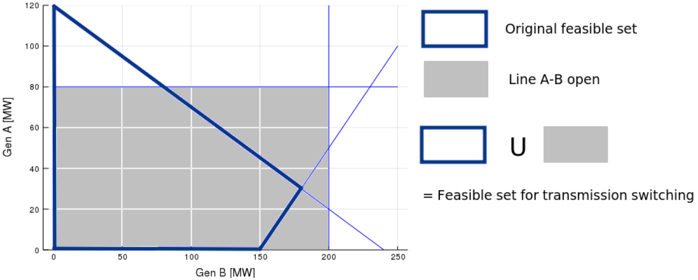


$p \in \mathcal{P}_t$

$$-50 \leq \frac{1}{3}\mathrm{GEN_A} - \frac{1}{3}\mathrm{GEN_B} \leq 50$$

$$-80 \leq \frac{1}{3}\mathrm{GEN_A} + \frac{2}{3}\mathrm{GEN_B} \leq 80$$

$$-200 \leq \frac{2}{3}\mathrm{GEN_A} + \frac{1}{3}\mathrm{GEN_B} \leq 200$$



→ solve on the union of polytopes

Acceptable set of net positions

- Put the two together

$$
\begin{aligned}
\mathcal{P}_t = \Big\{ & p \in \mathbb{R}^{|Z|} : \exists(\bar{v}, f, \theta, t) \in [0,1]^{|\mathcal{G}|} \times \mathbb{R}^{|L|} \times \mathbb{R}^{|N|} \times \{0,1\}^{|L|} : \\
& \sum_{g \in \mathcal{G}(z)} Q_g \bar{v}_g - p_z = \sum_{n \in N(z)} Q_n, \quad \forall z \in Z \\
& \sum_{g \in \mathcal{G}(n)} Q_g \bar{v}_g - \sum_{l \in L(n,\cdot)} f_l + \sum_{l \in L(\cdot,n)} f_l = Q_n, \quad \forall n \in N \\
& -t_l F_l \le f_l \le t_l F_l, \quad \forall l \in L \\
& f_l \le B_l(\theta_{m(l)} - \theta_{n(l)}) + M(1 - t_l), \quad \forall l \in L \\
& f_l \ge B_l(\theta_{m(l)} - \theta_{n(l)}) - M(1 - t_l), \quad \forall l \in L \Big\}
\end{aligned}
$$

Cost-based redispatch

Goal

Minimize the **cost** while respecting the constraints of the nodal grid

$$\min_{\substack{v\in[0,1],f,\theta \\ t\in\{0,1\}}} \sum_{g\in G} P_g Q_g v_g$$

$$\text{s.t.} \quad \sum_{g\in G(n)} Q_g v_g - \sum_{l\in L(n,\cdot)} f_l + \sum_{l\in L(\cdot,n)} f_l = Q_n, \qquad n \in N$$

$$-F_l t_l \leq f_l \leq F_l t_l, \qquad \forall l \in L$$

$$f_l \leq B_l(\theta_{m(l)} - \theta_{n(l)}) + M(1 - t_l), \qquad \forall l \in L$$

$$f_l \geq B_l(\theta_{m(l)} - \theta_{n(l)}) - M(1 - t_l), \qquad \forall l \in L$$

Case study: overview

- Simulation on 32 representative snapshots
- Benchmark against LMP-based market clearing
- We use generalized versions of the models presented that consider commitment (on-off) decisions for slow generators and reserves + N-1 security criterion
- Network: CWE area with
  - 346 slow generators with a total capacity of 154 GW
  - 301 fast thermal generators with a total capacity of 89 GW
  - 1312 renewable generators with a total capacity of 149 GW
  - 632 buses
  - 945 branches
- We use a switching budget of 6 lines
- All models are solved with JuMP 0.18.4 and Gurobi 8.0 on the Lemaitre3 cluster
- CPU time (all snapshots): 40.5 hours for cost-based redispatch with switching
  Median snapshot time: 51 min

Comparison of the cost of each TS option

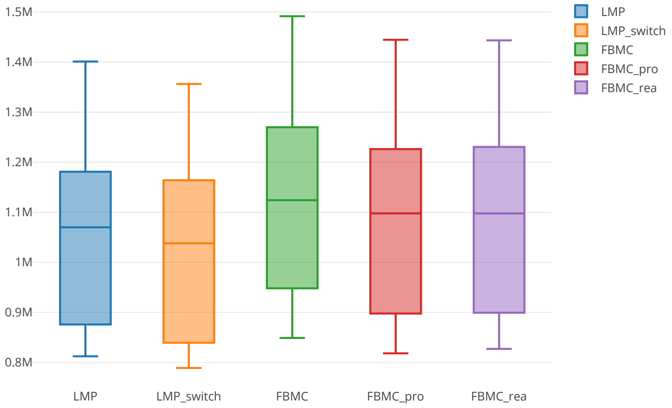


Figure 1: Total (DA+RT) hourly cost of the different policies on 32 snapshots of CWE.

Observations

1. Under min-cost redispatch, switching helps significantly in reducing the operating cost of the zonal design.
2. Incremental benefit of proactive switching in zonal is small.
3. Nodal market without switching still outperforms the zonal market with switching.
4. Benefits of switching in LMP and FBMC are comparable.

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Conclusion

- New framework for modeling FBMC with both proactive (day-ahead) as well as reactive (real-time) switching

- Transmission switching improves FBMC operational costs significantly
- LMP still outperforms zonal design significantly

Future research questions

- Compare fixing the switching budget with other heuristics
- Understand pricing implications of zonal design and switching

Thank you

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