Exploiting flexibility from batteries across hierarchies in the power system

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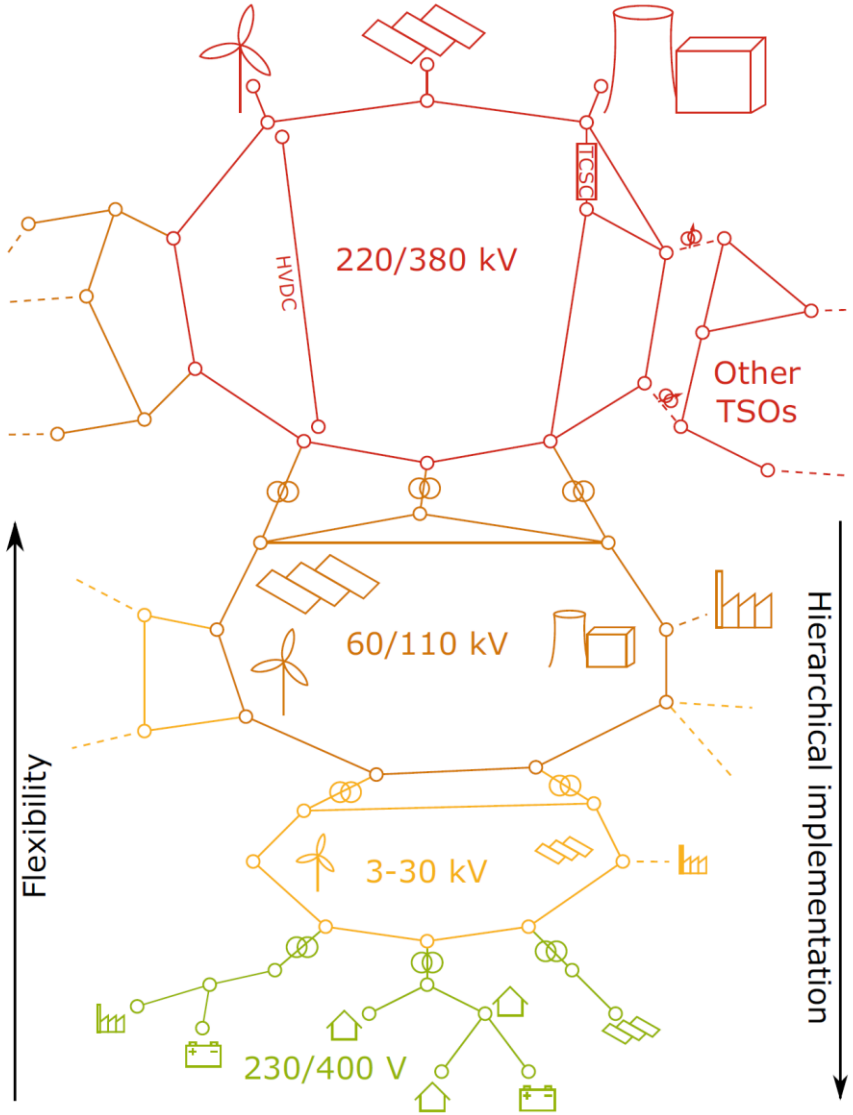
Tobias K. S. Ritschel
Department of Applied Mathematics and Computer Science
Technical University of Denmark

Hierarchical power system



Optimal exploitation of flexibility

Flexible distribution grid

Flexible assets

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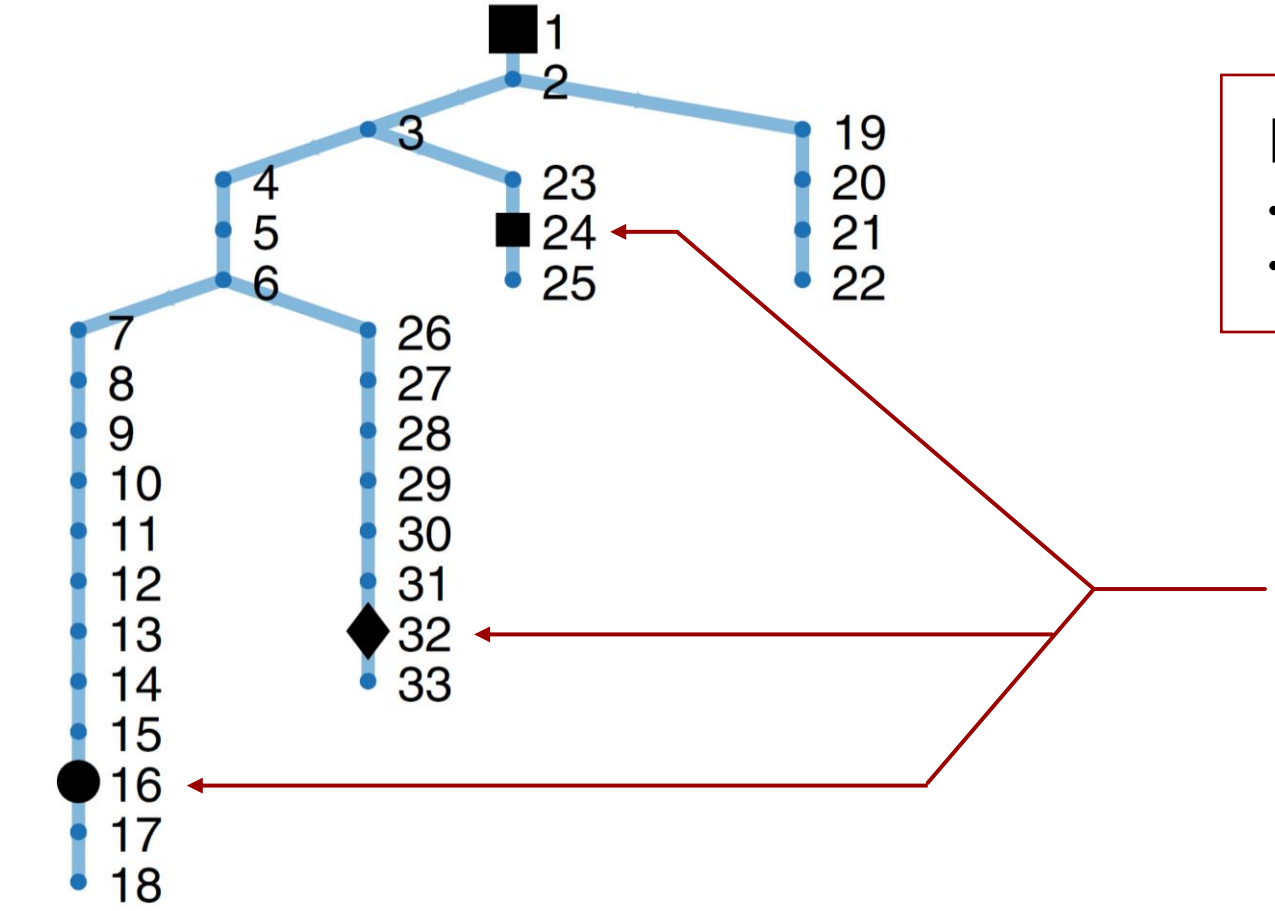
Distribution grid

Distribution grid

IEEE 33-bus grid



Min/max optimal power flow

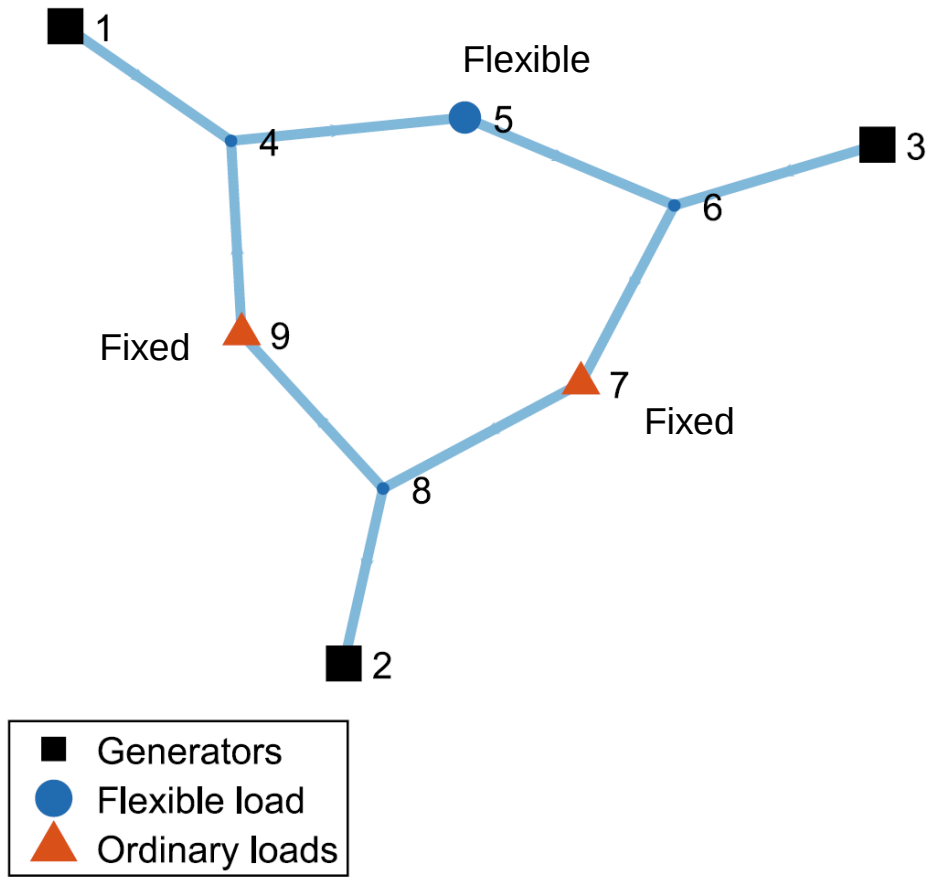
- Min/max total energy demand
- Demands of flexible nodes are free

Individual flexibility > flexible distribution grid

Transmission grid

Transmission grid

IEEE 9-bus grid



Economic optimal power flow

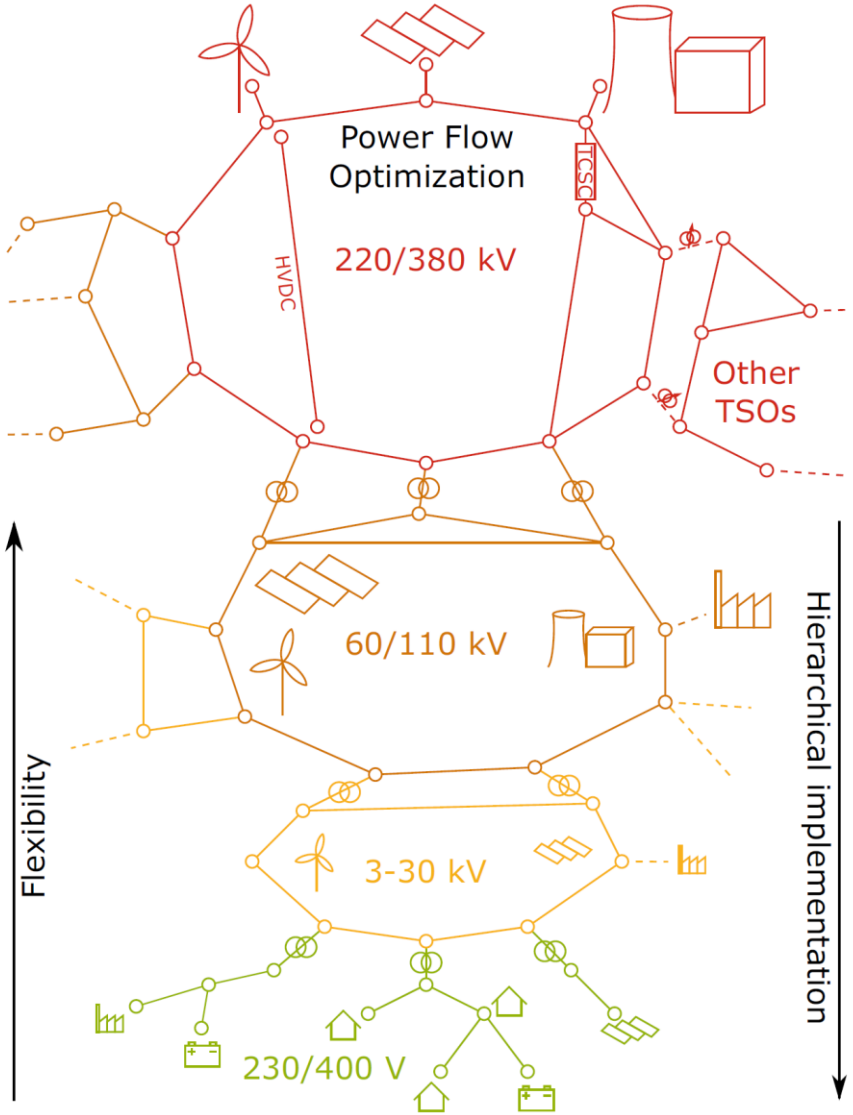
- Minimize cost
- Security constraints (N-1)
- Demand of flexible node is free

Transient stability

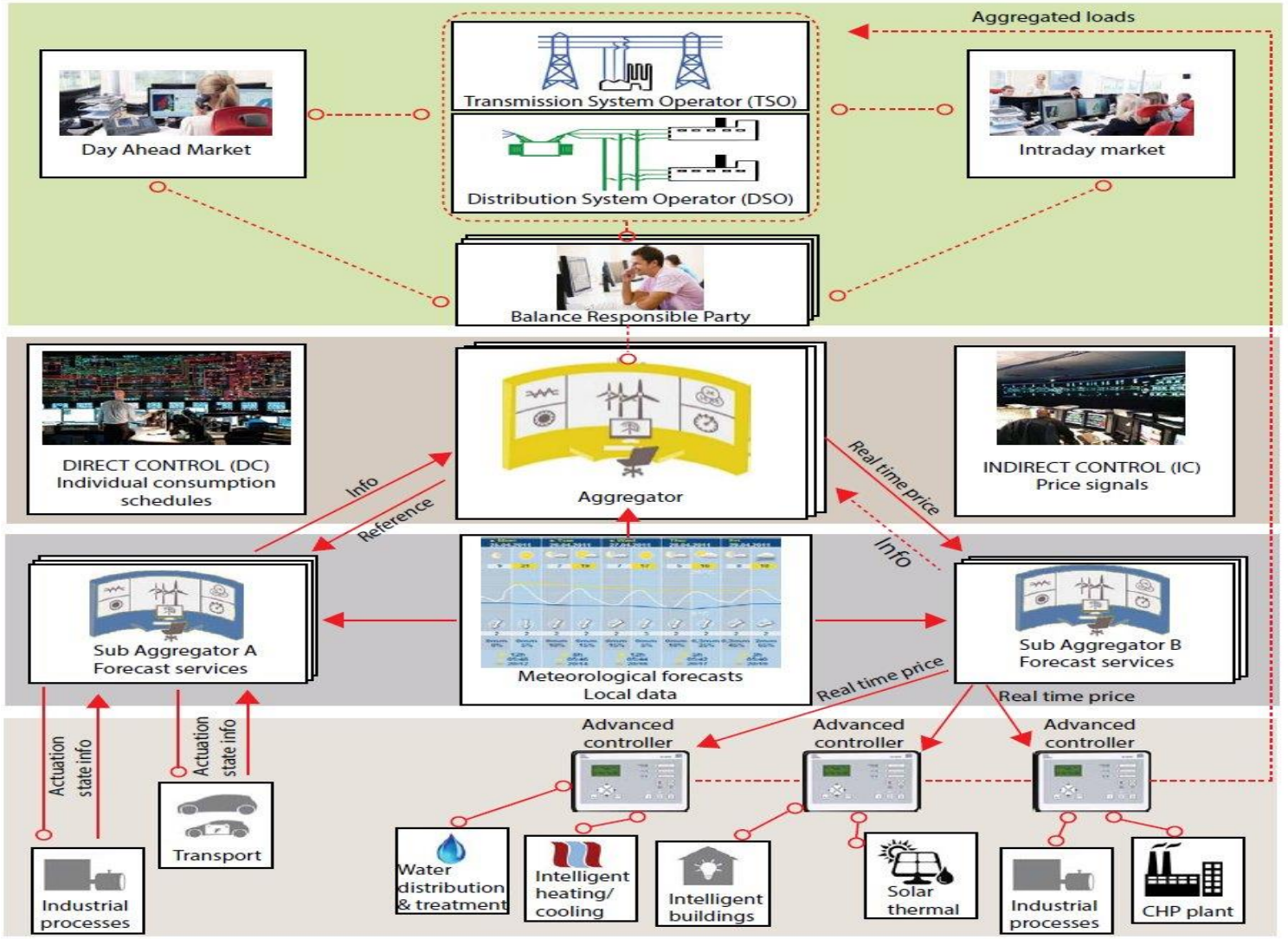
- Network Laplacian

Fundamental challenges

- High communication requirements
- Direct control of consumer demand
- Does not account for <u>finite</u> flexibility



Smart Energy Operating System (SE-OS)



(Static)

Conventional markets

Link markets to physics using MIMs

(Flexibility Functions)

(Dynamic)

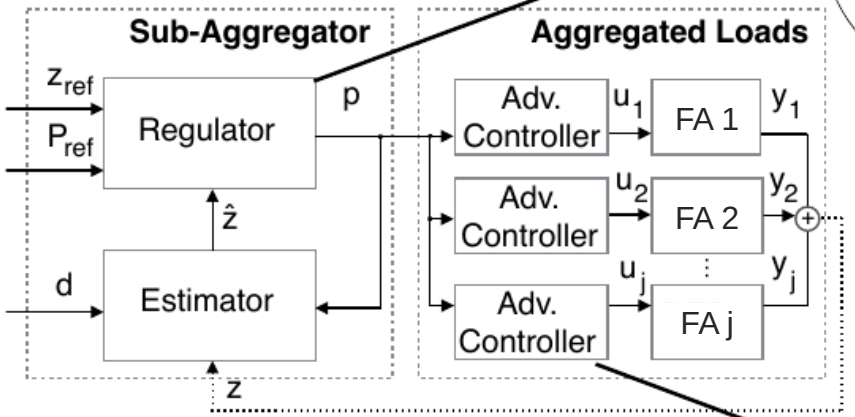
Local flexibility markets

(Hierarchy of controllers)

Interoperability through indirect control

Price signal generator

$$\min_{p} \quad \mathrm{E}[\sum_{k=0}^{N} w_{j,k}||\hat{z}_k - z_{ref,k}|| + \mu||p_k - p_{ref,k}||]$$
$$\text{s.t.} \quad \hat{z}_{k+1} = f(p_k)$$



We adopt a control-based approach where the **price** becomes the driver to **manipulate** the behaviour of a certain pool flexible prosumers.

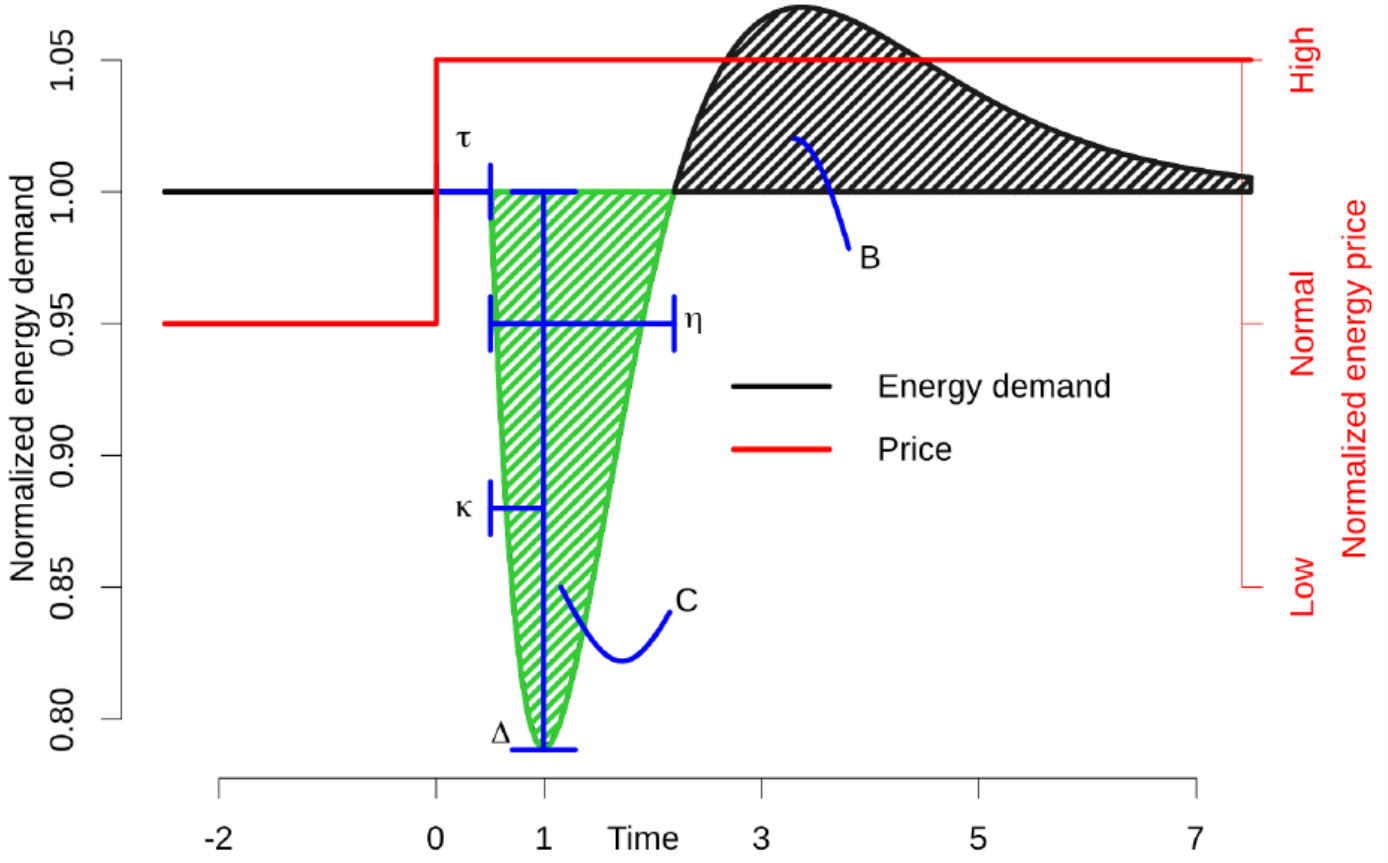
Price-sensitive control system

$$\min_{u} \quad \mathrm{E}[\sum_{k=0}^{N}\sum_{j=1}^{J} \phi_j(x_{j,k}, u_{j,k}, p_k)]$$
$$\text{s.t.} \quad x_{k+1} = Ax_k + Bu_k + Ed_k,$$
$$y_k = Cx_k,$$
$$y_k^{min} \le y_k \le y_k^{max},$$
$$u_k^{min} \le u_k \le u_k^{max}$$

Indirect control through flexibility functions

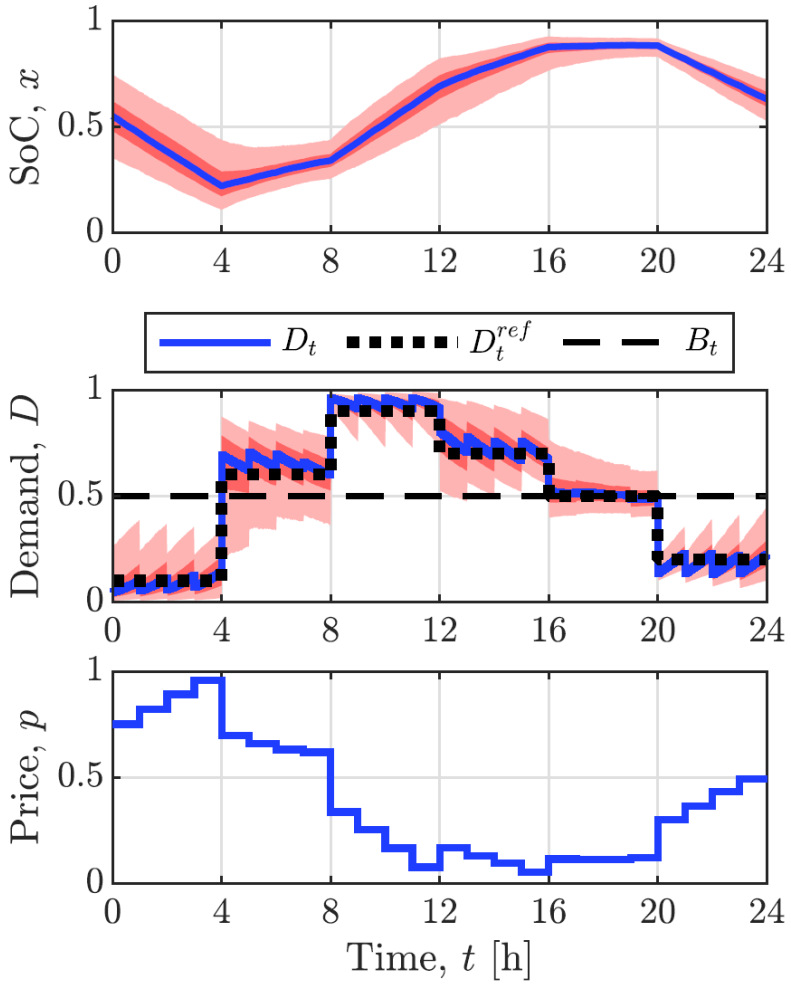
Flexibility function: Predict flexible demand as function of

- **Price**
- **State of charge** (aggregate)

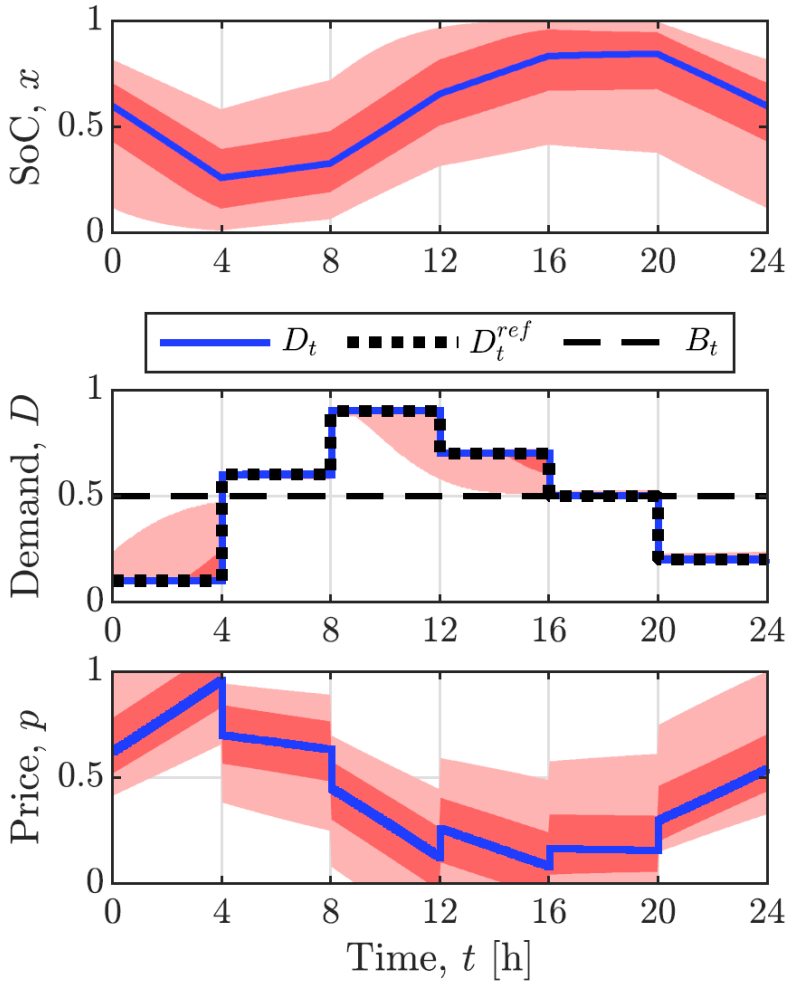


Generated price signals

Day-ahead prices
(open-loop)



Real-time prices
(idealized)



Thank you