Flexibility concepts in practice; case study on water towers

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Introduction

- Our starting point: Many water utilities have water towers as part of their network, which can be used as energy storages.

- The main concerns for utilities are water supply and water quality, and NOT power gird stability.

- The power consumption of the individual pumping stations is small, typically < 50 KW for the majority of the utilities.

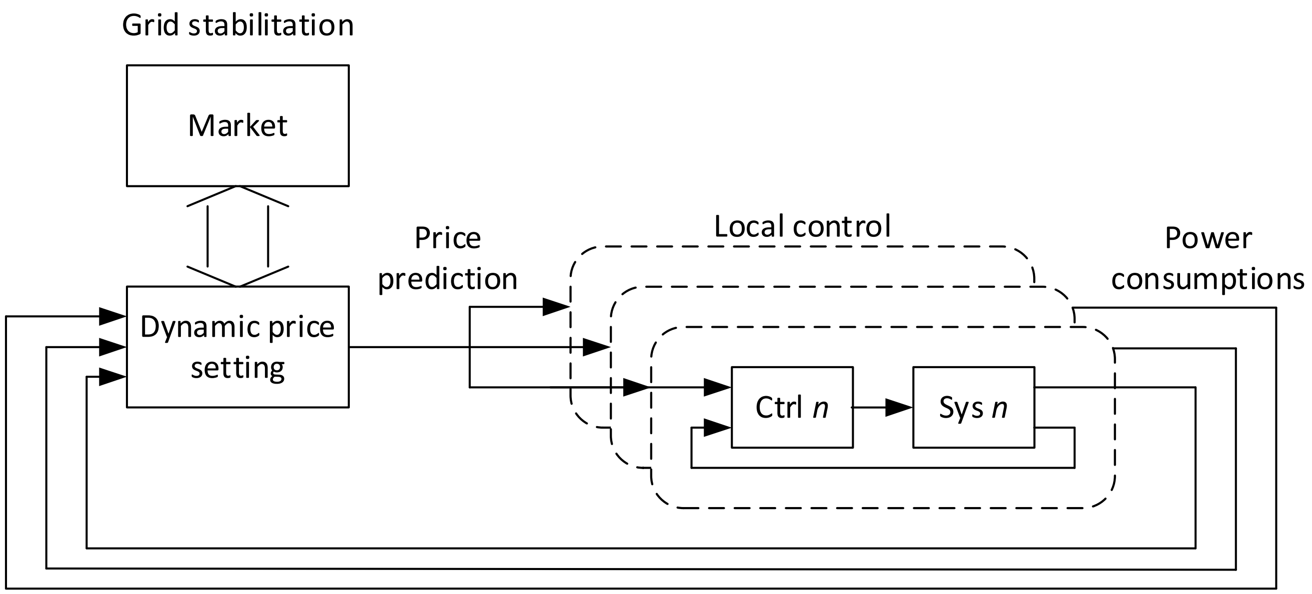
- Installation and cost of operating the system is of major concern, and the energy cost is not dominant.

- These statements indicate that an automated system that secures local system requirements, and make it easy to enter the energy marked is necessary.

Introduction

- Requirements:
  1) Automated prediction of the system dynamics and optimization to local requirements, and
  2) automated optimization towards dynamic power prices.

- Basic idea:
  1) Introduce optimal control with auto-tuning features,
  2) optimize the operation towards electrical prices, and
  3) setup automated price handling towards the power grid.



Outlines

- Auto-commissioning and MPC for water distribution networks.
- Relation between Local control and grid stability.
- Flexibility function.
- Bidding Flexibility into Markets.
- Conclusion

Auto-commissioning and MPC for water distribution networks

Application setup

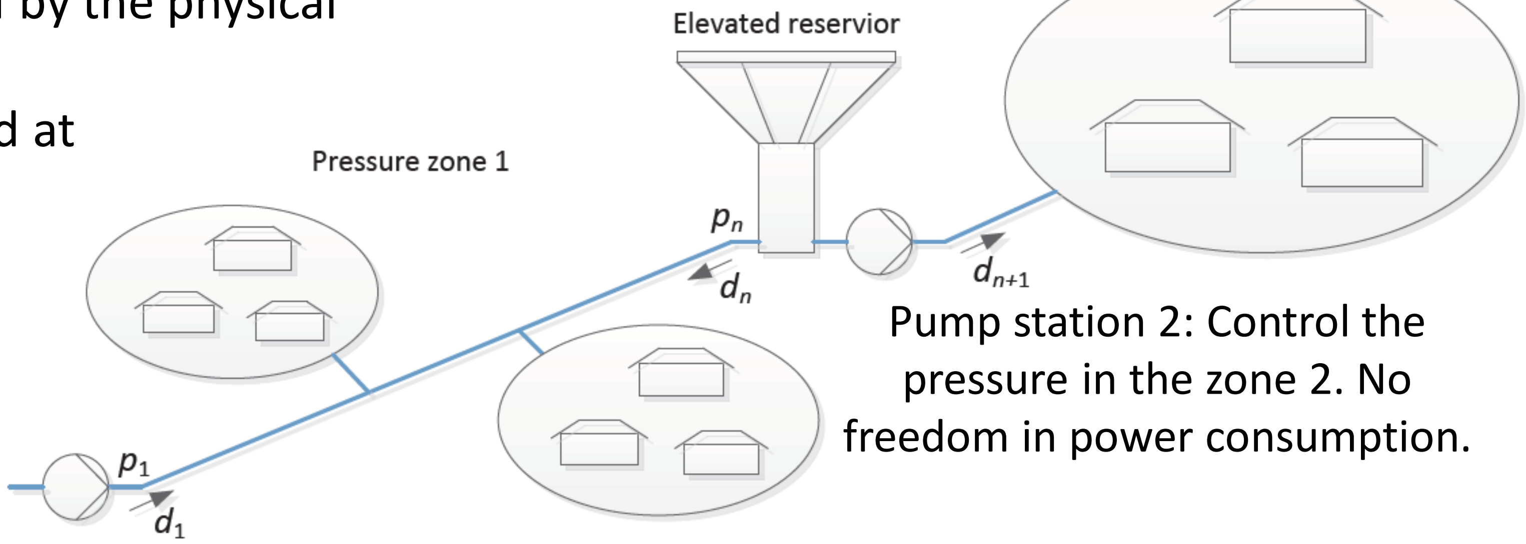
- or CO_2 level.

- Control objective: Control the pump station 1 to minimize the energy cost.

- Constraints:
  - The level in the water tower must be maintained within certain limits.
  - The pumping station flow is limited by the physical constraints of the pumps.
  - Water quality should be maintained at all times (water age).

- Disturbances:
  - Water consumption in zone 1 and zone 2.

Water tower: Adds an energy storage to the system.



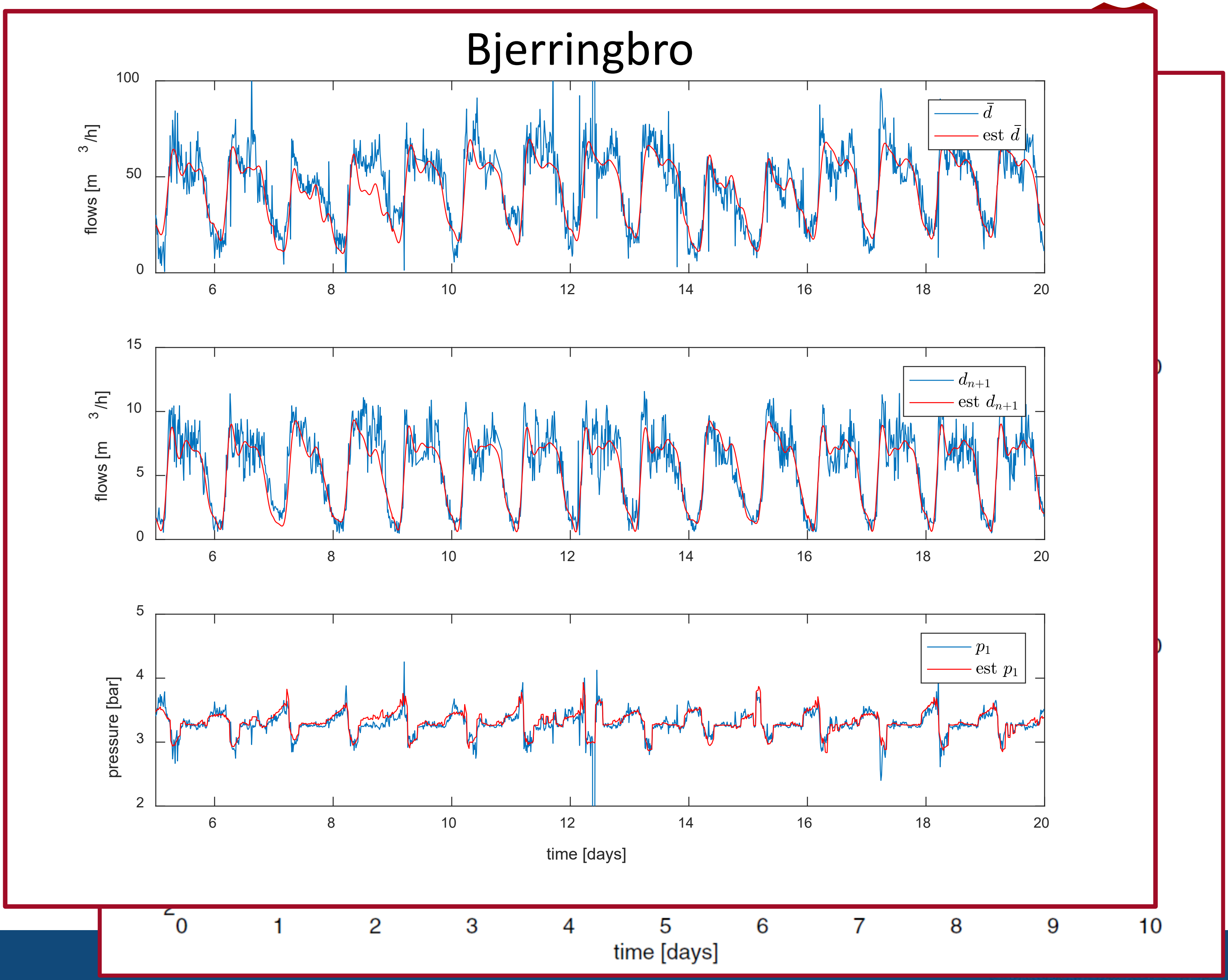
Pump station 2: Control the pressure in the zone 2. No freedom in power consumption.

Pump station 1: Supplying zone 1 and the water tower.

Auto-commissioning and MPC for water distribution networks

Disturbance prediction

- Models for predicting disturbances and system dynamics, from historical data.
- Results from numerical tests with artificial consumptions (Kallesøe et al., IFAC2017).
- Results from offline test with data from Bjerringbro.

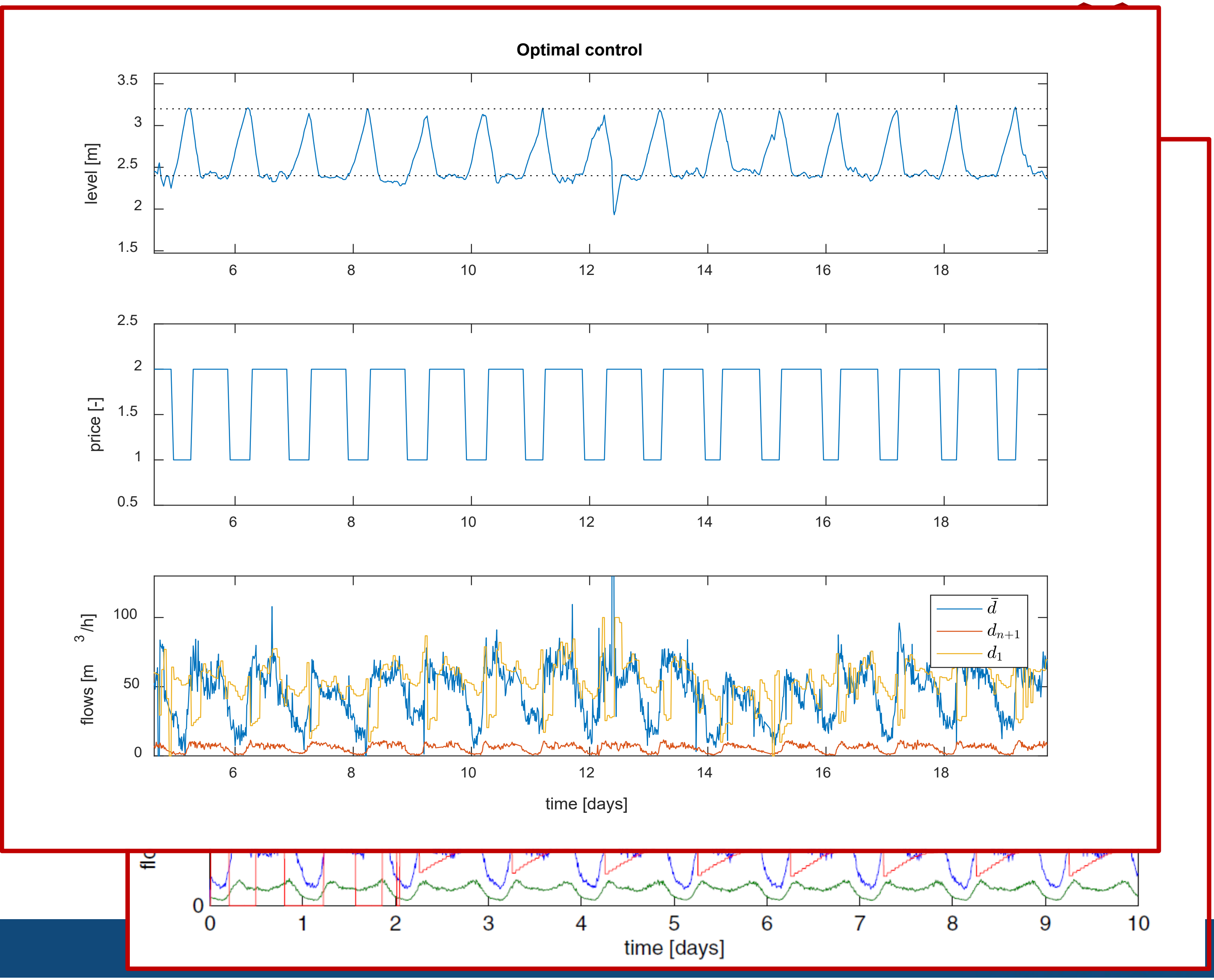


Auto-commissioning and MPC for water distribution networks

DTU

Optimal control

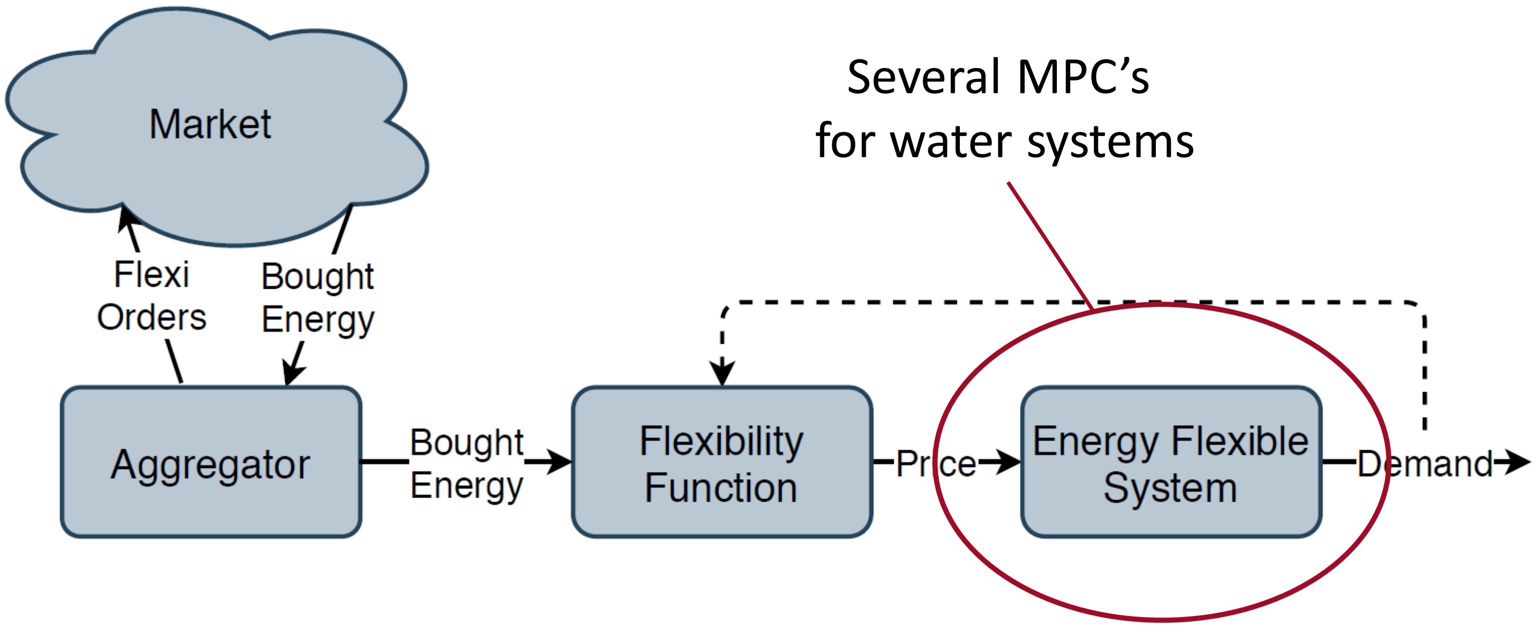
- Planning tool for deciding when to pump.
- Fill reservoir when the price is low (Periodic price to illustrate the behaviour).
- Results from numerical tests with artificial consumptions. (Kallesøe et al., IFAC2017).
- Results from numerical test using consumption data from Bjerringbro.



Relation between Local control and grid stability

Price prediction

- We can control the system, handling the concerns of the water utilities.
- We can optimize the operation to a known price profile 24h forward in time.
- Unfortunately, the actual electrical price is decided on the fly.
- Aggregation makes it possible to for small energy user to be part of stabilizing the power grid.
- How to handle price setting towards the market is the topic of the remain of this talk.



Grid balancing trough the power marked is handled globally.

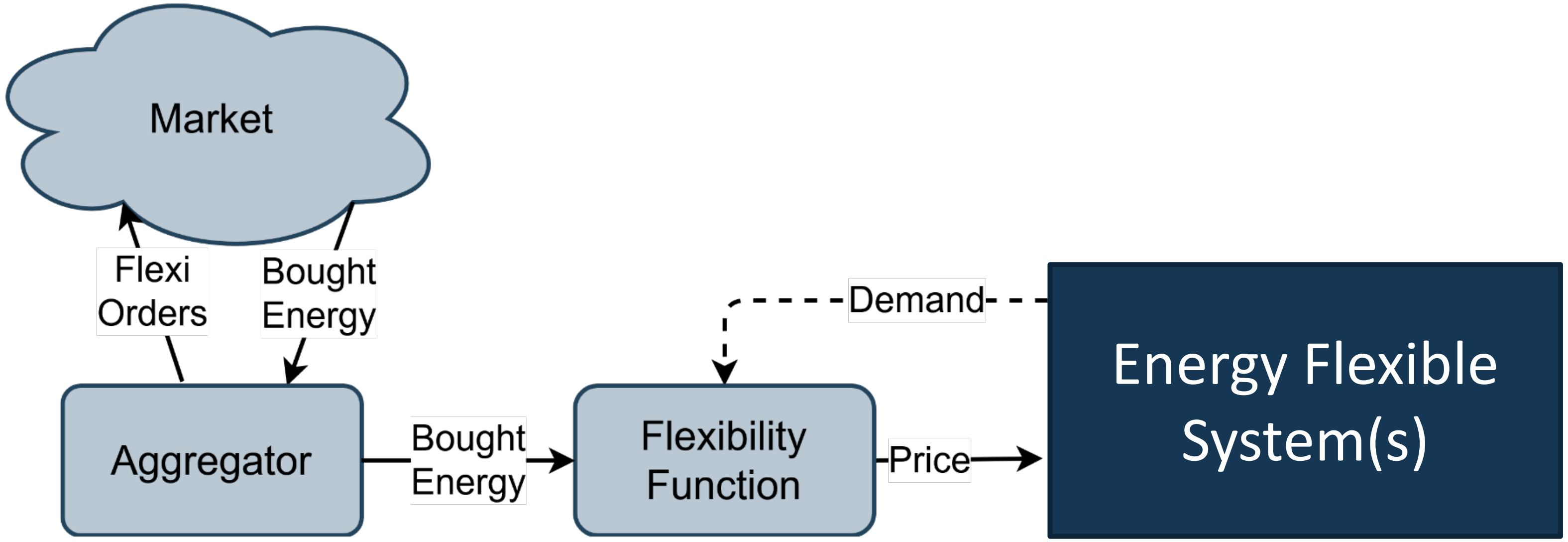
Local control is handled locally.

Flexibility Function

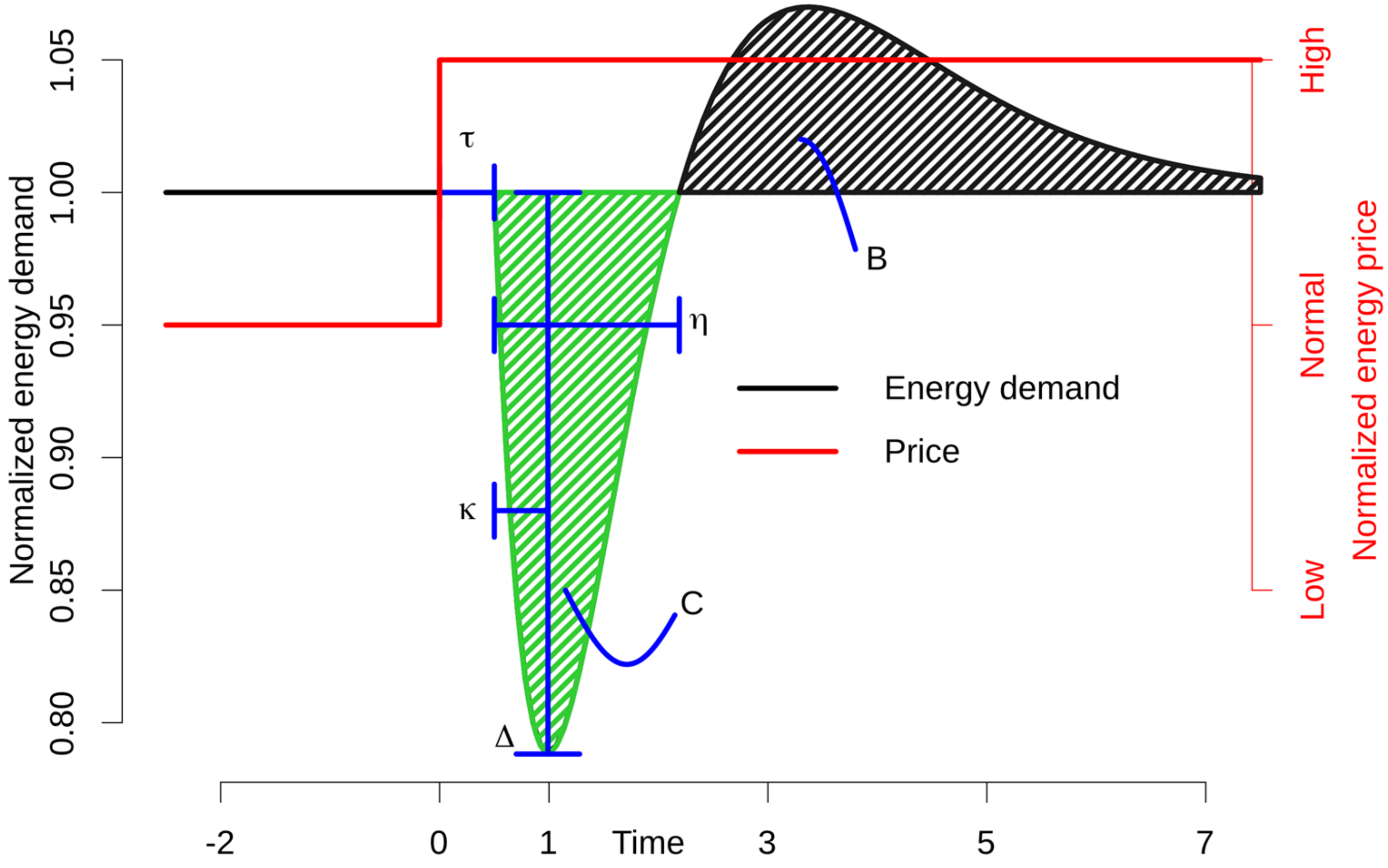
- Input: Price
- Output: Demand

- Estimate relation: Flexibility Function!

- Use Flexibility Function to design price signals.



Flexibility Function: General Reponse

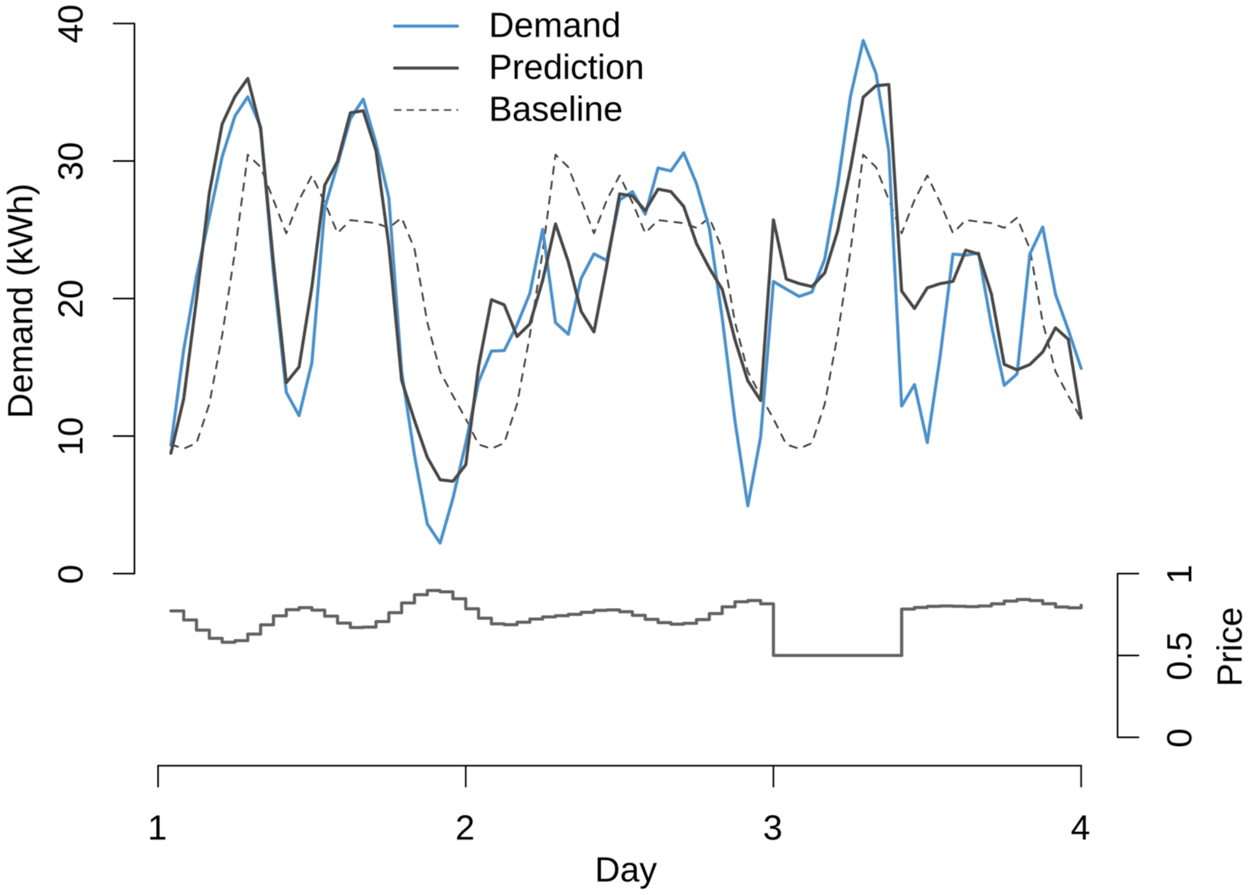


Flexibility Function: Equations

$$
\begin{aligned}
\mathrm{d}X_t &= \frac{1}{C}(D_t - B_t)\mathrm{d}t + X_t(1 - X_t)\sigma_X \mathrm{d}W_t \\
\delta_t &= f(X_t; \alpha) + g(\lambda_{t-\tau}; \beta) \\
D_t &= B_t + \delta_t \Delta \left(\mathbb{1}(\delta_t > 0)(1 - B_t) \; + \mathbb{1}(\delta_t < 0) B_t \right) \\
Y_t &= D_t + \sigma_Y \epsilon_t
\end{aligned}
$$

Flexibility Function: Accuracy

- Accurate several days ahead.
- We need only 24 hour predictions.

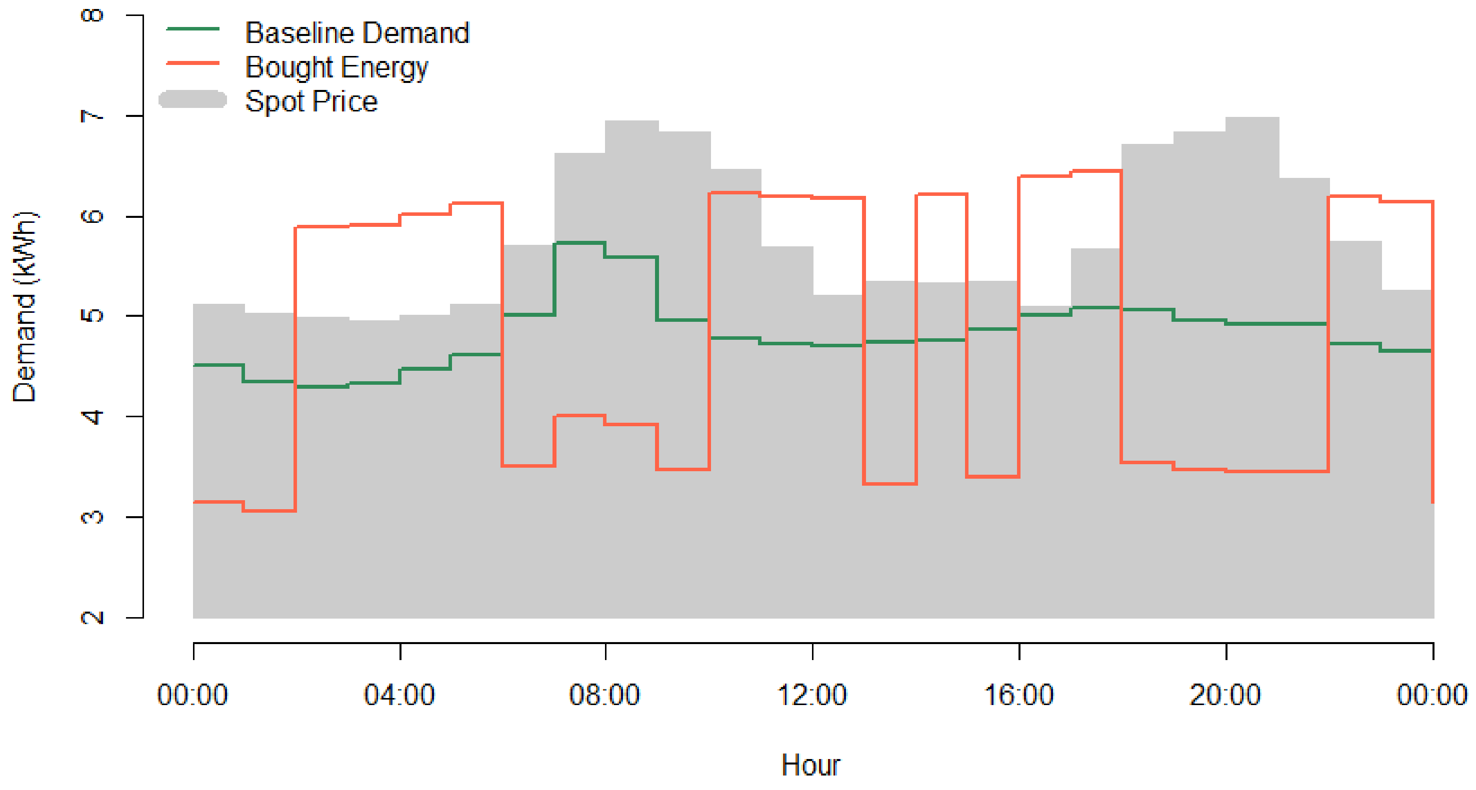


Bidding Flexibility into Markets

- Flexi orders consists of an **interval**, an amount of **energy**, and a **duration**.
- For example, **interval**: 08:00 – 12:00, **energy**: 1 MWh, **duration**: 2 hours.
- Result: 1 MWh bought in the 2 cheapest hours between 08:00 and 12:00.
- Can be combined with regular spot market bids to obtain part flexibility

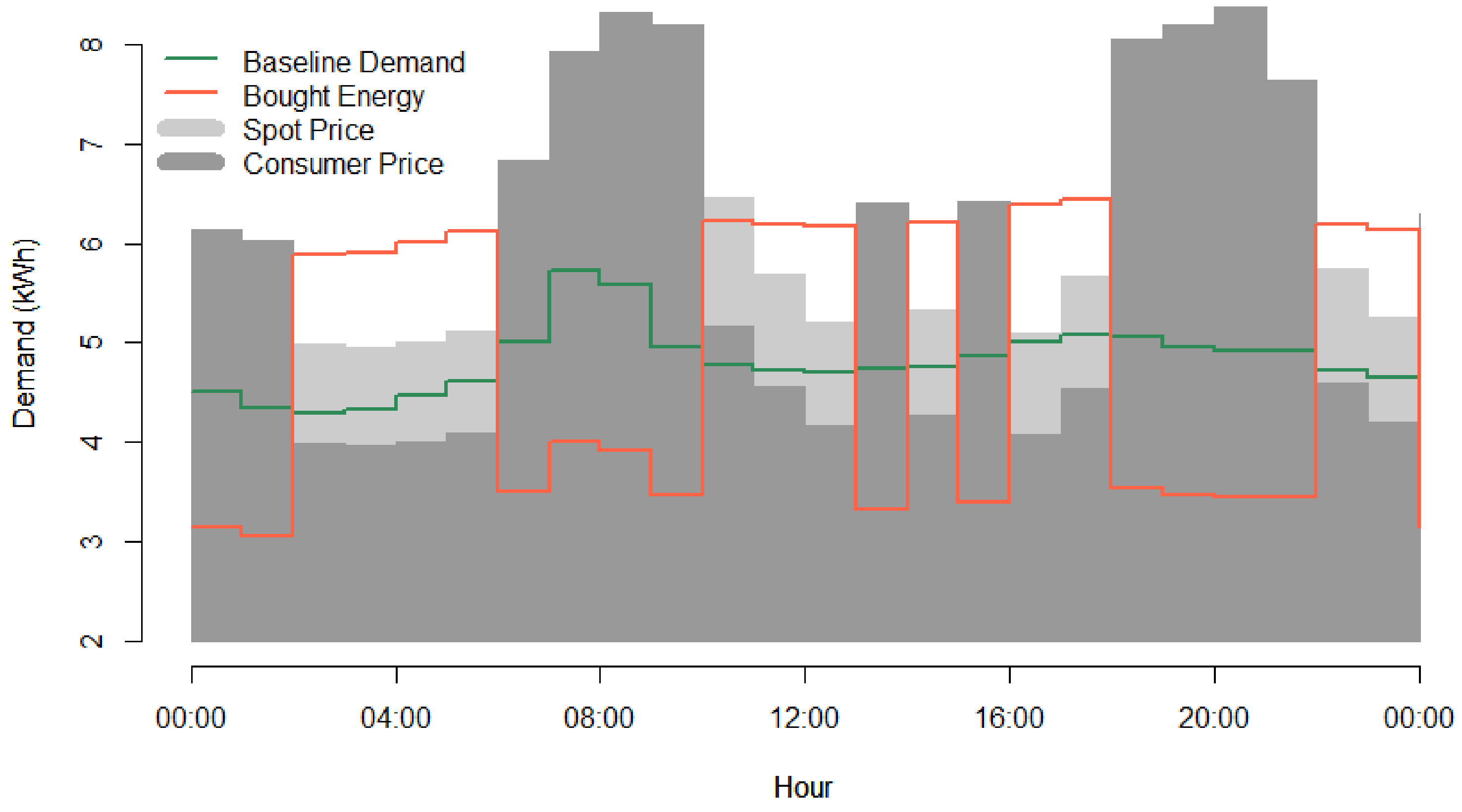
Bidding Flexibility into Markets

- 4 hours intervals consisting of 30% of consumption with durations of 2 hours:



Bidding Flexibility into Markets

Solve FF(Price)=Bought Energy:



Results

- For one year of current market conditions 4.1% of the costs can be saved.
- With perfect foresight of spot prices and demand 5.4% could be saved – often assumed by other researchers.

Strategy	Costs $\left(\frac{\text{EUR}}{\text{year}}\right)$	Price $\left(\frac{\text{EUR}}{\text{MWh}}\right)$	Energy $\left(\frac{\text{MWh}}{\text{year}}\right)$
Baseline	44457	65.2	682
Flexible	42627 (-4.1%)	62.0 (-4.8%)	687 (+0.75 %)
Potential	42070 (-5.4%)	61.6 (-5.4%)	683 (+0.05%)