A quantitative analysis of the effect of flexible loads on reserve markets

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Outline

Introduction

Electricity is a **complex** commodity.

- **Few** possibilities of **storage**.
- Every **second**, **production** must **equal consumption**.
- Ensured in practice by the following steps:
  1. **Before real-time**, actors trade **expected quantities** and
  2. the system operator contracts **reserve** in case of mismatch.
  3. In **real-time**, the system operator ensures the **balance** by **activating the reserve**.
  4. Actors pay an **imbalance fee** proportional to their quantity of imbalance.

Historically, reserve has always been provided by production units.

Objective of the paper

Quantify the impact of the introduction of **flexible loads** in the **secondary reserve market**.

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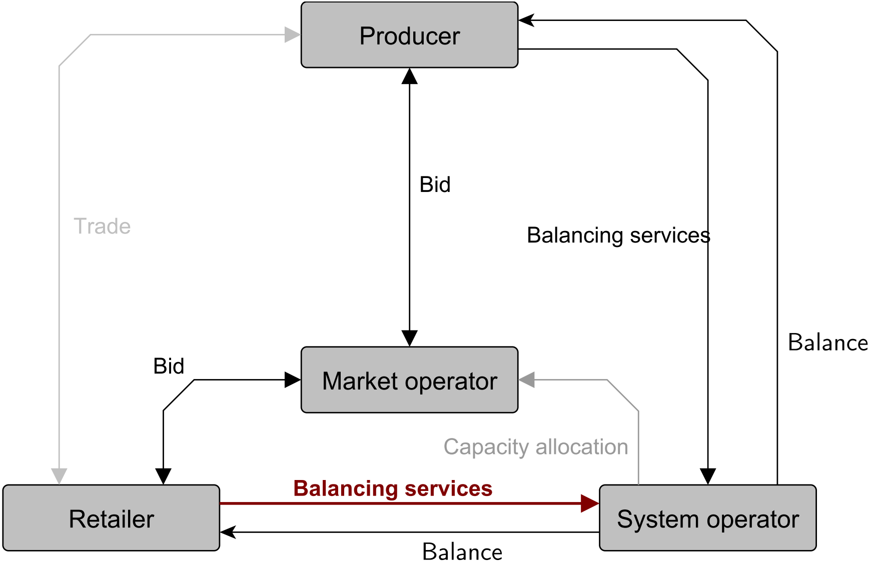
Interaction model



Agent-based modeling

Actor model

- Each actor is modeled individually in an **agent-based system** and solves its own **linear optimization problems**.
- These problems are based on a **forecast** of the different **prices**.

Hypotheses

- Each retailer and producer is responsible of its own balance.
- Energy and reserve market are **pool day-ahead markets**.
- No gaming on the costs of the submitted bids.

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Market operator

Role

- Collects **demand** and **offer** bids.
- For **each period** t, settles a **unique price**.

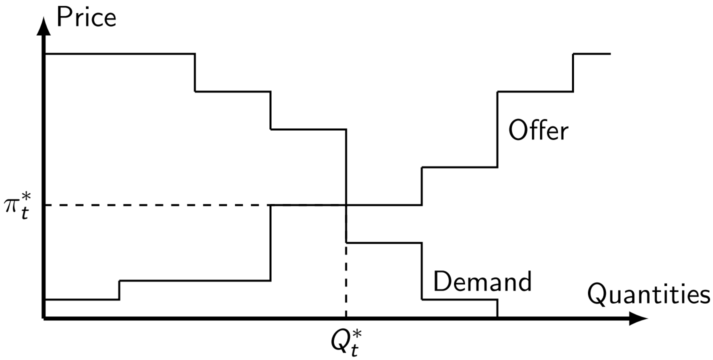

Figure: Clearing of single period market.

System operator

For each period t, ensure that the **quantity of reserve** contracted is **adequate**, in this work, at least 2% of the total consumption cleared on the day-ahead energy market.

Optimization problem

- **Data:** Flexibility offers of producers and retailers (quantities and prices).
- **Variables:** Acceptation of each offer.
- **Objective:** Minimize reserve costs.
- **Constraints:** Ensure a minimum quantity of reserve for each period .

If the **contracted** secondary reserve is **not sufficient** to restore balance, the SO may use (expensive) **non-contracted reserve**.

Retailer

The retailer is also an **aggregator**.
Part of its consumption is **static**.
Another part is **flexible**.
For these loads, there is a **trade-off** between minimizing the **energy costs** and providing **flexibility**.

Optimization problem

- **Objective:** Minimize energy costs and maximize expected revenues from flexibility.
- **Variables:** Consumption of the flexible loads in each period.
- **Data:** Forecast of the energy prices.
- **Constraints:** Utility and usage of the loads.

Bids of flexible loads for the reserve market

Unlike production, **changing** the **consumption** in one period **impacts** the consumption in the **future**.

We use a reserve **service adapted** for **flexible loads**.

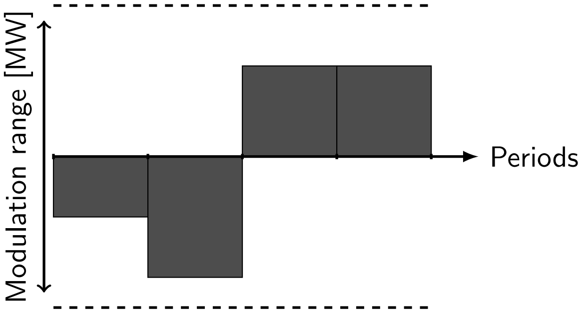

Figure: Example of usage of a secondary reserve bid of flexible load

Producer

$$\max \sum_{t=1}^{T} [\hat{\pi}_t^E P_t - (\pi^{cap} + \hat{\pi}_t^E) \max\{0, P_t^{\min} - P_t\}$$
$$- \hat{\pi}_t^{I+} I_t^+ - (\pi^{nc} - \hat{\pi}^{I+}) \max\{0, I_t^+ - I_t^{+\max}\}$$
$$- \hat{\pi}_t^{I-} I_t^- - (\pi^{nc} - \hat{\pi}^{I-}) \max\{0, I_t^- - I_t^{-\max}\}$$
$$+ \epsilon U_t + \epsilon L_t - \sum_i c_{i,t} p_{i,t}] \quad (1)$$

subject to, for $t \in \{1, ..., T\}$, for each production unit i:

$$p_{i,t} + u_{i,t} \leq p_{i,t}^{\max} \qquad (u_{i,t} \geq 0) \quad (2)$$
$$p_{i,t}^{\min} \leq p_{i,t} - l_{i,t} \qquad (l_{i,t} \geq 0) \quad (3)$$
$$(p_{i,t} + u_{i,t}) - p_{i,t-1} \leq \rho_i^u \quad (4)$$
$$p_{i,t-1} - (p_{i,t} - l_{i,t}) \leq \rho_i^d \quad (5)$$

$\forall t \in \{1, ..., T\}$:

$$P_t + I_t^+ - I_t^- = \sum_i p_{i,t} \quad (6)$$
$$U_t = \sum_i u_{i,t}, L_t = \sum_i l_{i,t} \quad (7)$$

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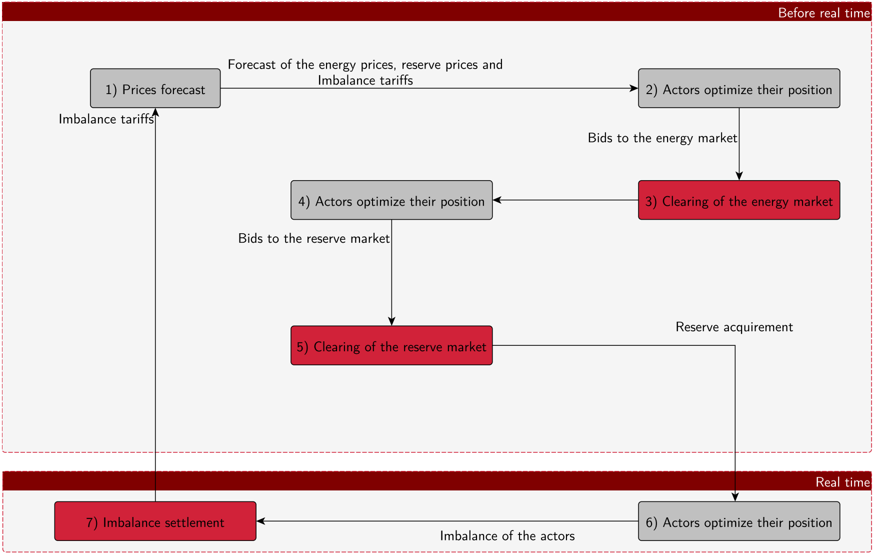
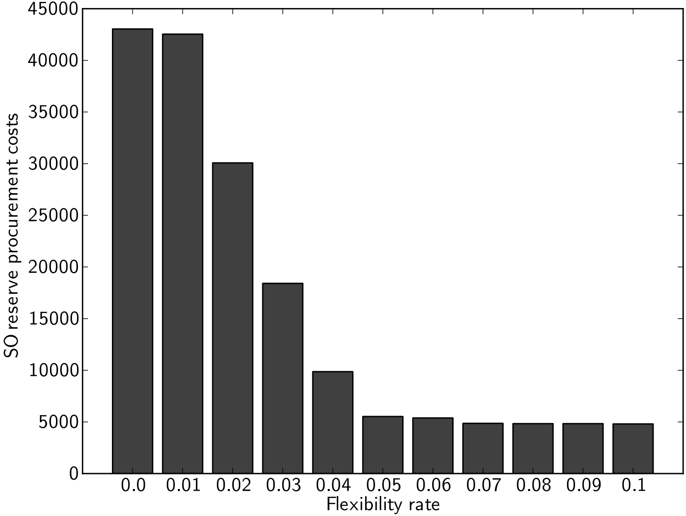
General view of the simulated system

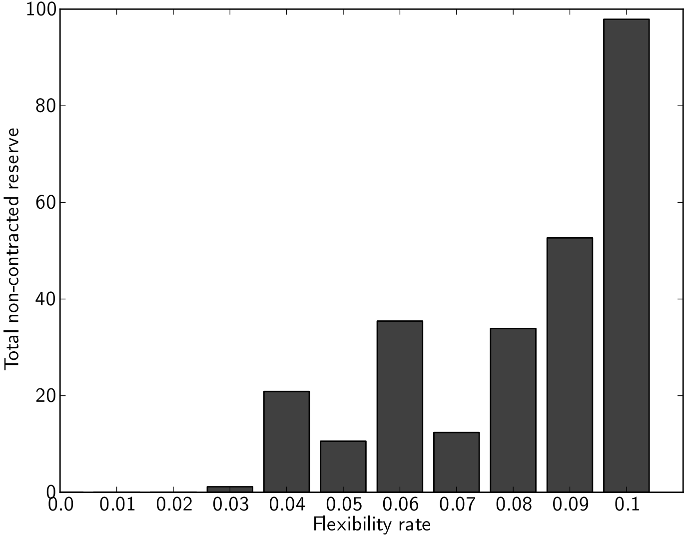


Results - System operator procurement costs in €



$$\text{flexibility rate} = \frac{\text{flexible consumption}}{\text{overall consumption}}$$

Results - Total non-contracted reserve used in MWh



At most 1% of the total consumption in the system.

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Conclusion

We use an **agent-based** method to simulate each actor individually using **optimization problems**.

Introducing **loads flexibility** in the reserve market may **decrease** drastically the **costs for reserve procurement**.

Future work

- Use the method for **different market models**. For instance:
  - Include energy constrained bids in the energy market.
  - Use market-based capacity prices for the reserve procurement instead of regulated ones.
- Extend the analysis to the provision of services to solve **congestion** or over-voltage problems in **distribution networks**.