Control-based Ancillary Services Provision from the Flexibility of Electricity Customers

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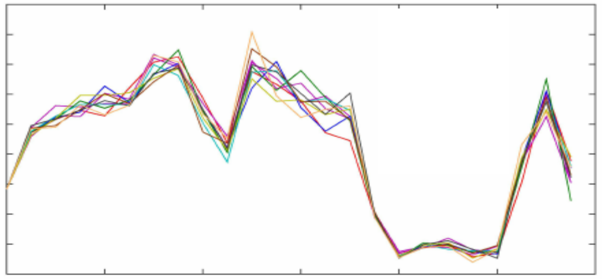
Outline

- Motivations
- Coordinating flexible resources: AS.4.0
- Study case
- Results
- Conclusions

The electricity supply service
Challenges introduced by RES

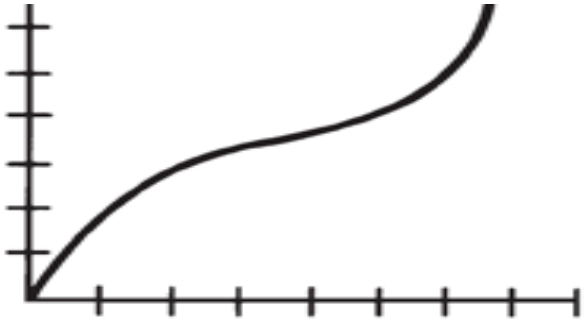
Adding RES to the generation portfolio affects the quality of service and power system operation because of:

Stochasticity



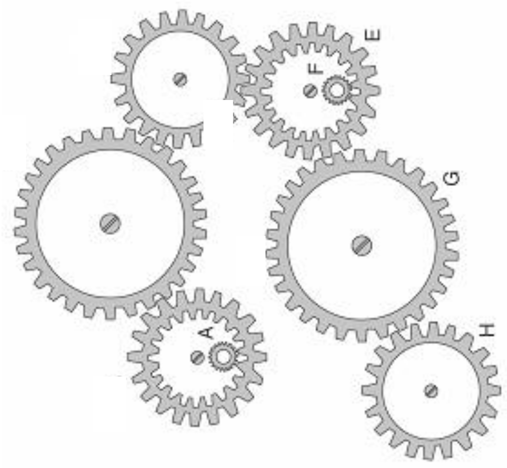
The generation from RES **cannot be planned** in the same way as conventional power plants.

Non-linearity



The generation can follow a **non-linear trend** in spite of the linear bidding and clearing process.

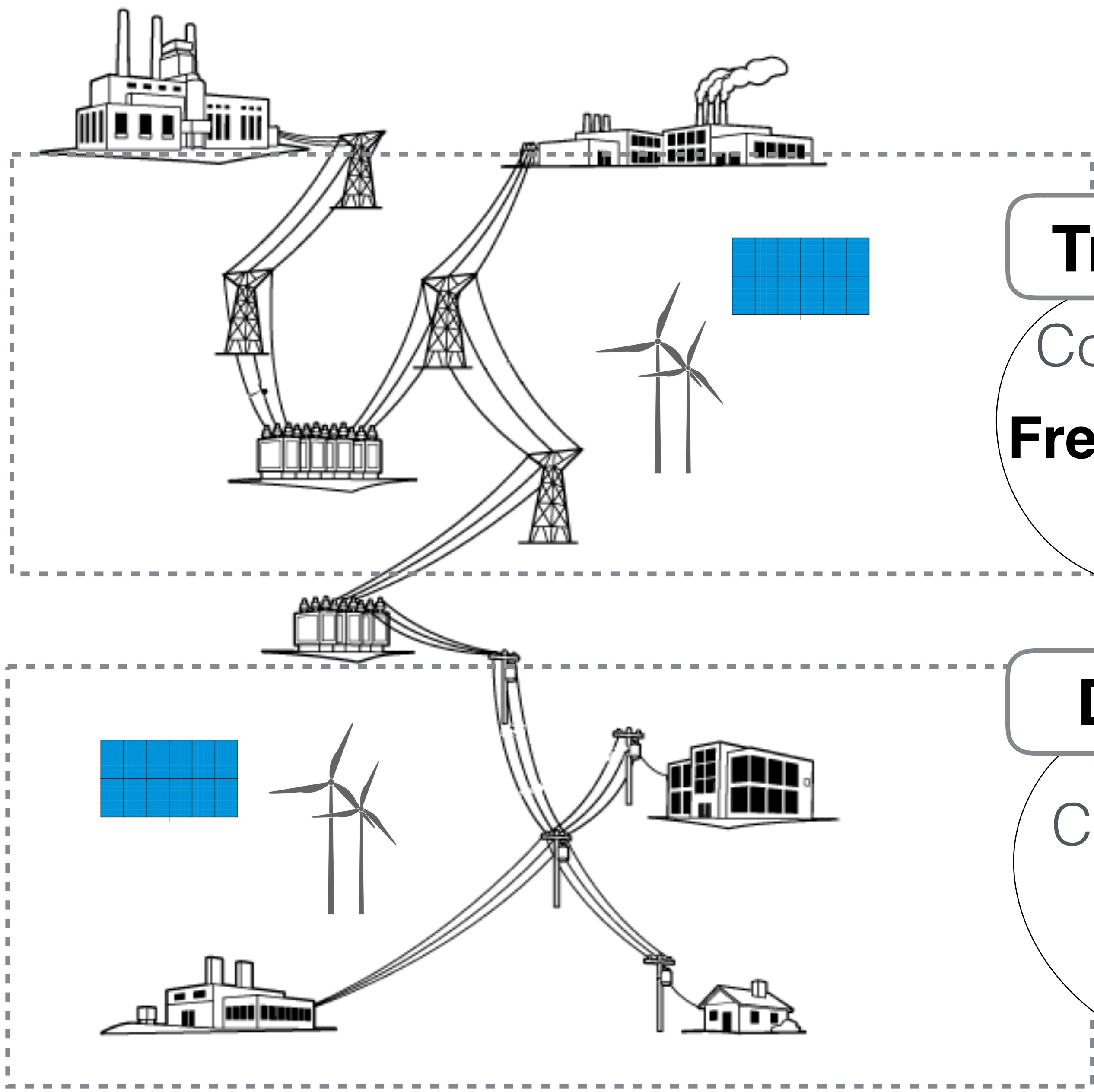
Dynamics



Voltage and **frequency** levels **fluctuate** due to the power imbalance.

The electricity supply service
Consequences for the AS

This situation is particularly affecting the provision of the ancillary services:



Transmission

Congestion management

Frequency management

Distribution

Congestion management

Voltage management

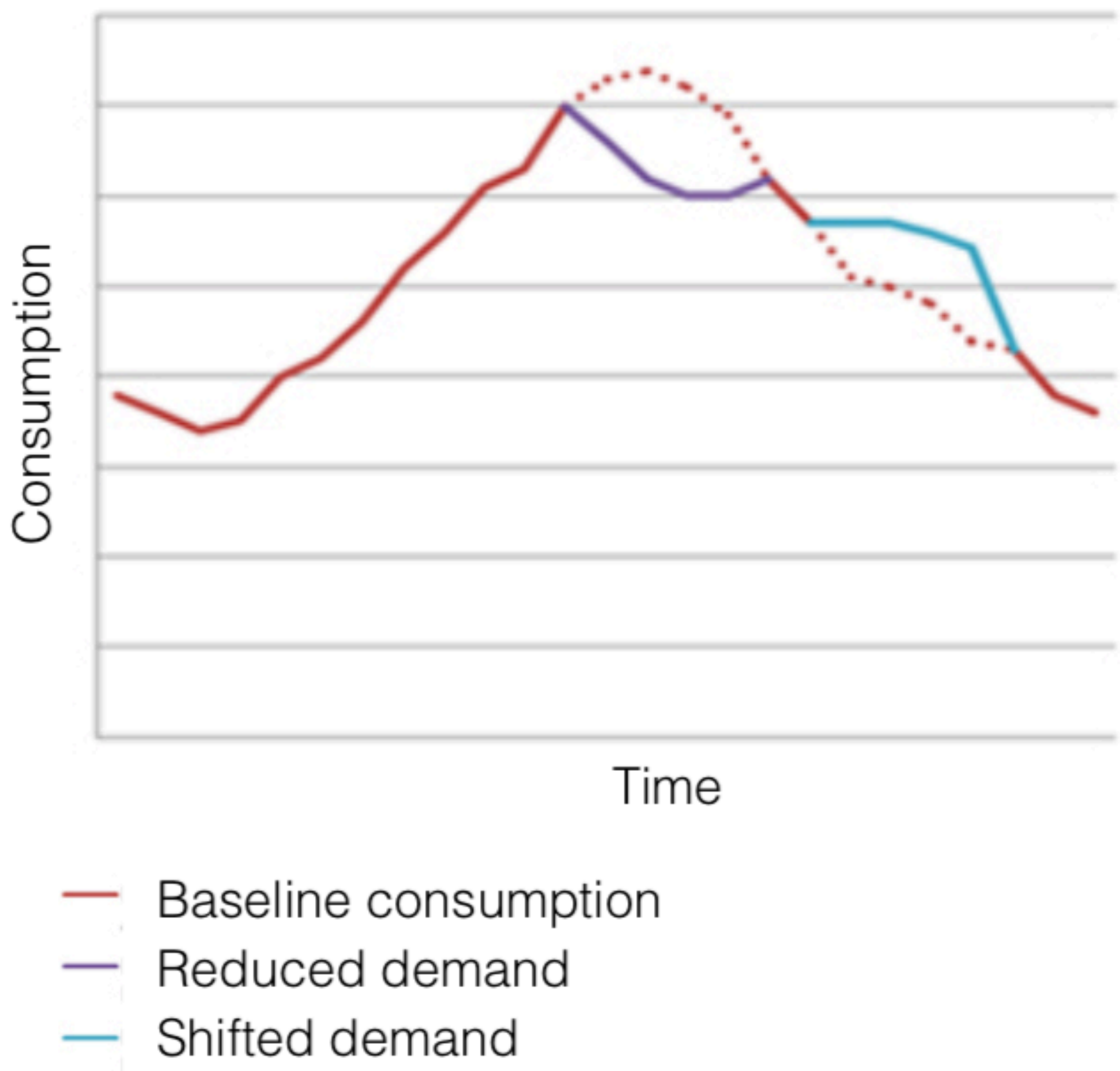
Balancing

The electricity supply service
Exploiting the energy flexibility

Flexible resources

Flexible loads, energy storage and generation are able to **adapt** their **behaviour** according to the **necessity** of the grid.

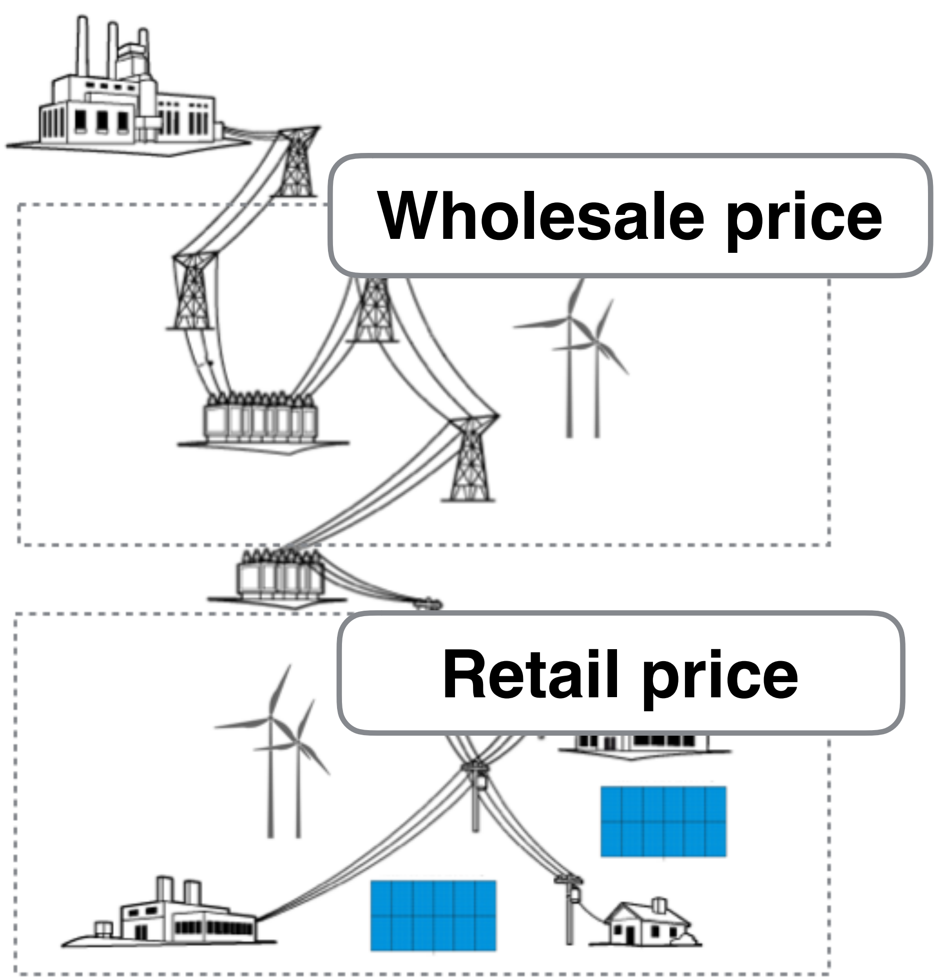
They need to be **coordinated** in a **fast** and **efficient** manner in order to be valuable.

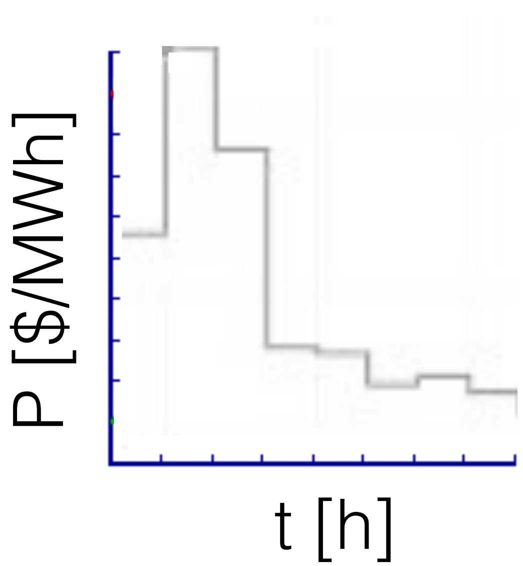


The electricity supply service

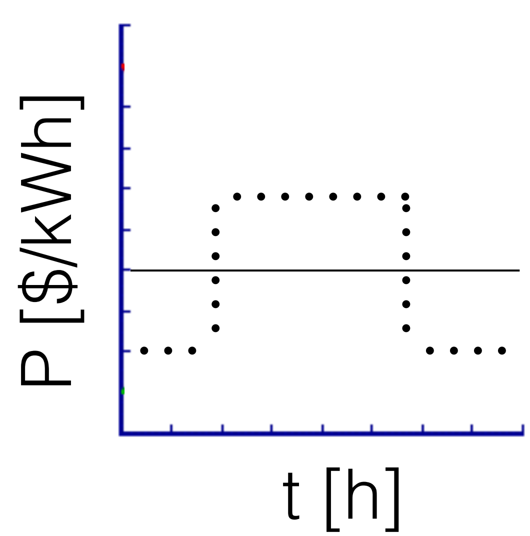
The electricity price

The submission of **time-varying electricity prices** can support the exploitation of the **price responsiveness** for **flexible** energy resources.





Nowadays, the **wholesale** electricity price is **flexible** and **changes** sub- hourly through a market and clearing process.

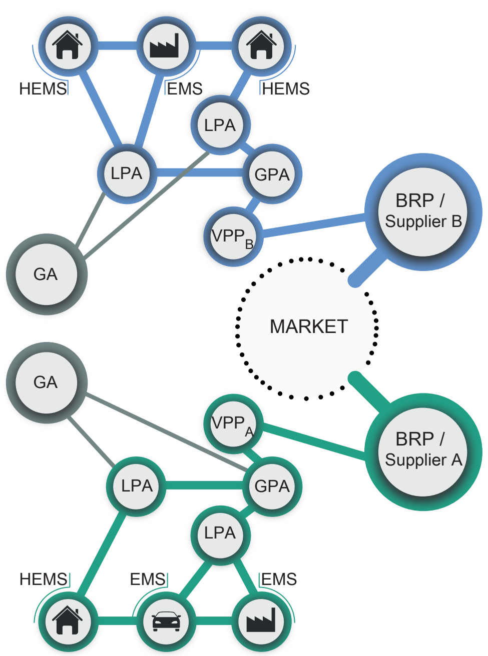


However, the **retail** electricity price is **fixed** by the **utility** and **does not change over time.**

The electricity supply service
Engaging the energy flexibility

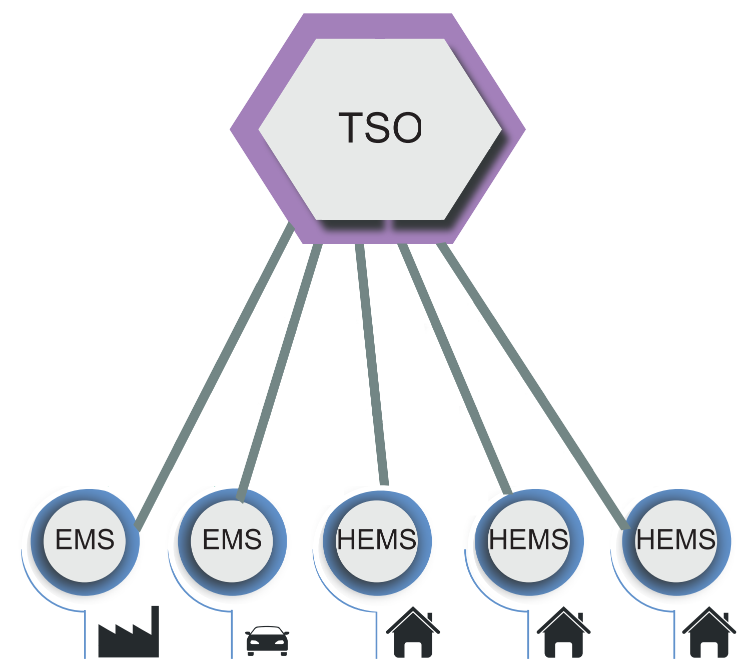
In order to coordinate the energy flexibility, it is important to develop an **approach** that can handle stochasticity, dynamics and non linearity in a **fast, secure** and **scalable** manner.

Two-way communication



Transactive energy exploits a feedback to know the reaction of the consumers to prices. It requires **significant infrastructure** and might perform **slowly**.

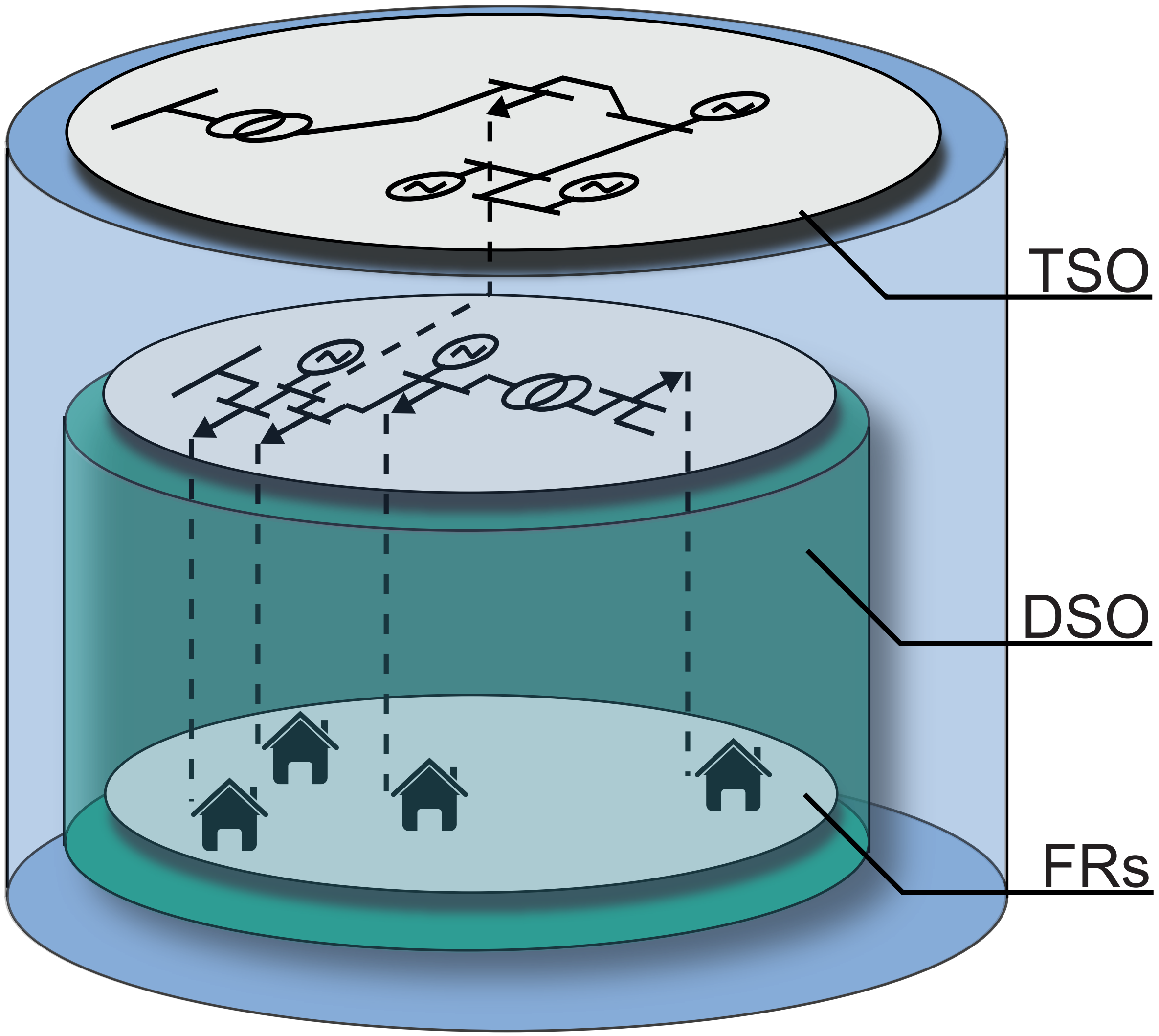
One-way communication

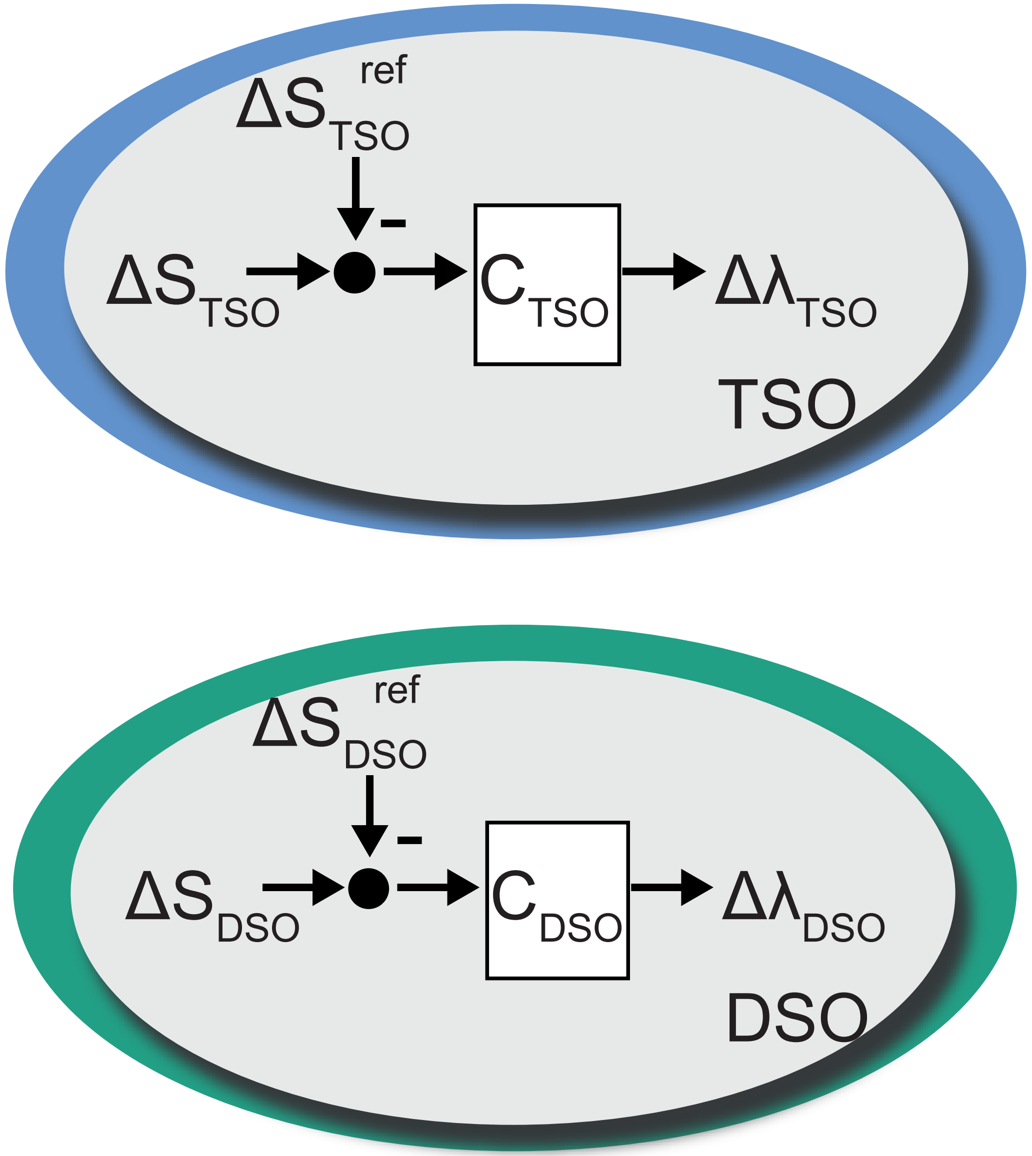


A one-way communication fastens the process, however it is fundamental to **understand** the **consumers' behaviour** and their **price response**.

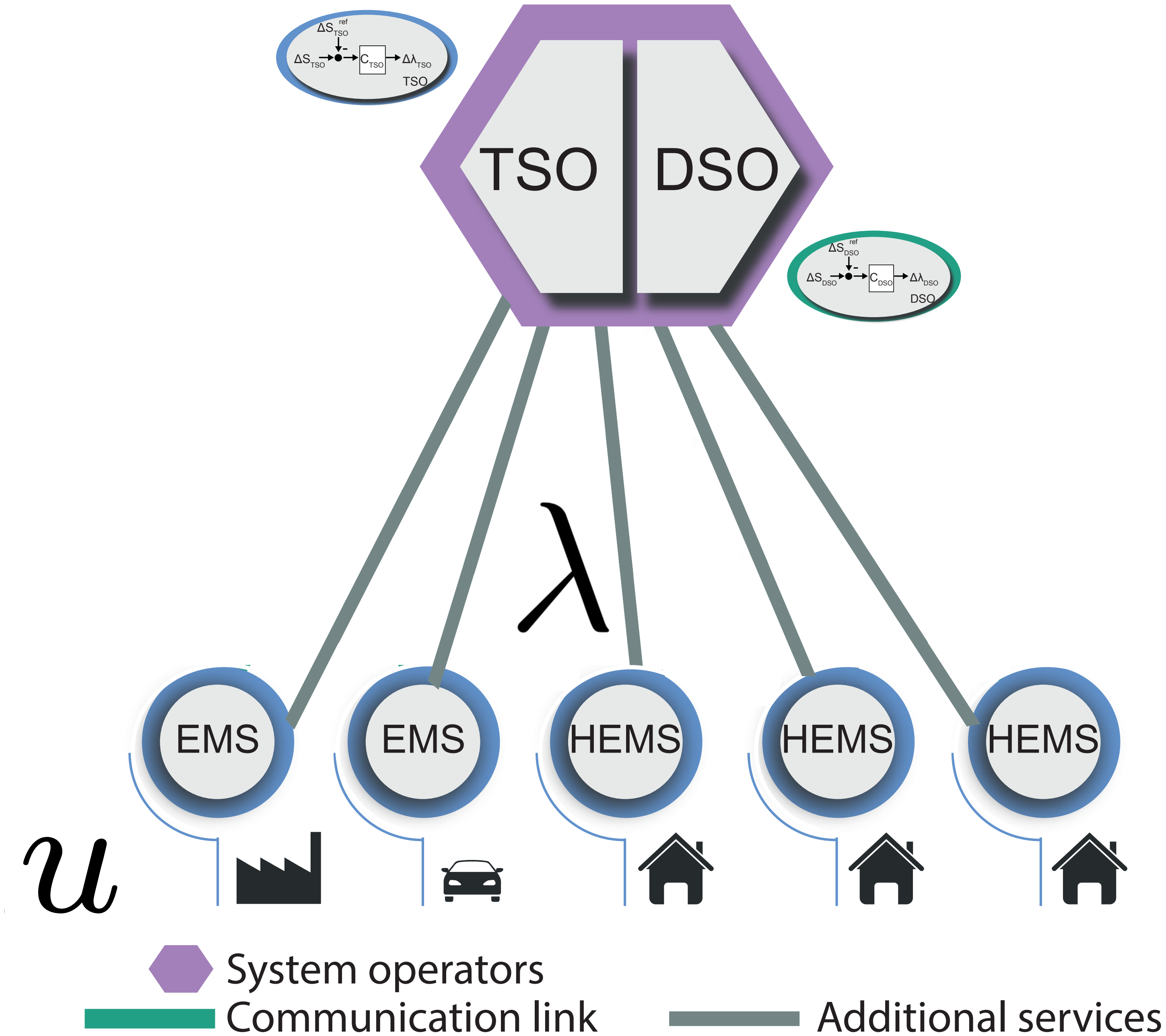
Coordinating flexible resources
AS4.0: Concept

What if system operators could formulate **real-time varying prices** according to the flexibility needed and exploit a **one-way communication**?



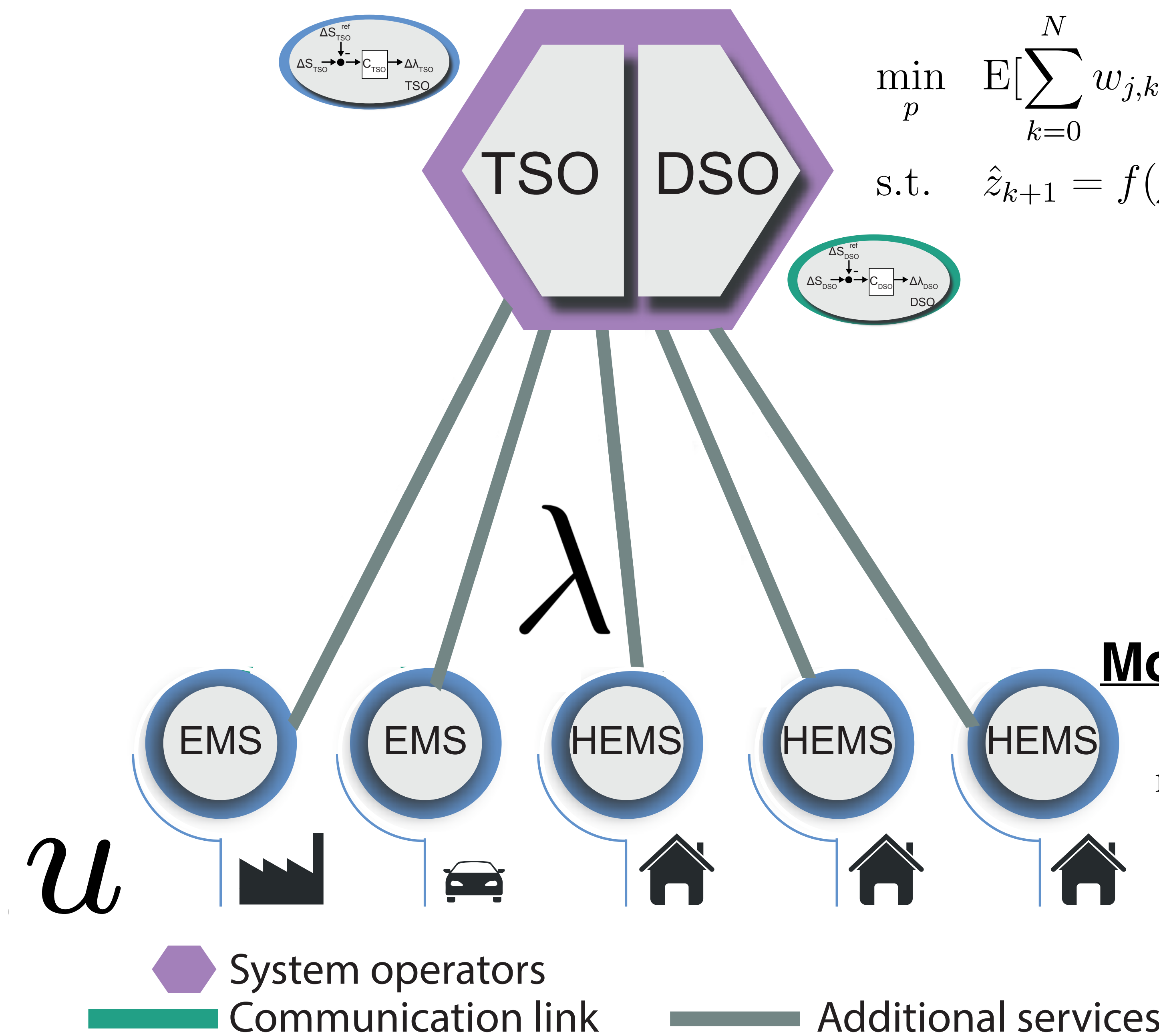


Coordinating flexible resources
AS4.0: Concept



Coordinating flexible resources

AS4.0: Concept



Control-based approach

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

Model predictive control

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

AS.4.0
Study case

In the simulations, a **two-area LFC** is adopted to model the reaction of the transmission system.

For the distribution system, we use **33-bus power flow** (3.7 MW) from MathPower in Matlab. The buses of the system are divided into **two clusters**, to formulate different price signals according to the local operational issue.

Finally, we use data related to the **Danish consumption** for different end-users' categories from **Elforbrugspanel** (2008). The data are provided in hourly-resolution and used in the MILP model to simulate the reaction of the consumers to different prices.

A different power disturbance is injected in the system every 30 seconds.

Results

Price formulation

Artificial neural network

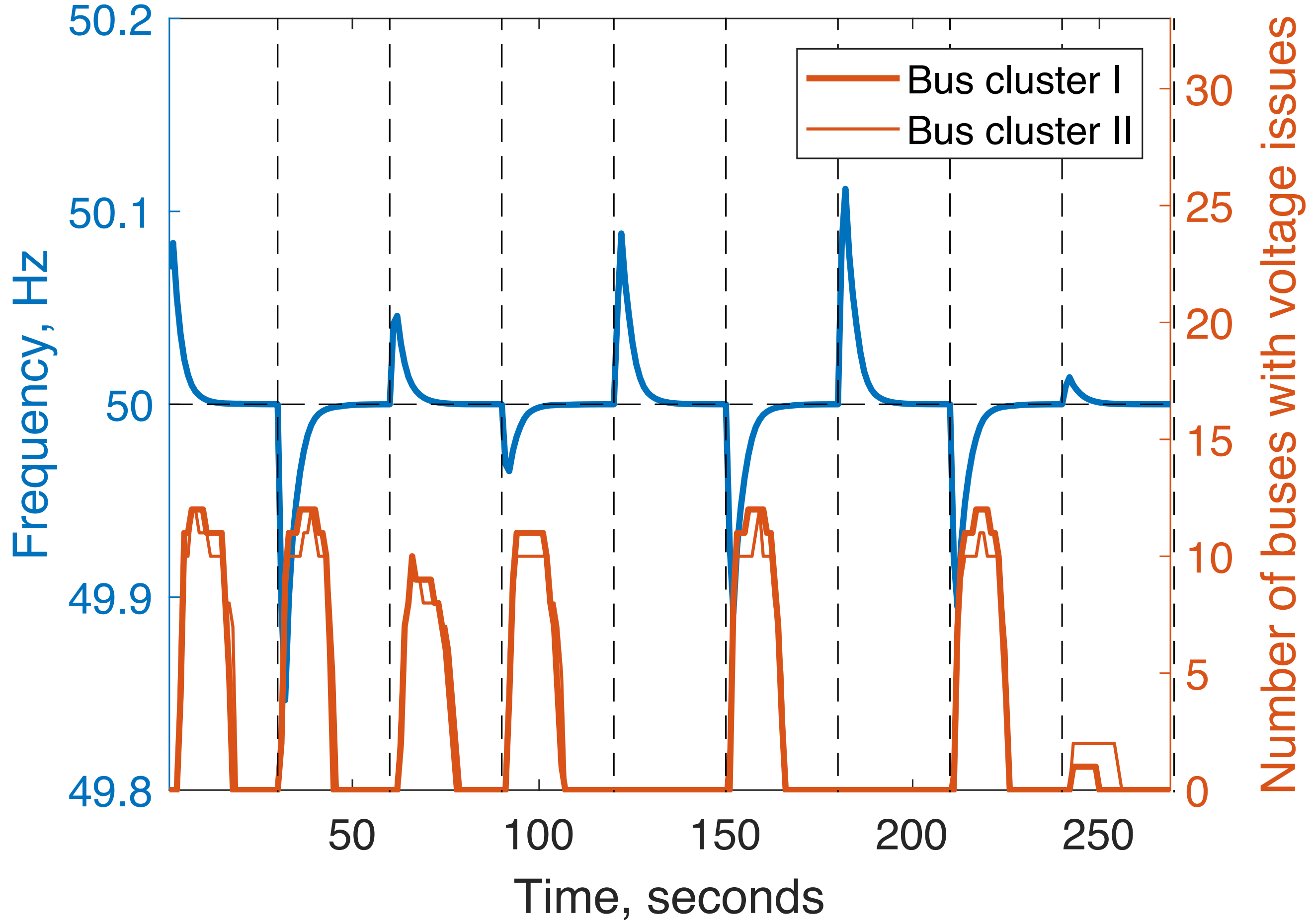
PERFORMANCE BENCHMARK BETWEEN DIFFERENT ANN MODELS.

Observations sample size	Neurons in the first layer	Training performance MSE	Training performance R	Testing performance MSE	Testing performance R
1000	10	2.53e-1	6.57e-1	2.70e-1	6.23e-1
2000	10	2.52e-1	6.57e-1	2.64e-1	6.39e-1
5000	10	2.57e-1	6.47e-1	2.61e-1	6.39e-1
1000	20	6.64e-2	9.22e-1	8.58e-2	9.01e-1
2000	20	6.98e-2	9.17e-1	7.48e-2	9.12e-1
5000	20	7.05e-2	9.17e-1	7.18e-2	9.15e-1
1000	24	1.78e-2	9.79e-1	2.32e-2	9.73e-1
2000	24	1.13e-2	9.87e-1	1.26e-2	9.85e-1
5000	24	1.15e-2	9.87e-1	1.19e-2	9.86e-1

Results

Handling operational issues

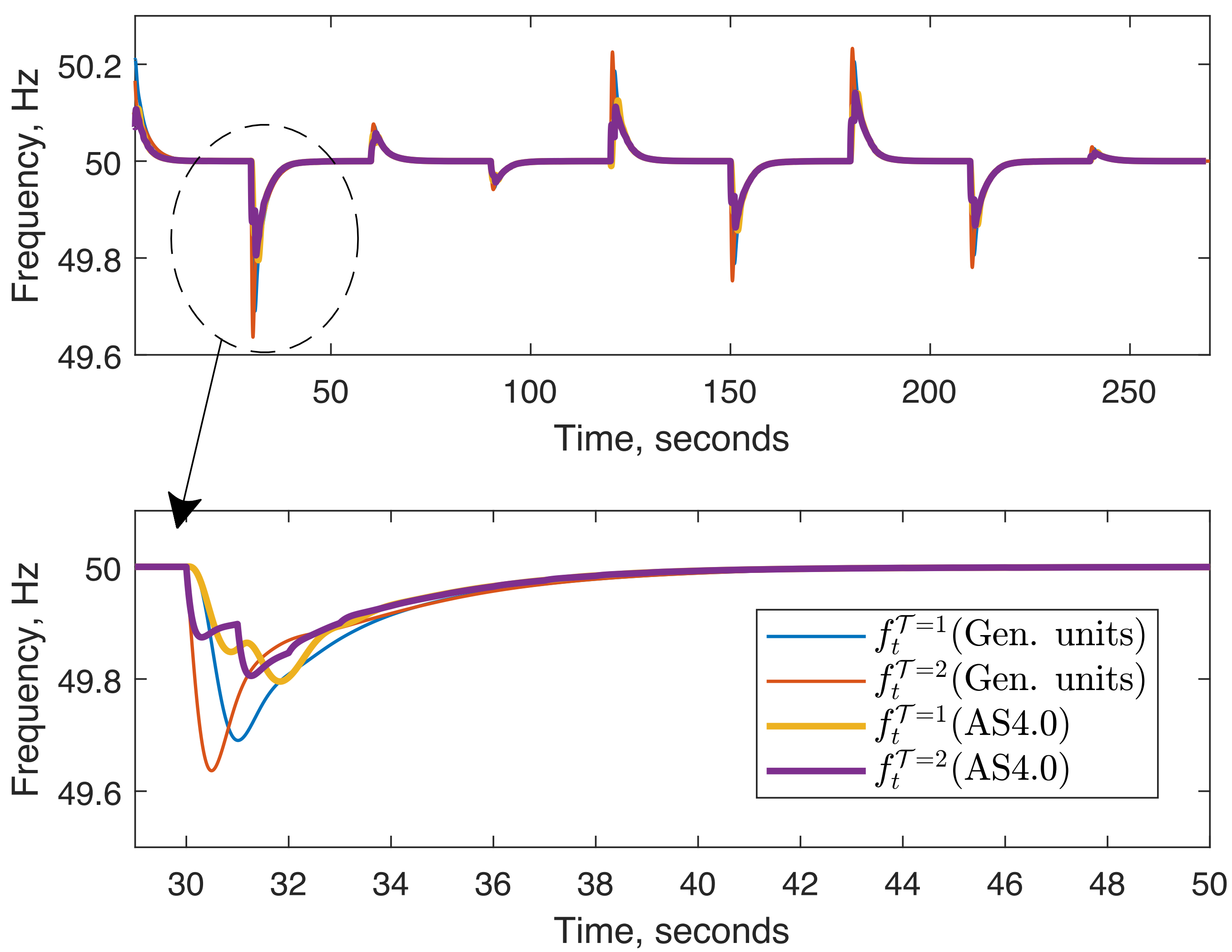
Frequency and voltage issues trend in power system



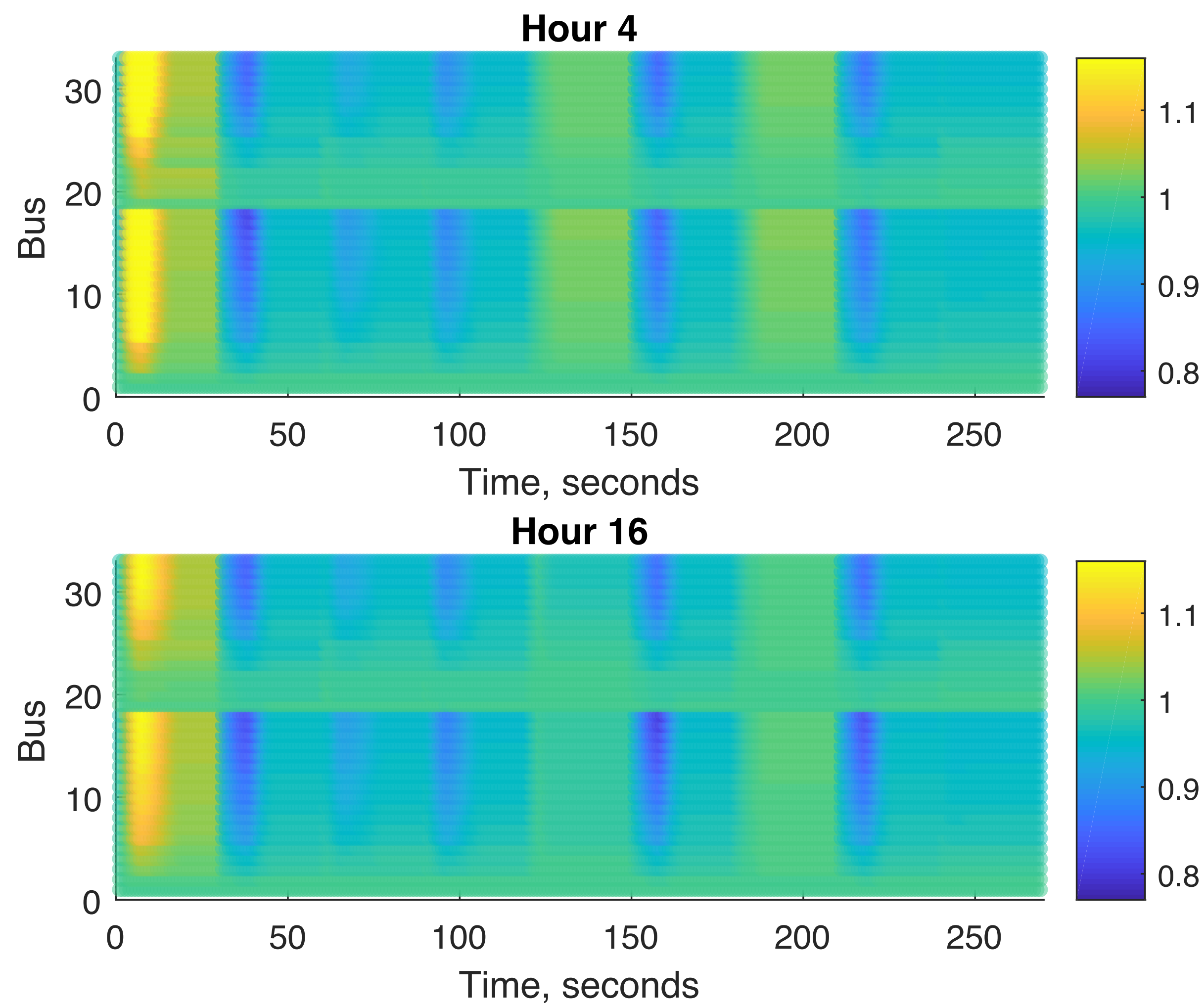
We are able to **address every operational issue** in the system, handling frequency and voltage deviations.

Results
Handling operational issues

Frequency trend at TSO

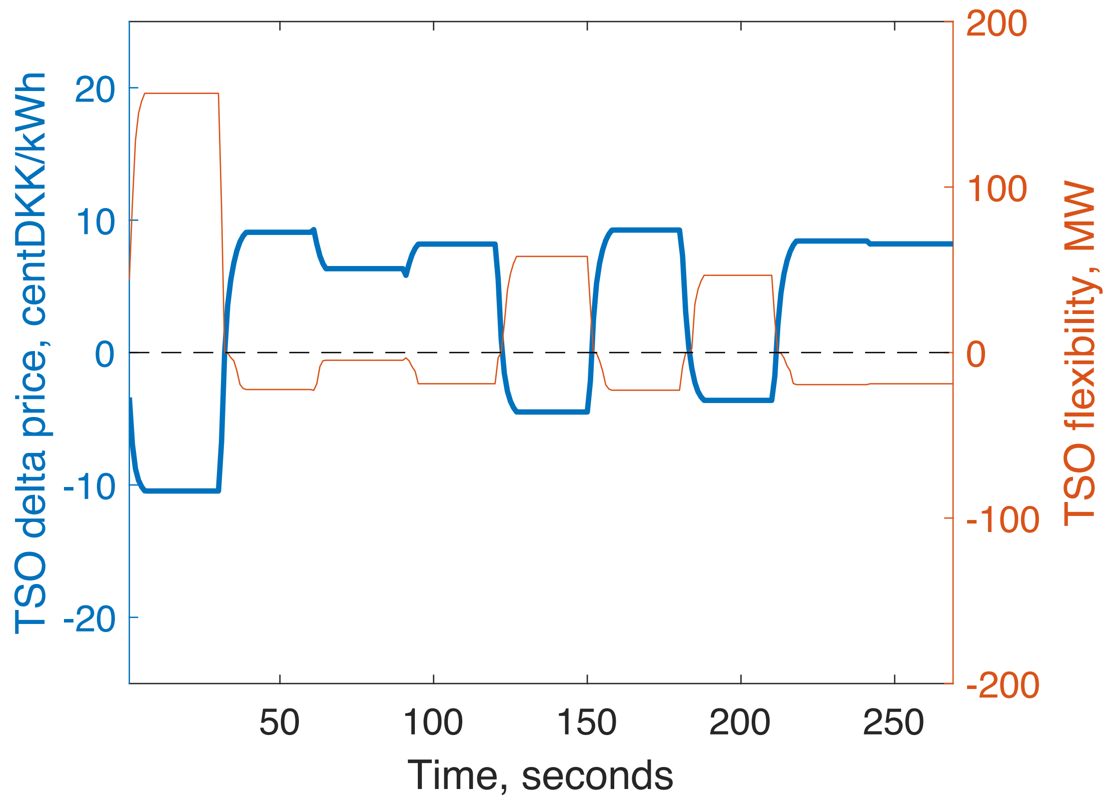


Voltage trend at DSO

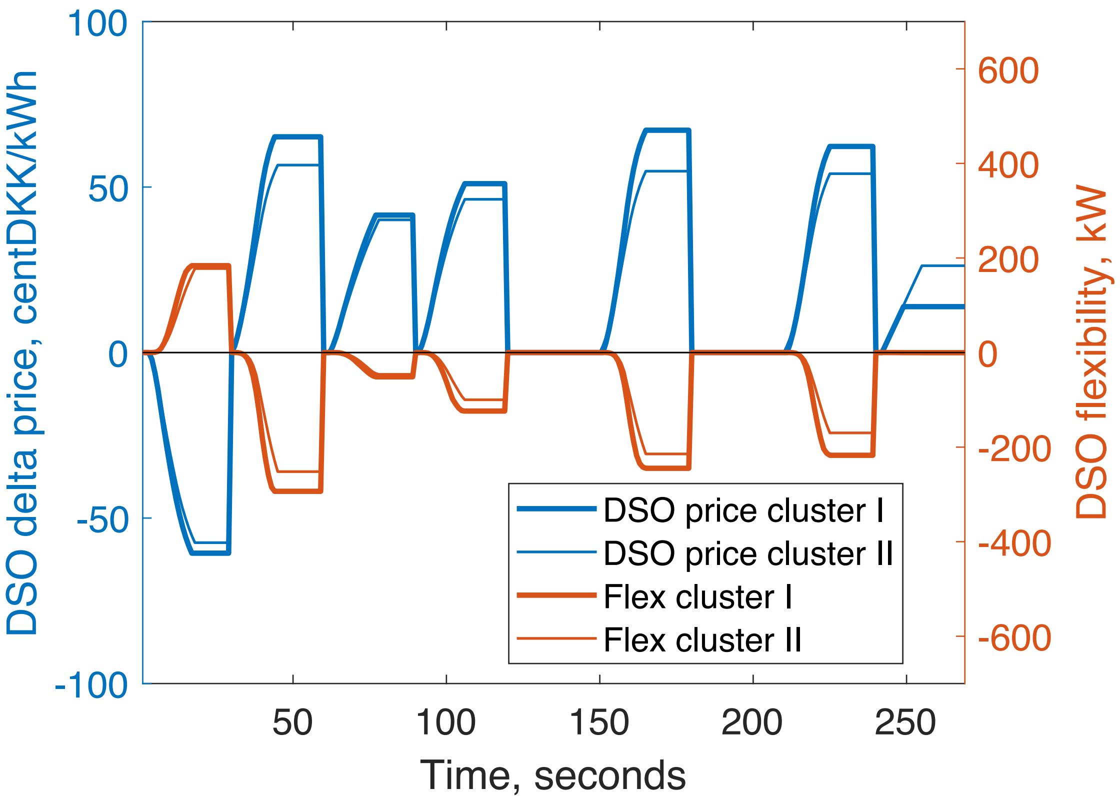


Results
Price response

Price response from TSO



Price response from DSO



Different prices are formulated at different levels of the grid. Each price is submitted until the power disturbance is solved in the power system.

Conclusions

We present **AS4.0**, a one-way communication approach which exploits controls to handle the ancillary services provision in smart grids.

This new method potentially satisfies the various **requirements** of the grid with high penetration of RES, handling stochasticity, non-linearity and dynamics in a fast and simple manner.

In the future, the higher penetration of **energy management systems** will facilitate to get a fast reaction from the consumers to different price signals.

Future work

- Investigating alternative methods to handle the **conflicts of interest.**
- Formulating different **voltage signals** than the average.
- Modelling of a bigger **distribution system**.

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Thank you!