Impacts of Transmission Switching on Zonal Markets

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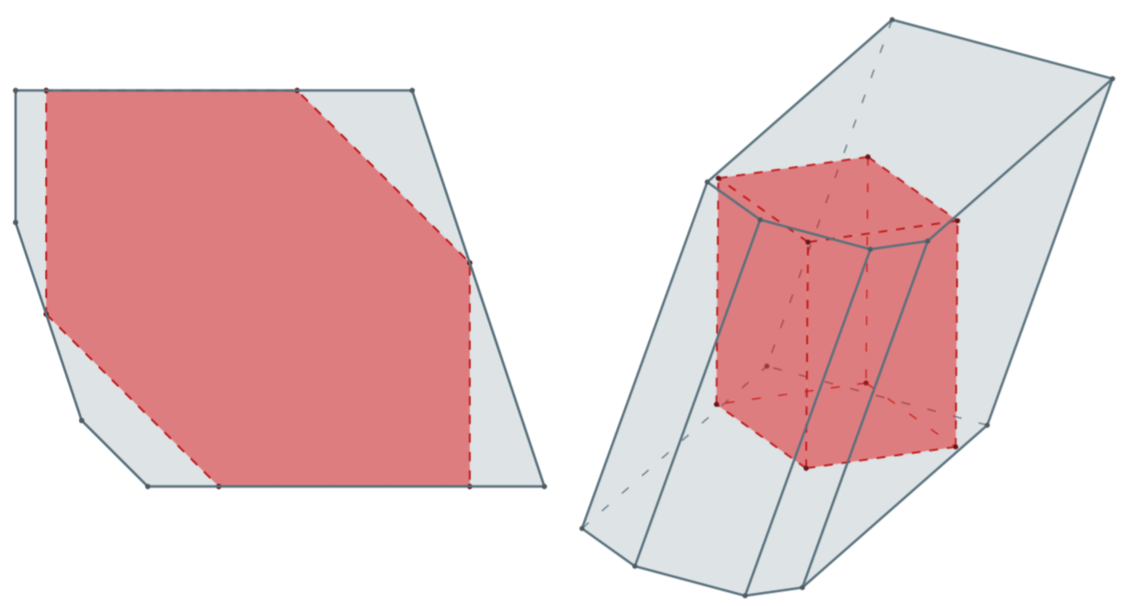
Motivation

Day-ahead electricity market design has been a long-lasting debate among European power system economists. A central question in this debate is the question of **market coupling**, i.e. the transmission constraints to impose at the inter-zonal level. There are two main models:

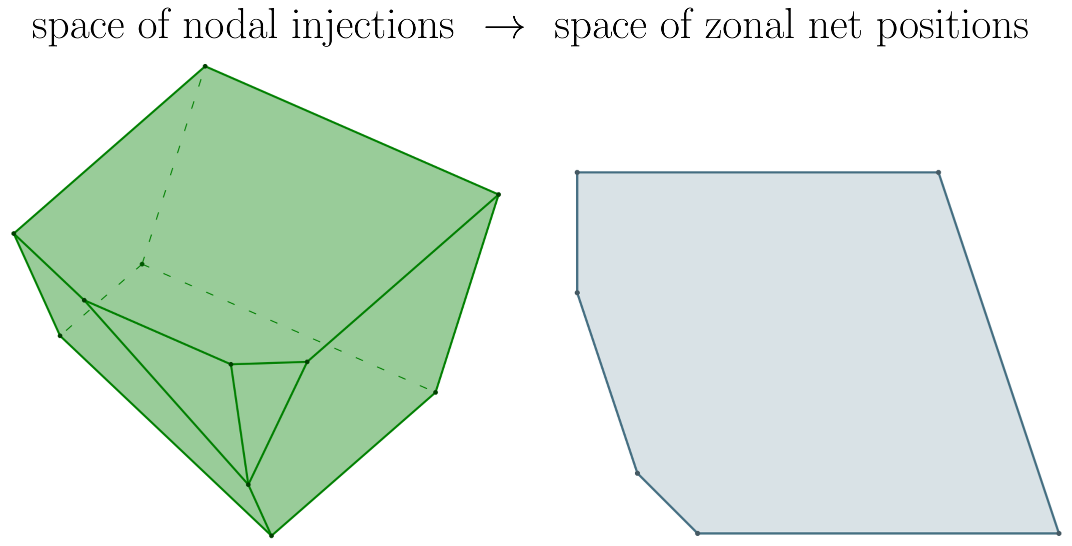
1. Available Transfer Capacity Market Coupling: **box** constraints on power exchange.

space of zonal net positions $\rightarrow$ space of exchanges



2. Flow Based Market Coupling: **polyhedral** constraints on the net positions.

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



Research questions

- How to extend to Transmission Switching ?
- Can Transmission Switching help to decrease Unit Commitment inefficiencies ?

Model

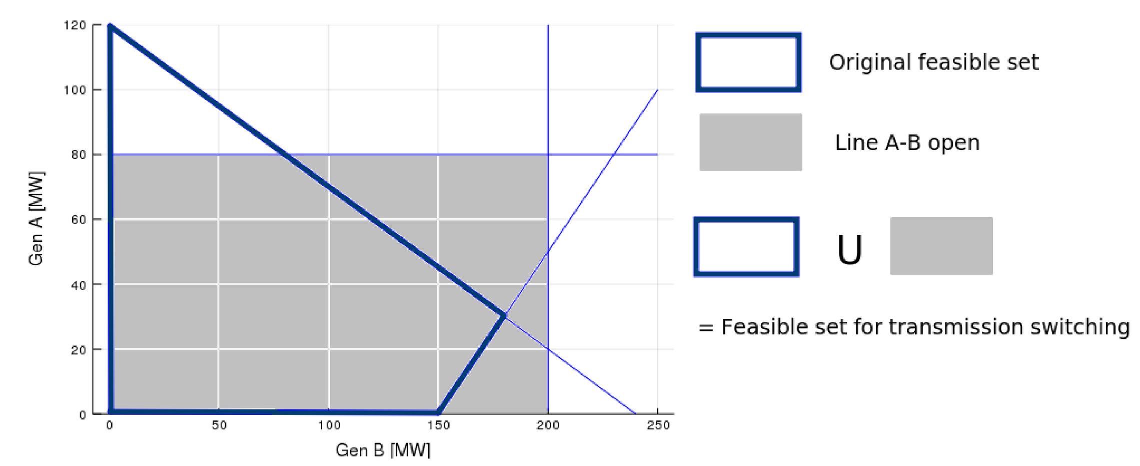
Extending the formulation in [1], we can write a zonal market clearing model with transmission switching in its simplest form as follows:

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

where the set $\mathcal{P}_t$ corresponds to the feasible set of net positions.

Extension to Transmission Switching

We can obtain the set of acceptable net positions for every topology by taking the union of all these polytopes corresponding to a particular topology, as schematically represented below for 2-dimensional polytopes:



Algorithm

Our idea for solving the day-ahead market clearing problem with proactive transmission switching and N-1 security criterion is to rewrite it as an adaptive robust optimization problem with mixed integer recourse (AROMIP), and to use a known column-and-constraint generation algorithm for this class of problems. The reformulation of our problem to an AROMIP can be done in the three following steps:

1. Rewrite the constraint $p \in \bigcap_{\|u\|_1\leq 1} \mathcal{P}_t(u)$ as

$$d(p, \bigcap_{\|u\|_1\leq 1} \mathcal{P}_t(u)) = 0$$

2. Move it in the objective

$$
\begin{aligned}
\min_{v\in[0,1],p,t} \ & \sum_{g\in G} P_g Q_g v_g + \lambda^* \Big(d(p, \bigcap_{\|u\|_1\leq 1} \mathcal{P}_t(u)) \Big) \\
\text{s.t. } & \sum_{g\in G(z)} Q_g v_g - p_z = \sum_{n\in N(z)} Q_n \quad \forall z \in Z
\end{aligned}
$$

3. Write the distance as an adversarial max-min problem :

$$
\begin{aligned}
d(p, \bigcap_{\|u\|_1\leq 1} \mathcal{P}_t(u)) = \max_{u\in\mathbb{U}} \min_{\tilde{p},t} \ & \|p-\tilde{p}\|_1 \\
\text{s.t. } & \tilde{p} \in \mathcal{P}_t(u)
\end{aligned}
$$

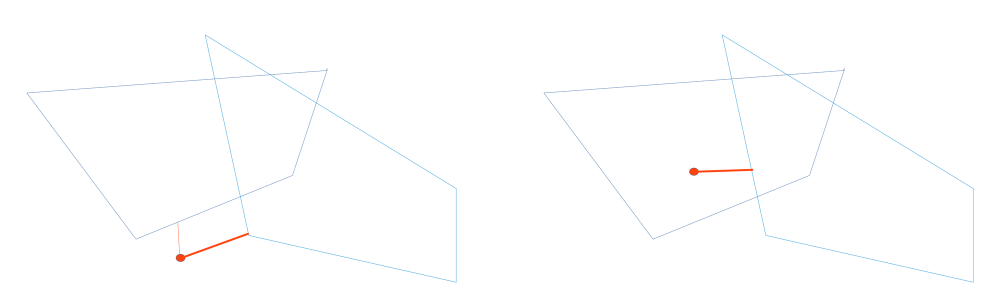


Fig. 4: In both cases, define the distance to the intersection as the maximum of both single set distances.

With these three steps, our problem has been rewritten in the form of an AROMIP:

$$\min_{\mathbf{x}\in\mathbb{X}} \mathbf{cx} + \max_{\mathbf{u}\in\mathbb{U}} \min_{\mathbf{z},\mathbf{y}\in\mathbb{F}(\mathbf{u},\mathbf{x})} \mathbf{dy} + \mathbf{gz}$$

The column-and-constraint generation algorithm developed by Zhao and Zeng [2] involves a subproblem that corresponds in our case to the distance to the set of net positions.

Interdiction Game

Reformulate as:

$$
\begin{aligned}
\max_{u\in\mathbb{U}} \min_{\tilde{p},t} \ & |p-\tilde{p}| \\
\text{s.t. } & (\tilde{p},t) \in \mathcal{Q} \\
& t_l u_l = 0 \ \ \forall l \in L
\end{aligned}
$$

and then:

$$
\begin{aligned}
\max_{u\in\mathbb{U}} \ & \eta \\
\text{s.t. } & \eta \leq |p-\tilde{p}| + \sum_{l\in L} \lambda_l t_l u_l, \\
& \forall (\tilde{p},t) \in \text{ext}(\mathcal{Q})
\end{aligned}
$$

Solving using a **cutting plane** algorithm is faster than nested column-and-constraint. Possible choice for λ_l: **the cost of robustness** without switching recourse.

Results

Simulation on 32 snapshots of Central Western Europe (632 buses, 345 lines):

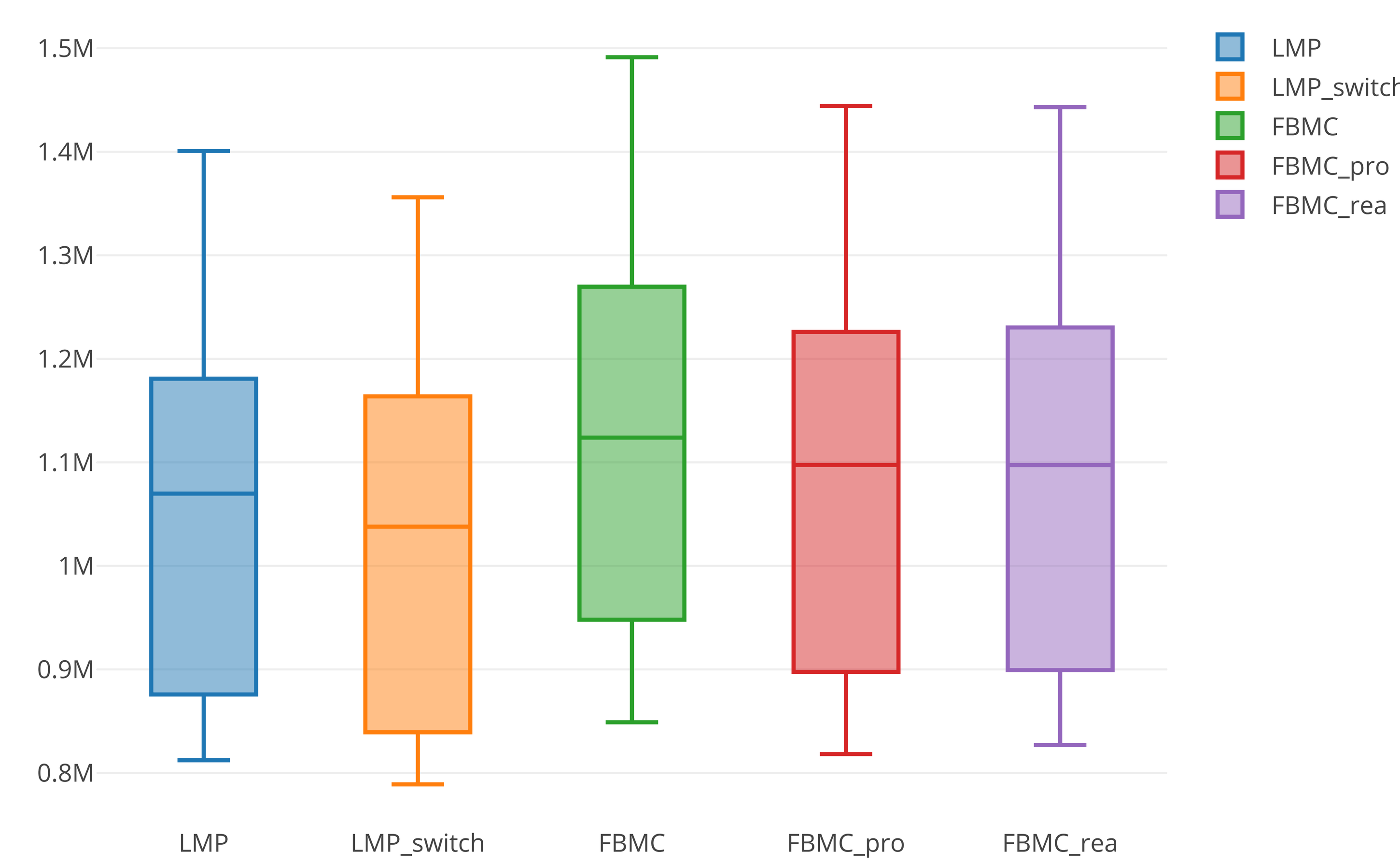


Fig. 5: Hourly total cost of the different cases studied on 32 snapshots of CWE.

Our main observations can be summarized as follows:

1. Transmission switching reduces operating costs significantly.
2. The additional benefits of proactive switching are small.
3. Nodal pricing without switching outperforms flow-based market coupling with switching in terms of operational cost.
4. The benefits of switching are comparable in both the nodal and zonal designs.

References

[1] Ignacio Aravena. "Analysis of renewable energy integration in transmission-constrained electricity markets using parallel computing". Prom. : Anthony Papavasiliou. PhD thesis. Université catholique de Louvain, Sept. 2018. URL: `http://hdl.handle.net/2078.1/203018`.

[2] Long Zhao and Bo Zeng. *An Exact Algorithm for Two-stage Robust Optimization with Mixed Integer Recourse Problems.* Tech. rep. 2012. URL: `https://pdfs.semanticscholar.org/6b15/8459656b321a0791cc9df4a09af161c8f5e2.pdf`.