An analysis of zonal electricity pricing from a long-term perspective

INFORMS Annual Meeting 2021

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October 26, 2021

Outline

Research questions

Modeling zonal electricity markets

Capacity expansion with transmission constraints

Results and conclusion

Research questions

What are the impacts of FBMC on investment ?

- Zonal distorts the price $\rightarrow$ cash flows to producers $\rightarrow$ investment
- In the energy transition era, this may be important

How to model capacity expansion with FBMC ?

- Nodal and well-defined zonal: single optimization problem
- FBMC: no equivalence between centralized and decentralized
- Generalized Nash equilibrium

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Modeling zonal electricity markets

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Results and conclusion

Transmission constraints in a nodal market

Two basic principles:

- Exchanges withtin the same node are not restricted
- Constraints are imposed on the vector of net injections r

Let us call $\mathcal{R}$ the feasible set of net injections: $r \in \mathcal{R}$

DC approximation:

$$\mathcal{R} = \Big\{ r \in \mathbb{R}^{|N|} \,\Big|\, \exists f \in \mathbb{R}^{|K|} : \\ f_k = \sum_{n \in N} PTDF_{kn} \cdot r_n, k \in K \\ \sum_{n \in N} r_n = 0, -TC_k \leq f_k \leq TC_k, k \in K \Big\}$$

Transmission constraints in a zonal market

Two basic principles:

- Exchanges withtin the same zone are not restricted
- Constraints are imposed on the vector of net positions p

Let us call $\mathcal{P}$ the feasible set of net positions: $p \in \mathcal{P}$

Unlike nodal, no unique way for defining $\mathcal{P}$. We compare two models:

1. the Price Aggregation model $\mathcal{P}^{\text{PA}}$
2. the Flow-Based Market Coupling Model $\mathcal{P}^{\text{FBMC}}$

The Price Aggregation model

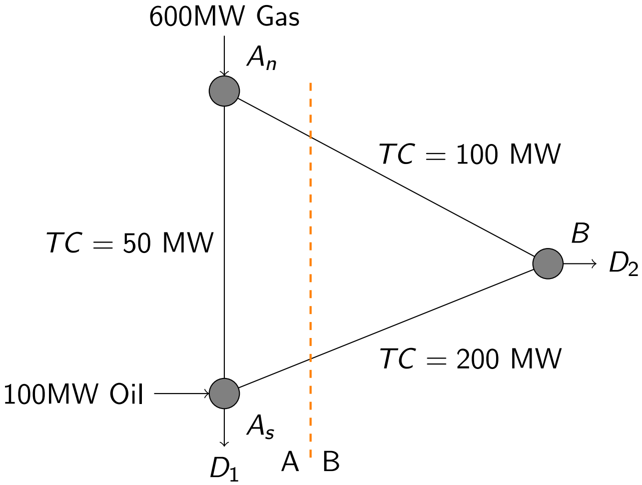
Go back to the basics of zonal

- There is a unique price per zone
- nodal primal $\rightarrow$ nodal dual $\xrightarrow{\text{prices }=}$ zonal dual $\rightarrow$ zonal

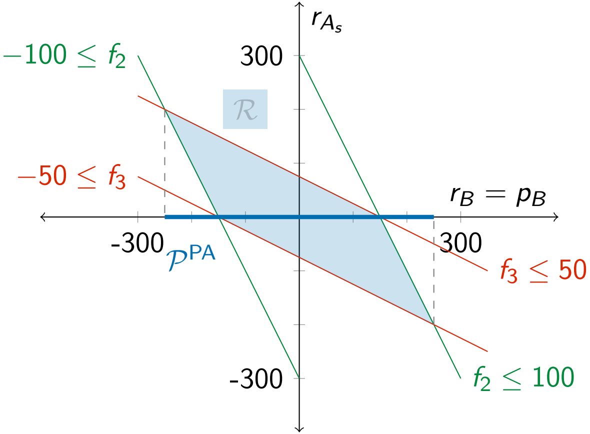
$$\mathcal{P}^{\mathrm{PA}} = \left\{ p \in \mathbb{R}^{|Z|} \;\middle|\; \exists r \in \mathbb{R}^{|N|} : p_z = \sum_{n \in N(z)} r_n \;\; \forall z \in Z, \right.$$
$$\left. r \in \mathcal{R} \right\}$$

- Projection of the set of feasible net injections into the space of net positions
- Direct extension of nodal pricing

Illustrative example



PA model: projection



The Flow-Based Market Coupling model

Main principle

- Use forecast of the dispatch
- And knowledge of existing capacity
- To further restrict the space of feasible net positions

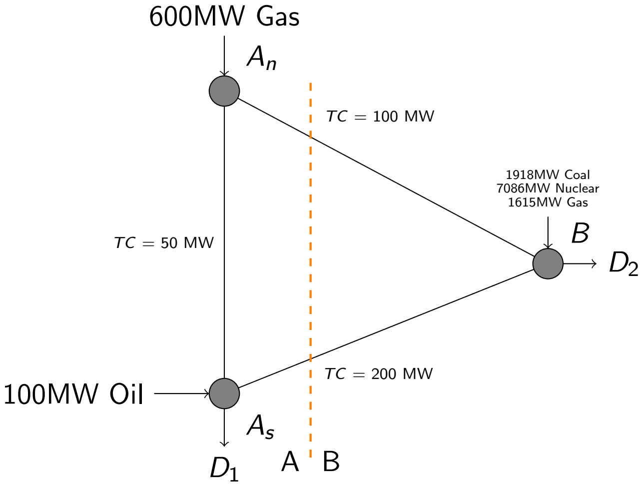
$$\mathcal{P}^{\mathrm{FBMC}} = \left\{ p \in \mathbb{R}^{|Z|} \;\middle|\; \exists (r, \tilde{y}) : p_z = \sum_{n \in N(z)} r_n \;\; \forall z \in Z, \right.$$

$$r \in \mathcal{R},$$

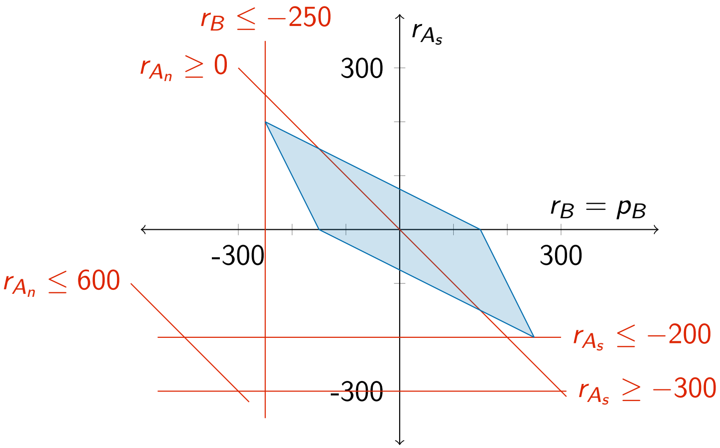
$$r_n = \tilde{y}_{int} - D_{nt} \;\; \forall n \in N,$$

$$\left. 0 \leq \tilde{y}_{int} \leq X_{in} \;\; \forall i \in I, n \in N \right\}$$

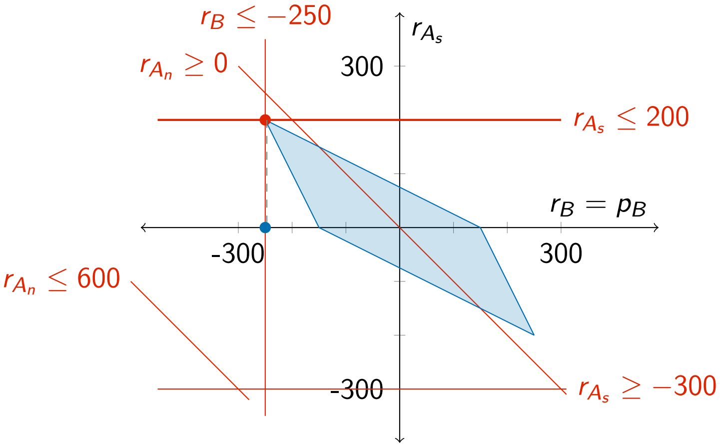
Illustrative example with capacity expanded



FBMC additional constraints



FBMC constraints with more capacity



→ Capacity influence the shape of the network constraints

PA vs FBMC

PA

- Basic principle of zonal
- Direct extension of nodal
- Depends only on network quantities
- Stable over time
- Large feasible set

FBMC

- Difficult to model
- Depends on generation capacity
- Changes every hour
- Restricted feasible set

Equivalence to decentralized solution is broken

Producers:

$$\max_{x_{iz}} \sum_{t \in T} \Big((\rho_{zt} - MC_i) y_{izt} \Big) - IC_i x_{iz}$$

$$\text{s.t. } X_{iz} + x_{iz} - y_{izt} \geq 0$$

$$x_{iz} \geq 0, y_{izt} \geq 0$$

TSO:

$$\max_{p_{zt}} - \sum_{z \in Z, t \in T} p_{zt} \rho_{zt}$$

$$\text{s.t. } p_{:t} \in \mathcal{P}^{\text{FBMC}}(x_{in}), t \in T$$

Consumers:

$$\max_{s_{zt}} \sum_{t \in T} VOLL(D_{zt} - s_{zt}) - \rho_{zt}(D_{zt} - s_{zt})$$

$$\text{s.t. } D_{zt} - s_{zt} \geq 0, t \in T$$

$$s_{zt} \geq 0$$

Auctioneer:

$$\max_{\rho_{zt}} \ \rho_{zt}(p_{zt} + D_{zt} - \sum_i y_{izt} - s_{zt})$$

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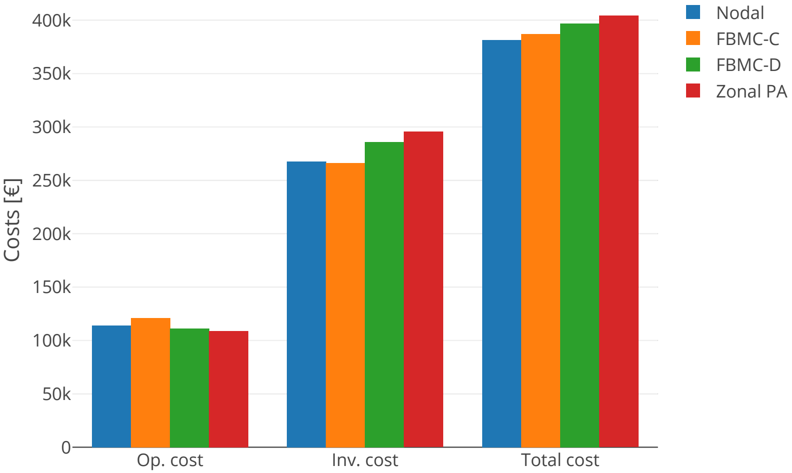
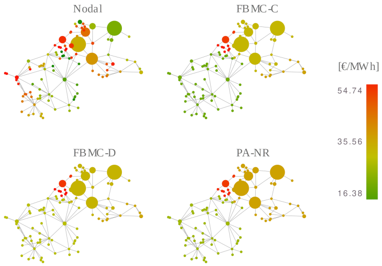
Results: costs comparison



Results: case study on the Central Western European network

- 100 nodes and 20 time periods
- Based on realistic data of CWE
- Splitting based algorithm to solve the FBMC-D



Observations

- Same ranking than illustrative example
- Large efficiency gaps between the four designs
- Reallocation of technologies in different locations of the same zone cannot occur in decentralized FBMC and PA

Conclusion

Equivalence between central planner and decentralized solution is broken in FBMC.

Consequences:

- Multiple equilibria: not clear what the output will be.
- Intervention from the TSO is necessary (network reserve).
- Market efficiency is degraded:
  Nodal > FBMC-C > FBMC-D > Zonal-PA

Thank you

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