A Control-Based Approach for Solving Ancillary Service Problems in Smart Grids

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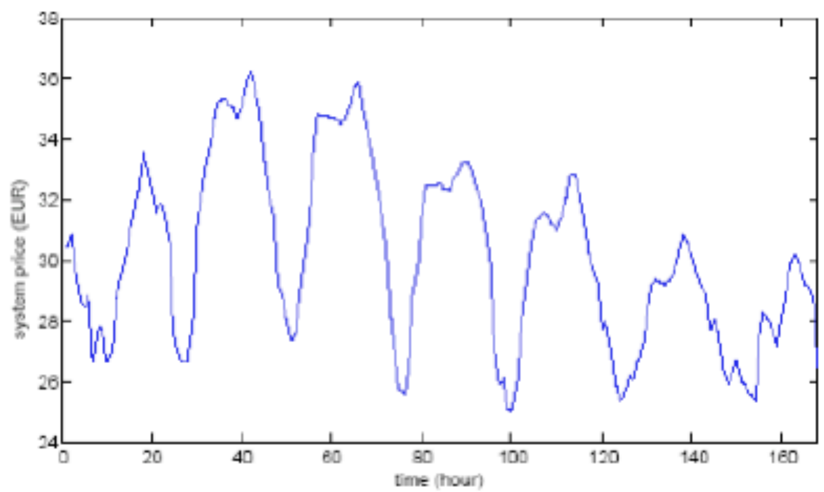
Outline

- Applying Control Theory to the Study of Power Markets
- Smart-Energy Operating Systems
- Control and Optimisation
- Grey Box Modelling
- CITIES and SmartNet Projects

Applying Control Theory to the Study of Power Markets

Advantages in handling effectively

Dynamics



control theory provides ways of modeling the dynamics which is intrinsic in energy markets

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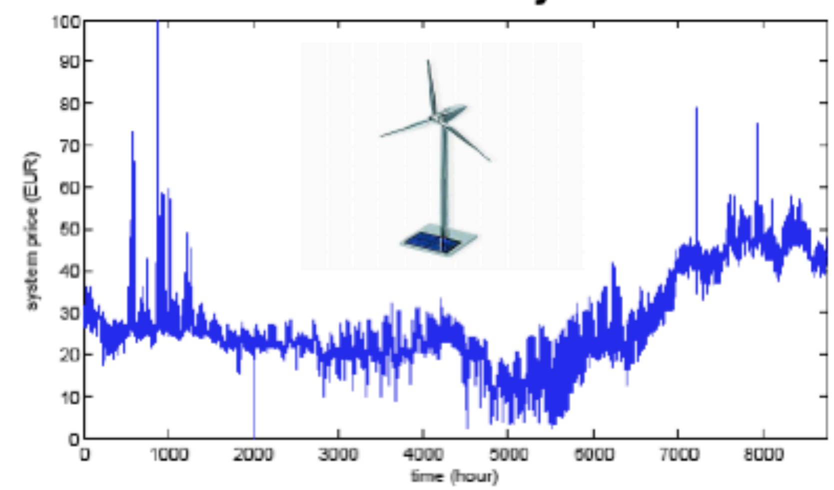
it is possible to develop advanced bidding strategies which exploit the inclusion of the dynamics in the model

Uncertainty



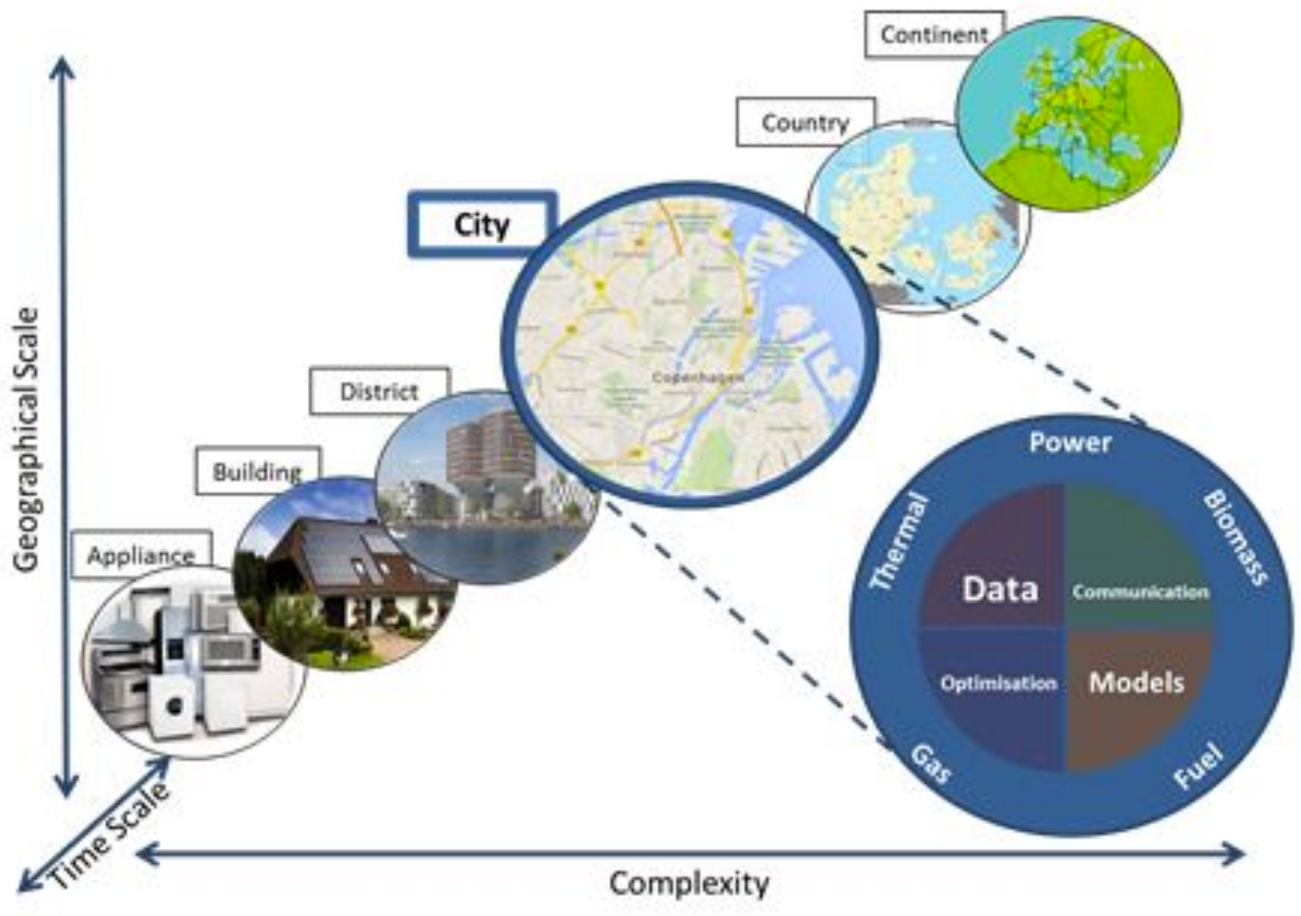
stochastic control theory allows for taking into account different sources of uncertainty (wind, ...)

↓

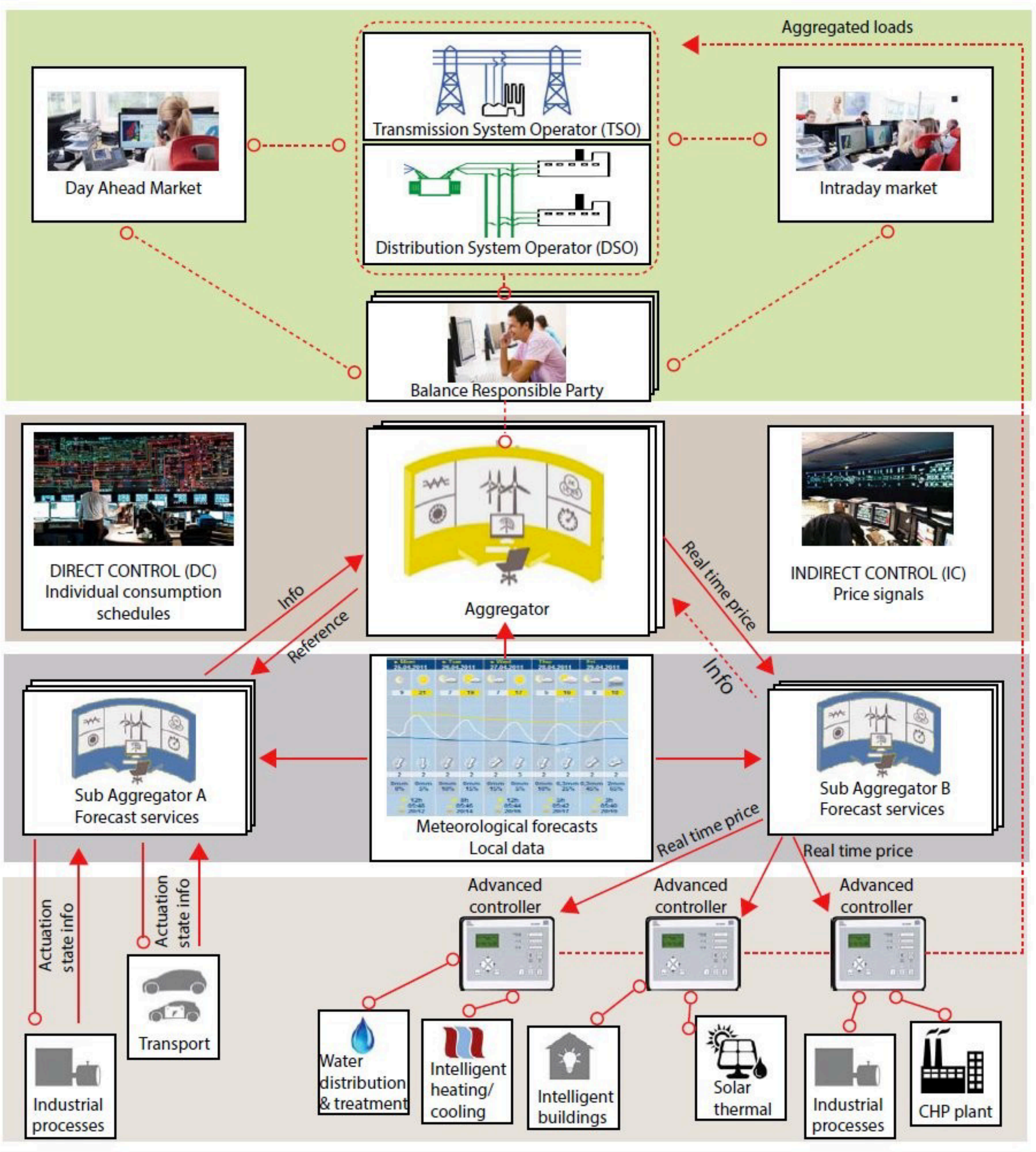
it is possible to develop bidding strategies which are optimal with respect to the stochastic characteristics of the market

Smart-Energy Operating Systems
Temporal and Spatial Scales

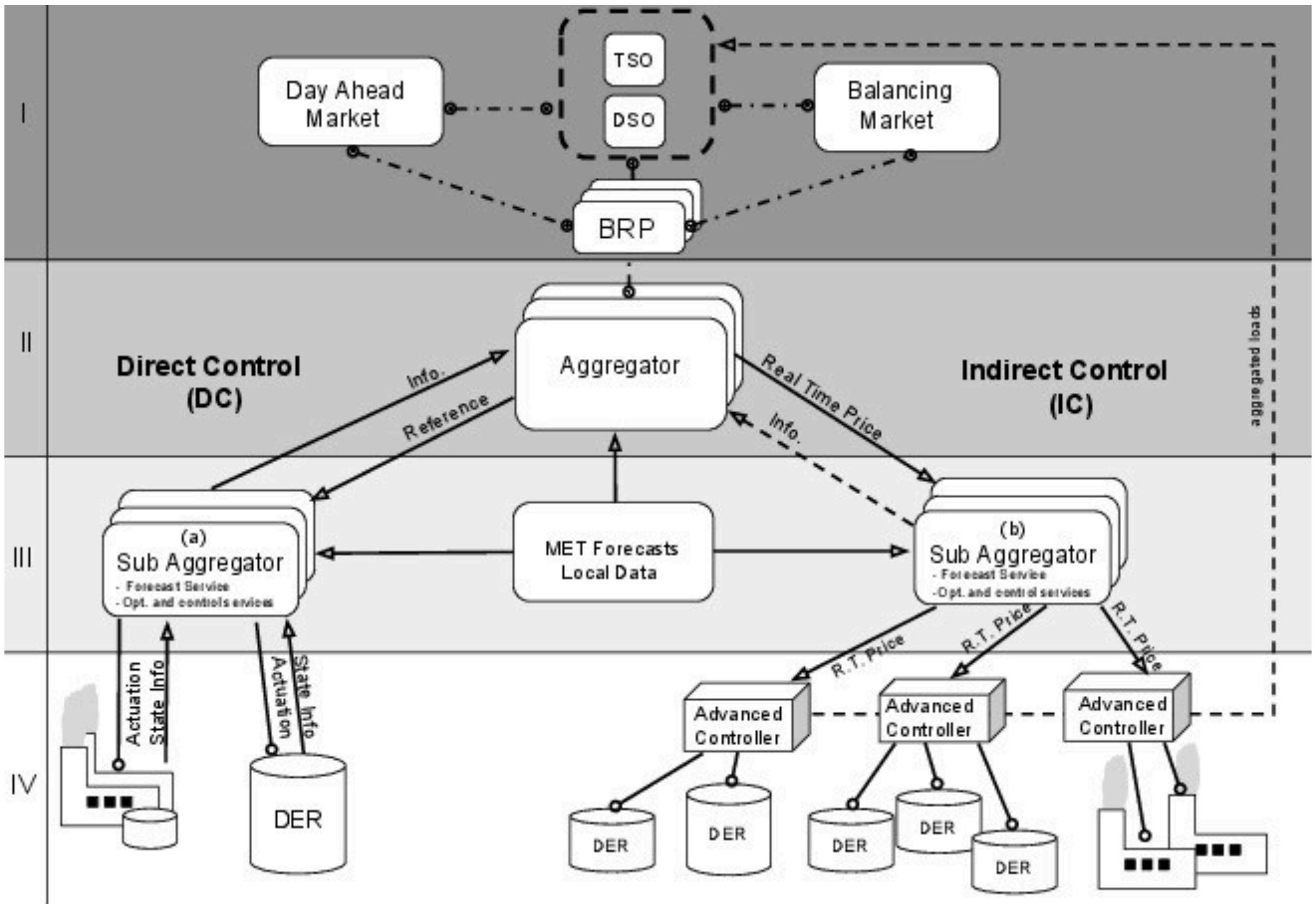
The Smart-Energy Operating Systems (SE-OP) is used to develop, implement and test the solutions (layers: data, models, optimisation, control, communication) for operating flexible electrical energy systems at all scales.



Smart-Energy Operating Systems



Control and Optimisation



Day-Ahead:

Stochastic programming based on scenarios

Direct Control:

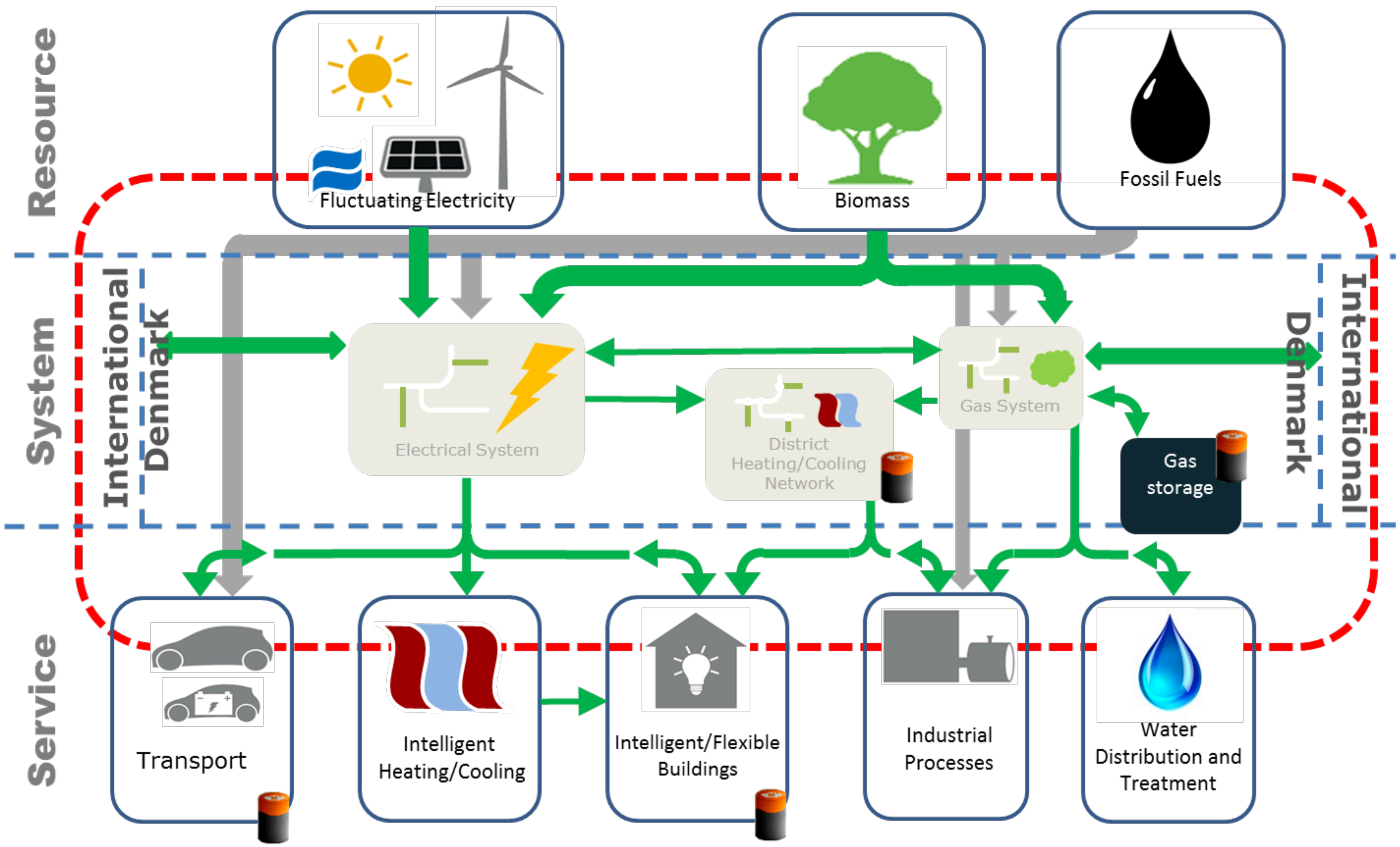
Actuator: Power
Two way communication

Indirect Control:

Actuator: Price
One way communication

Grey Box Modelling

Intelligent systems integration using data and ICT solutions are based on grey-box models for real-time operations of flexible power/energy systems



CITIES Project

CITIES

Centre for IT-Intelligent Energy Systems in cities

Demo projects | Software solutions | Work Packages | Partners | Events | Communications | Publications | Vacant positions | Contacts

Software solutions

Software for combined physical and statistical modelling

Continuous Time Stochastic Modelling (CTSM) is a software package for modelling and simulation of combined physical and statistical models. You find a technical description and the software at CTSM.info.

Software for Model Predictive Control

HPMPC is a toolbox for High-Performance implementation of solvers for Model Predictive Control (MPC). It contains routines for fast solution of MPC and MHE (Moving Horizon Estimation) problems on embedded hardware. The software is available on GitHub.

MPCR is a toolbox for building Model Predictive Controllers written in R, the free statistical software. It contains several examples for different MPC problems and interfaces to opensource solvers in R . The software is available on GitHub.

Search ...

Latest news

- Summer School at DTU, Lyngby, Denmark – July 4th-8th 2016
- Summer School – Granada, Spain, June 19th-24th 2016
- Third general consortium meeting – DTU, May 24th-25th 2016
- Smart City Challenge in Copenhagen – April 20th 2016
- Guest lecture by Pierluigi Mancarella at DTU, April 6th

SmartNet Project

SmartNet

European Commission

Horizon 2020
European Union funding
for Research & Innovation

The **SmartNet** project arises from the need to find answers and propose new practical solutions to the increasing integration of Renewable Energy Sources in the existing electricity transmission network.

Existing Markets: Challenges

- Dynamics
- Stochasticity
- Non-linearity
- Many power-related services
- Interaction between grid (voltage) levels
- Speed/ problem size
- Characterisation of flexibility
- Requirements on user installations

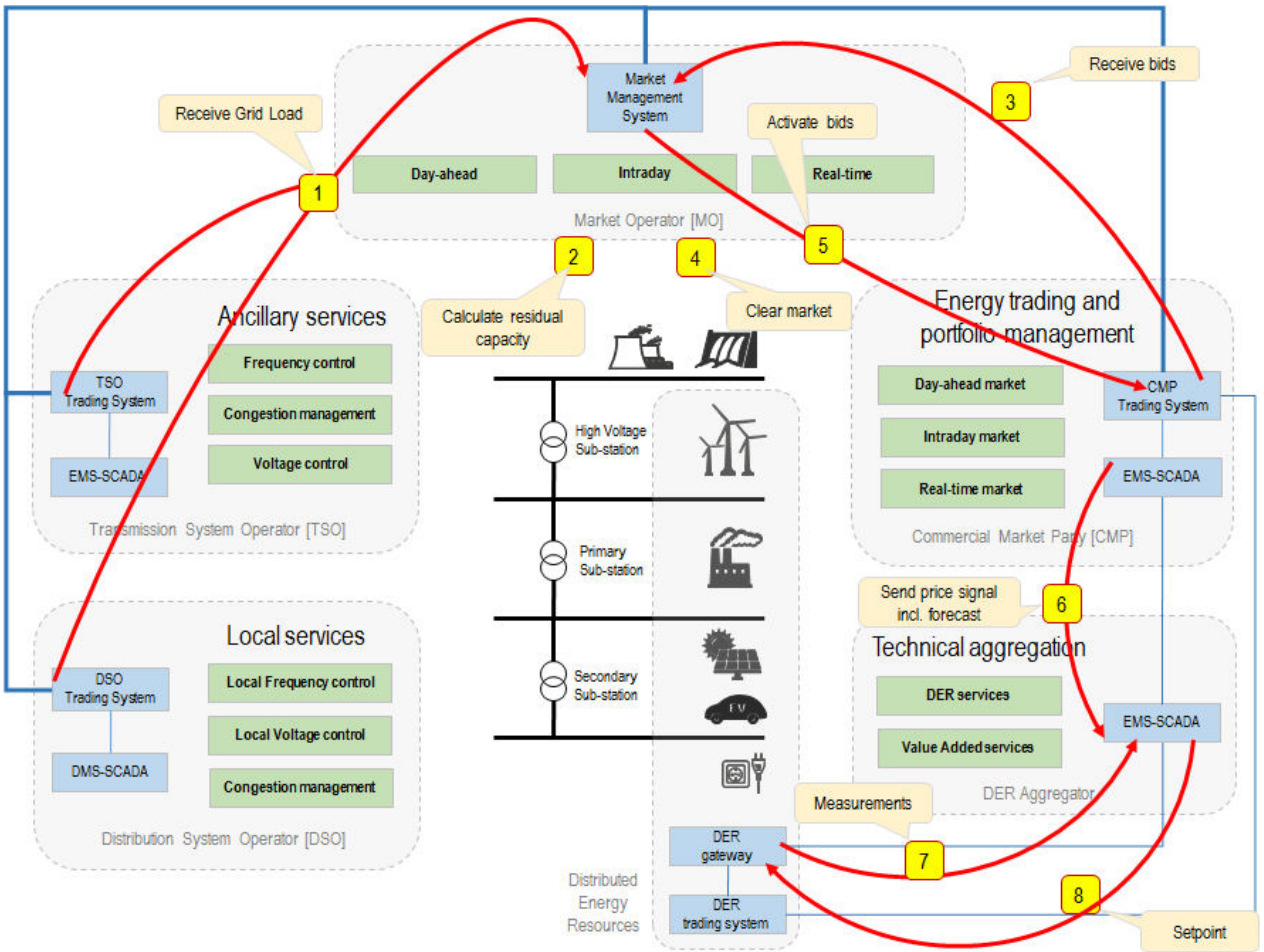
SE- OS Characterisation

- ‘Bidding – clearing – activation’ at higher levels
- Nested sequence of systems – systems of systems
- Hierarchy of optimisation (or control) problems
- Control principles at higher spatial/temporal resolutions
- Cloud or Fog (IoT, IoS) based solutions
- Facilitates energy systems integration
- Allow for new players (specialised aggregators)
- Simple setup for the communication and contracts
- Provides a solution for all ancillary services
- Harvest flexibility at all levels

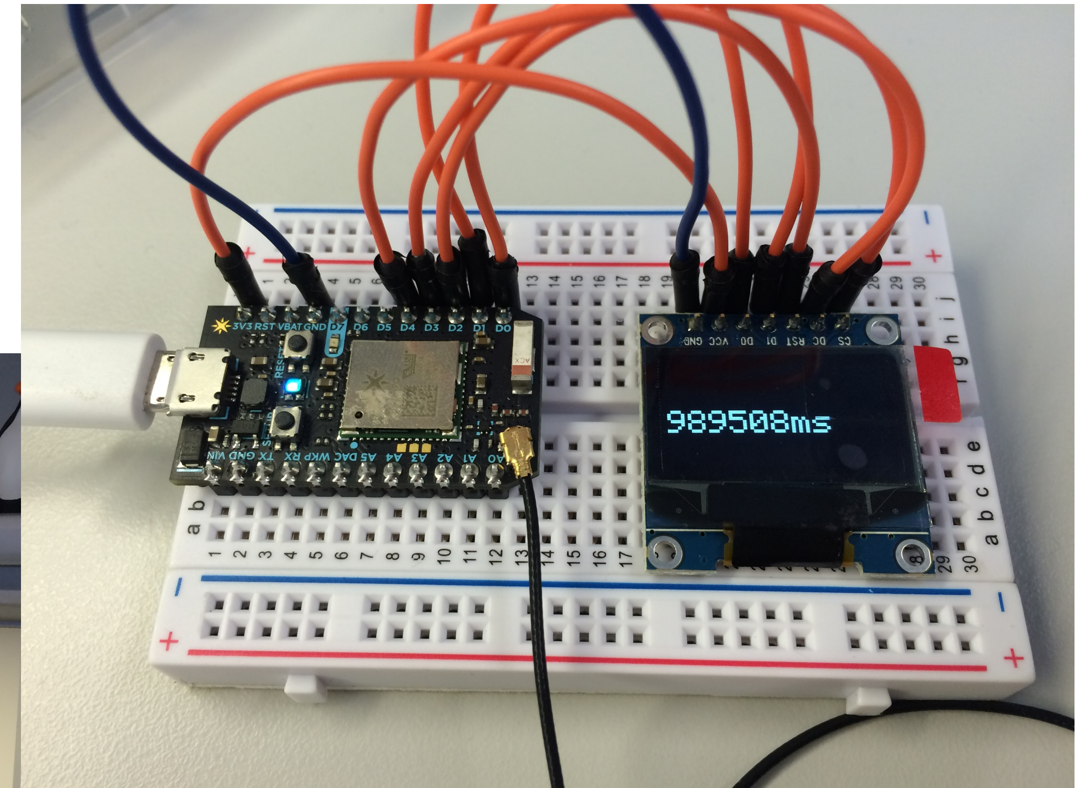
Goals for Pilot Project

Aggregation	Demonstrate aggregation services
Communication	Implementation in field of ICT technology to exchange data between TSO, DSO, aggregator and summer houses
Forecasting	Use of on-line services for price and load forecasting + model predictive
Ancillary Services	Development of architecture for ancillary services

Overview: Danish Pilot



Lab Testing



Outline

- Coordinating flexible resources
- Proposed methodology
- Main advantages of the proposed methodology
- Main concerns to be addressed
- Conclusions

The electricity supply service
Consequences for the AS

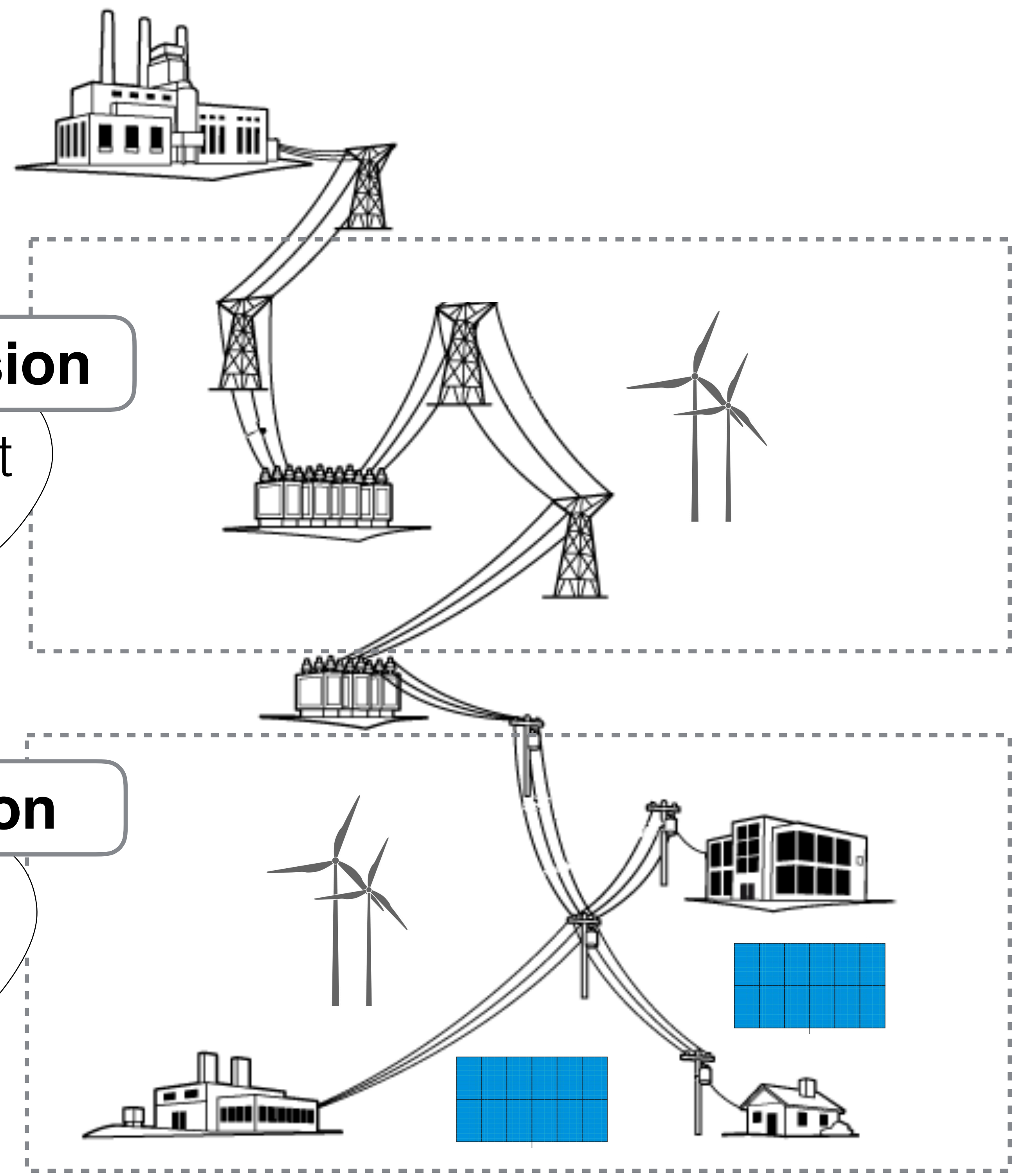
This is particularly affecting the provision of the ancillary services:

Transmission

- Congestion management
- Frequency control

Distribution

- Congestion management
- Voltage control
- Balancing



The electricity supply service
Exploiting the energy flexibility

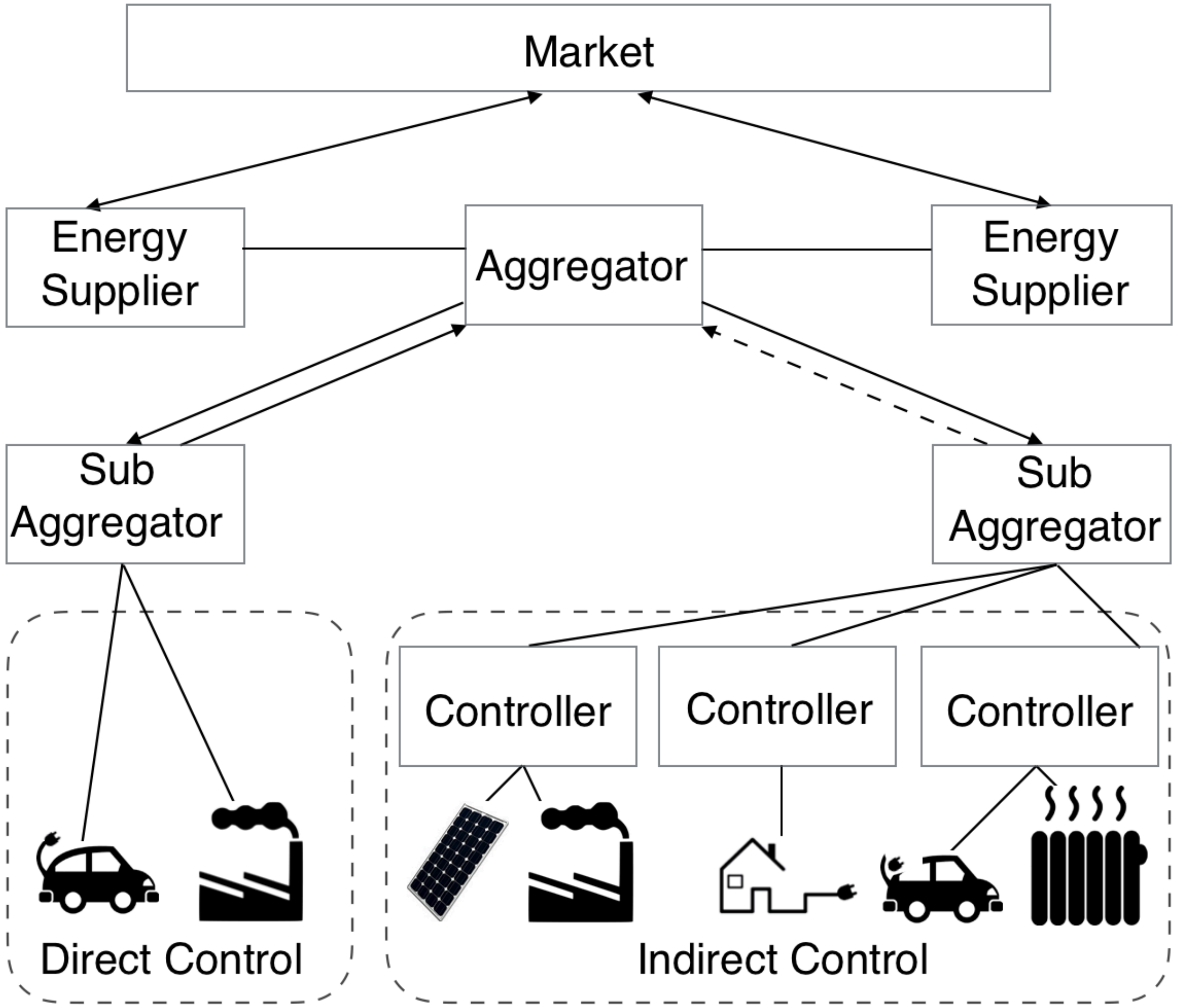
Flexible resources

Flexible loads, storage and generation can **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.

Coordinating flexible resources
Control-based approach

Different possibilities can be investigated for the coordination of the flexible resources:



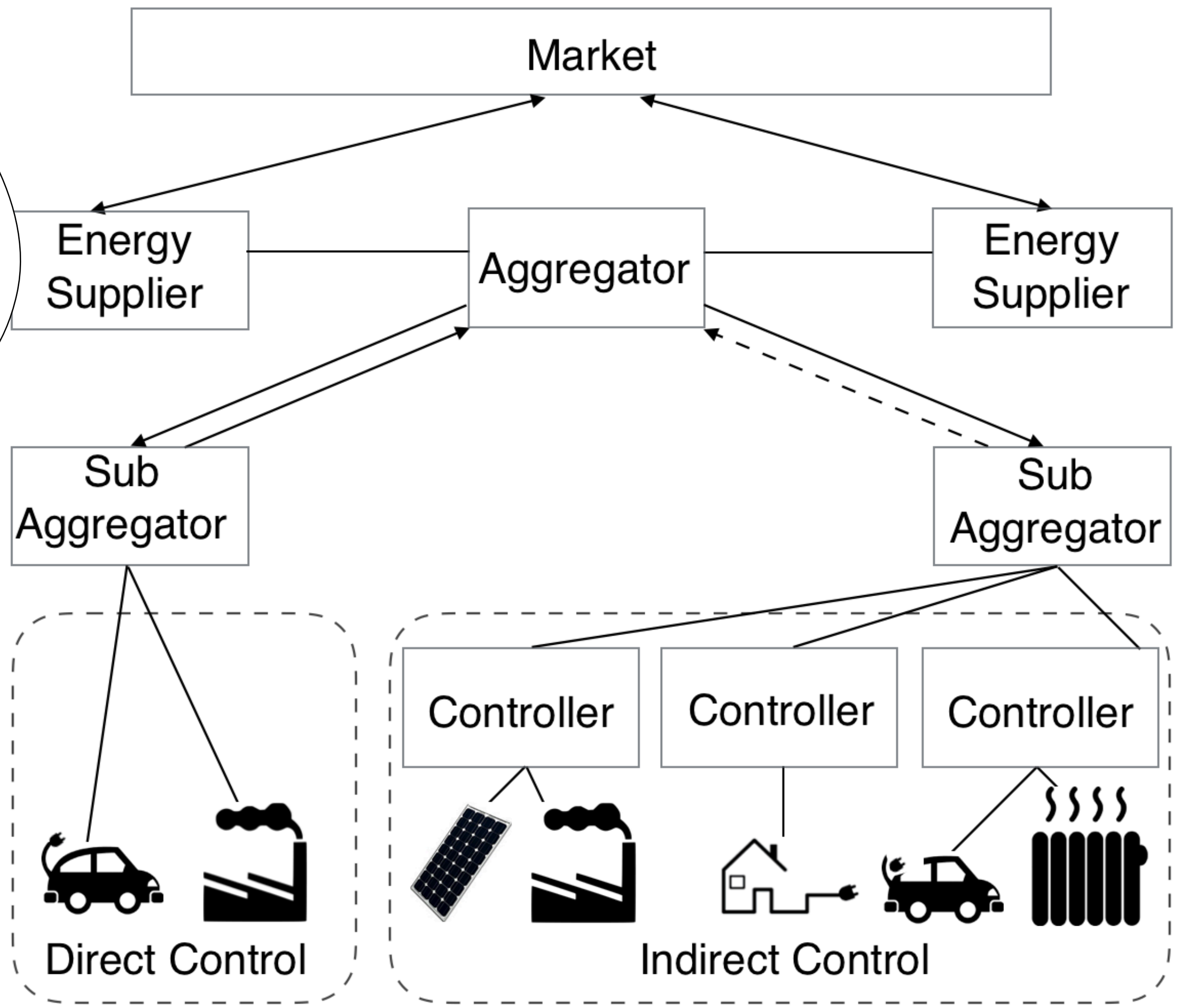
Control problem is formulated at the prosumers' level.

Coordinating flexible resources
Control-based approach

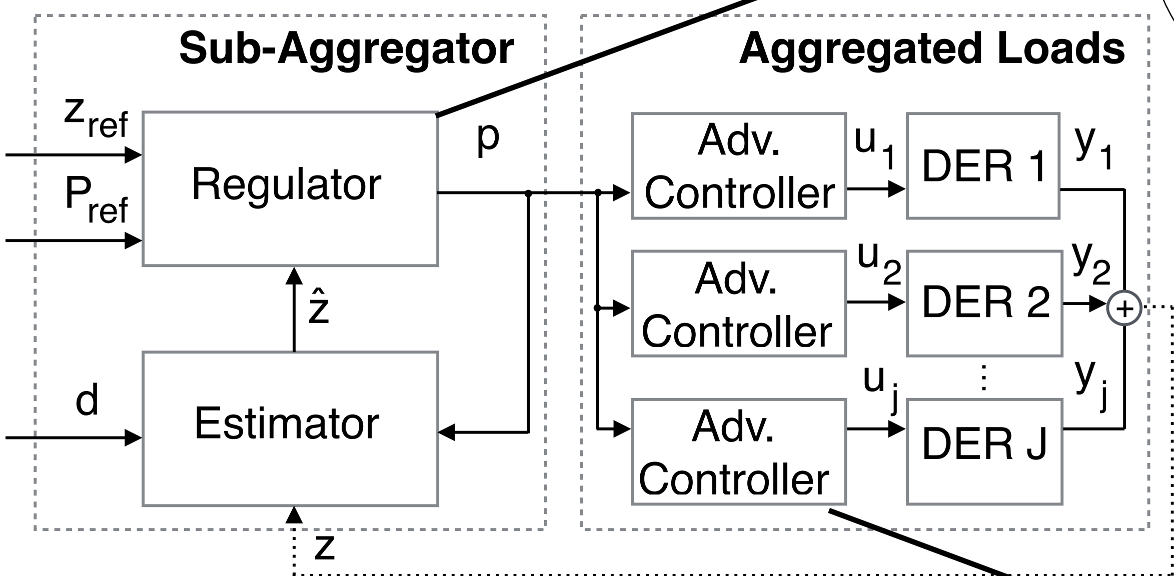
The control-based approach is formulated in two steps:

I. A **control problem** at the sub-aggregator level, to determine the appropriate Control (Price) signal to address ancillary services issues.

II. A **model-predictive control** at the consumer's level acting upon receiving the control signal.



Proposed methodology
Control-based methodology

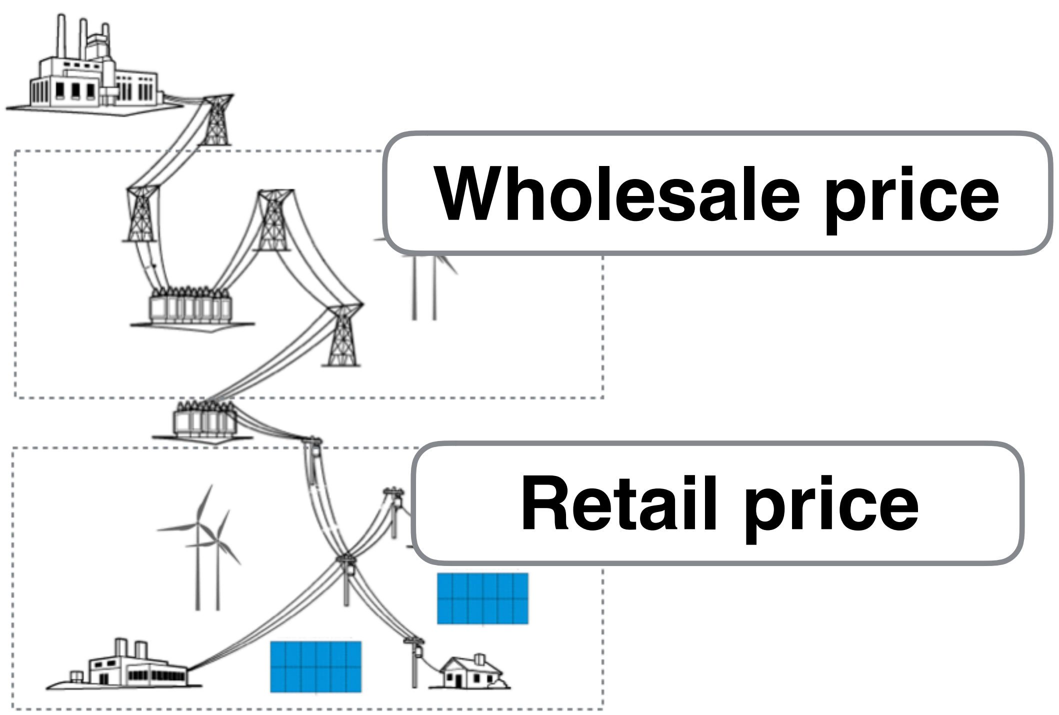


$$\begin{aligned} \min_{p} \quad & E[\sum_{k=0}^{N} w_{j,k}||\hat{z}_k - z_{ref,k}|| + \mu||p_k - p_{ref,k}||] \\ \text{s.t.} \quad & \hat{z}_{k+1} = f(p_k) \end{aligned}$$

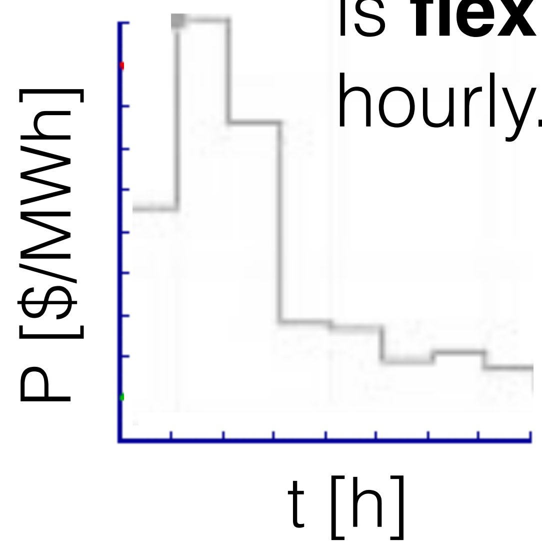
$$\begin{aligned} \min_{u} \quad & E[\sum_{k=0}^{N}\sum_{j=1}^{J} \phi_j(x_{j,k}, u_{j,k}, p_k)] \\ \text{s.t.} \quad & x_{k+1} = Ax_k + Bu_k + Ed_k, \\ & y_k = Cx_k, \\ & y_k^{min} \leq y_k \leq y_k^{max}, \\ & u_k^{min} \leq u_k \leq u_k^{max} \end{aligned}$$

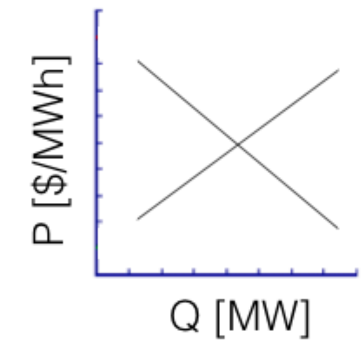
We adopt a control-based approach where the **price** becomes the driver to **manipulate** the behaviour of a certain pool flexible prosumers.

Proposed methodology
The electricity price

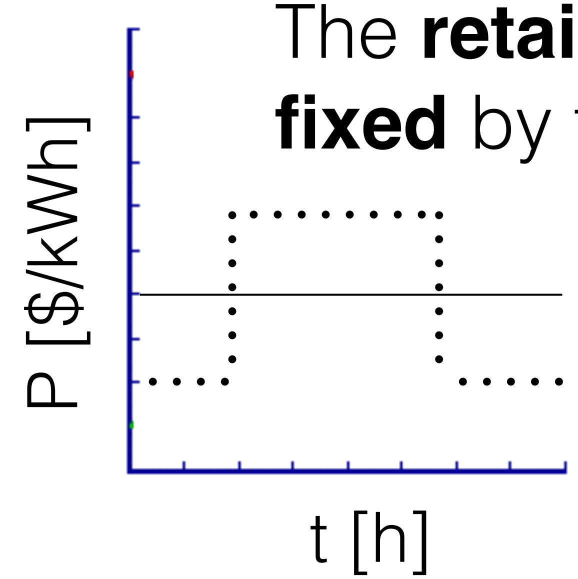


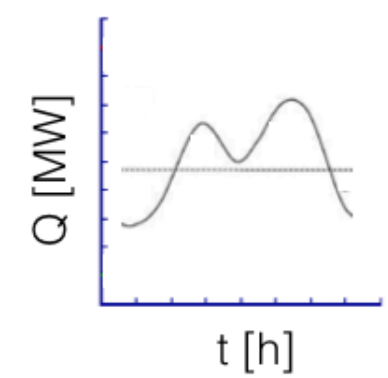
The **wholesale** electricity price is **flexible** and **changes** sub-hourly.





The **retail** electricity price is **fixed** by the **utility.**

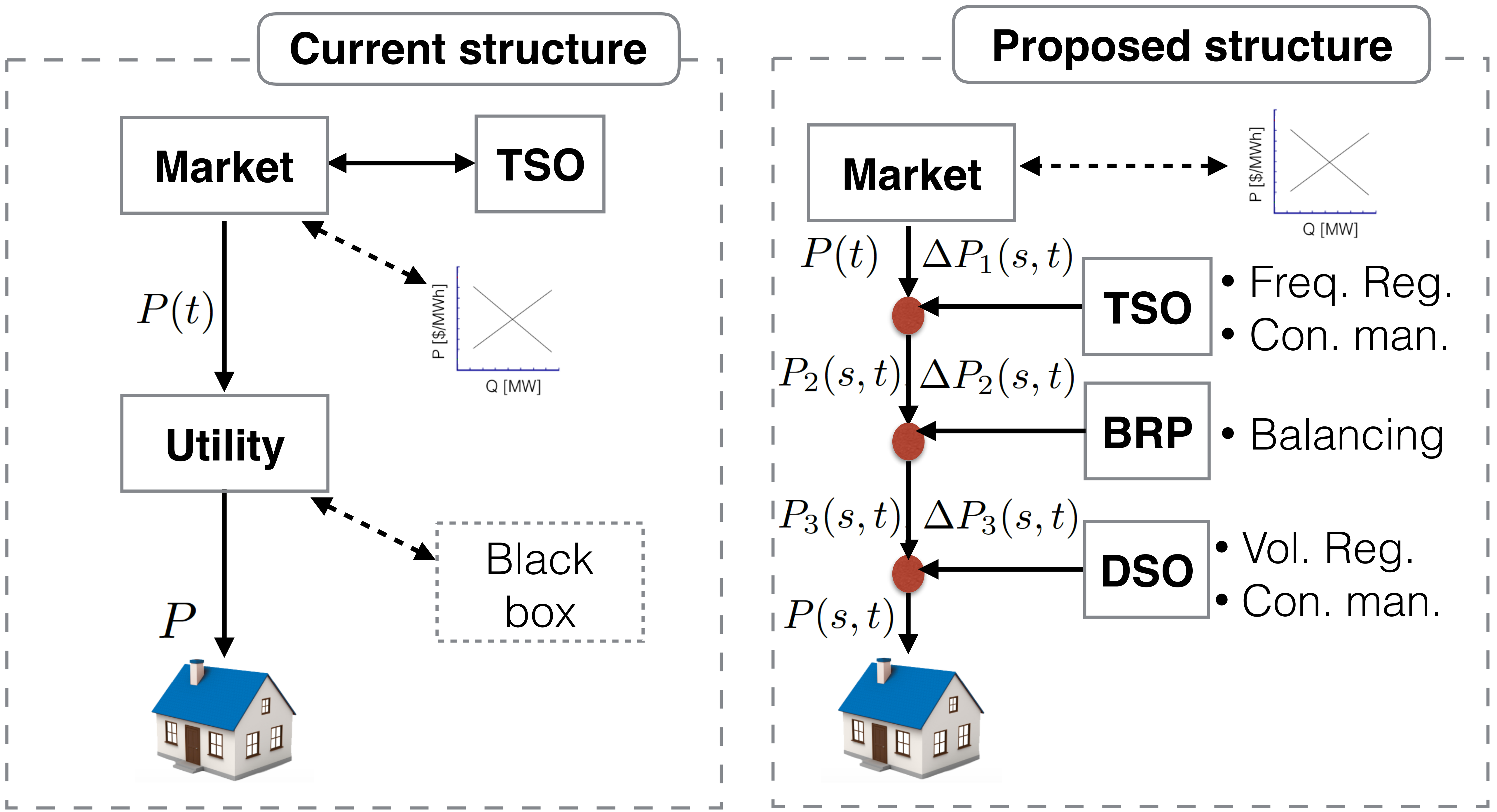




For the retail price there is no flexibility and the **prosumers do not consider the condition of the grid in their actions.**

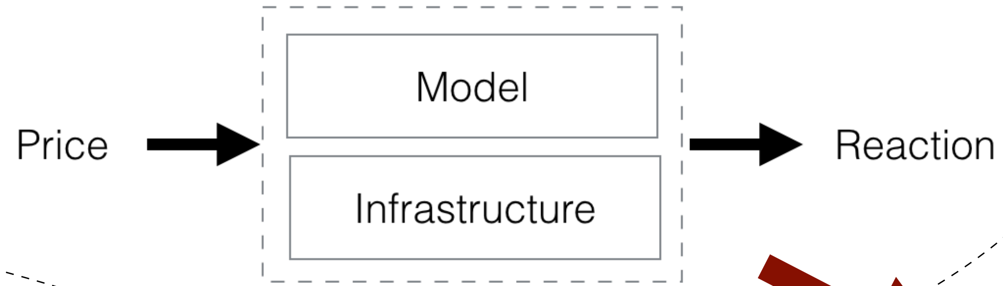
It is fundamental to **reconsider the formulation** of the **retail electricity price** to exploit the **price responsiveness** of the **flexible** energy resources.

Proposed methodology
Structures for the electricity price



Proposed methodology
Formulating the delta-prices

Understanding how the consumer reacts according to the price



Prosumers' model

Identifying the delta-prices

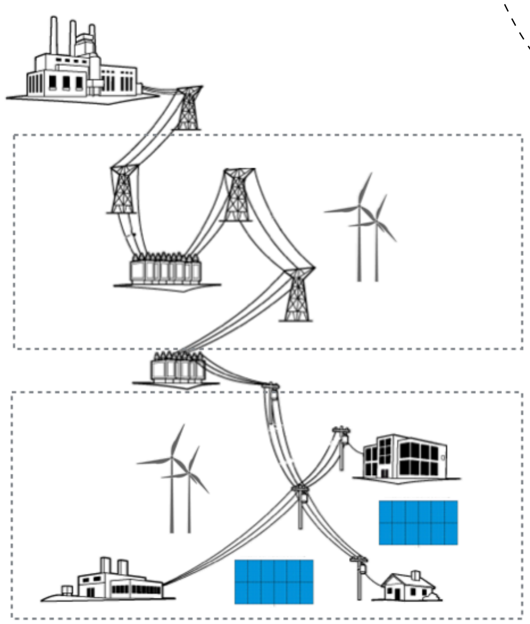
$$\Delta P\,(s,t)$$

Price

CBA

Running the optimisation problem including the operational constraints

Objective function



Defining the challenges of the grid and the objective to provide as ancillary services.

Main advantages of the proposed methodology

Several advantages can be identified for such methodology:

- It takes into account **stochasticity**, **non-linearity** and **dynamics**.
- It is able to **solve** all the **ancillary services' problems** in **one set.**
- It exploits the **potential** of flexible resources at the prosumers' level of **any size**.
- It is **fast** and fully **automated** at different levels.
- It facilitates the **integration** of the different energy carriers.

Conclusions

We present a **control based-approach** to solve the ancillary services problem in smart grids.

Such methodology is able to **solve all the problems in one set**, taking into account stochasticity, non linearity and dynamics.

We also suggest a change in the formulation of the **retail electricity price**, generating delta-prices that can replace the AS market.

Future **simulations** will test the stability of the method.

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