Hierarchical methods for exploiting flexible energy resources based on flexibility functions

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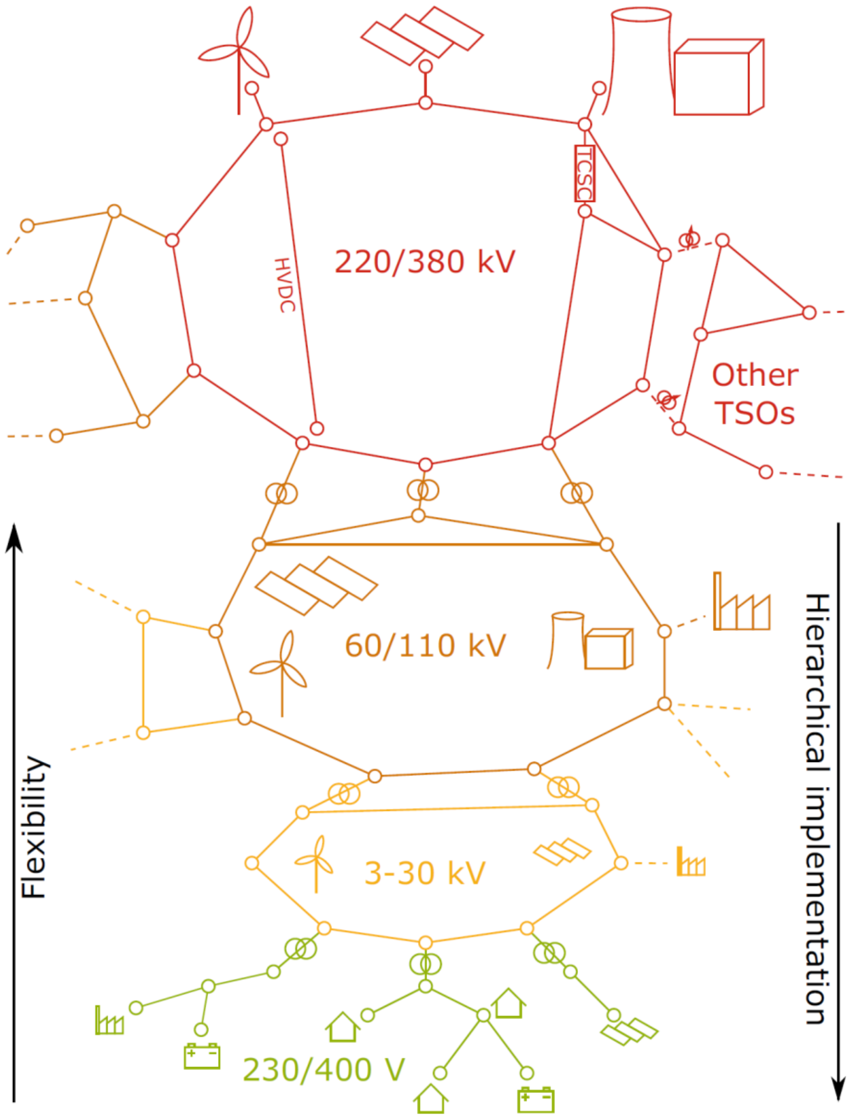
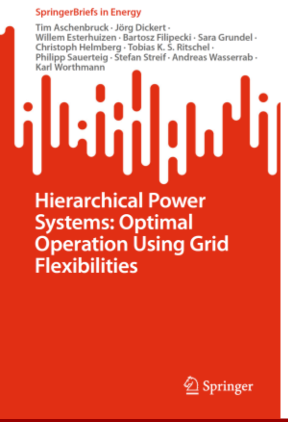
Hierarchical power systems: Grid flexibilities (2023)





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Transmission grid

Economic optimal power flow

- Minimize cost
- Security constraints (N-1)
- Transient stability (network Laplacian)
- <u>Demand of flexible nodes are free</u>

Flexible distribution grid

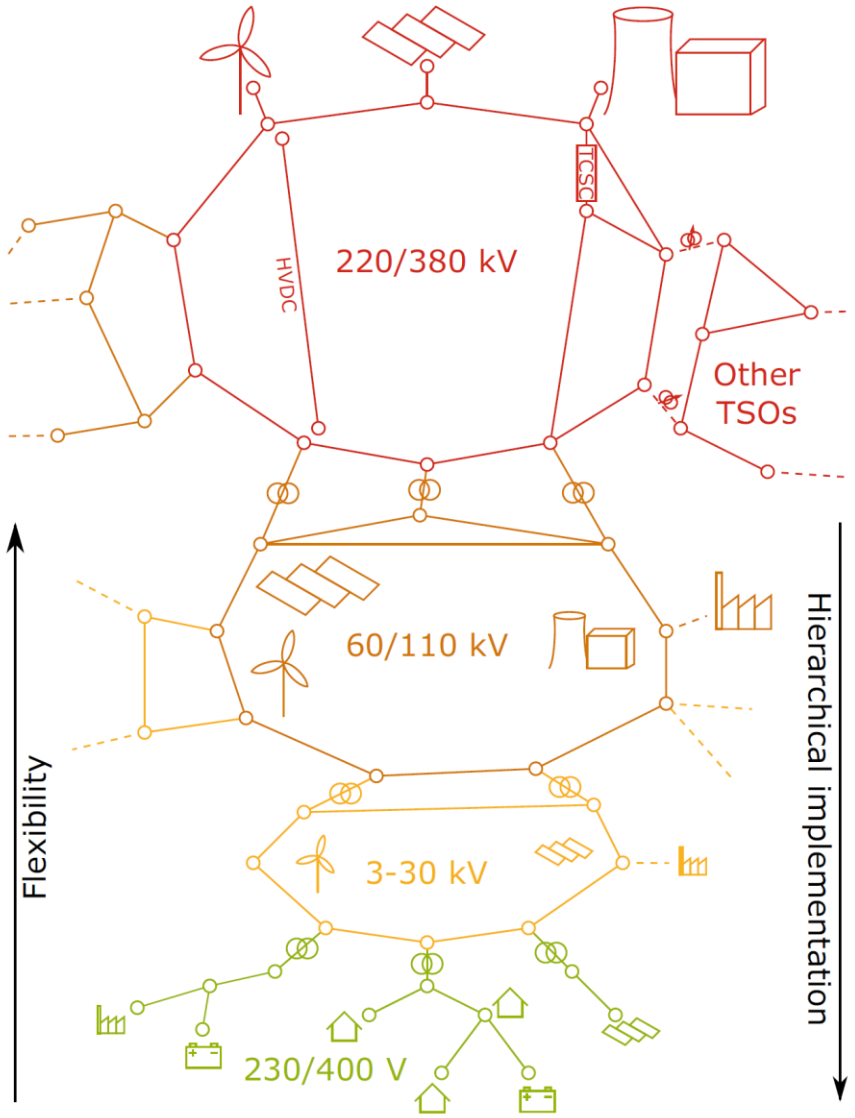
Min/max optimal power flow

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

Flexible assets (e.g., microgrids or vertical agriculture)

Economic (price-sensitive) control

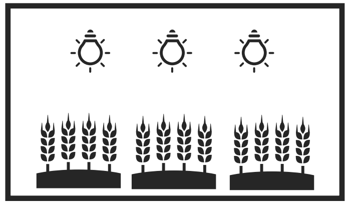
Remaining challenges



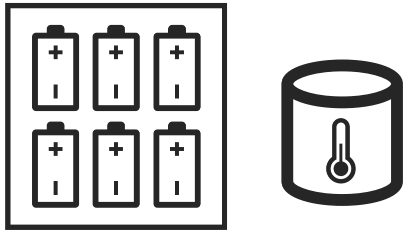
- Demand response depends on “state of charge”
- Flexibility may be finite
- Requires full control of energy demand

Types of flexible assets

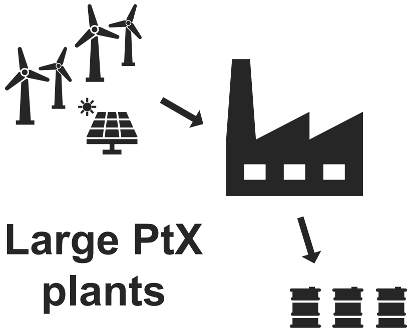
Large and intensive



Greenhouses

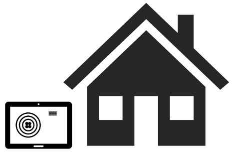


Energy storage facilities

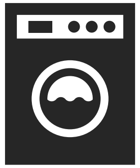


Large PtX plants

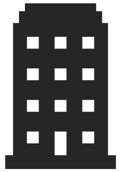
Small but widespread



Heat pumps



Smart appliances

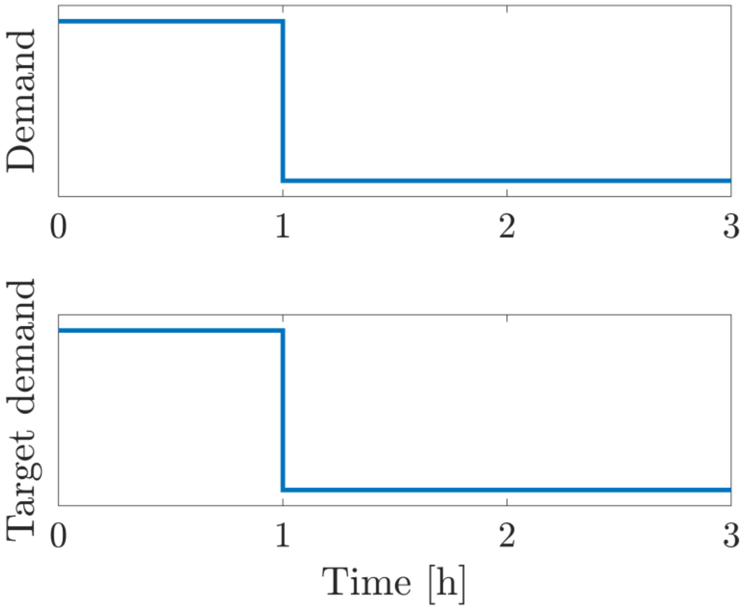


Households

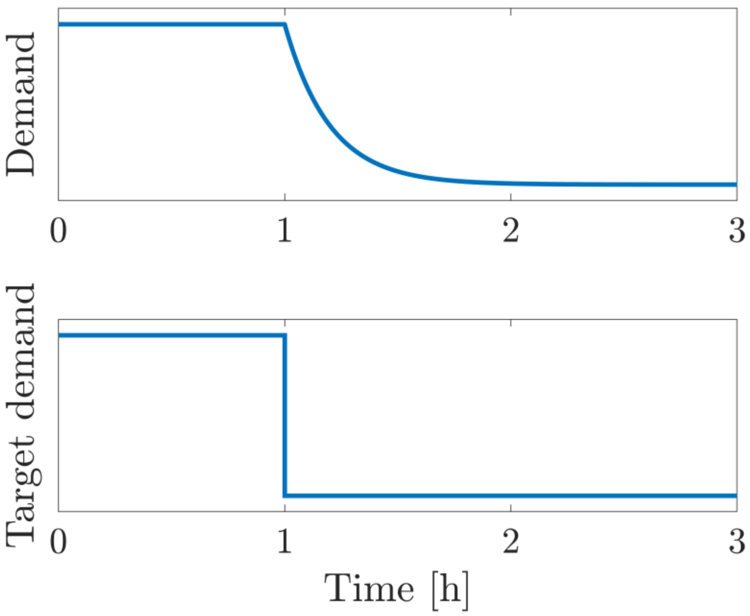
Electric vehicle charging

Types of flexibility

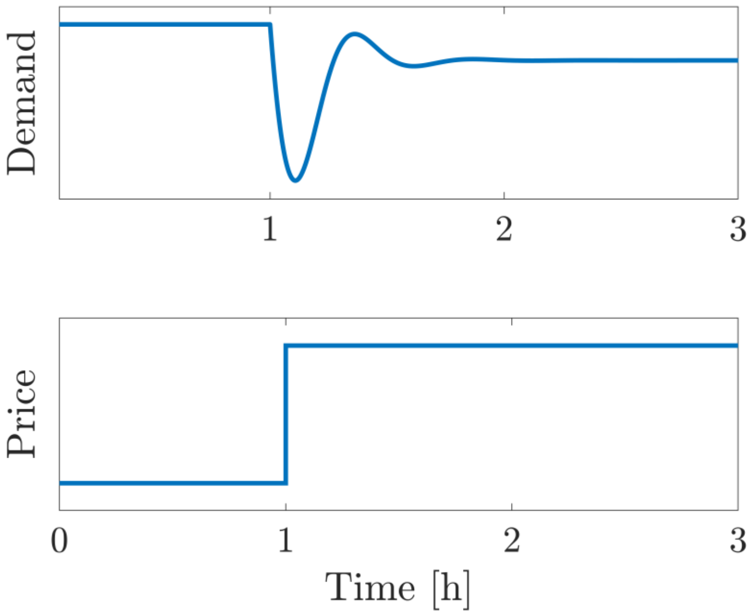
Flexible and fast



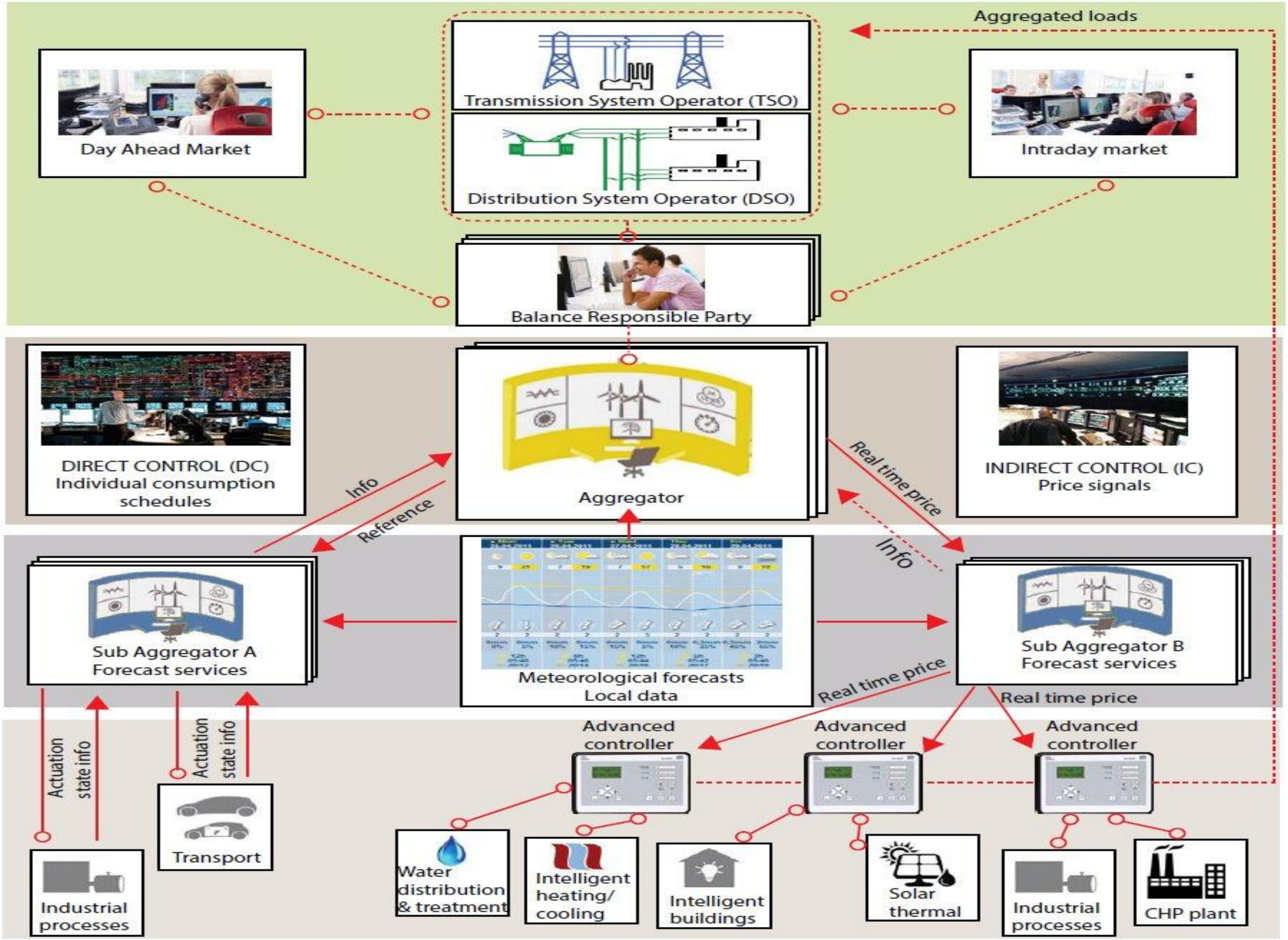
Flexible but slow



Complex



Smart Energy Operating System (SE-OS)



(Static)

Conventional markets

Link markets to physics using MIMs

(Flexibility Functions)

(Dynamic)

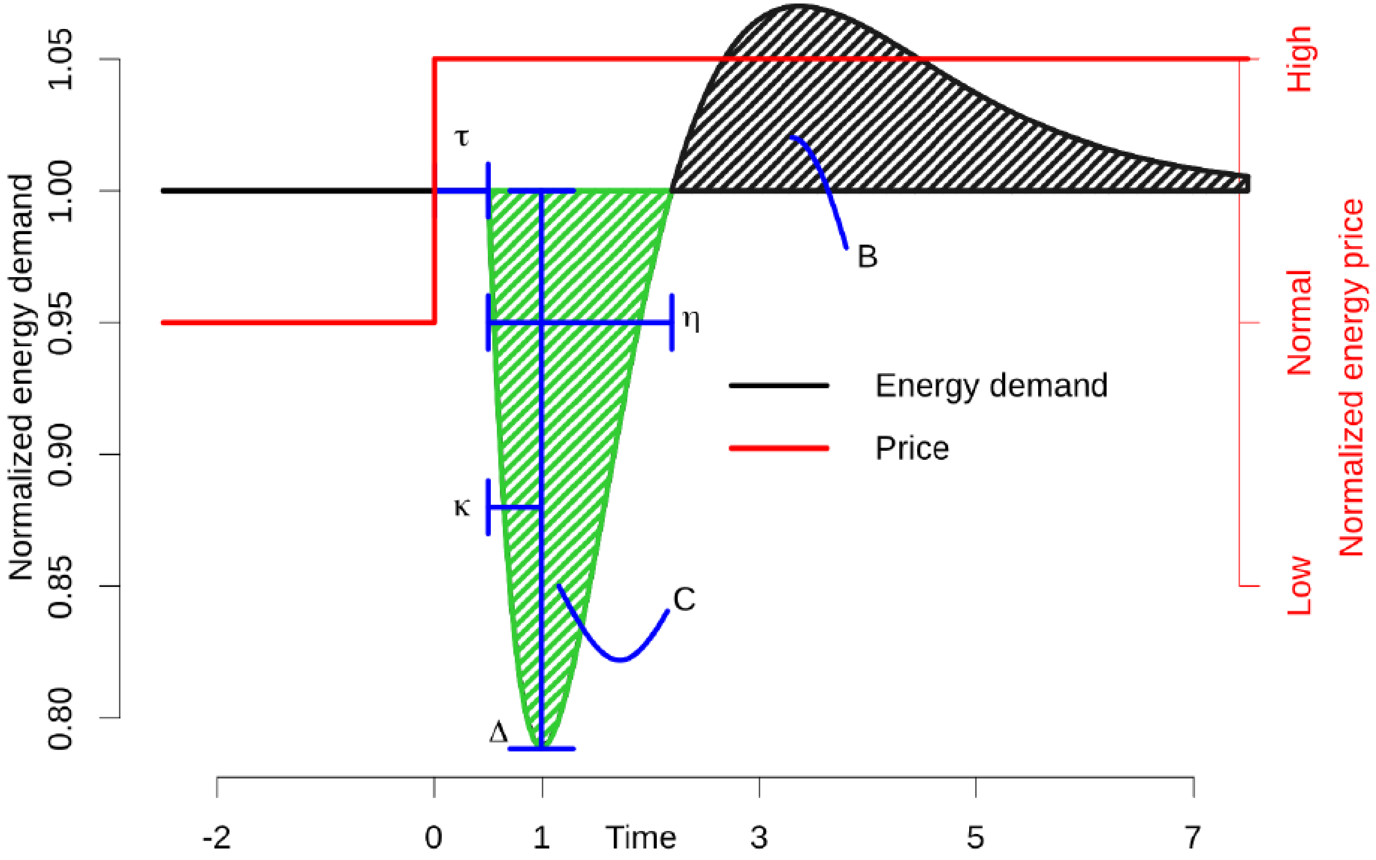
Local flexibility markets

(Hierarchy of controllers)

Minimal demand response models: Flexibility functions

Flexibility function: Predict flexible demand as function of

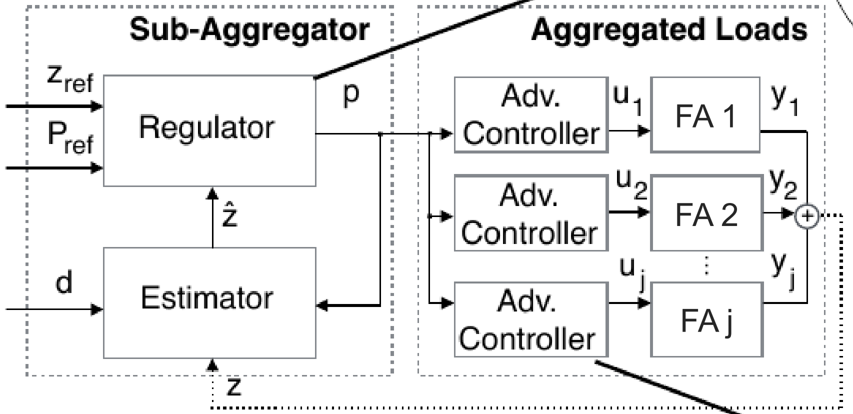
- **Price**
- **“State of charge”**



Interoperability through <u>incentivization</u>

Price signal generator

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

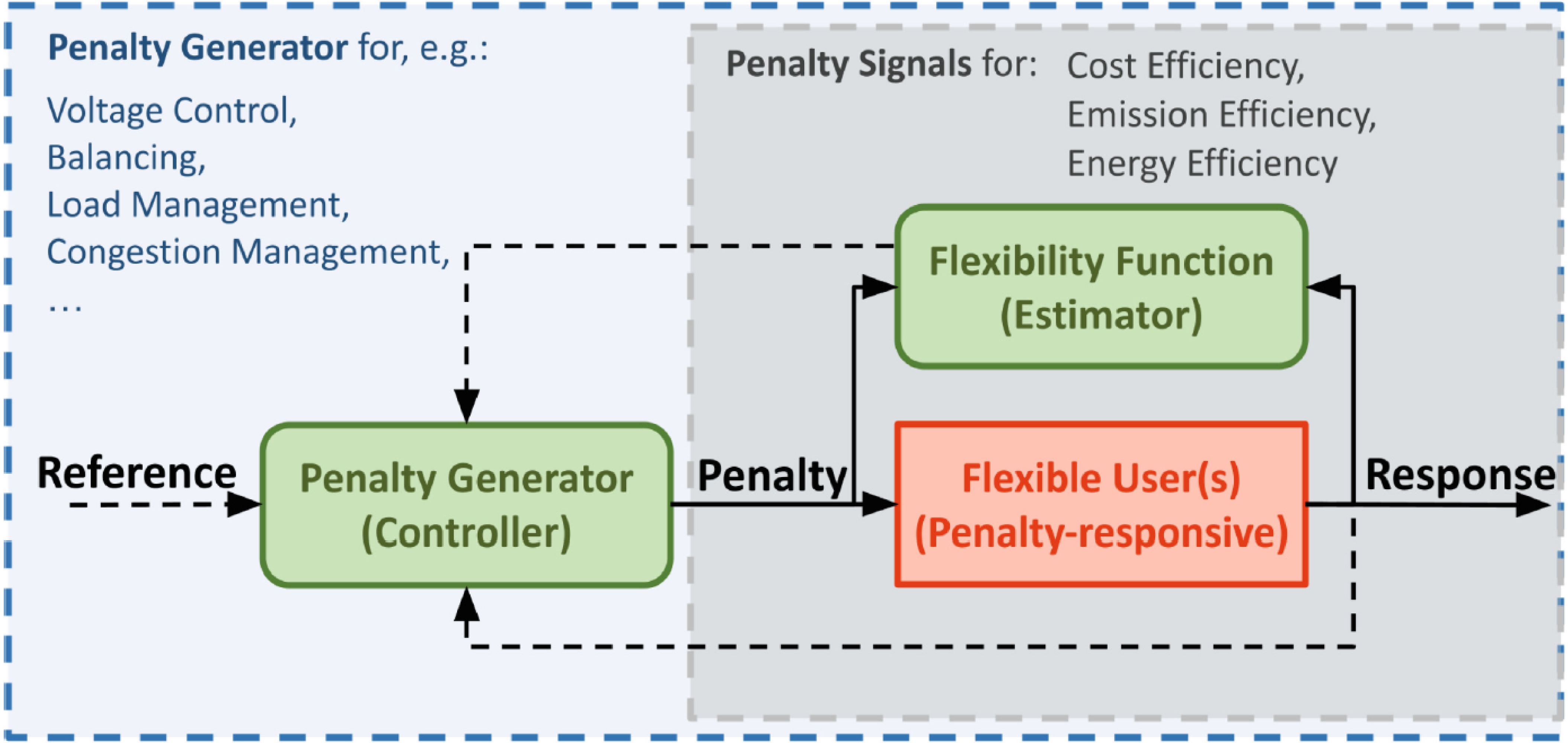


Price-sensitive control system

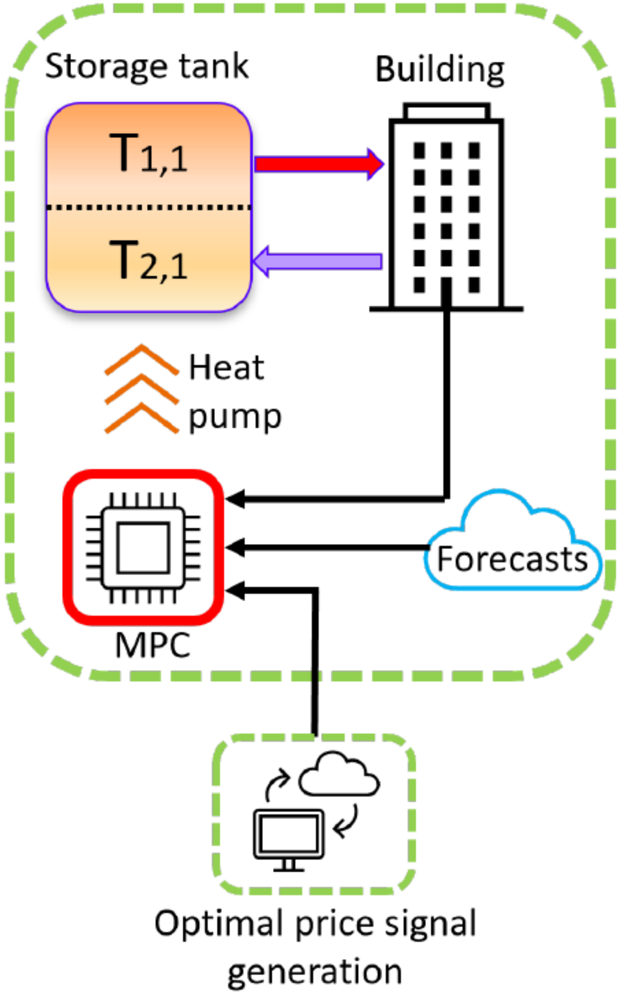
$$\min_{u} \quad \mathrm{E}\Big[\sum_{k=0}^{N}\sum_{j=1}^{J} \phi_j(x_{j,k}, u_{j,k}, p_k)\Big]$$
$$\begin{aligned} \text{s.t.} \quad x_{k+1} &= Ax_k + Bu_k + Ed_k, \\ y_k &= Cx_k, \\ y_k^{min} \leq y_k &\leq y_k^{max}, \\ u_k^{min} \leq u_k &\leq u_k^{max} \end{aligned}$$

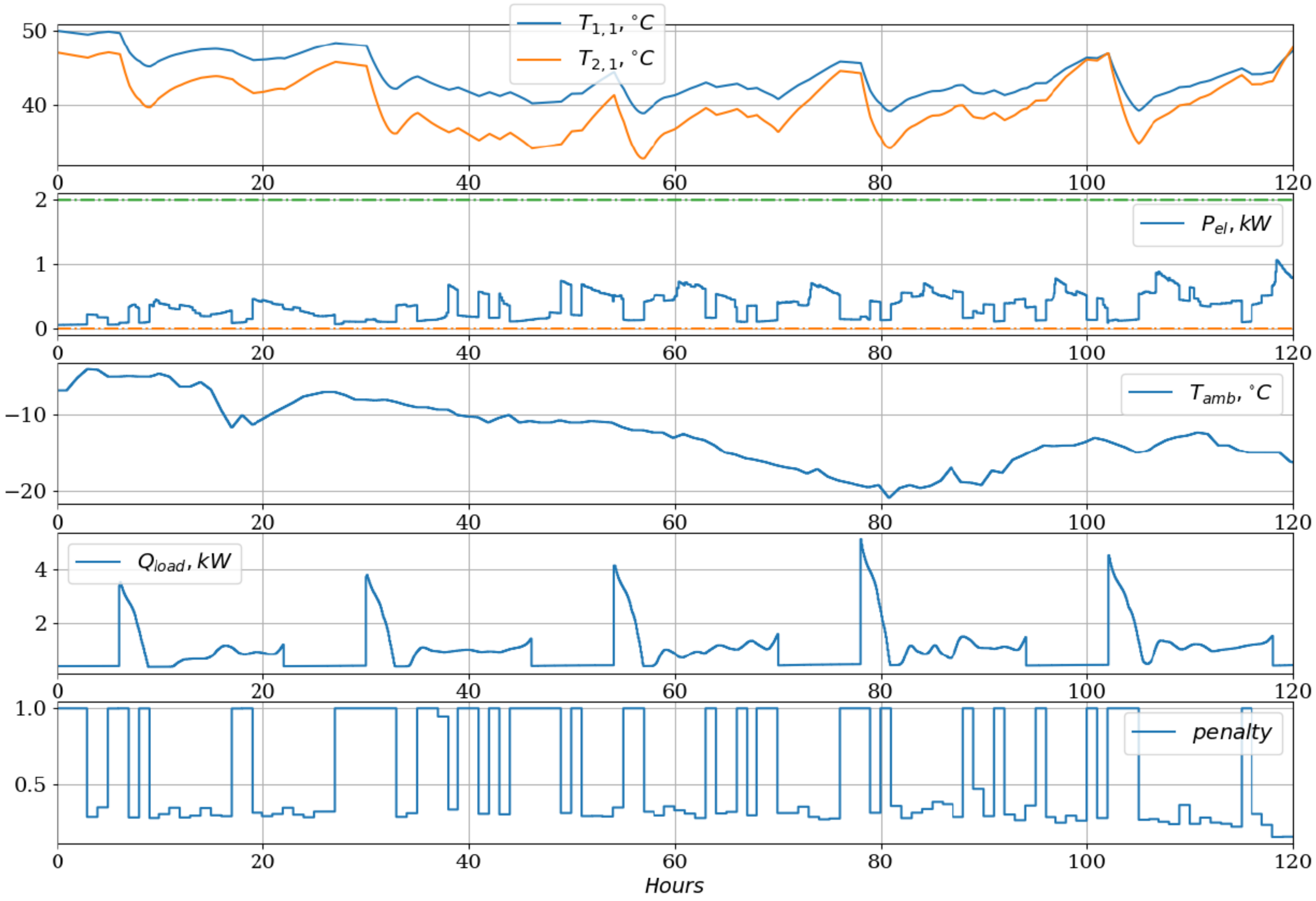
We adopt a control-based approach where the **price** becomes the driver to **manipulate** the behaviour of a certain pool flexible prosumers.

Dynamic price signal generation



Example: Flexible building energy management system





Flexibility across hierarchies

- Load shift incentivization
- Hierarchies of aggregators

Demand response model

- Flexibility functions
- Time-varying (flexibility is finite)
- Real-time data assimilation

Dynamic energy prices

- Day-ahead prices
- Real-time price adjustments

Thank you