An analysis of flow-based market coupling from a long-term perspective

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Outline

Flow-based market coupling (FBMC)

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

- Replaces ATCMC: limit on the bilateral exchanges between each pair of zones.
- FBMC adds more advanced polyhedral constraints on the zonal net positions.
- Mimics the nodal constraints but at the zonal level.

Research questions

What are the impacts of FBMC on investment ?

- Zonal distorts the price → cash flows to producers → 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

Methodology for evaluating a market design

"The goal of a well functioning market should be to reproduce the ideal central planning results"[1]

Steps:

1. Formulate the optimal long-term solution
2. Answer the following question: do there exist prices that allow to recover the centralized solution in a decentralized setting ?

[1] Paul Joskow, "The new energy paradigm", 2007.

Nodal pricing: optimal long term solution

Transmission constraints

Assume that the central planner considers all transmission constraints via the DC approximation

Feasible set of nodal net injections:

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

This set completely defines the network constraints.

Nodal pricing: optimal long term solution (2)

Capacity expansion

Minimize	the cost of production
s.t.	generators operational constraints
	transmission constraints
	the market clears

$$\min_{x,y,s,r} \sum_{i \in I, n \in N} IC_i \cdot x_{in} + \sum_{i \in I, n \in N, t \in T} MC_i \cdot y_{int} + \sum_{n \in N, t \in T} VOLL \cdot s_{nt}$$

$$(\mu_{int}) : y_{int} \leq x_{in} + X_{in}, i \in I, n \in N, t \in T$$

$$(\rho_{nt}) : r_{nt} = \sum_{i \in I} y_{int} + s_{nt} - D_{nt}, n \in N, t \in T$$

$$r_{:t} \in \mathcal{R}, t \in T$$

$$x \geq 0, y \geq 0, s \geq 0$$

Nodal pricing: Equivalence to decentralized solution

Producers:

$$\max_{x_{in}} \sum_{t \in T} \Big((\rho_{nt} - MC_i) y_{int} \Big) - IC_i x_{in}$$

$$\text{s.t. } X_{in} + x_{in} - y_{int} \geq 0$$

$$x_{in} \geq 0, y_{int} \geq 0$$

TSO:

$$\max_{r_{nt}} - \sum_{n \in N, t \in T} r_{nt} \rho_{nt}$$

$$\text{s.t. } r_{:t} \in \mathcal{R}, t \in T$$

Consumers:

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

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

$$s_{nt} \geq 0$$

Auctioneer:

$$\max_{\rho_{nt}} \; \rho_{nt}(r_{nt} + D_{nt} - \sum_i y_{int} - s_{zt})$$

Zonal pricing: optimal long term solution

Transmission constraints ?

- Unique price per zone
- nodal primal $\rightarrow$ nodal dual $\xrightarrow{\text{prices } =}$ zonal dual $\rightarrow$ zonal primal

Feasible set of **zonal** net injections:

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

Zonal pricing: Equivalence to decentralized solution

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:

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

$$\text{s.t. } p_{:t} \in \mathcal{P}^{\text{PA}}, t \in T$$

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:

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

FBMC: set of feasible net injections ?

Two main principles

1. No feasible transactions should be rejected
2. Cleared zonal net positions should be feasible

Important fact: TSOs use the knowledge of existing nodal capacity:

$$\mathcal{P}\mathcal{X}^{\text{FBMC}}(x_{in}) = \left\{ p \in \mathbb{R}^{|Z|} \;\middle|\; \exists (r, \tilde{y}) : p_z = \sum_{n \in N(z)} r_n \;\; \forall z \in Z, \right.$$
$$r \in \mathcal{R},$$
$$r_n = \tilde{y}_{int} - D_{nt} \;\; \forall n \in N,$$
$$\left. 0 \leq \tilde{y}_{int} \leq x_{in} + X_{in} \;\; \forall i \in I, n \in N \right\}$$

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:

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

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

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:

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

Investment conditions

Nodal:

$$0 \leq x_{in} \perp IC_i - \sum_{t \in T} \mu_{int} \geq 0 \;\; \forall i \in I, n \in N$$

Zonal PA:

$$0 \leq x_{iz} \perp IC_i - \sum_{t \in T} \mu_{izt} \geq 0 \;\; \forall i \in I, z \in Z$$

FBMC-C:

$$0 \leq x_{iz} \perp IC_i - \sum_{t \in T} \mu_{izt} - \sum_{m \in \{1,\ldots,M\}} U_{miz}\gamma_m \geq 0 \;\; \forall i \in I, z \in Z$$

FBMC-D:

$$0 \leq x_{iz} \perp IC_i - \sum_{t \in T} \mu_{izt} \geq 0 \;\; \forall i \in I, z \in Z$$

Illustrative example

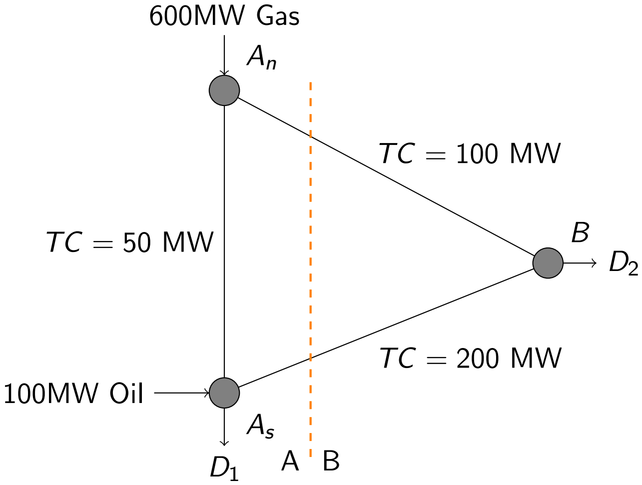


Figure 1: Three-node two-zone network used in the illustrative example.

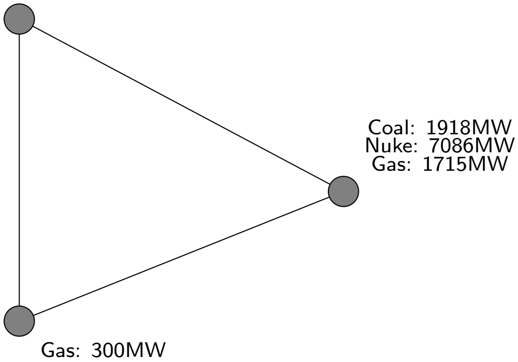
Illustrative example (2)

Technology	MC [€/MWh]	IC [€/MWh]
Coal	25	16
Gas	80	5
Nuclear	6.5	32
Oil	160	2

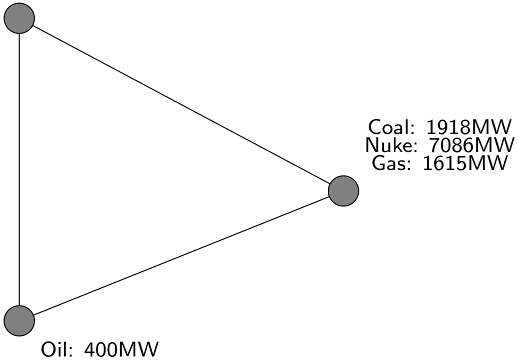
D_1 [MW]	D_2 [MW]	Duration [h]
0	7086	1760
0	9004	5500
300	10869	1500

$$\text{VOLL} = 3000€/\text{MWh}$$

Results: investment nodal



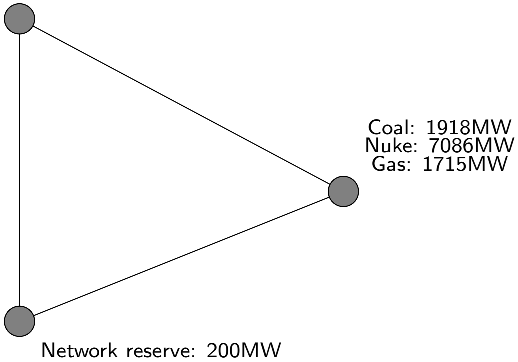
Results: investment FBMC-C



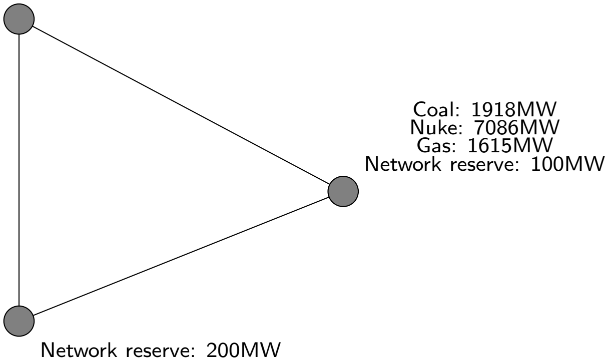
Investors do not recover their cost.

Gas in node B: profit in the peak period:
$97.52 - 80 = 17.52$€/MWh, which gives $\frac{17.52 \cdot 1500}{8760} = 3$€/MWh.
Net profit is below the investment cost of 5€/MWh.

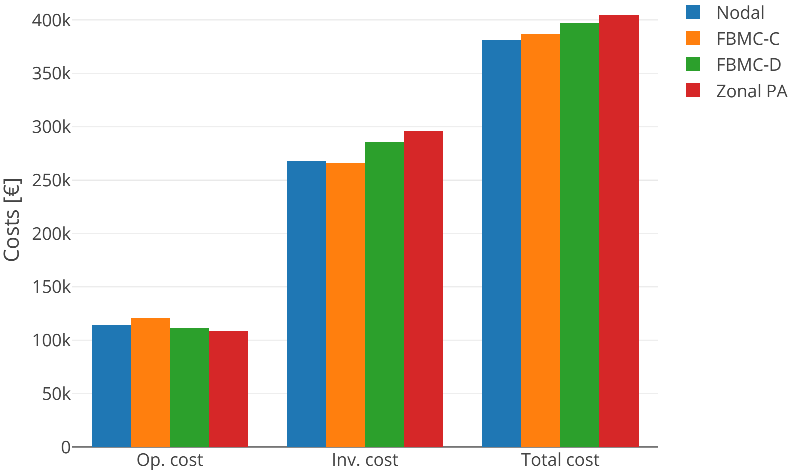
Results: investment FBMC-D



Results: investment zonal PA

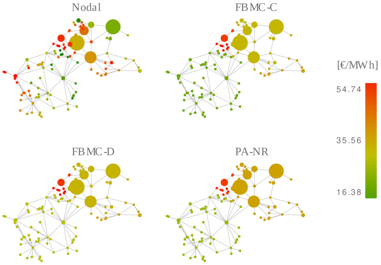


Results: costs comparison



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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