Model and Algorithm for Flow-based Market Coupling with Transmission Switching and N-1 Security

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Outline

Flow-based market coupling (FBMC)

Methodology for building the network constraints in the European day-ahead market.

Motivation

The **zonal pricing paradigm** of the European electricity is being increasingly challenged.

1. **Redispatch costs** have risen recently.
2. Hard to implement the right **zone delimitation**.

Motivation

Arguments in favor of zonal regarding **topology control**.

1. Zonal is better suited for implementing topology control.
2. Topology control can help to decrese redispatch costs.

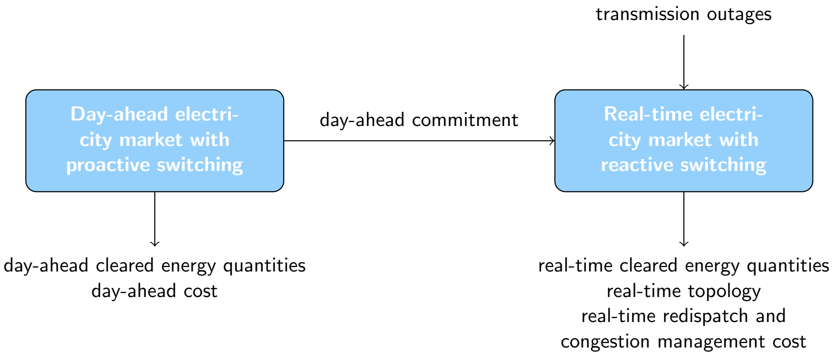
Research questions

What are the impacts of transmission switching on the European market ?

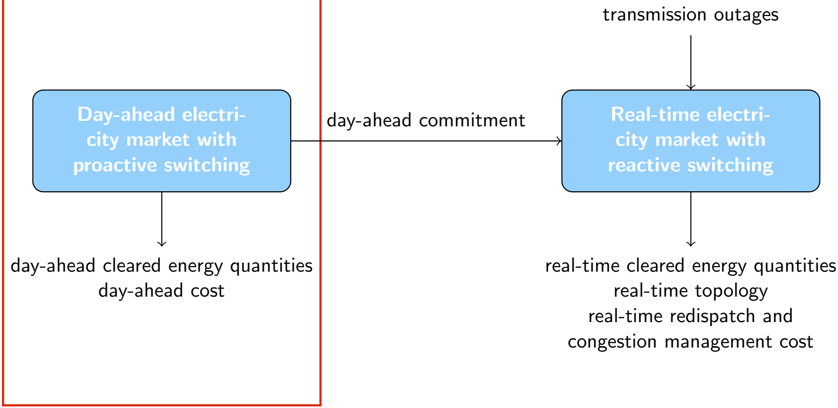
More precisely:
Zonal unit commitment in day-ahead with is inefficient (Aravena et al., 2020)

- Can proactive switching help to make better unit commitment decisions ?
- Is switching more beneficial in zonal than in nodal markets ?

Day-ahead and real-time model



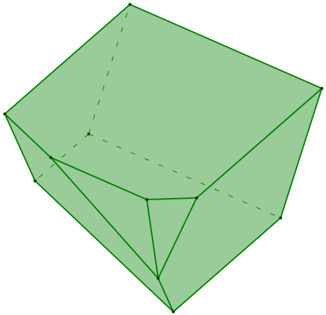
Day-ahead and real-time model

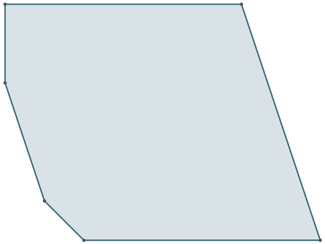


Acceptable set of net positions

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

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

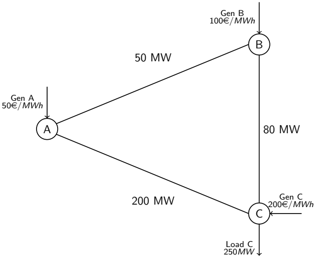




$$\mathcal{R} := \Big\{ r \in \mathbb{R}^{|N|} : r \text{ is feasible for the real network} \Big\}$$

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

Acceptable set of net positions with switching

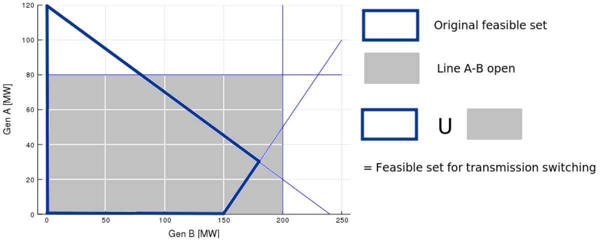


$p \in \mathcal{P}_t$

$$-50 \leq \frac{1}{3}\mathrm{GEN}_A - \frac{1}{3}\mathrm{GEN}_B \leq 50$$

$$-80 \leq \frac{1}{3}\mathrm{GEN}_A + \frac{2}{3}\mathrm{GEN}_B \leq 80$$

$$-200 \leq \frac{2}{3}\mathrm{GEN}_A + \frac{1}{3}\mathrm{GEN}_B \leq 200$$



→ solve on the union of polytopes

Day-ahead market clearing with proactive switching

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

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

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

- (P_g, Q_g) is the price quantity bid of generator g
- v_g is the acceptance of the bid of generator g
- p_z is the net position of zone z
- $\mathcal{P}$ is the acceptable set of net positions, which depends on the topology (t).

Acceptable set of net positions

- Put the two together

$$\mathcal{P}_t = \Big\{ p \in \mathbb{R}^{|Z|} : \exists(\bar{v}, f, \theta, t) \in [0,1]^{|\mathcal{G}|} \times \mathbb{R}^{|L|} \times \mathbb{R}^{|N|} \times \{0,1\}^{|L|} :$$

$$\sum_{g \in \mathcal{G}(z)} Q_g \bar{v}_g - p_z = \sum_{n \in N(z)} Q_n, \quad \forall z \in Z$$

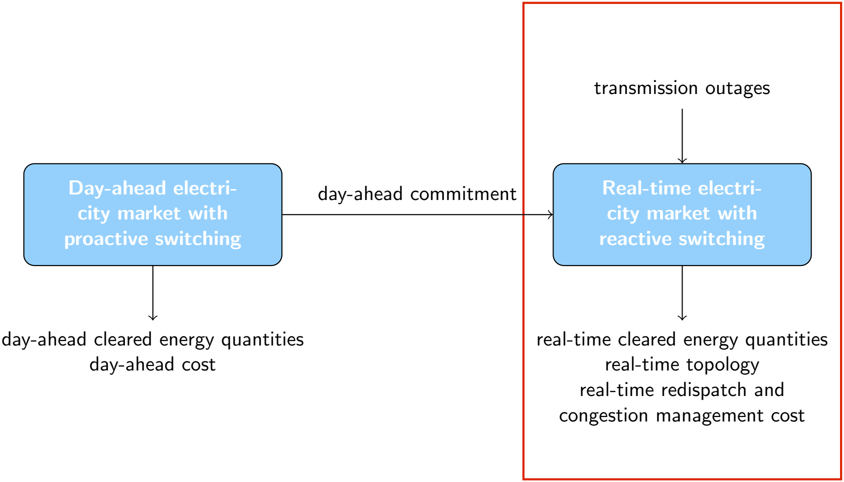
$$\sum_{g \in \mathcal{G}(n)} Q_g \bar{v}_g - \sum_{l \in L(n,\cdot)} f_l + \sum_{l \in L(\cdot,n)} f_l = Q_n, \quad \forall n \in N$$

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

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

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

Day-ahead and real-time model



Cost-based redispatch

Goal

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

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

Preventive vs curative remedial actions

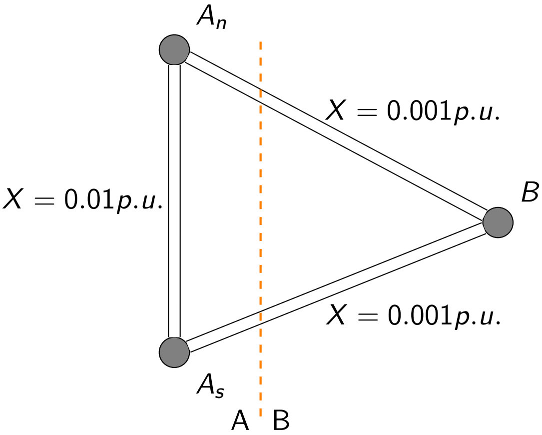
Central distinction in N-1 modeling.

- **Preventive:** Performed before the realization of a contingency.
- **Curative:** Performed in reaction to the contingency.

TSO practices:

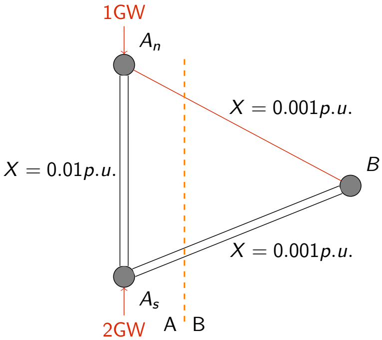
- Topological changes (PST settings, line switching, ...) can be curative.
- **Most** redispatching is preventive.

Illustrative example: Preventive vs curative

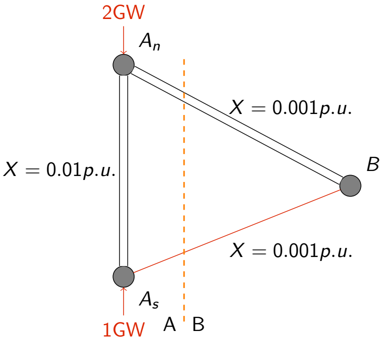


What is the largest acceptable net position of zone A in a N-1 setting ?

Illustrative example: curative

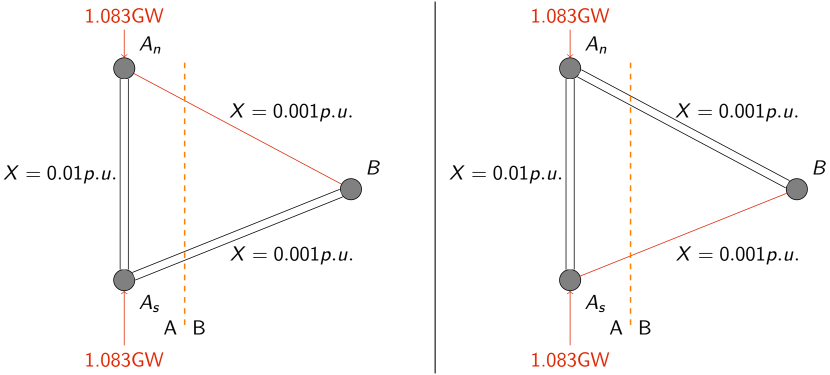


$$p_A = 3GW$$



$$p_A = 3GW$$

Illustrative example: preventive



$$p_A = 2.17GW$$

Curative redispatching

$$p \in \bigcap_{\|u\|_1 \leq 1} \mathcal{P}_t^{\text{cur}}(u)$$

with

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

Preventive redispatching

$$\mathcal{P}_t^{\text{prev}} = \Big\{ p \in \mathbb{R}^{|Z|} : \exists\ \bar{v} \in [0,1]^{|G|} :$$

$$\sum_{g \in G(z)} Q_g \bar{v}_g - p_z = \sum_{n \in N(z)} Q_n, \quad \forall z \in Z$$

$$\bar{v} \in \bigcap_{\|u\|_1 \le 1} \mathcal{V}_t(u) \Big\}$$

with

$$\mathcal{V}_t(u) = \Big\{ v \in [0,1]^{|G|} :$$

$$\exists (f, \theta, t) \in \mathbb{R}^{|L|} \times \mathbb{R}^{|N|} \times \{0,1\}^{|L|} :$$

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

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Simulation results

Main result: Considering switching in the market coupling methodology has a negligable effect. Performing UC with nodal pricing remains more efficient.

- Reactive transmission switching has considerable value.
- Transmission switching benefits more to FBMC than to LMP.
- Perfect TSO coordination in redispatch is highly valuable.

Discussion and conclusion

Answer to pro-zonal arguments:

1. Is zonal better suited for topology control ?
   - Yes: Zonal $\rightarrow$ less price variability $\rightarrow$ more acceptable to have a sub-optimal solution
   - No: Proactive switching does not help much

2. Topology control is more beneficial to zonal ?
   - True for reactive switching

Further research directions: Impacts in terms of pricing

Thank you

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