Incentives for Optimal Integration of Fluctuating Power Generation

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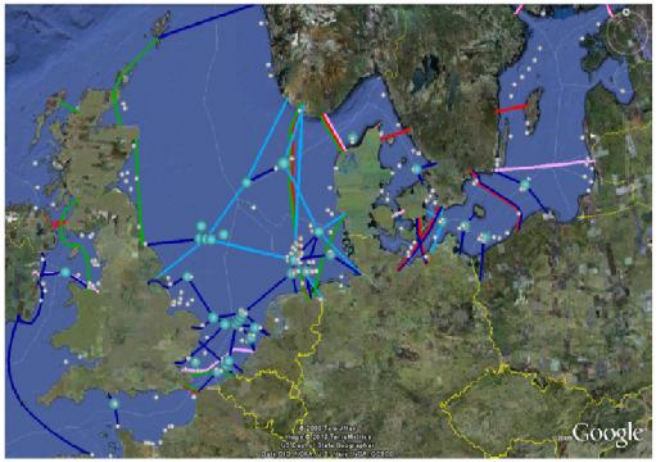
Motivation (1/2)

- RES power will play a significant role in the electricity mix
  (e.g. North Sea Grid in Europe,
  33% RES in California by 2020)



Offshore grid scenario 3: Wind-driven approach (blue = changes to base case, red = existing, pink = under construction, green = planned)

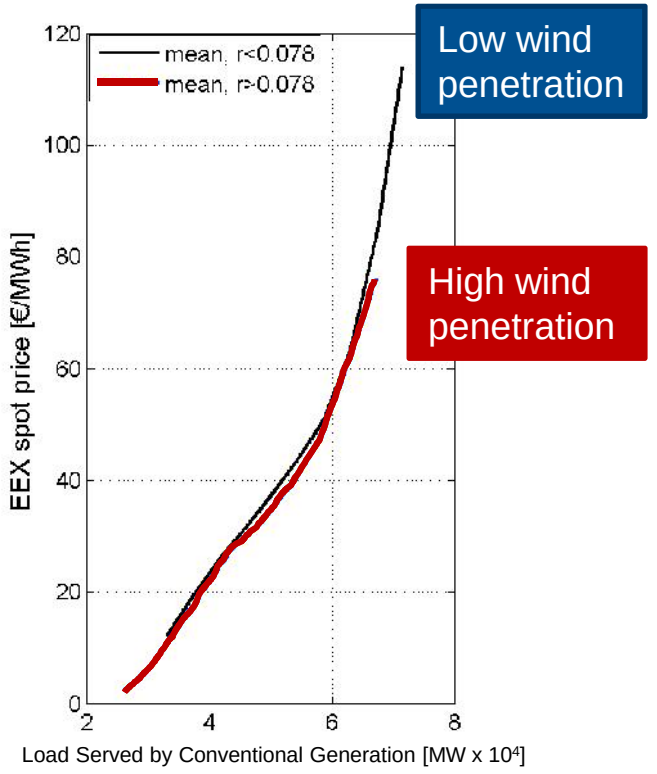
- Storage will be necessary in order to mitigate the variability of RES power

- Except of large-scale storage, new concepts emerge such as the “Distributed Bulk Storage”
  - Community Energy Storage Systems at the distribution level
  - Plug-in Hybrid Electric Vehicles

Motivation (2/2)

- RES coupled with storage
- Two approaches:
  - Maximize the profits of the RES power plant
  - Maximize the social welfare of the whole system
- RES usually acts as a price-taker

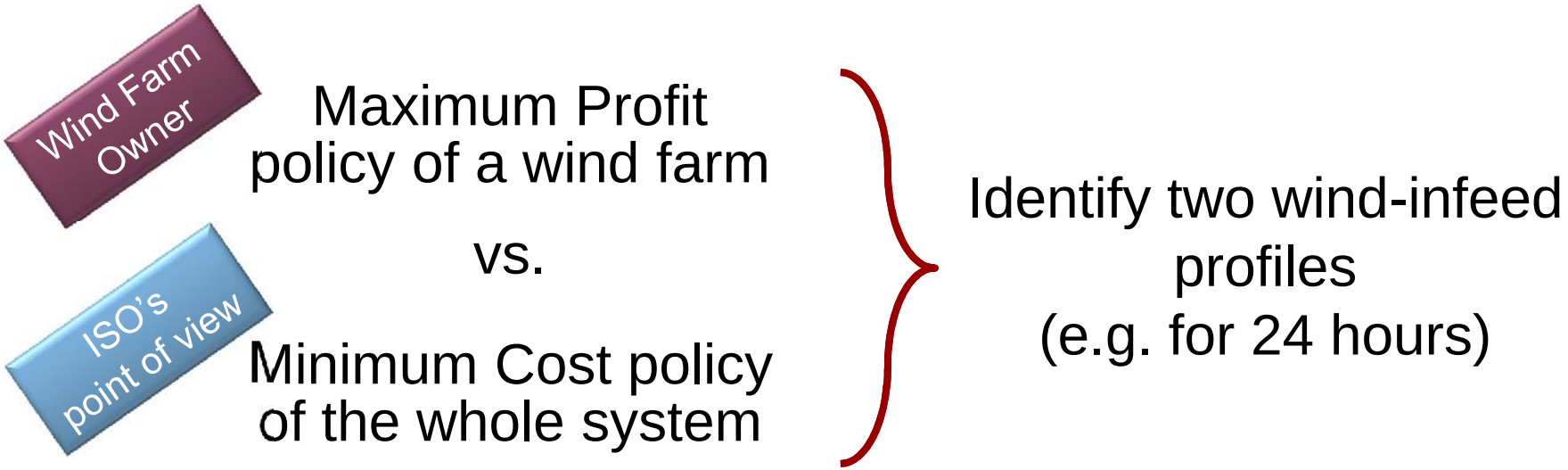
- *But:* Increasing wind penetration influences the electricity prices



B. Klöckl, P. Binson. Effects of increasing wind power penetration on the physical operation of large electricty market systems. Cigre 2009.

Goal

- Wind farm coupled with variable storage

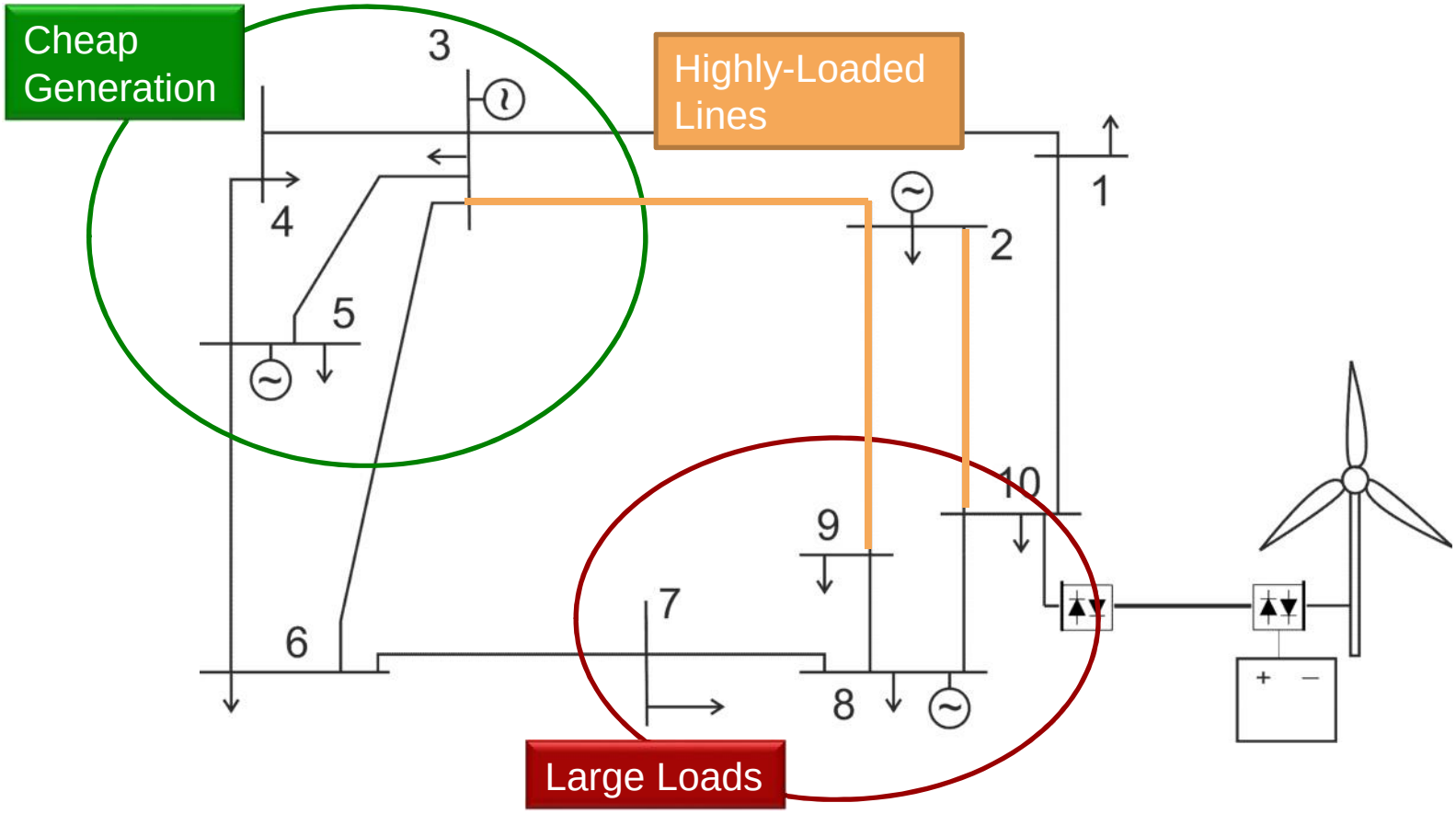


- Compare the two wind infeed profiles
- If necessary, identify incentives so that the wind farm follows the minimum cost policy of the whole system

OUTLINE

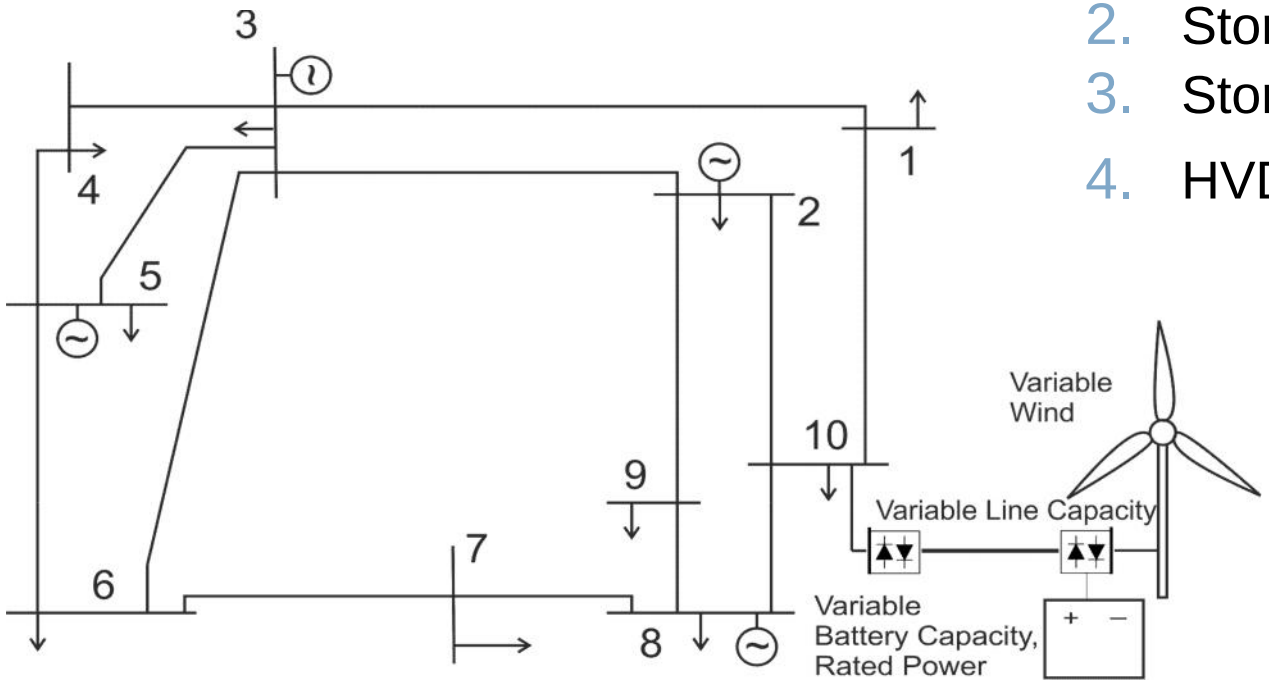
1. System Setup
2. Optimization Methods
3. Results
4. Incentives
5. Conclusions

10-bus system



System Setup

- Locational Marginal Pricing
  - Every Producer sends a cost function
  - ISO performs an Optimal Power Flow
  - Producer is paid the Loc. Marg. Price

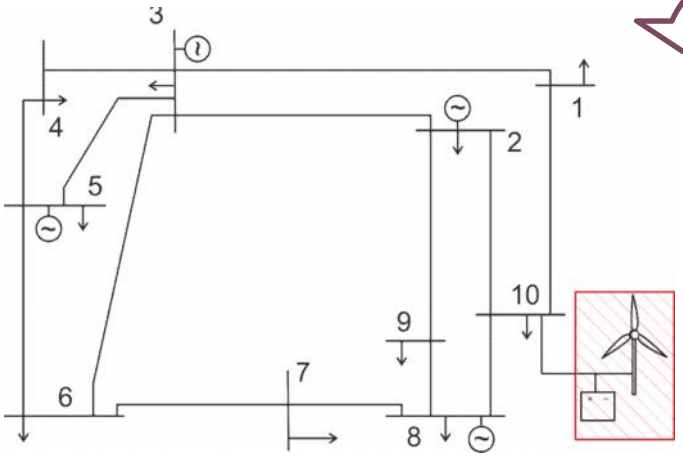


- Cost function of the Wind Farm
  1. Wind Farm operation (*low costs*)
  2. Storage Capacity
  3. Storage Rated Power
  4. HVDC Line

Wind Farm Profit Maximization

- The wind farm can influence the Locational Marginal Prices (LMPs) → the LMPs cannot be considered constant

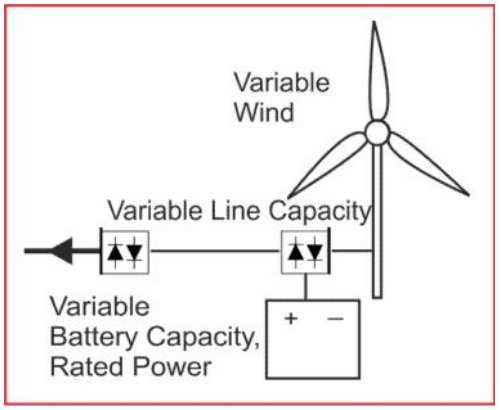
Multi-period DC-OPF



Cost Function

Power Infeed

Wind Farm Max. Profit



Determines for N=24 hours:

a. Production of each generator
b. LMPs

LMPs

Determines for N=24 hours:

a. Maximum Power Infeed
b. Cost Function (“bid”)

Wind Farm Profit Maximization

Multi-period DC-OPF

$$min \sum_{k=1}^{N} \left(\sum_{j=1}^{N_{gen}} C_{jk}(P_{jk}) + C_{\text{WF,tot}}(P_{\text{WF},k}^{\text{OPF}}) \right)$$

Conv. Generators cost functions

Wind farm cost function

LMPs

Wind Farm Max. Profit

$$max \sum_{k=1}^{N} (\text{LMP}_k \cdot P_{\text{inf},k} - C_{\text{WF,op}} \cdot P_{\text{WF},k}) -$$
$$- C_{\text{Bat,Q}} \cdot Q_{\text{Bat,max}} - C_{\text{Bat,P}} \cdot P_{\text{Bat,max}} - C_{\text{Line}} \cdot P_{\text{Line}}$$

subject to:

power system constraints

$$0 \leq P_{\text{WF},k}^{\text{OPF}} \leq P_{\text{inf},k}$$

Maximum power infeed of wind farm

Power infeed Cost function

subject to:

available wind power

battery constraints and efficiency

line constraints

Wind Farm Cost Function

$$C_{\text{WF,tot}}(\cdot) = \left(C_{\text{WF,op}} + \frac{C_{\text{Bat,Q}} + C_{\text{Bat,P}} + C_{\text{Line}}}{\sum_{k=1}^{N} P_{\text{inf},k}} \right) \cdot P_{\text{WF},k}^{\text{OPF}},$$

Overall Cost Minimization

- Multi-period optimization

Generators and Wind Farm Costs

$$min \sum_{k=1}^{N} \left(\sum_{j=1}^{N_{gen}} C_{jk}(P_{jk}) + C_{\text{WF,op}} \cdot P_{\text{WF},k} \right) + C_{\text{Bat,Q}} \cdot Q_{\text{Bat,max}} + C_{\text{Bat,P}} \cdot P_{\text{Bat,max}} + C_{\text{Line}} \cdot P_{\text{Line}}$$

Battery Costs *Line Costs*

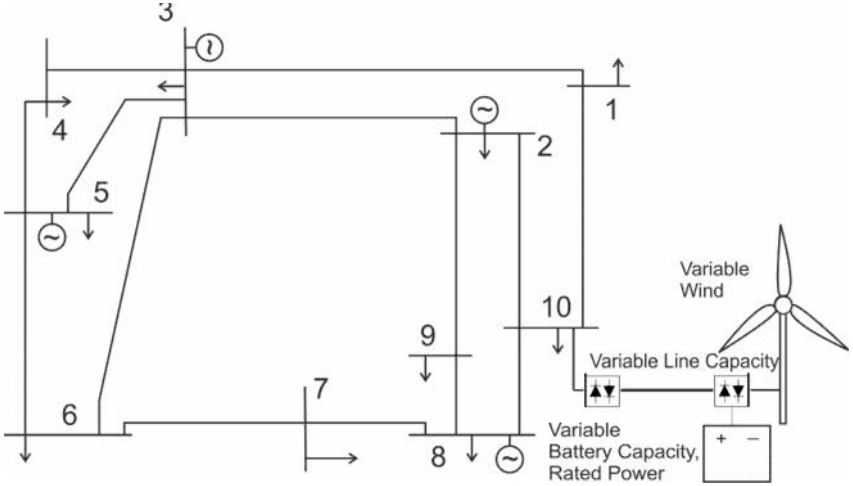
subject to:

power system constraints

available wind power

battery constraints and efficiency

line constraints



Determines for N=24 hours:

a. Production of each generator
b. Wind Power infeed
c. Storage and Line capacity
d. LMPs

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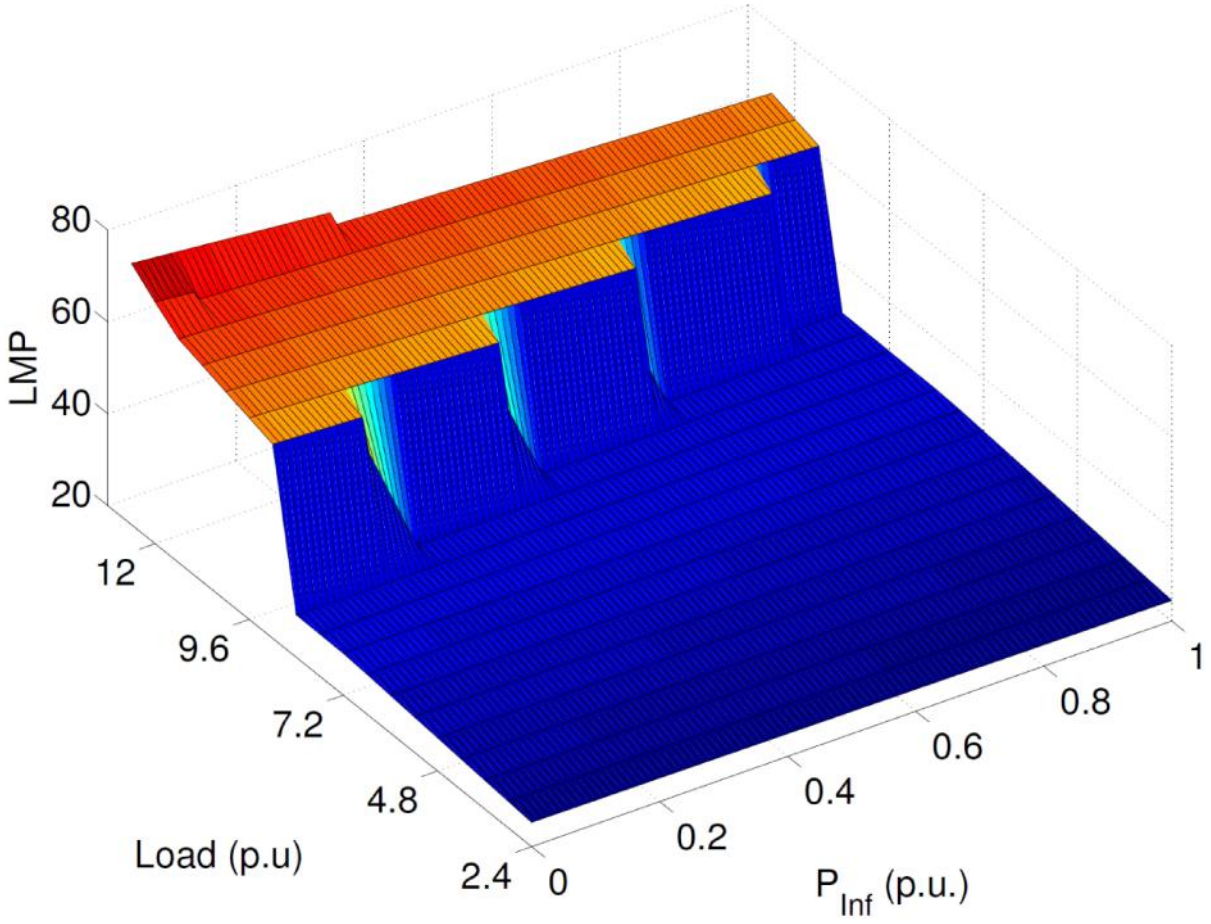
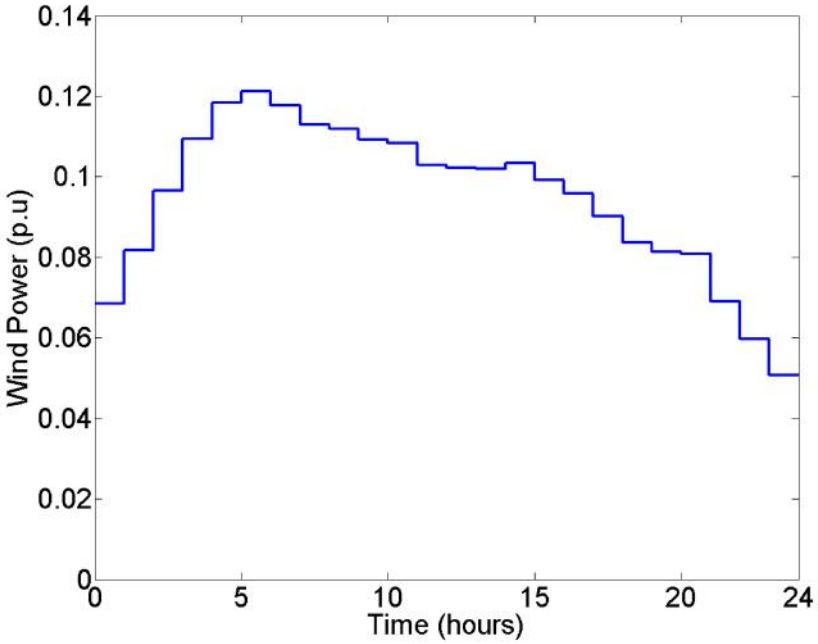
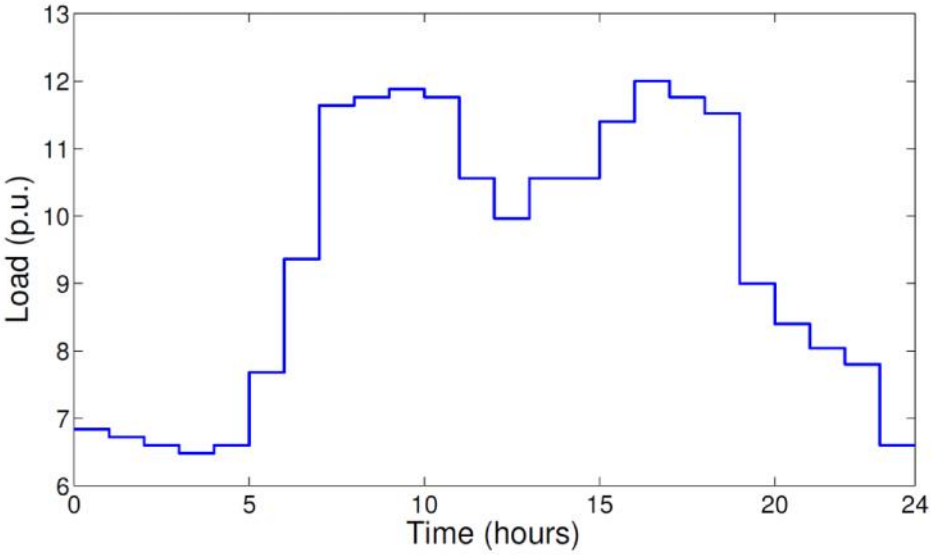
LMP Variation at Node 10



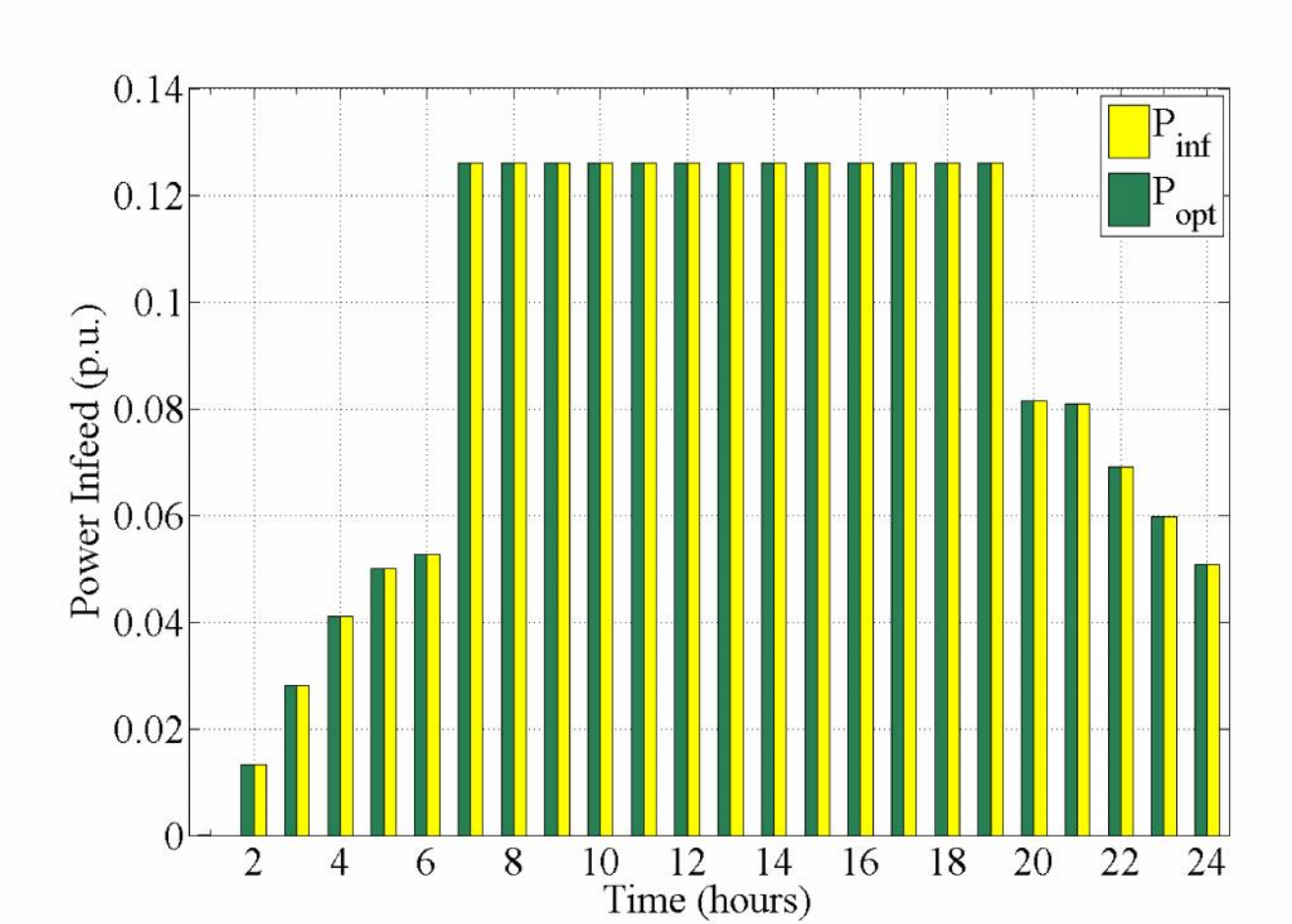
Small Wind Farm



Load profile



Small Wind Farm - Max Profit vs. Overall Cost Min.

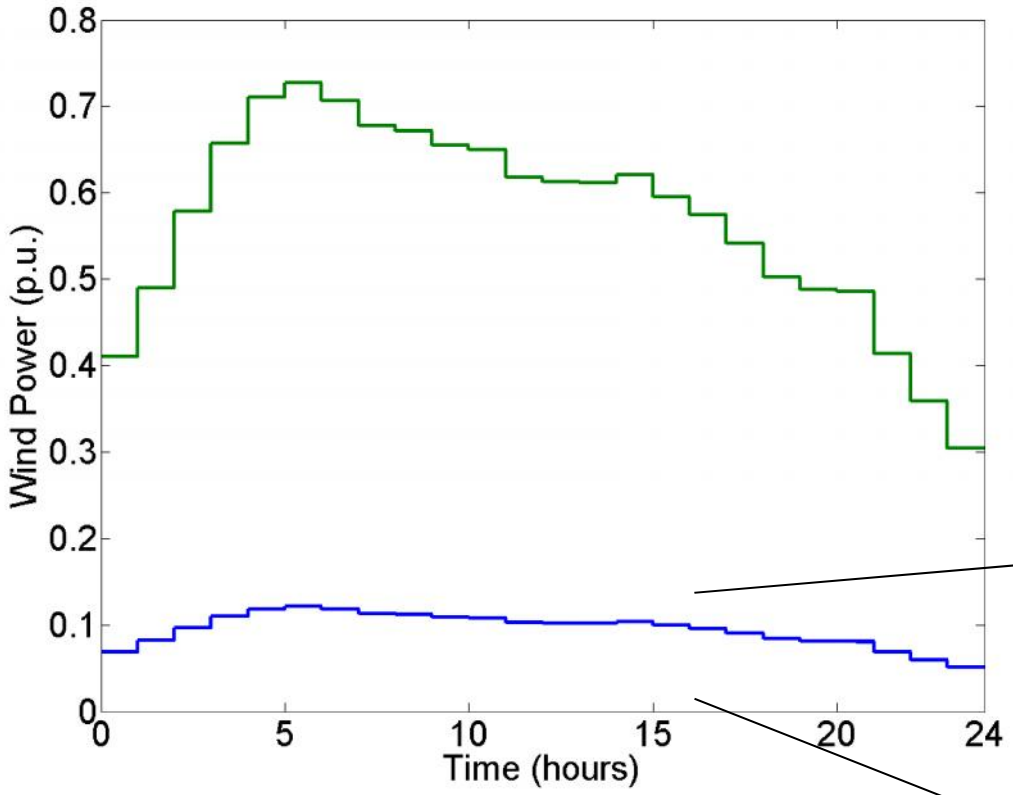


Small Wind Farm

	Wind Farm Profit	Generator Costs
Profit Maximization	~100’000	~6’000’000
Overall Cost Minimization	~100’000	~6’000’000

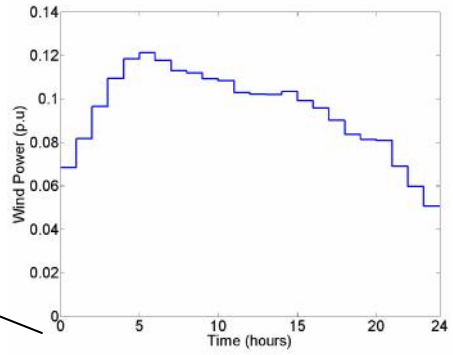
- The small wind farm acts as a price taker → cannot influence the LMPs
- Both optimizations lead to the same (desired) market outcome

Large Wind Farm

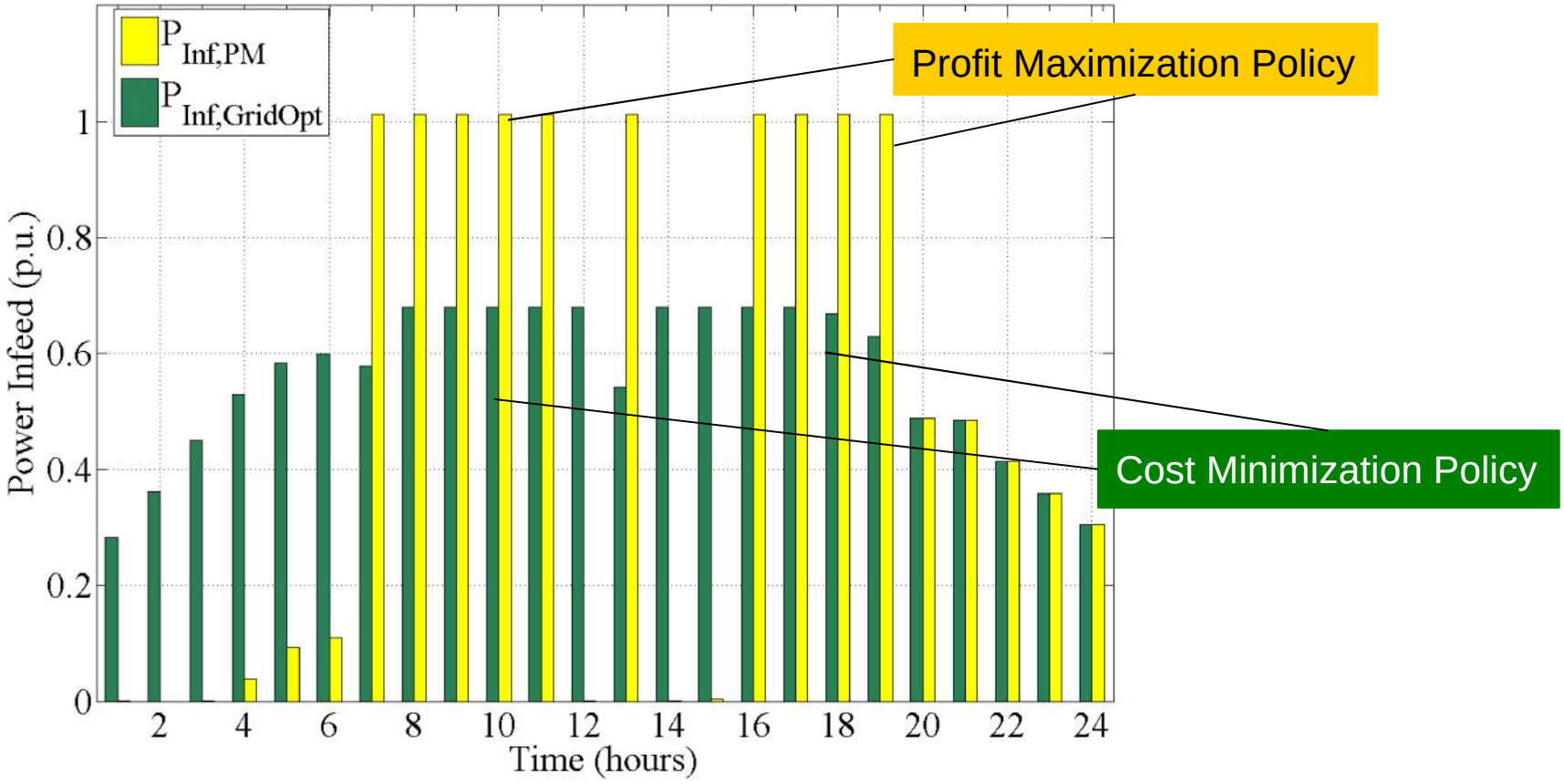


- Wind Profile scaled up by a factor of 6

Small Wind Farm



Large Wind Farm - Max Profit vs. Overall Cost Min.



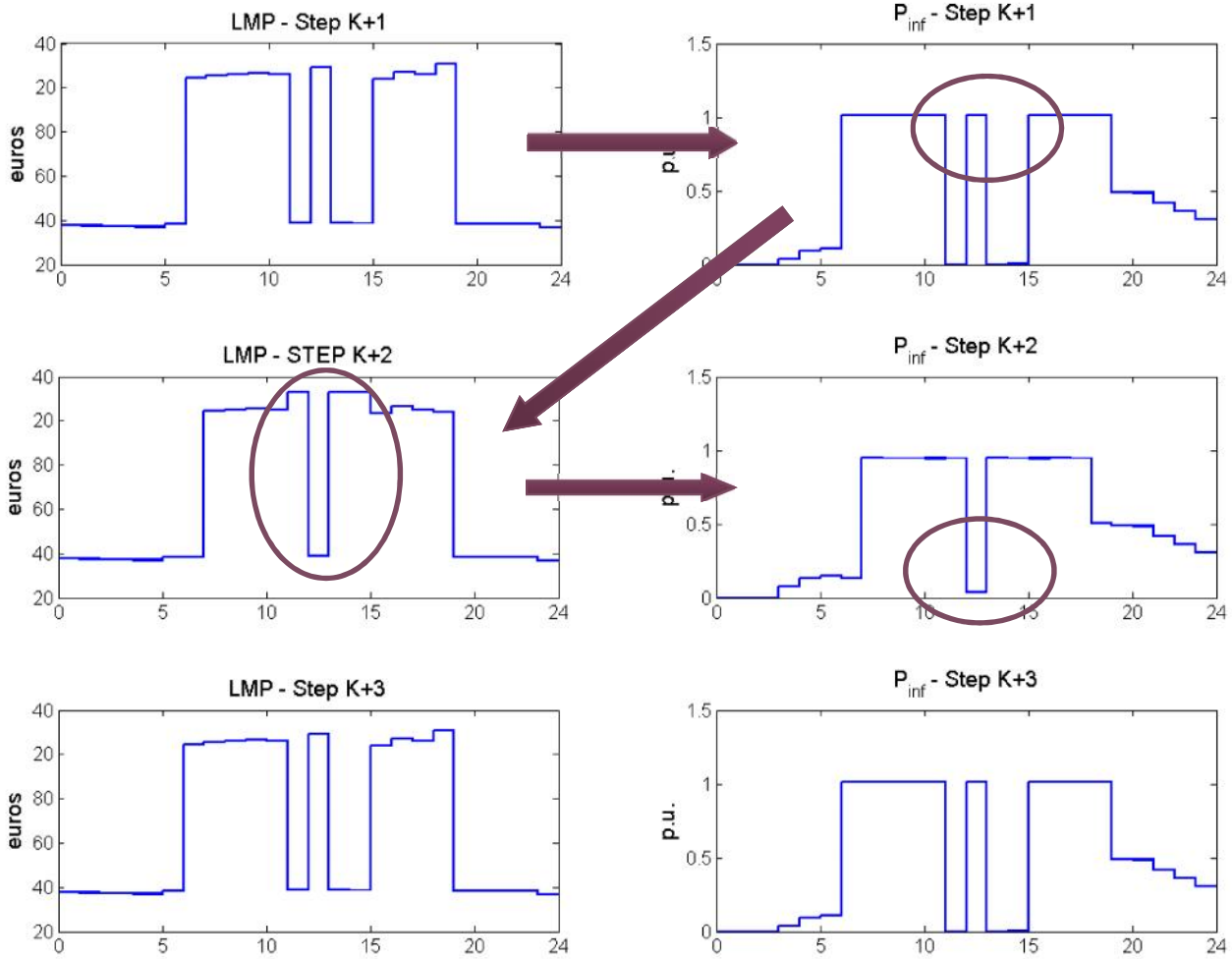
Large Wind Farm

	Wind Farm Profit	Generator Costs
Profit Maximization	~431’000	~5’656’000
Overall Cost Minimization	~517’000	~5’591’000

- The large wind farm acts as a price setter → but, it cannot know *how* it influences the LMPs
- Cost minimization yields larger profits to the wind farm than its own profit maximization
- Distorts market efficiency

Prices

Wind Power Infeed



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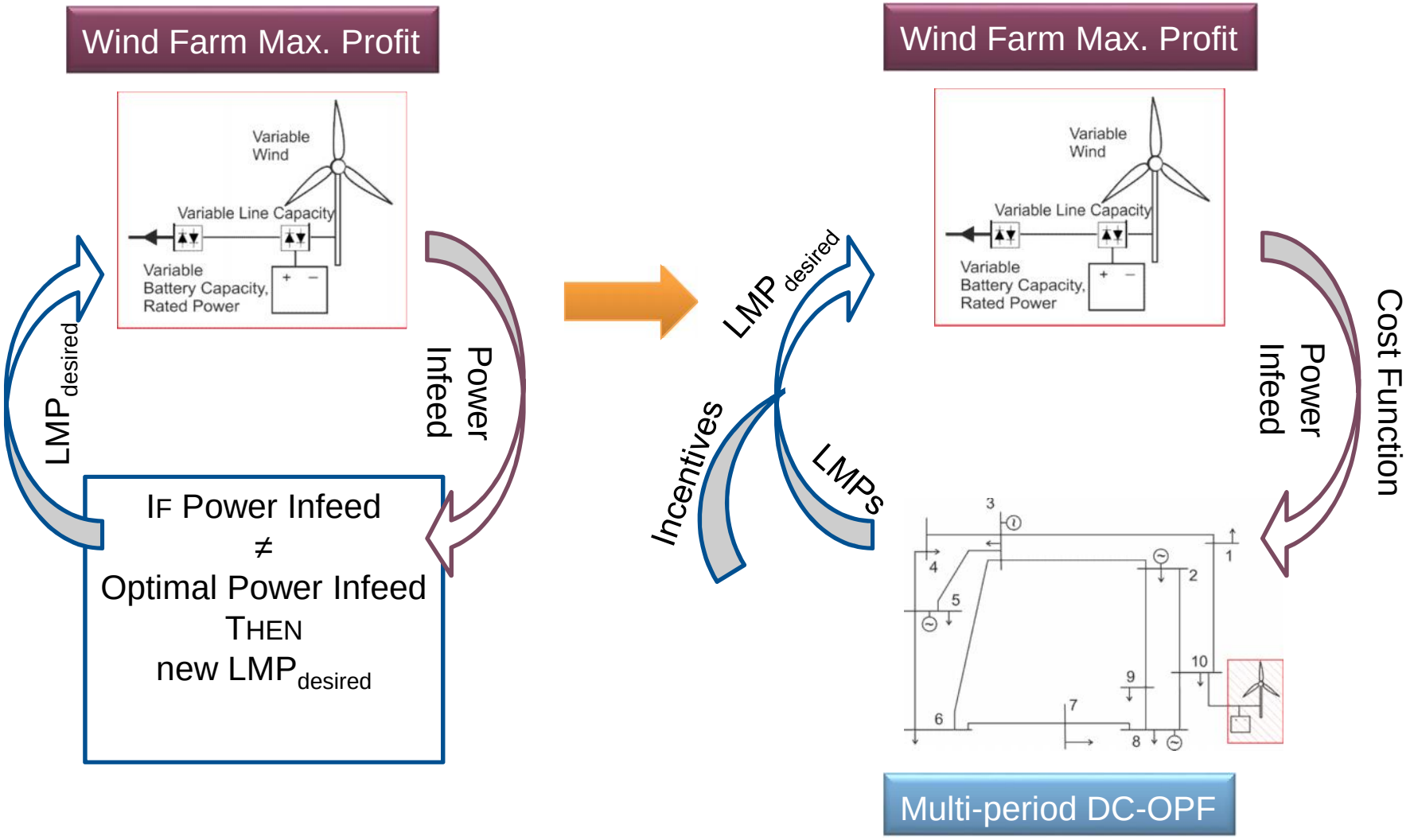
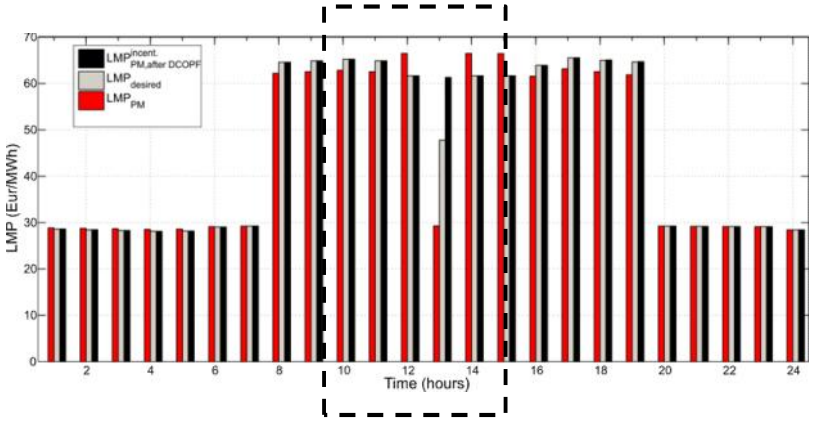
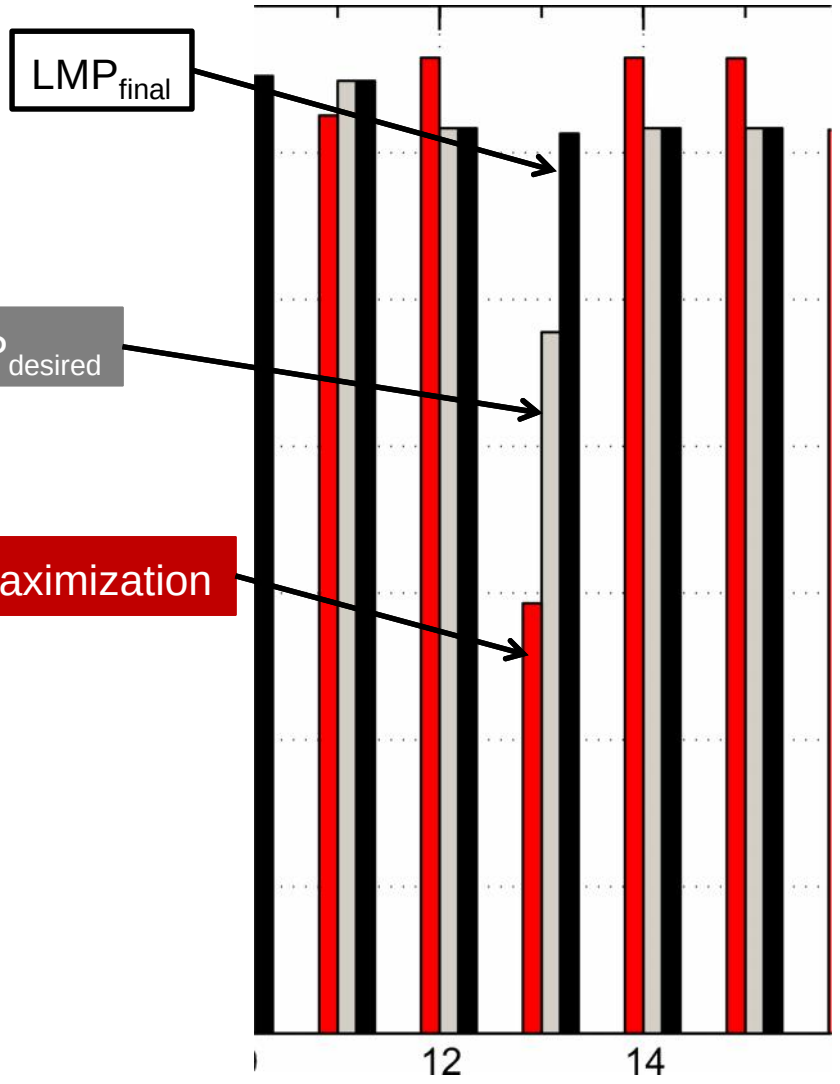


- Incentives = $LMP_{desired} - LMP$

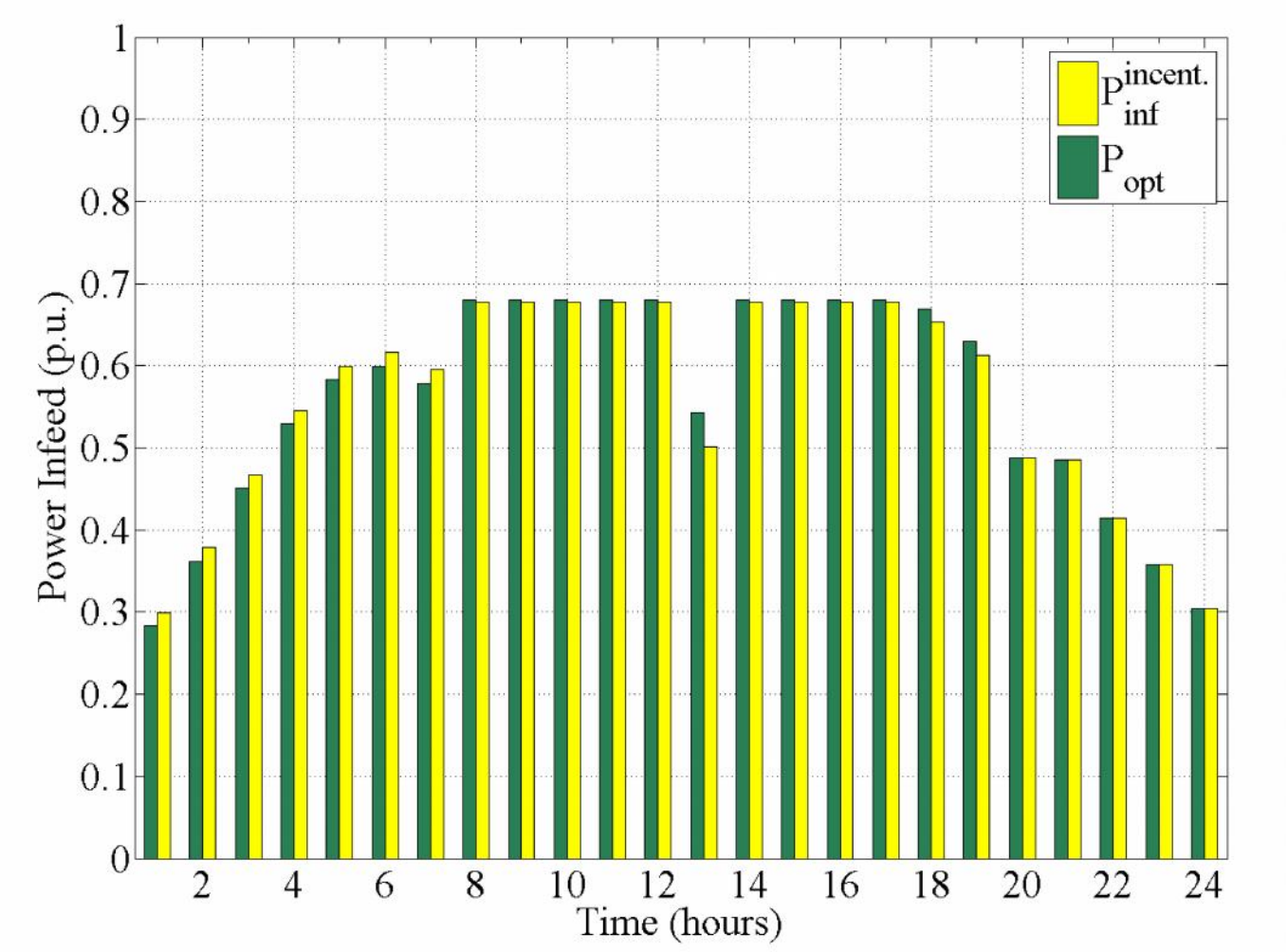
LMPs at node 10

- $LMP_{desired}$: price the wind farm is paid
- LMP_{final} : appears at node 10 because of the wind farm infeed





Power Infeed with Incentives



Large Wind Farm with Incentives

	Wind Farm Profit	Generator Costs
Profit Maximization	~431’000	~5’656’000
Overall Cost Minimization	~517’000	~5’591’000
Prof. Max with Incentives	~517’000	~5’591’000

- Cost of Incentives is negative (!) [-7’000 Eur/day]
  - ISO pays the wind farm less than the LMP at Node 10 at certain hours

Conclusions

- If the wind farm provides“cheap” energy and acts as a price taker, its interests coincide with the interest of the system operator (i.e. to maximize social welfare)

- If wind farms have no knowledge of the impact on the LMPs, they cannot identify the optimal policy for maximizing their profits → less profits for the wind farm and more incurred costs for the system

- Incentives do not necessarily have to result into extra costs for the system operator

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Thank you!

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