Clearing Forward Markets Based on Forecasts of Stochastic Production

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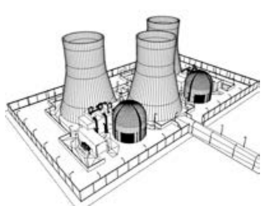
Problem description

(Motivation)

- Uncertainty $\uparrow$ (stochastic production $\uparrow$) and flexibility $\downarrow$ $\Rightarrow$ Balancing costs $\uparrow$

Day-ahead market → **Balancing market**



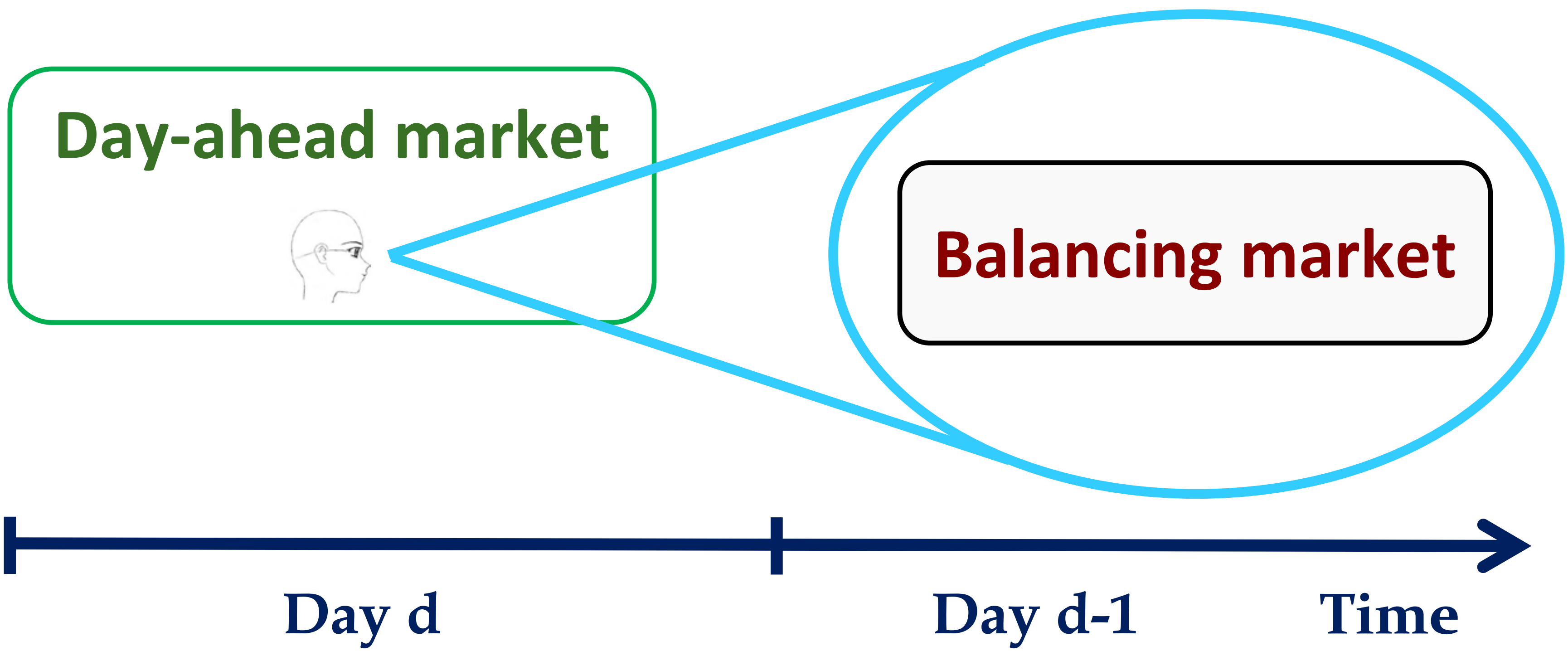
Time

Day d-1

Day d

Problem description
(Clearing mechanism)

- The day-ahead market is cleared by accounting for the projected impact on subsequent balancing operation



Clearing mechanism
(Conventional)

$$\underset{p_G,\, p_W,\, \delta^0}{Minimize} \quad C^D(p_G, p_W)$$

$$s.t. \quad h^D(p_G, p_W, \delta^0) - l = 0$$

$$g^D(p_G, \delta^0) \le 0$$

$$p_W \le \hat{W}$$

$$\downarrow \; p_G^*, p_W^*, \delta^{0*}$$

$$\underset{y_{\omega'}}{Minimize} \quad C^B(y_{\omega'})$$

$$s.t. \quad h^B(y_{\omega'}, \delta_{\omega'}, \delta^{0*}) + W_{\omega'} - p_W^* = 0$$

$$g^B(y_{\omega'}, \delta_{\omega'}, p_G^*; W_{\omega'}) \le 0$$

Clearing mechanism
(Conventional)

$$\underset{p_G, p_W, \delta^0}{\text{Minimize}} \quad \boxed{C^D(p_G, p_W)}$$

Day-ahead dispatch costs

$$\sum_{i=1}^{N_G} C_i P_i$$

$$\text{s.t.} \quad h^D(p_G, p_W, \delta^0) - l = 0$$

$$g^D(p_G, \delta^0) \le 0$$

$$p_W \le \hat{W}$$

$$p_G^*, p_W^*, \delta^{0*}$$

$$\underset{y_{\omega'}}{\text{Minimize}} \quad \boxed{C^B(y_{\omega'})}$$

Balancing dispatch costs

$$\sum_{i=1}^{N_G} (C_i^U r_{i\omega'}^U - C_i^D r_{i\omega'}^D) + \sum_{j=1}^{N_L} V_j^{LOL} L_{j\omega'}^{shed}$$

$$\text{s.t.} \quad h^B(y_{\omega'}, \delta_{\omega'}, \delta^{0*}) + W_{\omega'} - p_W^* = 0$$

$$g^B(y_{\omega'}, \delta_{\omega'}, p_G^*; W_{\omega'}) \le 0$$

Clearing mechanism (Conventional)

$$\underset{p_G, p_W, \delta^0}{\text{Minimize}} \quad C^D(p_G, p_W)$$

$$\text{s.t.} \quad \boxed{h^D(p_G, p_W, \delta^0) - l = 0}$$

$$g^D(p_G, \delta^0) \le 0$$

$$p_W \le \hat{W}$$

Power balance at the day-ahead stage

$$\sum_{i \in \Phi_n^{\mathrm{G}}} P_i + \sum_{q \in \Phi_n^{\mathrm{Q}}} W_q^{\mathrm{S}} - \sum_{j \in \Phi_n^{\mathrm{L}}} L_j - \sum_{\ell | o(\ell)=n} b_\ell \left(\delta_{o(\ell)}^0 - \delta_{e(\ell)}^0\right) + \sum_{\ell | e(\ell)=n} b_\ell \left(\delta_{o(\ell)}^0 - \delta_{e(\ell)}^0\right) = 0 \quad \forall n$$

$$p_G^*, p_W^*, \delta^{0*}$$

Actual production from "stochastic" energy sources

$$\underset{y_{\omega'}}{\text{Minimize}} \quad C^B(y_{\omega'})$$

$$\text{s.t.} \quad \boxed{h^B(y_{\omega'}, \delta_{\omega'}, \delta^{0*}) + W_{\omega'} - p_W^* = 0}$$

$$g^B(y_{\omega'}, \delta_{\omega'}, p_G^*; W_{\omega'}) \le 0$$

Power balance at the balancing stage

$$\sum_{i \in \Phi_n^{\mathrm{G}}} (r_{i\omega'}^{\mathrm{U}} - r_{i\omega'}^{\mathrm{D}}) + \sum_{j \in \Phi_n^{\mathrm{L}}} L_{j\omega'}^{\mathrm{shed}} + \sum_{q \in \Phi_n^{\mathrm{Q}}} (W_{q\omega'} - W_q^{\mathrm{S}} - W_{q\omega'}^{\mathrm{spill}}) + \sum_{\ell | o(\ell)=n} b_\ell \left(\delta_{o(\ell)}^0 - \delta_{o(\ell)\omega'} - \delta_{e(\ell)}^0 + \delta_{e(\ell)\omega'}\right) - \sum_{\ell | e(\ell)=n} b_\ell \left(\delta_{o(\ell)}^0 - \delta_{o(\ell)\omega'} - \delta_{e(\ell)}^0 + \delta_{e(\ell)\omega'}\right) = 0 \quad \forall n$$

Clearing mechanism (Conventional)

$$\underset{p_G, p_W, \delta^0}{\text{Minimize}} \quad C^D(p_G, p_W)$$

$$\text{s.t.} \quad h^D(p_G, p_W, \delta^0) - l = 0$$

$$\boxed{g^D(p_G, \delta^0) \le 0}$$

$$p_W \le \hat{W}$$

Typically the (conditional) expected production!

$$p_G^*, p_W^*, \delta^{0*}$$

$$\underset{y_{\omega'}}{\text{Minimize}} \quad C^B(y_{\omega'})$$

$$\text{s.t.} \quad h^B(y_{\omega'}, \delta_{\omega'}, \delta^{0*}) + W_{\omega'} - p_W^* = 0$$

$$\boxed{g^B(y_{\omega'}, \delta_{\omega'}, p_G^*; W_{\omega'}) \le 0}$$

Offer limits

$$P_i \le P_i^{\max}, \forall i$$

Offer limits

$$r_{i\omega'}^{\mathrm{U}} \le R_i^{\mathrm{U},\max}, \forall i$$

$$r_{i\omega'}^{\mathrm{D}} \le R_i^{\mathrm{D},\max}, \forall i$$

$$\boxed{P_i^*} - r_{i\omega'}^{\mathrm{D}} \ge 0, \forall i$$

$$\boxed{P_i^*} + r_{i\omega'}^{\mathrm{U}} \le \overline{P}_i, \forall i$$

Clearing mechanism
(Conventional)

$$\underset{p_G, p_W, \delta^0}{\text{Minimize}} \quad C^D(p_G, p_W)$$

$$\text{s.t.} \quad h^D(p_G, p_W, \delta^0) - l = 0$$

$$\boxed{g^D(p_G, \delta^0) \le 0}$$

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$$\text{s.t.} \quad h^B(y_{\omega'}, \delta_{\omega'}, \delta^{0*}) + W_{\omega'} - p_W^* = 0$$

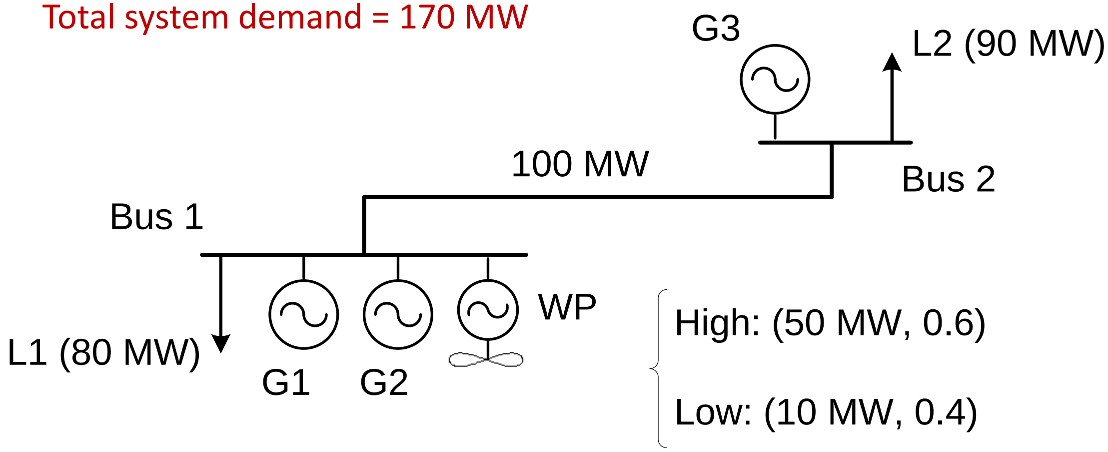
$$\boxed{g^B(y_{\omega'}, \delta_{\omega'}, p_G^*; W_{\omega'}) \le 0}$$

- Transmission capacity limits, variable bounds, reference node …
- Non convexities are disregarded!

Clearing mechanism

(Example)

Total system demand = 170 MW



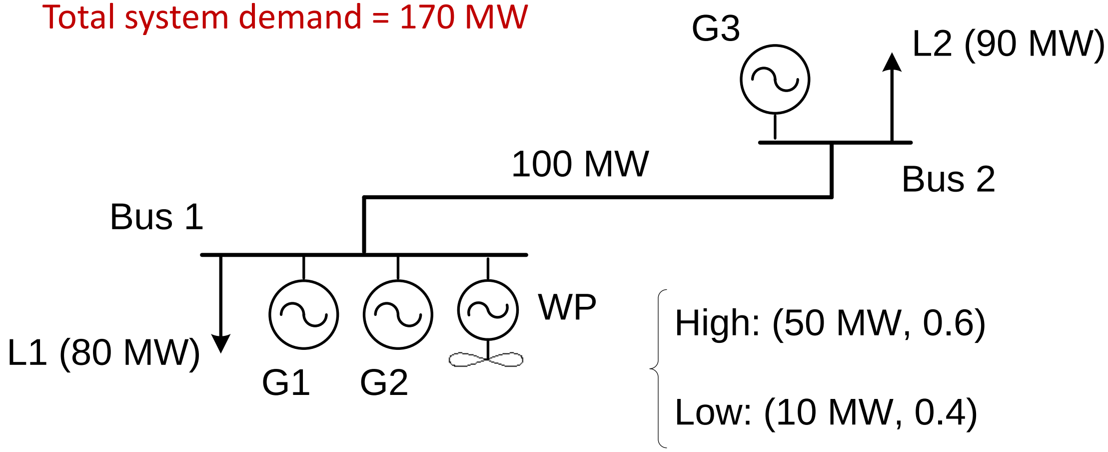
- Unit capacity and offer cost in DAM

Unit	$P^{\max}$	C	C^U	C^D	$R_U^{\max}$	$R_D^{\max}$
G1	100	35	40	34	20	40
G2	110	30	–	–	0	0
G3	50	10	–	–	0	0

Powers in MW; costs in $/MWh

Clearing mechanism
(Example)

Total system demand = 170 MW



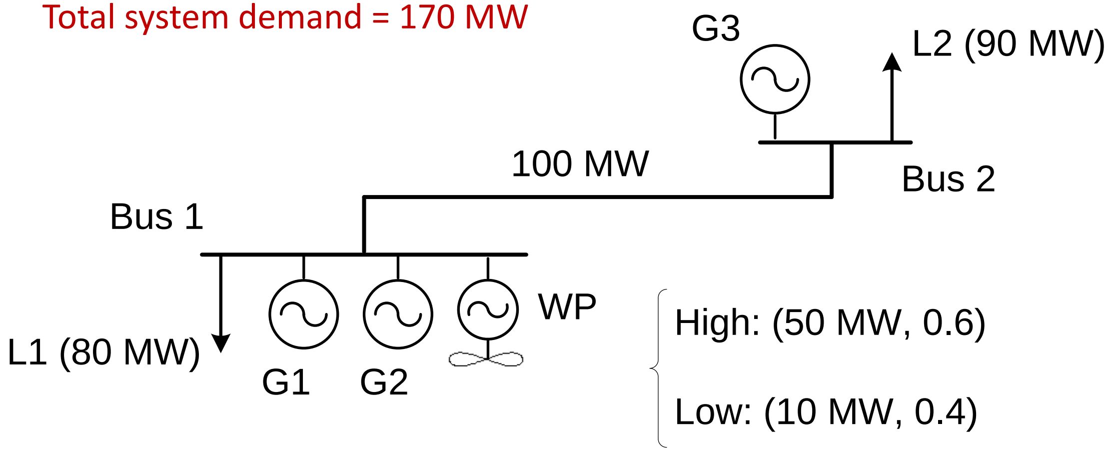
- Unit capacity and offer cost in DAM
- Offer limit and cost for the energy sold in BM

Unit	$P^{\max}$	C	C^U	C^D	$R_U^{\max}$	$R_D^{\max}$
G1	100	35	40	34	20	40
G2	110	30	–	–	0	0
G3	50	10	–	–	0	0

Powers in MW; costs in $/MWh

Clearing mechanism
(Example)

Total system demand = 170 MW



- Unit capacity and offer cost in DAM
- Offer limit and cost for the energy sold in BM
- Offer limit and cost for the energy repurchased in BM

Unit	$P^{\max}$	C	C^U	C^D	$R_U^{\max}$	$R_D^{\max}$
G1	100	35	40	34	20	40
G2	110	30	–	–	0	0
G3	50	10	–	–	0	0

Powers in MW; costs in $/MWh

Clearing mechanism
(Example)

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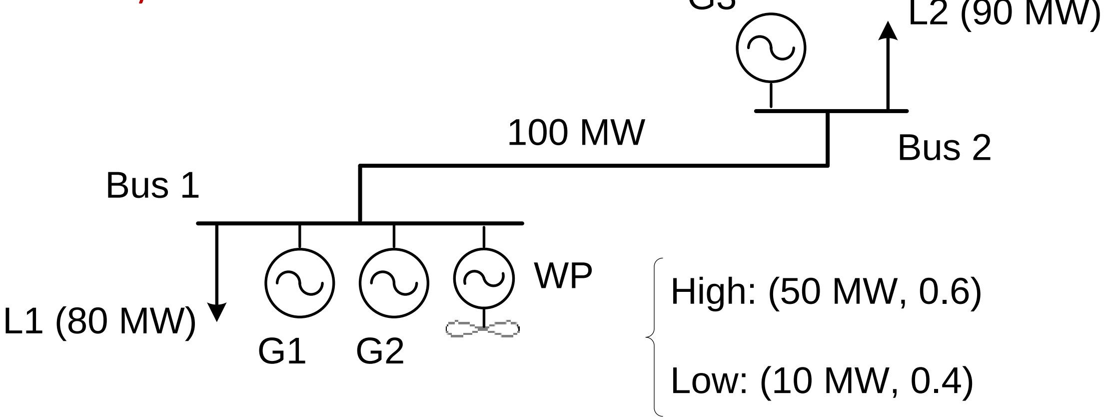


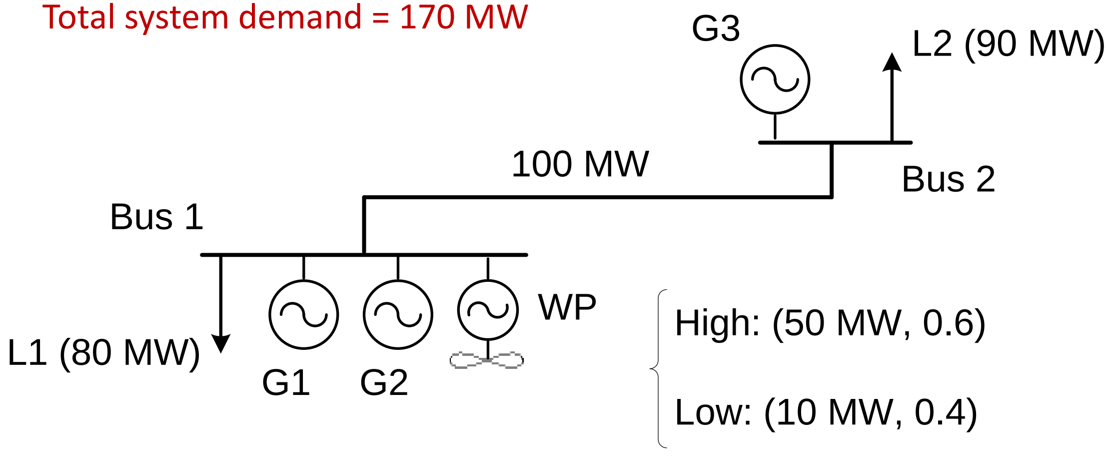
Expensive, but flexible

Unit	$P^{\max}$	C	C^{U}	C^{D}	$R_U^{\max}$	$R_D^{\max}$
G1	100	35	40	34	20	40
G2	110	30	–	–	0	0
G3	50	10	–	–	0	0

Powers in MW; costs in $/MWh

Clearing mechanism
(Example)

Total system demand = 170 MW



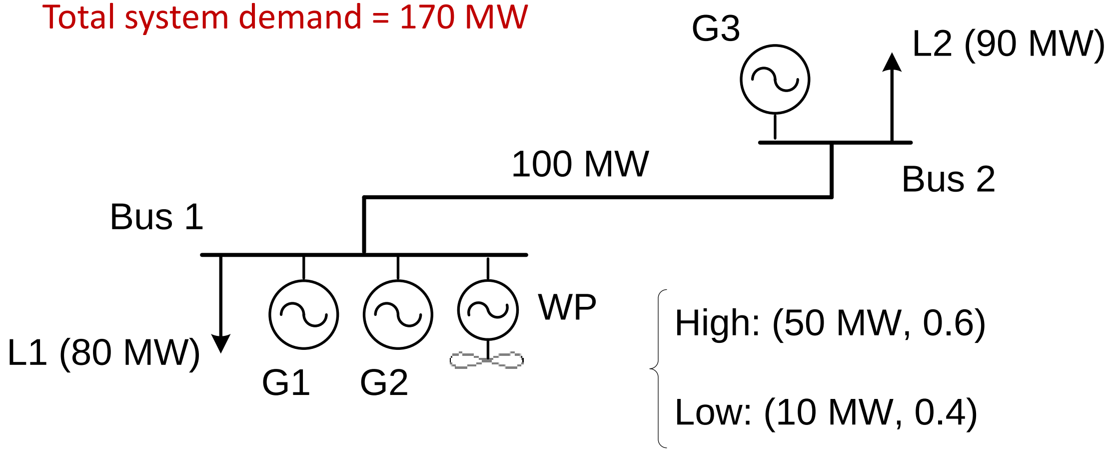
Less expensive, but inflexible

Unit	$P^{\max}$	C	C^U	C^D	$R_U^{\max}$	$R_D^{\max}$
G1	100	35	40	34	20	40
G2	110	30	–	–	0	0
G3	50	10	–	–	0	0

Powers in MW; costs in $/MWh

Clearing mechanism
(Example)

Total system demand = 170 MW



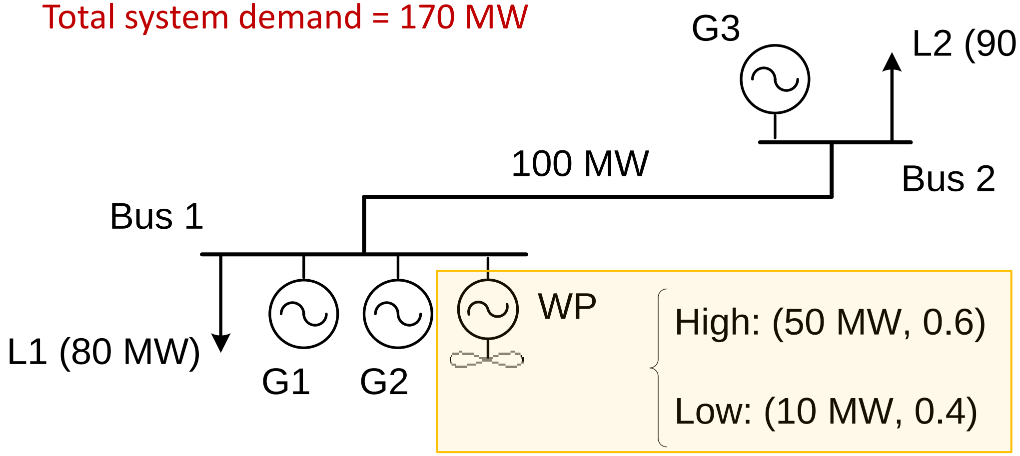
Unit	$P^{\max}$	C	C^U	C^D	$R_U^{\max}$	$R_D^{\max}$
G1	100	35	40	34	20	40
G2	110	30	–	–	0	0
G3	50	10	–	–	0	0

Cheap, but inflexible

Powers in MW; costs in $/MWh

Clearing mechanism
(Example)

Total system demand = 170 MW



Wind power production modeled using two scenarios

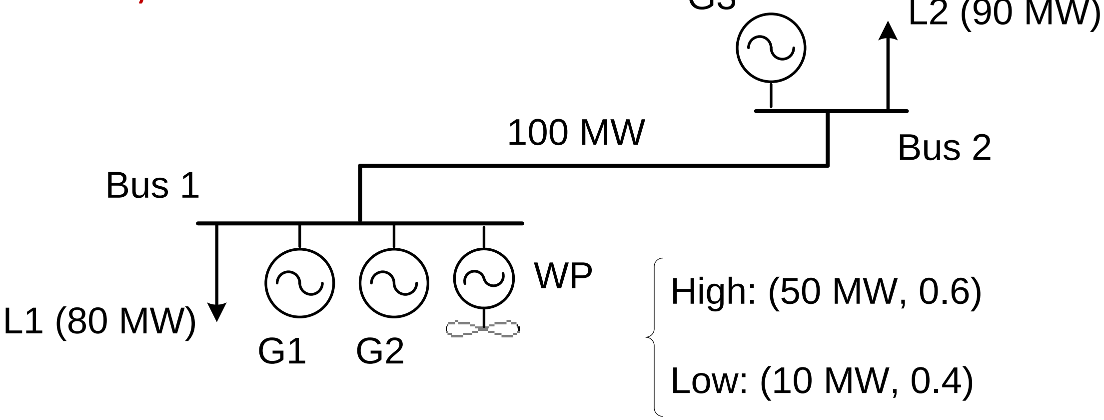
Expected production = 34 MW

Unit	$P^{\max}$	C	C^U	C^D	$R_U^{\max}$	$R_D^{\max}$
G1	100	35	40	34	20	40
G2	110	30	–	–	0	0
G3	50	10	–	–	0	0

Powers in MW; costs in $/MWh

Clearing mechanism
(Example)

Total system demand = 170 MW



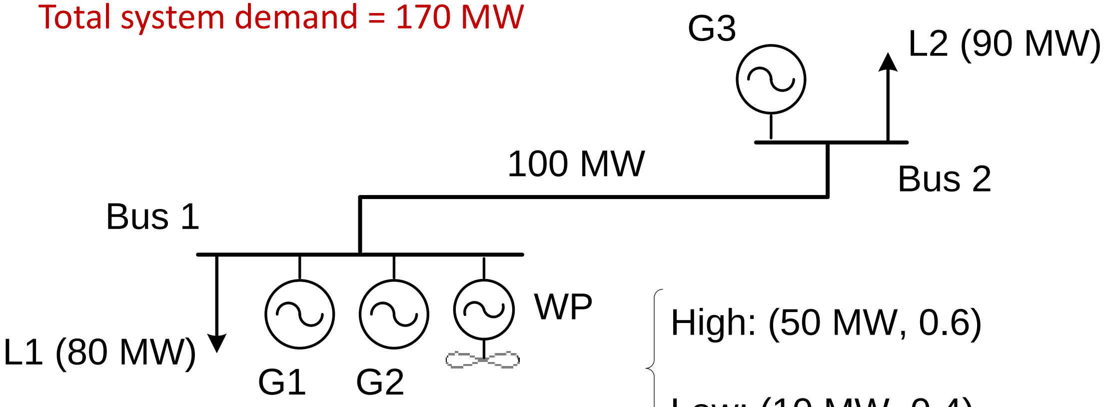
Conventional

Unit	P^{max}	C	P^{sch}
G1	100	35	0
G2	110	30	86
G3	50	10	50
WP	34	0	34

Powers in MW; costs in $/MWh

Clearing mechanism
(Example)

Total system demand = 170 MW



High: (50 MW, 0.6)

Low: (10 MW, 0.4)

Conventional

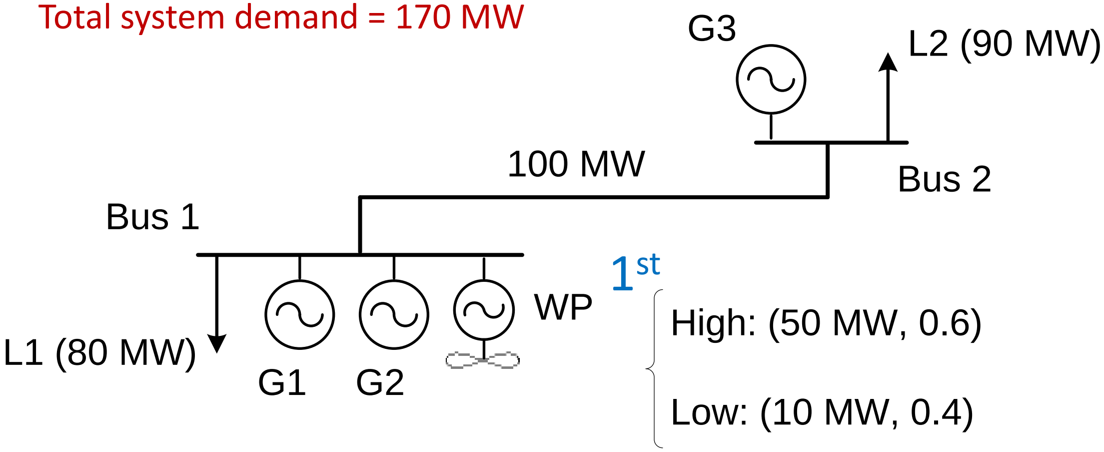
Unit	$P^{\max}$	C	P^{sch}
G1	100	35	0
G2	110	30	86
G3	50	10	50
WP	34	0	34

Powers in MW; costs in $/MWh

Expected production

Clearing mechanism
(Example)

Total system demand = 170 MW



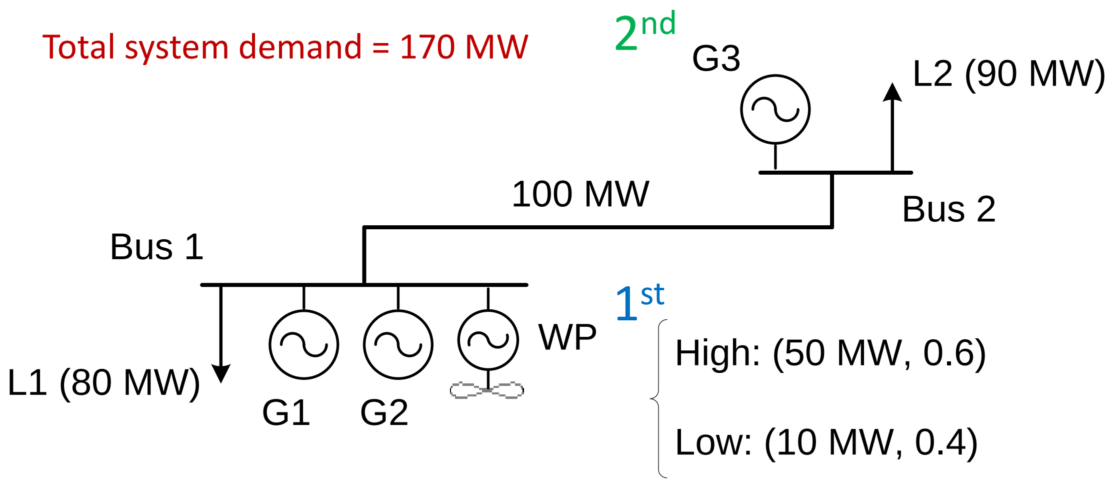
Conventional

Unit	P^{max}	C	P^{sch}
G1	100	35	0
G2	110	30	86
G3	50	10	50
WP	34	0	34

Powers in MW; costs in $/MWh

Clearing mechanism (Example)

Total system demand = 170 MW



Conventional

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G1	100	35	0
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G3	50	10	50
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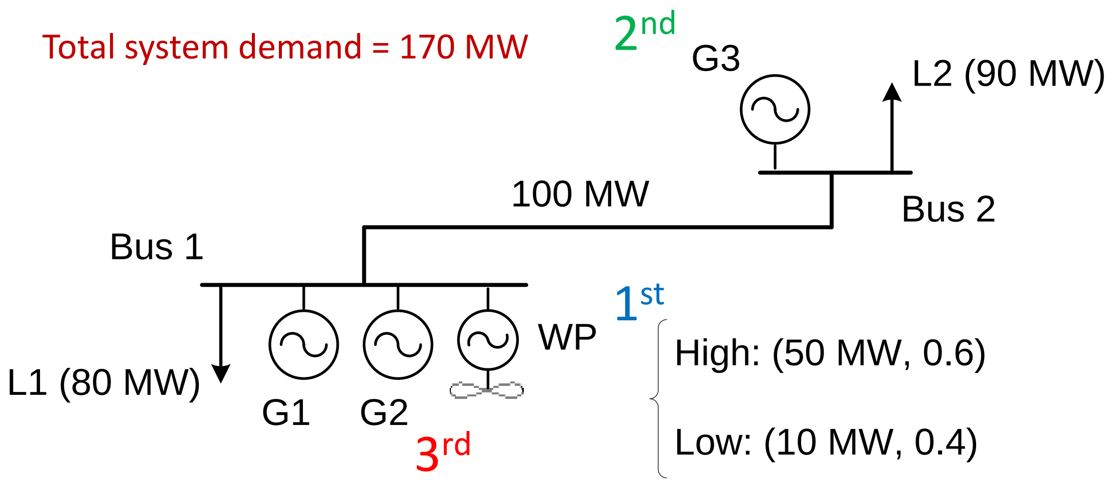
Powers in MW; costs in $/MWh

Clearing mechanism
(Example)

Total system demand = 170 MW



Conventional

Unit	$P^{\max}$	C	P^{sch}
G1	100	35	0
G2	110	30	86
G3	50	10	50
WP	34	0	34

Powers in MW; costs in $/MWh

Units are dispatched in a **cost merit-order**

Clearing mechanism
(Stochastic)

$$\underset{p_G, p_W, \delta^0}{Minimize} \quad C^D(p_G, p_W)$$
$$s.t. \quad h^D(p_G, p_W, \delta^0) - l = 0$$
$$g^D(p_G, \delta^0) \leq 0$$
$$p_W \leq \hat{W}$$

$$p_G^*, p_W^*, \delta^{0*}$$

$$\underset{y_{\omega'}}{Minimize} \quad C^B(y_{\omega'})$$
$$s.t. \quad h^B(y_{\omega'}, \delta_{\omega'}, \delta^{0*}) + W_{\omega'} - p_W^* = 0$$
$$g^B(y_{\omega'}, \delta_{\omega'}, p_G^*; W_{\omega'}) \leq 0$$

$$\underset{p_G, p_W, \delta^0; y_\omega, \forall \omega}{Minimize} \quad C^D(p_G, p_W) + \mathrm{E}_\omega\left[C^B(y_\omega)\right]$$
$$s.t. \quad h^D(p_G, p_W, \delta^0) - l = 0$$
$$g^D(p_G, \delta^0) \leq 0$$
$$p_W \leq \overline{W}$$
$$h^B(y_\omega, \delta_\omega, \delta^0) + W_\omega - p_W = 0, \quad \forall \omega$$
$$g^B(y_\omega, \delta_\omega, p_G; W_\omega) \leq 0, \quad \forall \omega$$

Clearing mechanism
(Stochastic)

$$\underset{p_G,\,p_W,\,\delta^0}{\text{Minimize}} \quad C^D(p_G, p_W)$$
$$\text{s.t.} \quad h^D(p_G, p_W, \delta^0) - l = 0$$
$$g^D(p_G, \delta^0) \le 0$$
$$p_W \le \hat{W}$$

$$p_G^*, p_W^*, \delta^{0*}$$

$$\underset{y_{\omega'}}{\text{Minimize}} \quad C^B(y_{\omega'})$$
$$\text{s.t.} \quad h^B(y_{\omega'}, \delta_{\omega'}, \delta^{0*}) + W_{\omega'} - p_W^* = 0$$
$$g^B(y_{\omega'}, \delta_{\omega'}, p_G^*; W_{\omega'}) \le 0$$

$$\underset{p_G,\,p_W,\,\delta^0;\,y_\omega,\,\forall\omega}{\text{Minimize}} \quad C^D(p_G, p_W) + \boxed{\mathrm{E}_\omega\left[C^B(y_\omega)\right]}$$
$$\text{s.t.} \quad h^D(p_G, p_W, \delta^0) - l = 0$$
$$g^D(p_G, \delta^0) \le 0$$
$$p_W \le \overline{W}$$
$$\boxed{\begin{aligned} &h^B(y_\omega, \delta_\omega, \delta^0) + W_\omega - p_W = 0, \quad \forall\omega \\ &g^B(y_\omega, \delta_\omega, p_G; W_\omega) \le 0, \quad \forall\omega \end{aligned}}$$

Balancing prognosis

Clearing mechanism
(Stochastic)

- Expectation of the balancing costs: It requires a **centralized forecasting tool**
- Scenario-based modeling of uncertainty

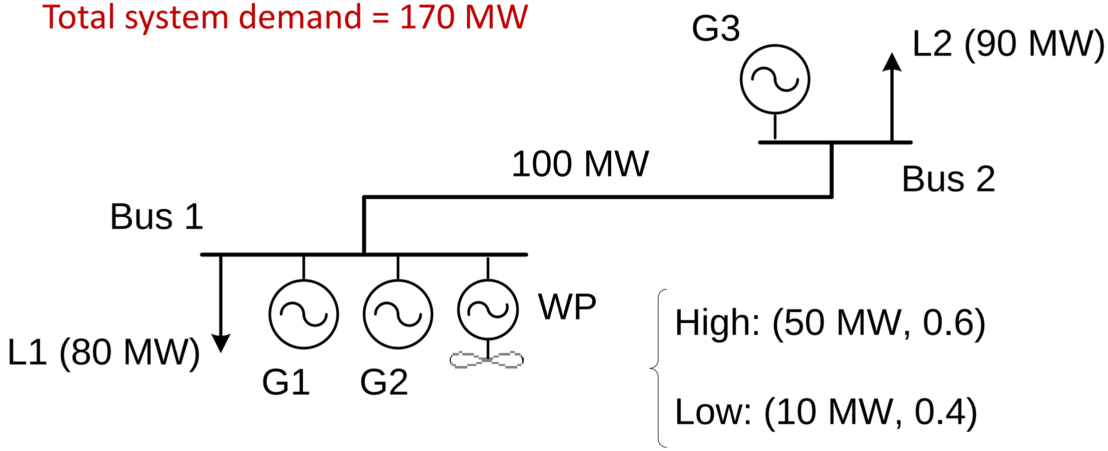
$$\sum_{i=1}^{\mathrm{N_G}} C_i P_i + \boxed{\sum_{\omega=1}^{\mathrm{N}_\Omega} \pi_\omega \left[\sum_{i=1}^{\mathrm{N_G}} (C_i^{\mathrm{U}} r_{i\omega}^{\mathrm{U}} - C_i^{\mathrm{D}} r_{i\omega}^{\mathrm{D}}) + \sum_{j=1}^{\mathrm{N_L}} V_j^{\mathrm{LOL}} L_{j\omega}^{\mathrm{shed}} \right]}$$

- Two-stage stochastic programming problem

$$\begin{aligned}
\underset{p_G, p_W, \delta^0; y_\omega, \forall\omega}{\mathit{Minimize}} \quad & C^D(p_G, p_W) + \boxed{\mathrm{E}_\omega\left[C^B(y_\omega)\right]} \\
s.t. \quad & h^D(p_G, p_W, \delta^0) - l = 0 \\
& g^D(p_G, \delta^0) \le 0 \\
& p_W \le \overline{W} \\
& h^B(y_\omega, \delta_\omega, \delta^0) + W_\omega - p_W = 0, \quad \forall\omega \\
& g^B(y_\omega, \delta_\omega, p_G; W_\omega) \le 0, \quad \forall\omega
\end{aligned}$$

Clearing mechanism
(Example)

Total system demand = 170 MW



Conventional

Unit	$P^{\max}$	C	P^{sch}
G1	100	35	0
G2	110	30	86
G3	50	10	50
WP	34	0	34

Powers in MW; costs in $/MWh

Stochastic

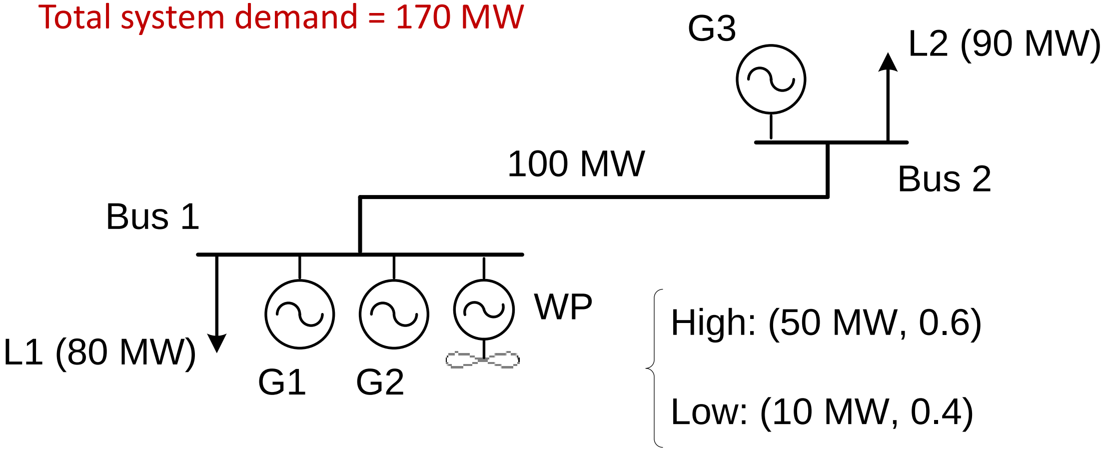
Unit	$P^{\max}$	C	P^{sch}
G1	100	35	40
G2	110	30	70
G3	50	10	50
WP	34	0	10

Powers in MW; costs in $/MWh

- The wind producer is dispatched only to 10 MW
- G1 is dispatched to 40, even though it is more expensive than G2
- The “traditional” cost merit-order principle does not hold in the stochastic dispatch
- G1 is dispatched to exploit its ability to reduce production in real time

Clearing mechanism
(Example)

Total system demand = 170 MW



Conventional

Unit	$P^{\max}$	C	P^{sch}
G1	100	35	0
G2	110	30	86
G3	50	10	50
WP	34	0	34

Powers in MW; costs in $/MWh

	Total	Day ahead	Balancing	Load shedding
Conv	3720	3080	320	320
Stoch	3184	4000	-816	0

Stochastic

Unit	$P^{\max}$	C	P^{sch}
G1	100	35	40
G2	110	30	70
G3	50	10	50
WP	34	0	10

"Stoch" results in a more expensive day-ahead dispatch that leads, however, to a much more efficient balancing operation

Powers in MW; costs in $/MWh

Clearing mechanism
(Prices & Revenues)

$$\underset{p_G, p_W, \delta^0}{Minimize} \quad C^D(p_G, p_W)$$

$$\begin{aligned} s.t. \quad & h^D(p_G, p_W, \delta^0) - l = 0 : \boxed{\lambda^D} \\ & g^D(p_G, \delta^0) \le 0 \\ & p_W \le \hat{W} \end{aligned}$$

$$\underset{p_G, p_W, \delta^0; y_\omega, \forall \omega}{Minimize} \quad C^D(p_G, p_W) + \mathrm{E}_\omega\left[C^B(y_\omega)\right]$$

$$\begin{aligned} s.t. \quad & h^D(p_G, p_W, \delta^0) - l = 0 : \boxed{\lambda^D} \\ & g^D(p_G, \delta^0) \le 0 \\ & p_W \le \overline{W} \\ & h^B(y_\omega, \delta_\omega, \delta^0) + W_\omega - p_W = 0, \quad \forall \omega \\ & g^B(y_\omega, \delta_\omega, p_G; W_\omega) \le 0, \quad \forall \omega \end{aligned}$$

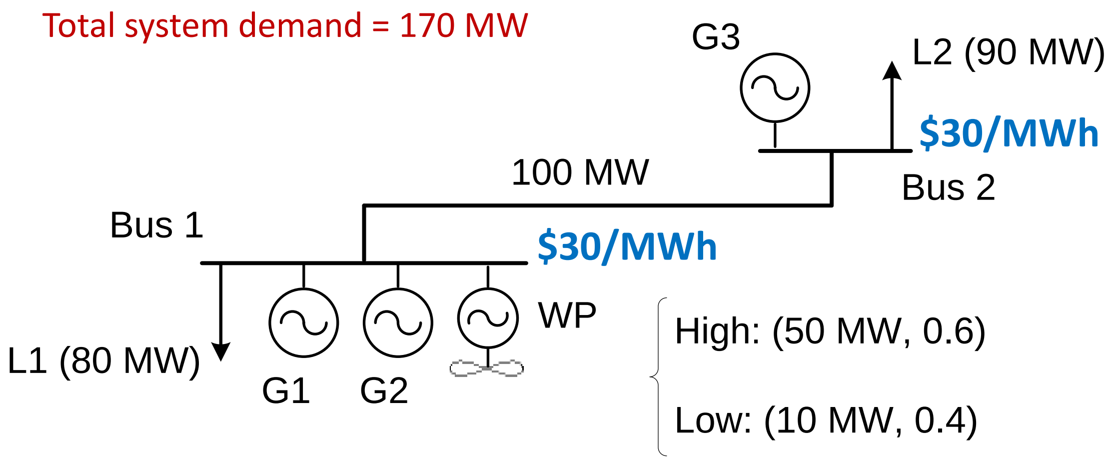
$$\downarrow \; p_G^*, p_W^*, \delta^{0*}$$

$$\underset{y_{\omega'}}{Minimize} \quad C^B(y_{\omega'})$$

$$\begin{aligned} s.t. \quad & h^B(y_{\omega'}, \delta_{\omega'}, \delta^{0*}) + W_{\omega'} - p_W^* = 0 : \boxed{\lambda_{\omega'}^B} \\ & g^B(y_{\omega'}, \delta_{\omega'}, p_G^*; W_{\omega'}) \le 0 \end{aligned}$$

Clearing mechanism

(Example: Day-ahead market prices)



Conventional

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Powers in MW; costs in $/MWh

Stochastic

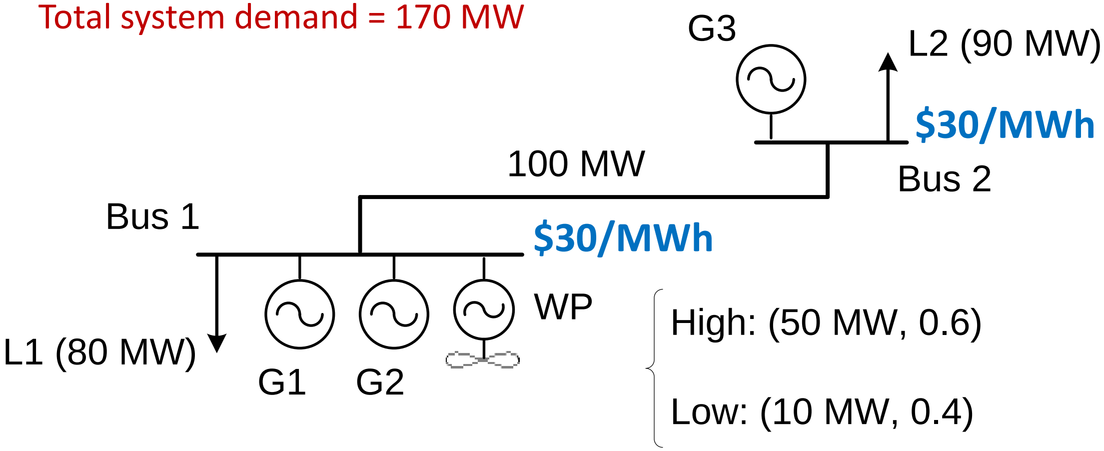
Unit	$P^{\max}$	C	P^{sch}
G1	100	35	40
G2	110	30	70
G3	50	10	50
WP	34	0	10

Powers in MW; costs in $/MWh

In "stochastic" unit G1 is dispatched day ahead in a **loss-making position**

Clearing mechanism
(Example: Day-ahead market prices)

Total system demand = 170 MW



Conventional

Unit	$P^{\max}$	C	P^{sch}
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G2	110	30	86
G3	50	10	50
WP	34	0	34

Powers in MW; costs in $/MWh

Profit G1	Expected	Per scenario	
		High	Low
Conv	1320	0	3300
Stoch	24	173.33	-200

In “Stochastic” unit G1 incur losses if scenario “low” happens

Stochastic

Unit	$P^{\max}$	C	P^{sch}
G1	100	35	40
G2	110	30	70
G3	50	10	50
WP	34	0	10

Powers in MW; costs in $/MWh

Clearing mechanism
(Alternatives)

✓ The stochastic dispatch is more efficient, but …

- may schedule flexible units in a loss-making position;
- guarantees cost recovery for flexible producers **only in expectation**, not per scenario;
- this expectation depends on a centralized forecasting tool out of producers’ control.

✓ We try to approach the stochastic dispatch ideal by **improving the conventional dispatch**

Clearing mechanism

(Conventional)

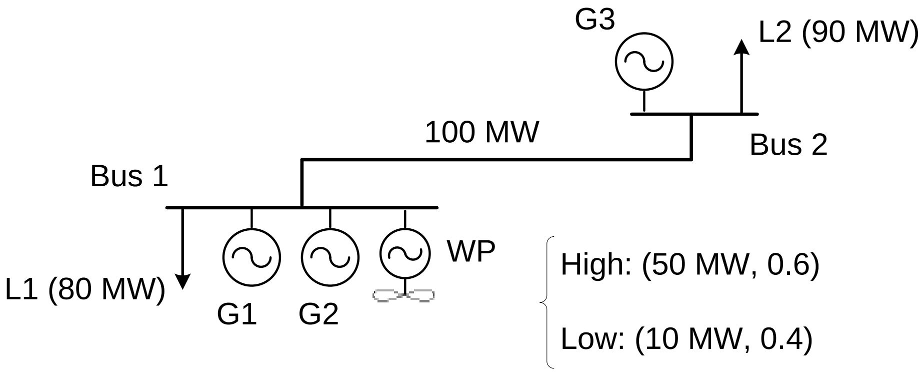
$$\begin{aligned}
\underset{p_G, p_W, \delta^0}{\text{Minimize}} \quad & C^D(p_G, p_W) \\
\text{s.t.} \quad & h^D(p_G, p_W, \delta^0) - l = 0 \\
& g^D(p_G, \delta^0) \leq 0 \\
& p_W \leq \hat{W}
\end{aligned}$$

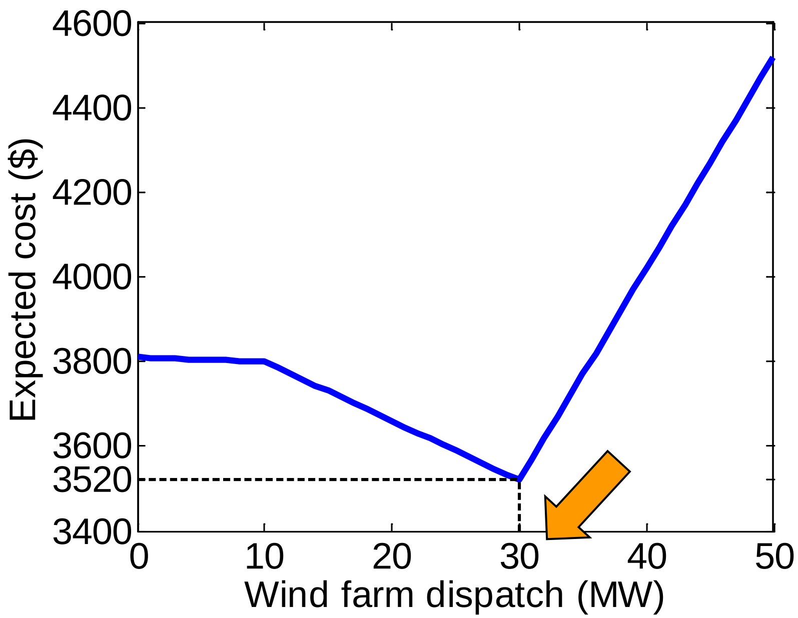
Do we have something better than the expected production?

$$p_G^*, p_W^*, \delta^{0*}$$

$$\begin{aligned}
\underset{y_{\omega'}}{\text{Minimize}} \quad & C^B(y_{\omega'}) \\
\text{s.t.} \quad & h^B(y_{\omega'}, \delta_{\omega'}, \delta^{0*}) + W_{\omega'} - p_W^* = 0 \\
& g^B(y_{\omega'}, \delta_{\omega'}, p_G^*; W_{\omega'}) \leq 0
\end{aligned}$$

Clearing mechanism
(Example: Improved dispatch)





Conventional

Unit	P^{max}	C	P^{sch}
G1	100	35	0
G2	110	30	86
G3	50	10	50
WP	34	0	34

Powers in MW; costs in $/MWh

Improved

Unit	P^{max}	C	P^{sch}
G1	100	35	0
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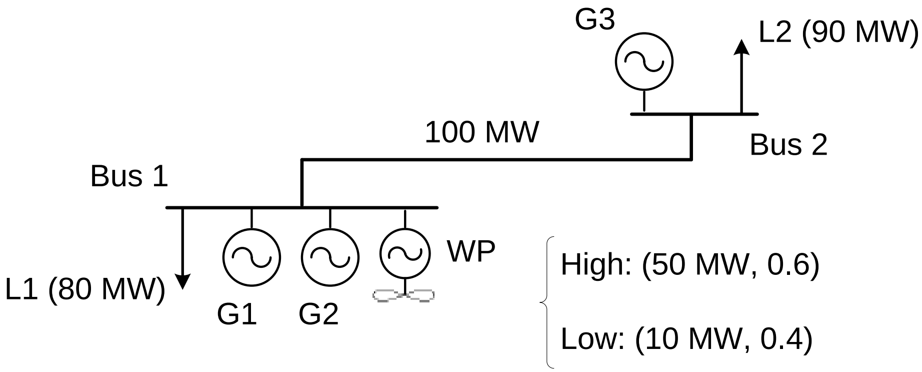
Powers in MW; costs in $/MWh

Clearing mechanism
(Example: Improved dispatch)



Conventional

Unit	P^{max}	C	P^{sch}
G1	100	35	0
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Powers in MW; costs in $/MWh

	Total	Day ahead	Balancing	Load shedding
Conv	3720	3080	320	320
Stoch	3184	4000	-816	0
Imp	3520	3200	320	0

Improved

Unit	P^{max}	C	P^{sch}
G1	100	35	0
G2	110	30	90
G3	50	10	50
WP	34	0	30

Powers in MW; costs in $/MWh

Clearing mechanism
(Improved dispatch)

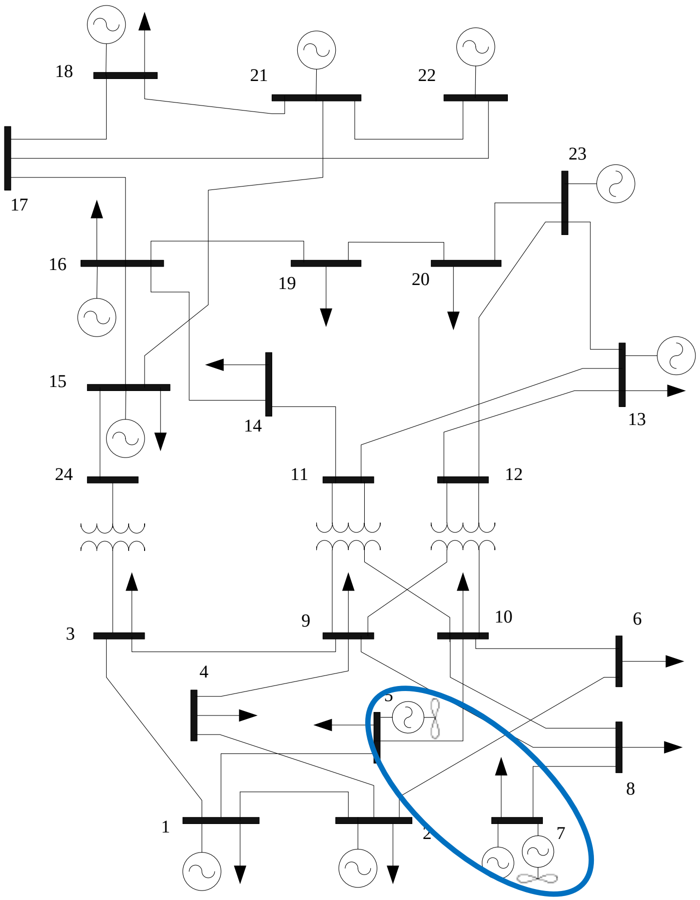
✓ How do we compute the “best” schedule for stochastic generation?

$$\underset{p_G, p_W, \delta^0, p_W^{\max}; y_\omega, \delta_\omega, \forall\omega}{\text{Minimize}} \quad C^D(p_G, p_W) + \mathrm{E}_\omega\left[C^B(y_\omega)\right]$$

$$\begin{aligned}
s.t. \quad & h^B(y_\omega, \delta_\omega, \delta^0) + W_\omega - p_W = 0, \quad \forall\omega \\
& g^B(y_\omega, \delta_\omega, p_G; W_\omega) \le 0, \quad \forall\omega \\
& 0 \le p_W^{\max} \le \overline{W} \\
& (p_G, p_W, \delta^0) \in \arg\Big\{ \underset{x_G, x_W, \theta}{\text{Minimize}} \quad C^D(x_G, x_W) \\
& \qquad s.t. \quad h^D(x_G, x_W, \theta) - l = 0 \\
& \qquad\qquad g^D(x_G, \theta) \le 0 \\
& \qquad\qquad x_W \le p_W^{\max} \Big\}
\end{aligned}$$

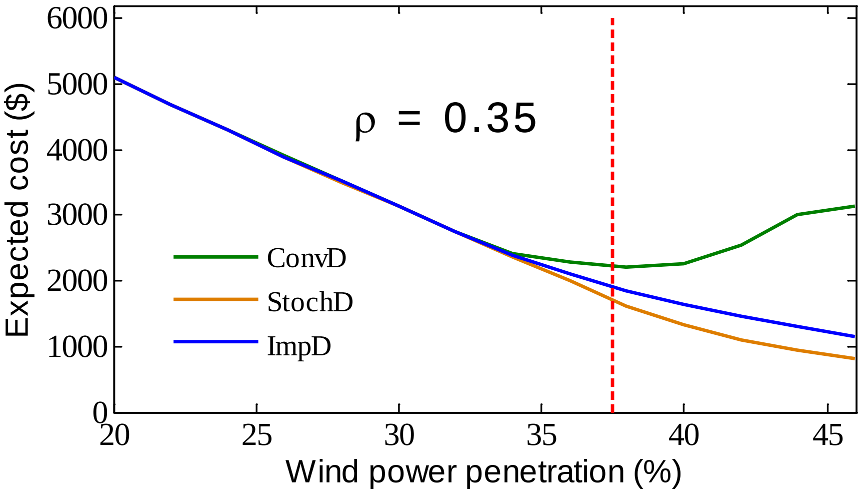
The “marginal cost” of a stochastic generator is the cost of its uncertainty

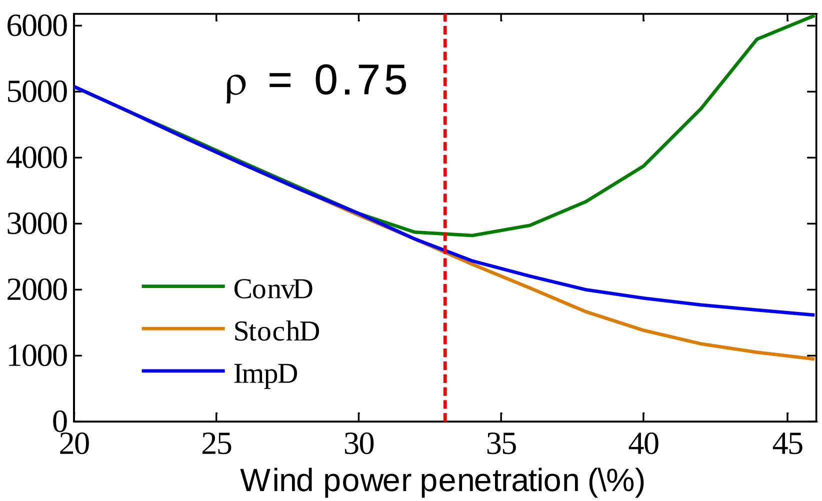
Clearing mechanism
(24-bus case study)



- Based on the IEEE Reliability test System
- Total system demand = 2000 MW
- Per-unit wind power productions are modeled using Beta distributions with a correlation coefficient ρ

Clearing mechanism
(24-bus case study)





- Under “ImpD” and “StochD”, higher penetrations of stochastic production never lead to an increase in the expected cost
- “ImpD” and “StochD” are robust to the spatial correlation of stochastic energy sources

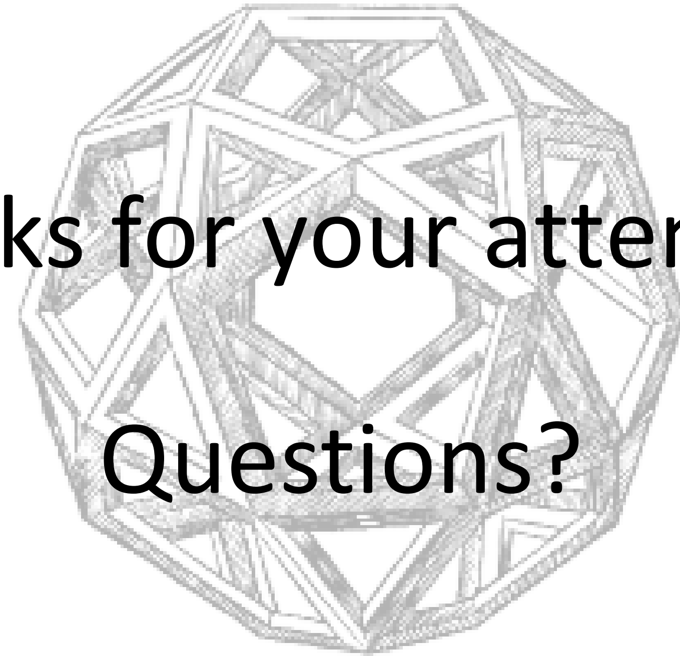
Clearing mechanism
(24-bus case study)

Wind penetration 38% ρ = 0.35		Unit			
		1	6	11	12
Stoch	Expected profit ($)	47.9	49.4	102.2	67.4
	Avearge losses ($)	–14.9	–10.7	–16.5	–9.7
	Probability profit < 0	**0.81**	0.71	0.71	0.75
Conv	Expected profit ($)	379.8	359.7	724.9	389.1
Imp	Expected profit ($)	170.2	263.7	531.6	178.7

Clearing mechanism
(Final remarks)

- Day-ahead markets should not clear the expected stochastic production by default.

- The amount of stochastic generation to be scheduled in advance should not be driven only by its marginal cost, which is usually very low or zero, but also by the **cost of its uncertainty**.

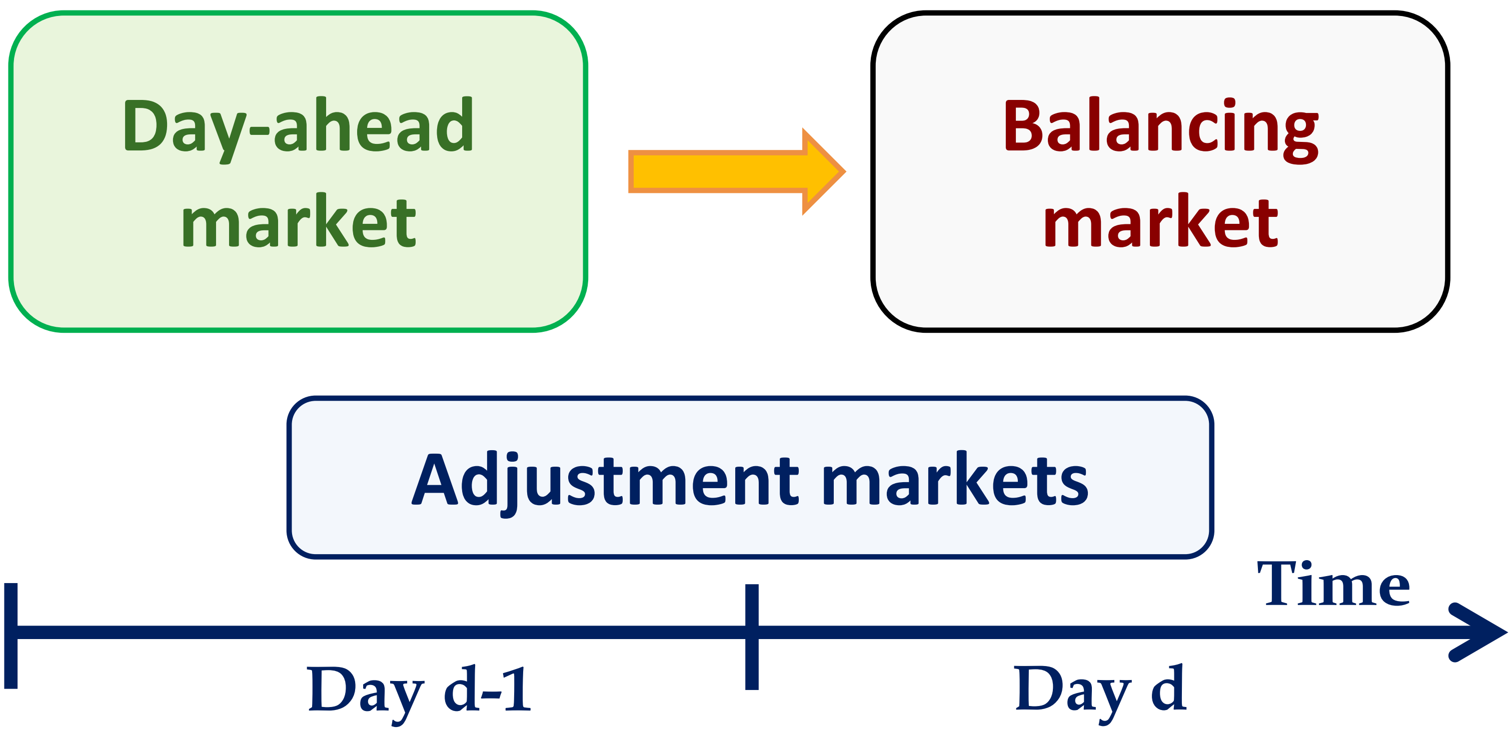


Thanks for your attention!

Questions?

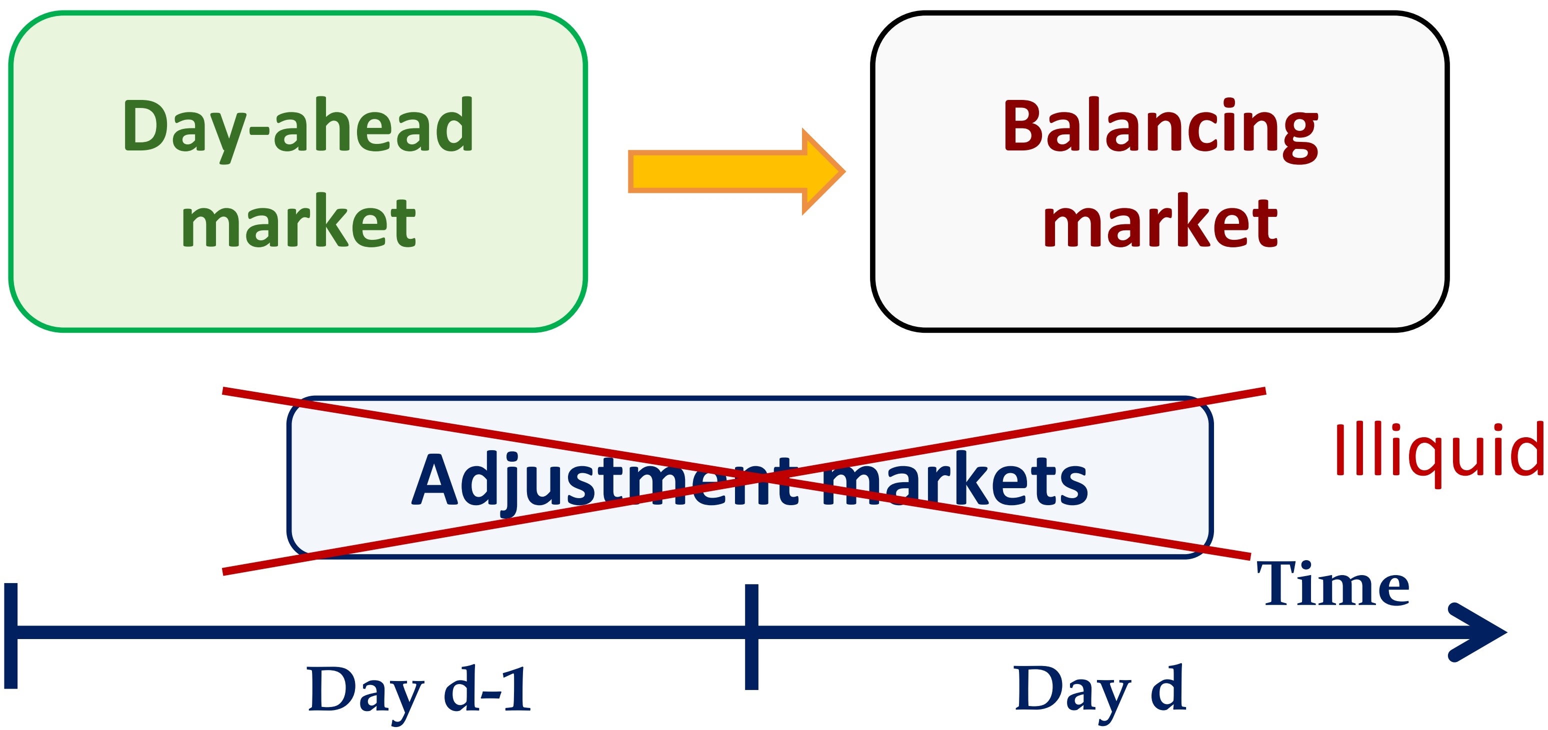
Problem description
(Adjustment markets)

• Adjustment markets allow redefining forward positions and trading with a lesser degree of uncertainty



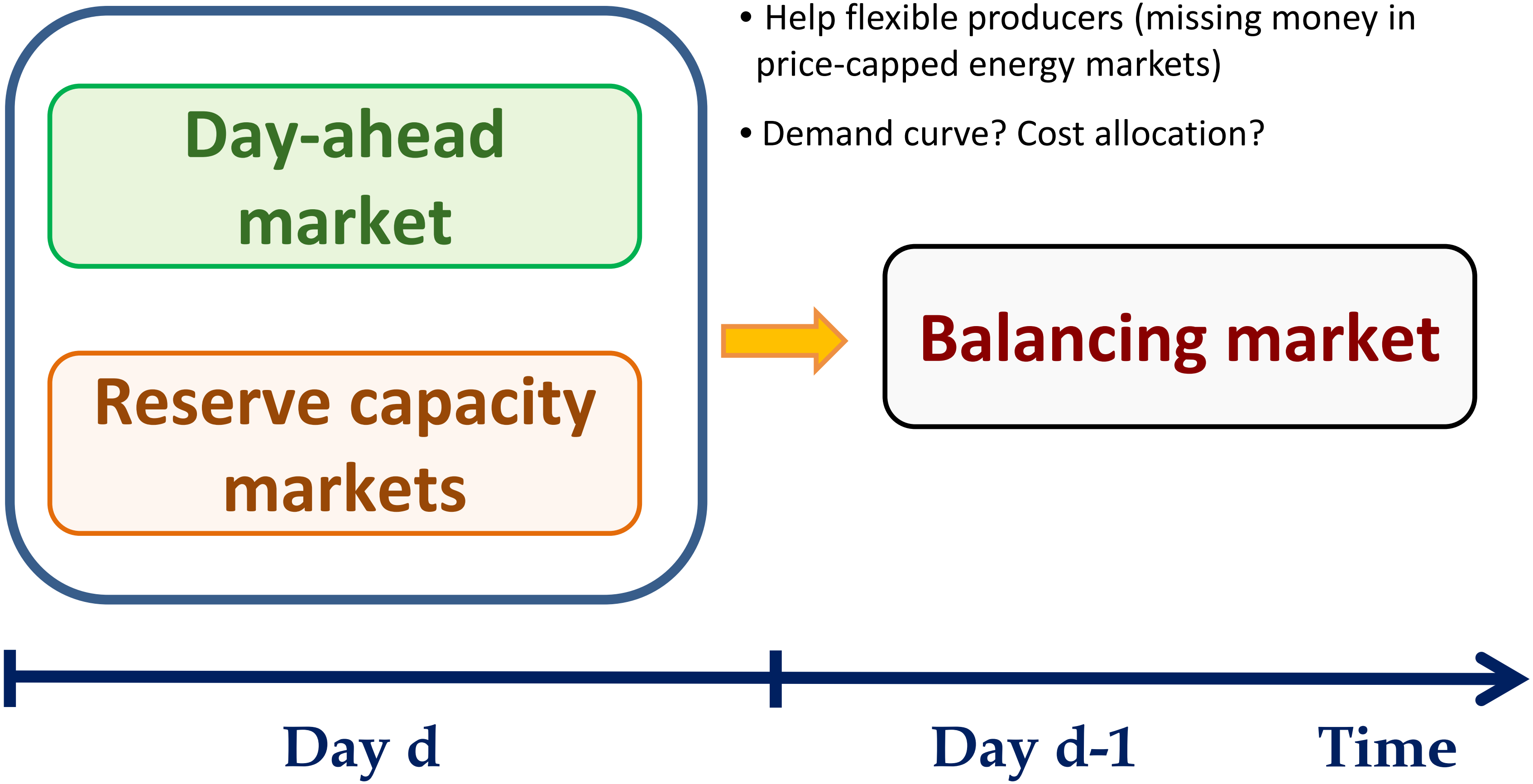
Problem description
(Adjustment markets)

• Adjustment markets allow redefining forward positions and trading with a lesser degree of uncertainty



Problem description
(Capacity markets)

- Guarantee balancing resources
- Help flexible producers (missing money in price-capped energy markets)
- Demand curve? Cost allocation?



Problem description

(Energy-only market)