Impacts of transmission switching on zonal markets

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European Grid Service Markets
July 2019

Introduction

Models of zonal markets with transmission switching

Case study: Impacts of transmission switching on CWE

Conclusion

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
- Zonal flow representation may lead to suboptimal unit commitment decisions $\rightarrow$ importance of congestion management

Transmission switching - practices

Switching is much more widespread in Europe than in the US.

In Belgium (ELIA):

- Corrective measure for congestion management
- Decided in day-ahead
- Based on a list of candidate lines that can be switched ($\sim$ 50 lines)

At the Central Western European level:

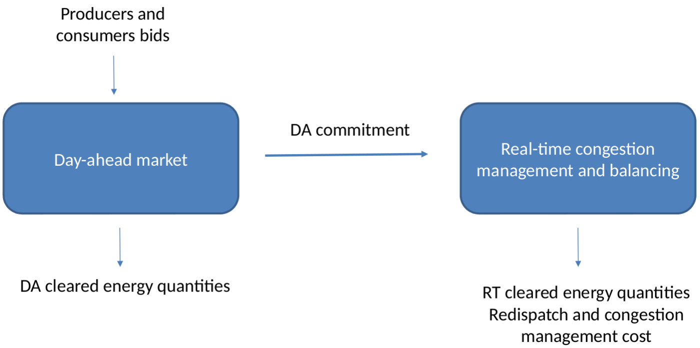
- Coordinated by CORESO
- Based on grid state forecast and topological correction plans of each TSO

We are not aware of any implementation of transmission switching by means of optimization.

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?

Day-ahead and real-time model



Overview of zonal market

- Two-stage model: Day-ahead market clearing + real-time congestion management and balancing.
- Day ahead:
  - Participants submit price-quantity bids
  - Market cleared to maximize welfare while respecting net position constraints which are described by a **zonal flow-based polytope**
  - Account for day-ahead clearing of reserve capacity
- Real time:
  - Using nodal constraints, TSOs find a new dispatch that is feasible for the grid. Inc-dec payments are cost-based.

Day-ahead market clearing with proactive switching

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

$$\text{s.t.} \sum_{g\in G(z)} Q_g v_g - p_z = \sum_{n\in N(z)} Q_n \qquad \forall z \in Z$$

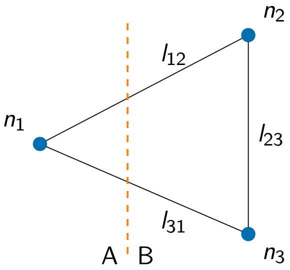
$$p \in \mathcal{P}_t$$

The acceptable set of net positions depends on the topology.
It can be derived directly from physics.

Deriving $\mathcal{P}$ directly from physics: an example

Physics:

$$r_1 + r_2 + r_3 = 0$$
$$-100 \leq r_1 \leq 100$$
$$-100 \leq r_2 \leq 100$$
$$-100 \leq r_3 \leq -50$$
$$-25 \leq f_{12} = 1/3\, r_1 - 1/3\, r_2 \leq 25$$



Zonal net positions:

$$p_A = r_1$$
$$p_B = r_2 + r_3$$

$$G = \{1, 2, 3\}$$
$$Q_1 = 200,\ \ Q_2 = 200,\ \ Q_3 = 50$$
$$N = \{n_1, n_2, n_3\}$$
$$L = \{l_{12}, l_{23}, l_{31}\},\ F_{12} = 25$$

100MW demand per node

Deriving $\mathcal{P}$ directly from physics: an example

Physics:

$$
\begin{aligned}
r_1 + r_2 + r_3 &= 0 \\
-100 \leq r_1 &\leq 100 \\
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\end{aligned}
$$

Zonal net positions:

$$
\begin{aligned}
p_A &= r_1 \\
p_B &= r_2 + r_3
\end{aligned}
$$

Are these zonal net positions feasible?

$$
\begin{aligned}
p_A &= 0 & p_B &= 0 \\
p_A &= 200 & p_B &= -200 \\
p_A &= -100 & p_B &= 100 \\
p_A &= 50 & p_B &= -50
\end{aligned}
$$

Deriving $\mathcal{P}$ directly from physics: an example

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$p_A = -100$	$p_B = 100$	
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Deriving $\mathcal{P}$ directly from physics: an example

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$p_A = 0$	$p_B = 0$	Yes
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Deriving $\mathcal{P}$ directly from physics: an example

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$p_A = -100$	$p_B = 100$	No
$p_A = 50$	$p_B = -50$	Yes

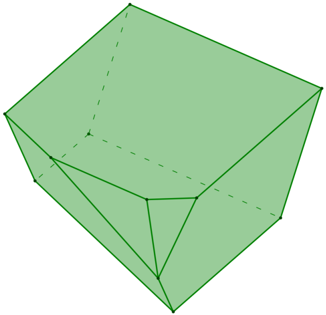
True net position feasible set $\mathcal{P}$:

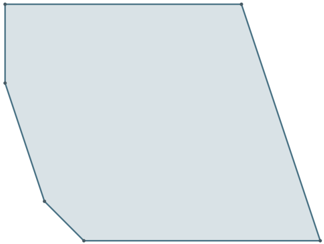
$$p_A + p_B = 0$$
$$-12.5 \leq p_A \leq 87.5$$

Acceptable set of net positions

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

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

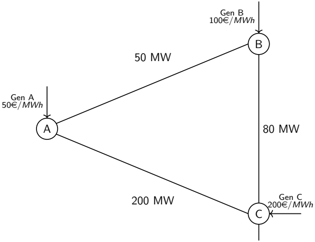




$$\mathcal{R} := \left\{ r \in \mathbb{R}^{|N|} : r \text{ is feasible for the real network} \right\}$$

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

Acceptable set of net positions with switching

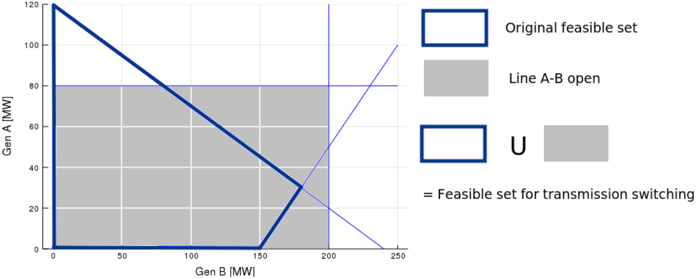


$$p \in \mathcal{P}_t$$

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

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

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



→ solve on the union of polytopes

Acceptable set of net positions

- Put the two together

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

Cost-based redispatch

Goal

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

$$
\begin{aligned}
\min_{\substack{v\in[0,1],f,\theta \\ t\in\{0,1\}}} \sum_{g\in G} P_g Q_g v_g & \\
\text{s.t.} \quad \sum_{g\in G(n)} Q_g v_g - \sum_{l\in L(n,\cdot)} f_l + \sum_{l\in L(\cdot,n)} f_l = Q_n, & \quad n \in N \\
- F_l t_l \leq f_l \leq F_l t_l, & \quad \forall l \in L \\
f_l \leq B_l(\theta_{m(l)} - \theta_{n(l)}) + M(1 - t_l), & \quad \forall l \in L \\
f_l \geq B_l(\theta_{m(l)} - \theta_{n(l)}) - M(1 - t_l), & \quad \forall l \in L
\end{aligned}
$$

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Case study: overview

- Simulation on 32 representative snapshots of 7 zonal options
- 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 robustness
- 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

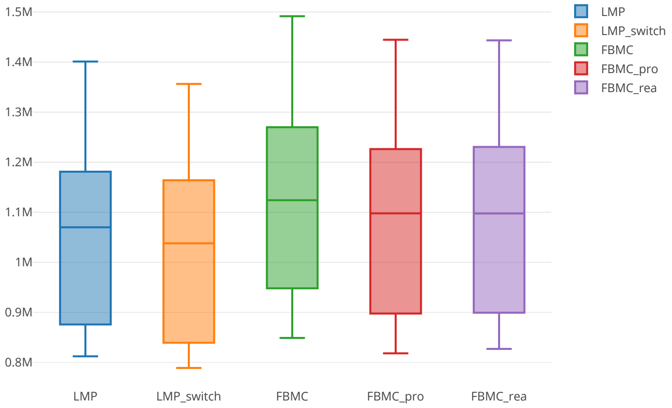

Figure 1: Total (DA+RT) hourly cost of the different policies on 32 snapshots of CWE.

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. Benefits of switching in LMP and FBMC are comparable.

Conclusion

Summary

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

Main message

- Reactive switching improves FBMC operational costs significantly
- Additional benefits of proactive switching are small

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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