Zonal Pricing

Anthony Papavasiliou, National Technical University of Athens (NTUA)

Source: section 5.3, Papavasiliou [1]

Outline

- Motivations for zonal pricing
- Zonal pricing models
- Redispatch
- INC-DEC gaming

Motivations for zonal pricing

Zonal pricing throughout the world

- Original design in the US, transition to nodal pricing in early 2000
- Dominant design in Europe (despite problems in Germany and Great Britain)
- Candidate design in China, India

Criticisms of nodal pricing

Criticisms	**Counter-arguments**
Institutional compatibility: • Exchange of sensitive information about national infrastructure • Keeping low energy cost for some consumers	The fact that some consumers prefer to pay a low price for energy does not mean that neighbors should bear transmission costs
Implementation complexity: • Technological complexity • Portfolio offers	• Implementation in the US proves that it is technologically feasible • Unit-based offers allow for better scheduling and market monitoring

Criticisms of nodal pricing

Criticisms	**Counter-arguments**
Market power: geographic splitting of the market leads to firms with a dominant position	All designs are exposed to manipulation due to market power, ignoring physical constraints of the network does not render a firm less able to exert market power
Cash transfers: zonal pricing achieves the same result with lower cash flows between market agents	But it does not achieve the same result if market participants deviate from truthful bidding
Non-intuitive price behavior	The behavior of prices is due to physical laws that cannot be ignored
Risk management and liquidity: too many pairs of nodes, difficult to hedge against transmission price differences between any pair of locations	Contract networks

Zonal pricing models

Two basic zonal pricing paradigms

(ZP):

$$\max_{p,d,r,f} \sum_{l \in L} \int_0^{d_l} MB_l(x)dx - \sum_{g \in G} \int_0^{p_g} MC_g(x)dx$$

(ρ_z):

$$r_z = \sum_{g \in G_z} p_g - \sum_{l \in L_z} d_l \, , z \in Z$$

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

$$p_g \geq 0, g \in G$$

$$d_l \geq 0, l \in L$$

Two dominant models:

- **Transportation network** (ATC market coupling)
- **Flow-based market coupling**

Same underlying mathematical model

$\mathcal{R}$: set of feasible zonal injections

Zonal pricing auction

Zonal pricing is a uniform price auction that is conducted as follows:

- Sellers and buyers submit price/quantity pairs
- The market operator solves (ZP) and announces ρ_z as the market clearing price for zone z

Transportation-based zonal pricing

Ignores Kirchhoff’s laws completely

Assume a transportation network on which we have perfect control over line flows

Crucial design choices:

- **Bidding zone configuration**
- **Available transfer capacities**

Set of feasible injections:

$$\mathcal{R} = \{r : r_z = \sum_{a=(z,\cdot)} f_a - \sum_{a=(\cdot,z)} f_a \,, z \in Z, \\ -ATC_a \leq f_a \leq ATC_a, a \in A\}$$

The model

(ZPT):

$$\max_{p,d,r,f} \sum_{l \in L} \int_0^{d_l} MB_l(x)dx - \sum_{g \in G} \int_0^{p_g} MC_g(x)dx$$

(ρ_z):

$$r_z = \sum_{g \in G_z} p_g - \sum_{l \in L_z} d_l \, , z \in Z$$

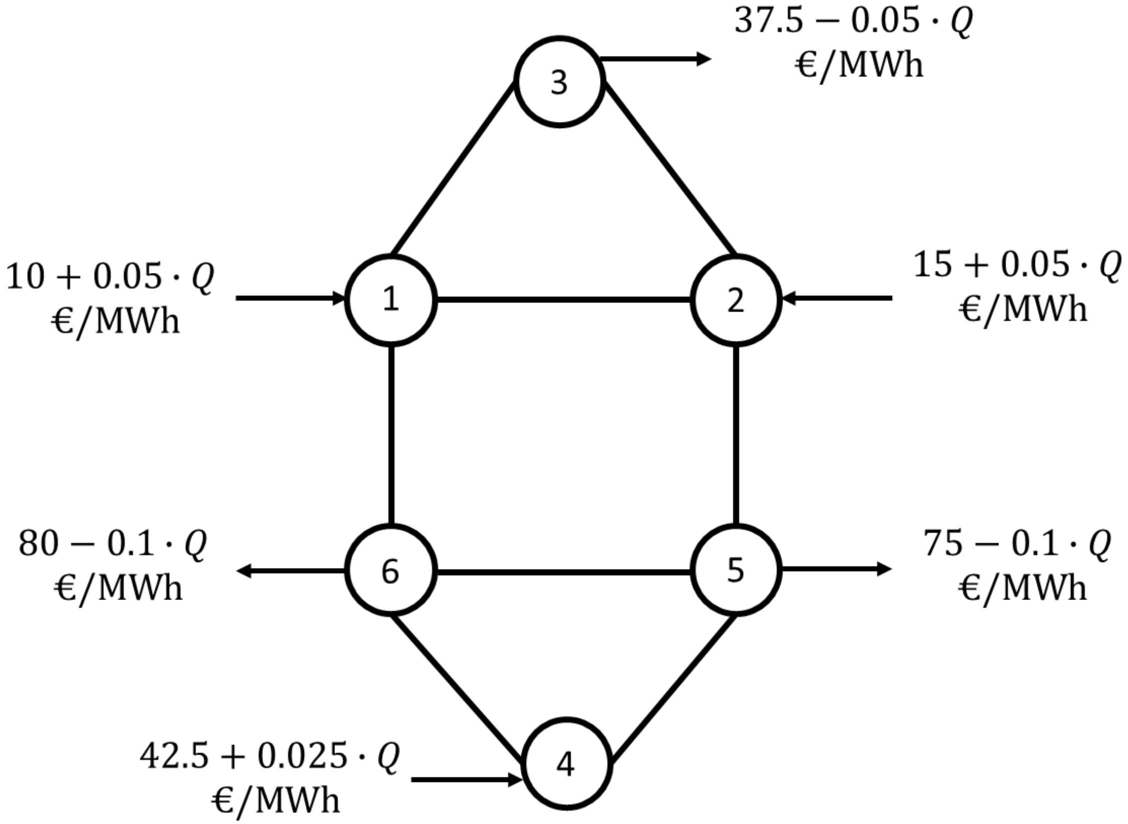
$$r_z = \sum_{a=(z,\cdot)} f_a - \sum_{a=(\cdot,z)} f_a \, , z \in Z$$

$$-ATC_a \leq f_a \leq ATC_a, a \in A$$

$$p_g \geq 0, g \in G$$

$$d_l \geq 0, l \in L$$

6-node example



$37.5 - 0.05 \cdot Q$ €/MWh

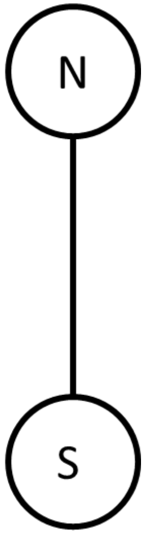
$10 + 0.05 \cdot Q$ €/MWh

$15 + 0.05 \cdot Q$ €/MWh

$80 - 0.1 \cdot Q$ €/MWh

$75 - 0.1 \cdot Q$ €/MWh

$42.5 + 0.025 \cdot Q$ €/MWh



6-node example: LMPs

	Node 1	Node 2	Node 3	Node 4	Node 5
Line 1-6	0.625	0.5	0.5625	0.0625	0.125
Line 2-5	0.375	0.5	0.4375	-0.0625	-0.125

PTDFs

Suppose that $T_{1-6} = 200 \text{ MW}, T_{2-5} = 250 \text{ MW}$

Locational marginal pricing:

- Welfare: 23000 €/h
- Different price at each node: $\rho_1 = 25 \frac{\$}{\text{MWh}}, \rho_2 = 30 \frac{\$}{\text{MWh}}, \rho_3 = 27.5 \frac{\$}{\text{MWh}}, \rho_4 = 47.5 \frac{\$}{\text{MWh}}, \rho_5 = 45 \frac{\$}{\text{MWh}}, \rho_6 = 50 \frac{\$}{\text{MWh}}$
- Line flows: $f_{1-6} = f_{2-5} = 200 \text{ MW}$

Zonal pricing model:

- $Z = \{N, S\}$
- $A = \{N - S\}$
- The north zone includes nodes 1, 2, 3
- The south zone includes nodes 4, 5, 6

- Zonal pricing with $ATC_{N-S} = 200 \text{ MW}$
  - Welfare: 18520 €/h
  - $\rho_N = 24.17 \frac{\$}{\text{MWh}}, \rho_S = 50.83 \frac{\$}{\text{MWh}}$
  - Flows: $f_{1-6} = 109.38 \text{ MW}, f_{2-5} = 90.63 \text{ MW}$

- Zonal pricing with $ATC_{N-S} = 450 \text{ MW}$
  - Welfare: 24145 €/h
  - $\rho_N = 28.33 \frac{\$}{\text{MWh}}, \rho_S = 46.77 \frac{\$}{\text{MWh}}$
  - Flows: $f_{1-6} = 234.38 \text{ MW}, f_{2-5} = 215.63 \text{ MW}$

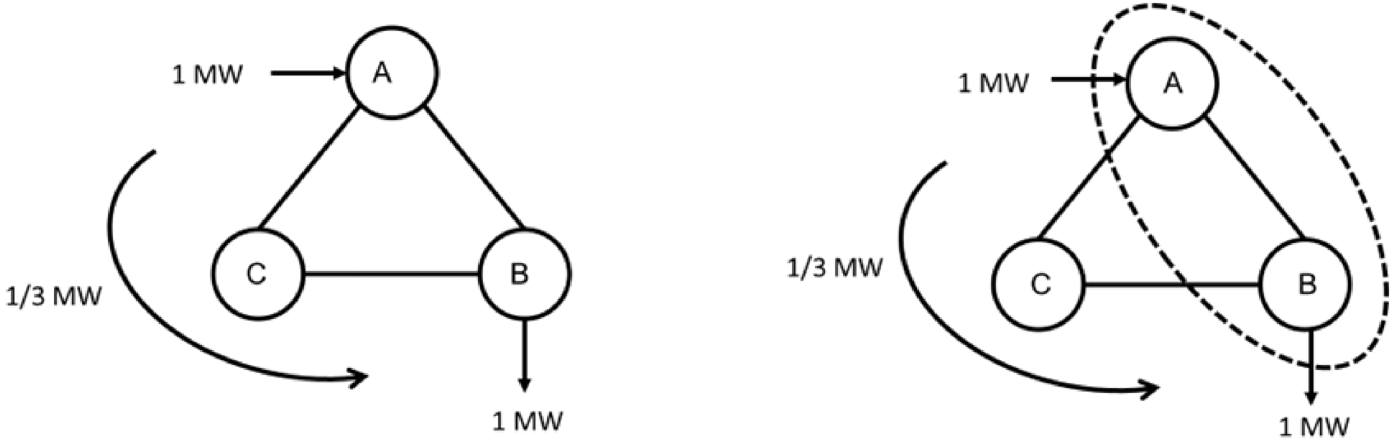
How do we confirm that these are market clearing prices for the zonal model?

Zonal model is either:

- Too conservative ($ATC = 200\ \mathrm{MW}$)
  - Flow constraints are respected
  - … but zonal pricing welfare < nodal pricing welfare
- Too aggressive ($ATC = 450\ \mathrm{MW}$)
  - Zonal pricing welfare > nodal pricing welfare
  - … but flow constraints are violated

Loop flows and transit flows

- **Loop flows**: flows within a zone that are caused by transactions *within* a neighboring zone
- **Transit flows**: flows within a zone that are caused by transactions *between* neighboring zones



Left: transit flows. Right: loop flows.

The idea of flow-based zonal pricing

- **Flow-based market coupling** attempts to approximate Kirchhoff laws through
  - **Critical branches** CB: set of network elements on which flow constraints are imposed
  - **Zone-to-line PTDFs** $PTDF_{zl}$
  - **Remaining available margin** (RAM), the estimation of which requires a **base case**
- All these parameters are problematic because their definition is **circular** (the choice of base case, and therefore RAM, affects the dispatch of the system, which affects the base case)

$$\mathcal{R} = \{r: \sum_{z \in Z} PTDF_{zl} \cdot r_z \leq RAM_l, l \in CB$$

$$\sum_{z \in Z} r_z = 0\}$$

The model

$(ZPFB)$:

$$\max_{p,d,r,f} \sum_{l \in L} \int_0^{d_l} MB_l(x)dx - \sum_{g \in G} \int_0^{p_g} MC_g(x)dx$$

(ρ_z):

$$r_z = \sum_{g \in G_z} p_g - \sum_{l \in L_z} d_l = 0, z \in Z$$

$$f_k = \sum_{z \in Z} PTDF_{zk} \cdot r_z \, , k \in CB$$

$$f_k \leq RAM_k, k \in CB$$

$$\sum_{z \in Z} r_z = 0$$

$$p_g \geq 0, g \in G$$

$$d_l \geq 0, l \in L$$

Flow-based feasible set

Critical branch AB: $\frac{1}{3}r_A - \frac{1}{3}r_B \leq 1000$

Critical branch BA: $-\frac{1}{3}r_A + \frac{1}{3}r_B \leq 1000$

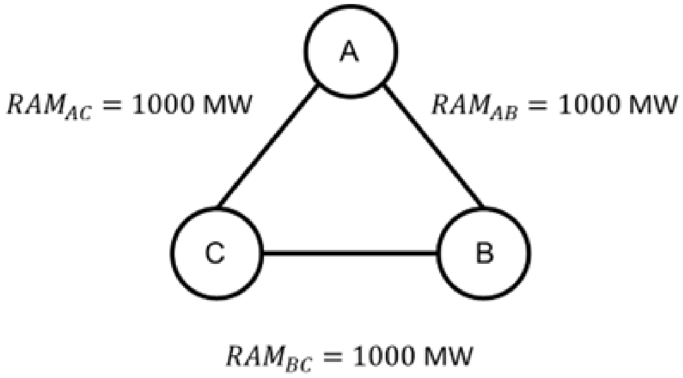
Critical branch BC: $\frac{1}{3}r_A + \frac{2}{3}r_B \leq 1000$

Critical branch CB: $-\frac{1}{3}r_A - \frac{2}{3}r_B \leq 1000$

Critical branch AC: $\frac{2}{3}r_A + \frac{1}{3}r_B \leq 1000$

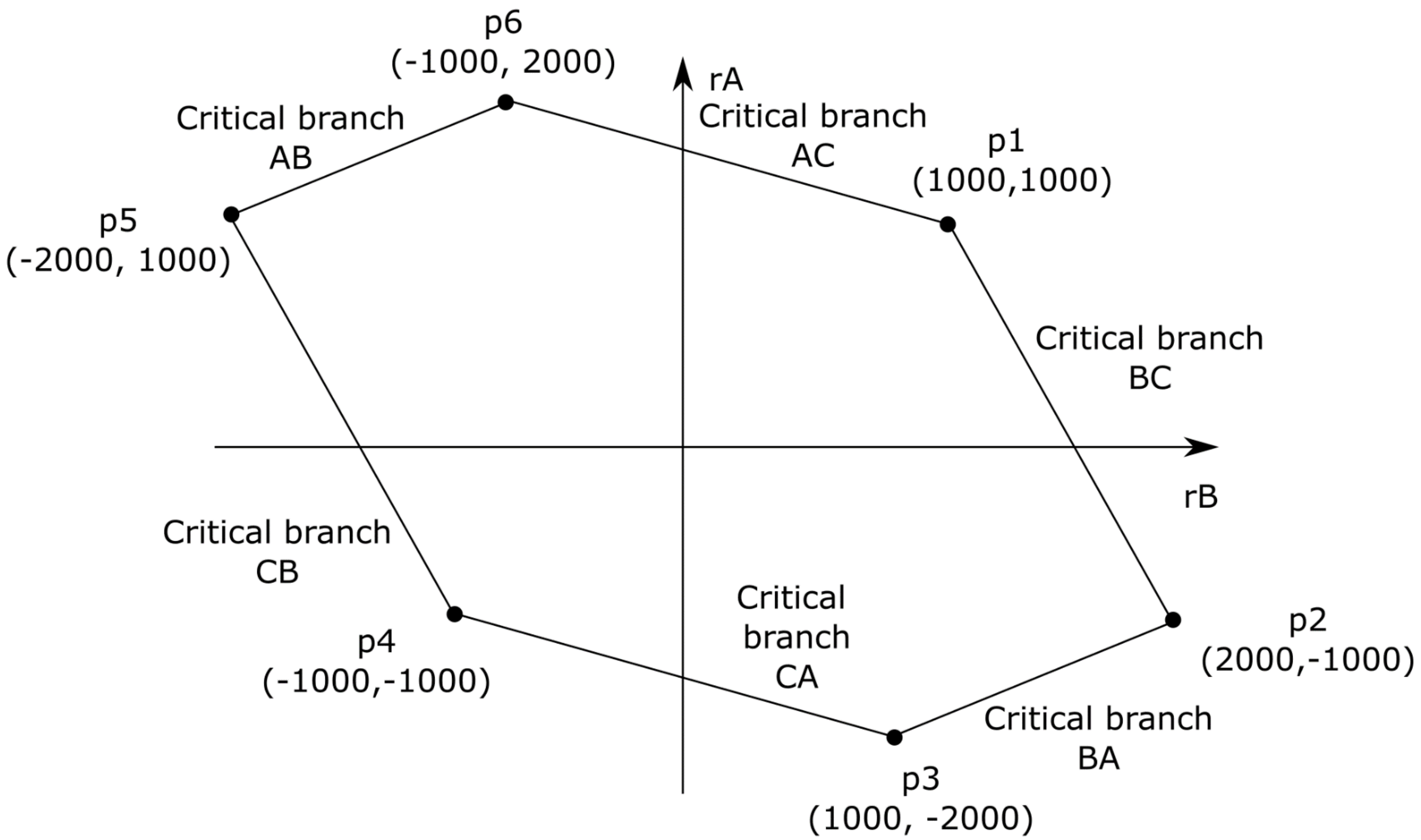
Critical branch CA: $-\frac{2}{3}r_A - \frac{1}{3}r_B \leq 1000$

$$r_A + r_B + r_C = 0$$



	A	B
AB	1/3	-1/3
BA	-1/3	1/3
BC	1/3	2/3
CB	-1/3	-2/3
AC	2/3	1/3
CA	-2/3	-1/3

Zone-to-line PTDFs $PTDF_{lz}$

p6
(-1000, 2000)
rA
Critical branch
AB
Critical branch
AC
p1
(1000,1000)
p5
(-2000, 1000)
Critical branch
BC
rB
Critical branch
CB
Critical
branch
CA
p2
(2000,-1000)
p4
(-1000,-1000)
Critical branch
BA
p3
(1000, -2000)

A zonal pricing model without circular parameter definitions

$$(FBP): \max_{p,d,\rho} \sum_{l\in L} \int_0^{d_l} MB_l(x)dx - \sum_{g\in G} \int_0^{p_g} MC_g(x)dx$$

$$0 \leq p_g \perp MC_g\left(p_g\right) - \rho_{z(g)} \geq 0, g \in G$$

$$0 \leq d_l \perp -MB_l\left(p_g\right) + \rho_{z(l)} \geq 0, l \in L$$

$$\sum_{g\in G} p_g - \sum_{l\in L} d_l = 0$$

$$-T_k \leq \sum_{n\in N} F_{kn} \cdot \left(\sum_{g\in G_n} p_g - \sum_{l\in L_n} d_l\right) \leq T_k, k \in K$$

Returning to the 6-node example

Recall that $T_{1-6} = 200 \text{ MW}, T_{2-5} = 250 \text{ MW}$

- Welfare: 22806.6 \$/h
- $\rho_N = 27.19 \frac{\$}{\text{MWh}}, \rho_S = 47.81 \frac{\$}{\text{MWh}}$
- Flows: $f_{1-6} = 200 \text{ MW}, f_{2-5} = 181.25 \text{ MW}$

How do these results compare to nodal pricing?

To ATC-based zonal pricing?

Redispatch

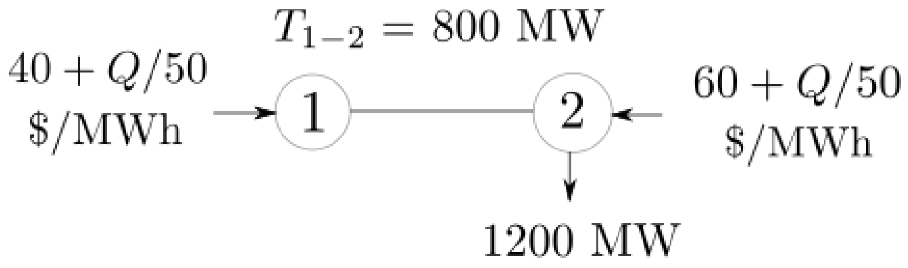
Redispatch

Redispatch: Pay-as-bid auction conducted after zonal pricing

- Sellers submit increment (inc) and decrement (dec) bids
- Inc bids: price producers are asking to provide additional power relative to zonal pricing auction
- Dec bids: price producers are willing to pay to market operator for decreasing production relative to zonal pricing auction
- Inc bids cleared to minimize payment to bidders
- Dec bids cleared to maximize payment to market operator

Example

- Under truthful bidding, zonal pricing followed by re-dispatch achieves the same result as nodal pricing with
    - Fewer prices
    - (Potentially) lower charges to consumers

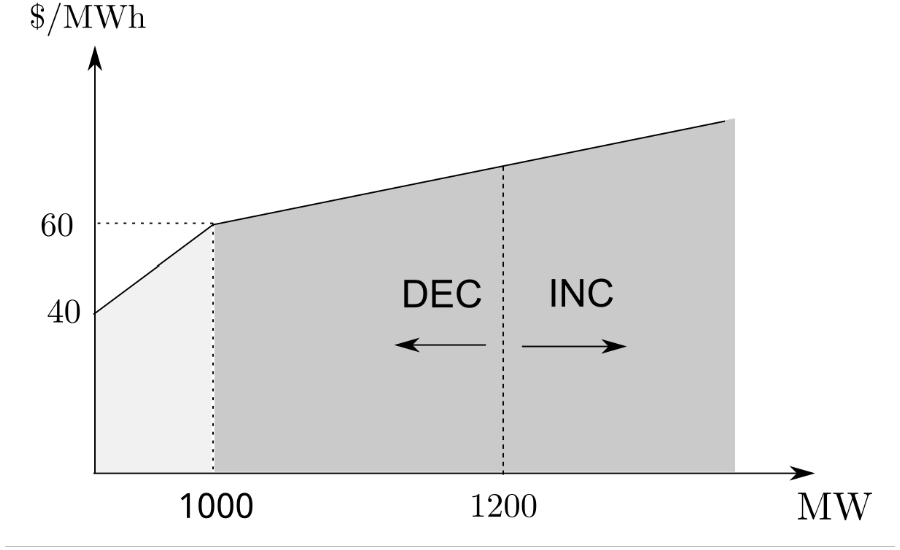


- LMP solution:
  - $p_1 = 800 \text{ MW}, p_2 = 400 \text{ MW}$
  - $\rho_1 = 56 \frac{\$}{\text{MWh}}, \rho_2 = 68 \frac{\$}{\text{MWh}}$
  - 9600 $/h remain to market operator

- Zonal pricing (one zone):
  - $p_1 = 1100 \text{ MW}, p_2 = 100 \text{ MW}$ (παραβίαση ορίου γραμμής)
  - $\rho = 62 \frac{\$}{\text{MWh}}$
  - Zero surplus for market operator

Re-dispatching under truthful bidding:

- 300 MW of inc bids cleared from node 2
- 300 MW of dec bids cleared from node 1
- Payment *to* market operator from dec bids: 17700 $/h
- Payment *from* operator to cleared inc bids: 19500 $/h
- Difference: 1800 $/h



INC-DEC gaming

Gaming zonal pricing

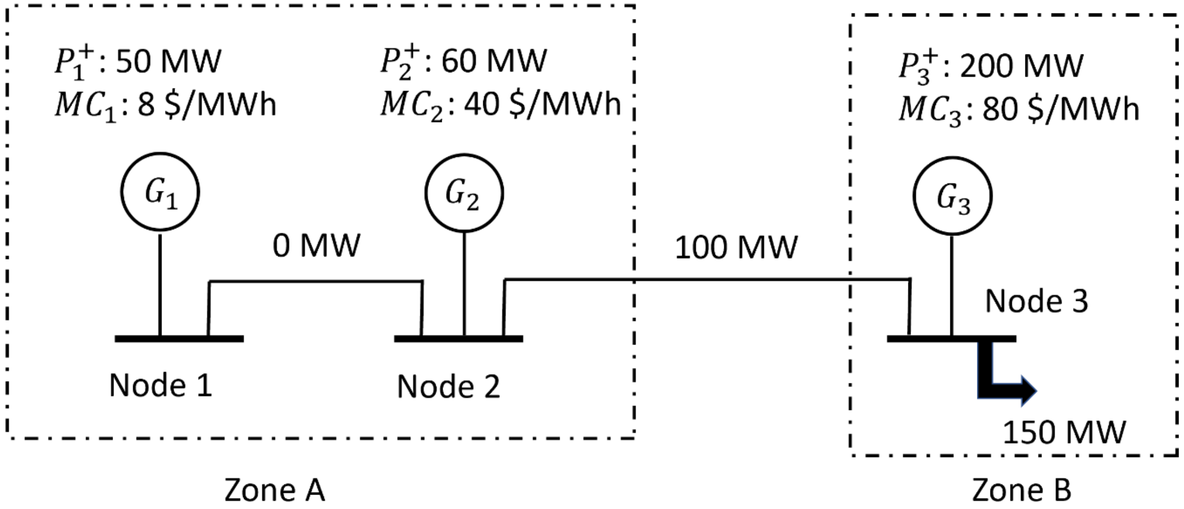
Zonal pricing with re-dispatch can be gamed easily

ENRON and other forms exploited INC-DEC gaming and other market manipulation trategies during the California market crisis of 2001

The idea of INC-DEC gaming

- A serious weakness of zonal pricing + redispatch is that it creates an inconsistency on the pricing of the same product in two different moments in time
- If agents can anticipate this price behavior, they can easily manipulate the mechanism:
  - Offer more power than the network can handle in the day-ahead market
  - And buy back the electricity that the network cannot absorb in redispatch at whatever price they want (even negative!)

INC-DEC gaming



- Zonal day-ahead auction
    - G1: 50 MWh, G2: 50 MWh, G3: 50 MWh
    - Zonal price zone A: 40 $/MWh
    - Congestion within zone A on line 1-2
    - Congestion between zones on line 2-3
- Redispatch offer of G1: -250 €/MWh
- For the 50 MWh that G1 over-schedules, it gets paid

$$(50\ \mathrm{MWh}) \cdot (40 +\ 250\ \$/\mathrm{MWh})$$

References

[1] A. Papavasiliou, Optimization Models in Electricity Markets, Cambridge University Press

https://www.cambridge.org/highereducation/books/optimization-models-in-electricity-markets/0D2D36891FB5EB6AAC3A4EFC78A8F1D3#overview