TotalFlex demonstration

- CITIES WP3 Flexibility and Buildings Workshop

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Agenda

- 10’ General introduction
- 15’ Typical prosumers
- 10’ Flex-offer basics
- 10’ Aggregator role
- 10’ DSO challenges and benefits
- 10’ Market Place for flexibility
- 5’ Introduction to live demo
- 15’ Live demo
- Questions

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General Introduction

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Background - Global challenge

- Electricity consumption increasing globally
  - Pressure on the grid (load and quality)
  - Two basic solutions
    - **Smoothen power consumption during the day**
    - Grid reinforcement
- Green transition ongoing
  - Fluctuating production (i.e. from PVs and wind turbines)
  - Decentralized production must be integrated
  - Two basic solutions
    - Install backup power
    - **Activate demand response**

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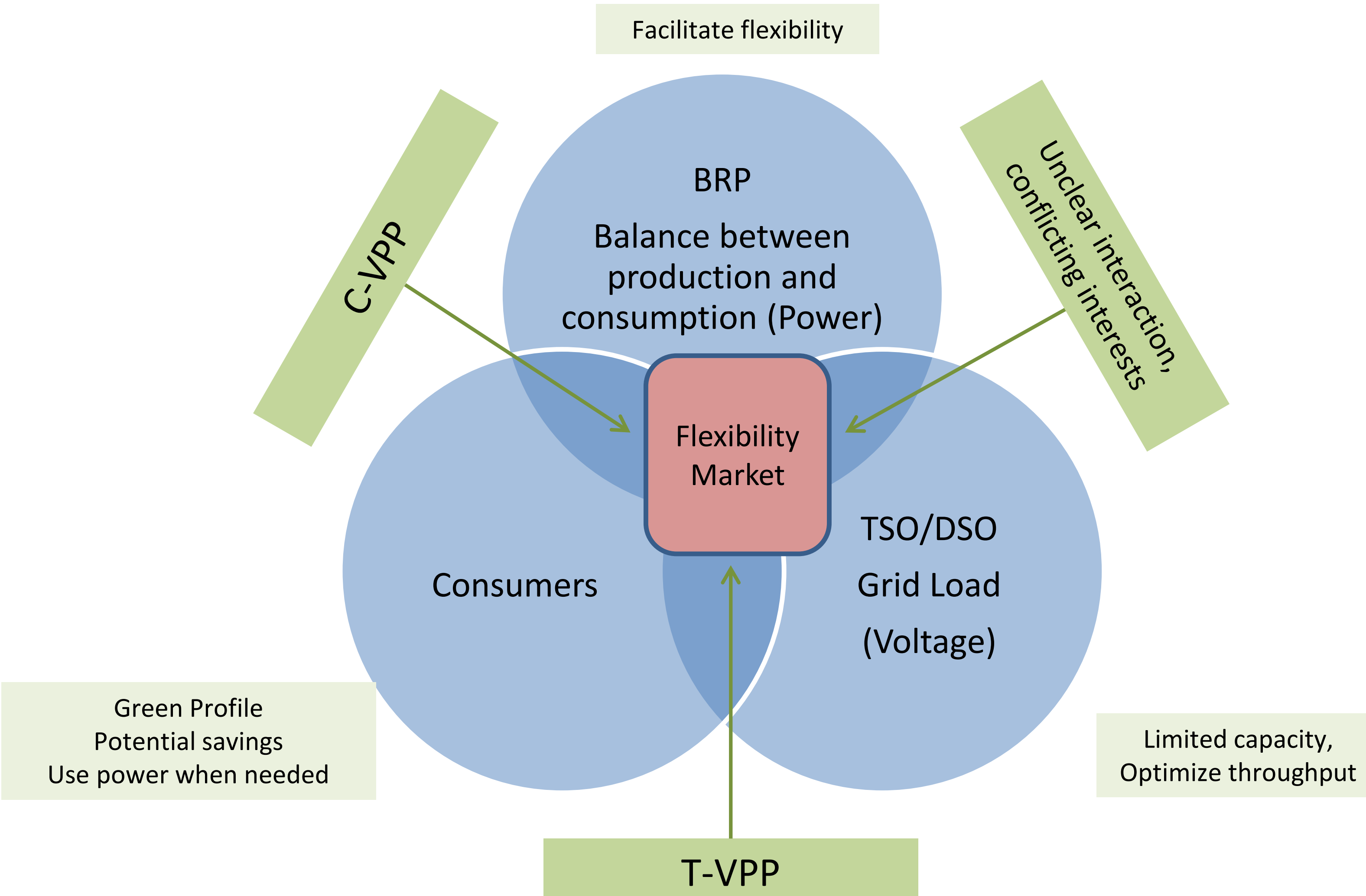
Background - built-in conflict



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Vision and scope

The *vision* of TotalFlex is to develop a cost-effective, market-based system that utilizes all available flexibility in energy consumption and production, taking balance and grid constraints into account.

This demonstration shows an on-line implementation of the key actors in TotalFlex, i.e.

Prosumer – aggregator – DSO – BRP - Market Place

To describe flexibility and make it operational, the flex-offer concept is used. The demonstration shows the flow of flex-offers from birth to grave going through its different phases:

Creation – Aggregation – Scheduling – Disaggregation – Execution

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Project highlights

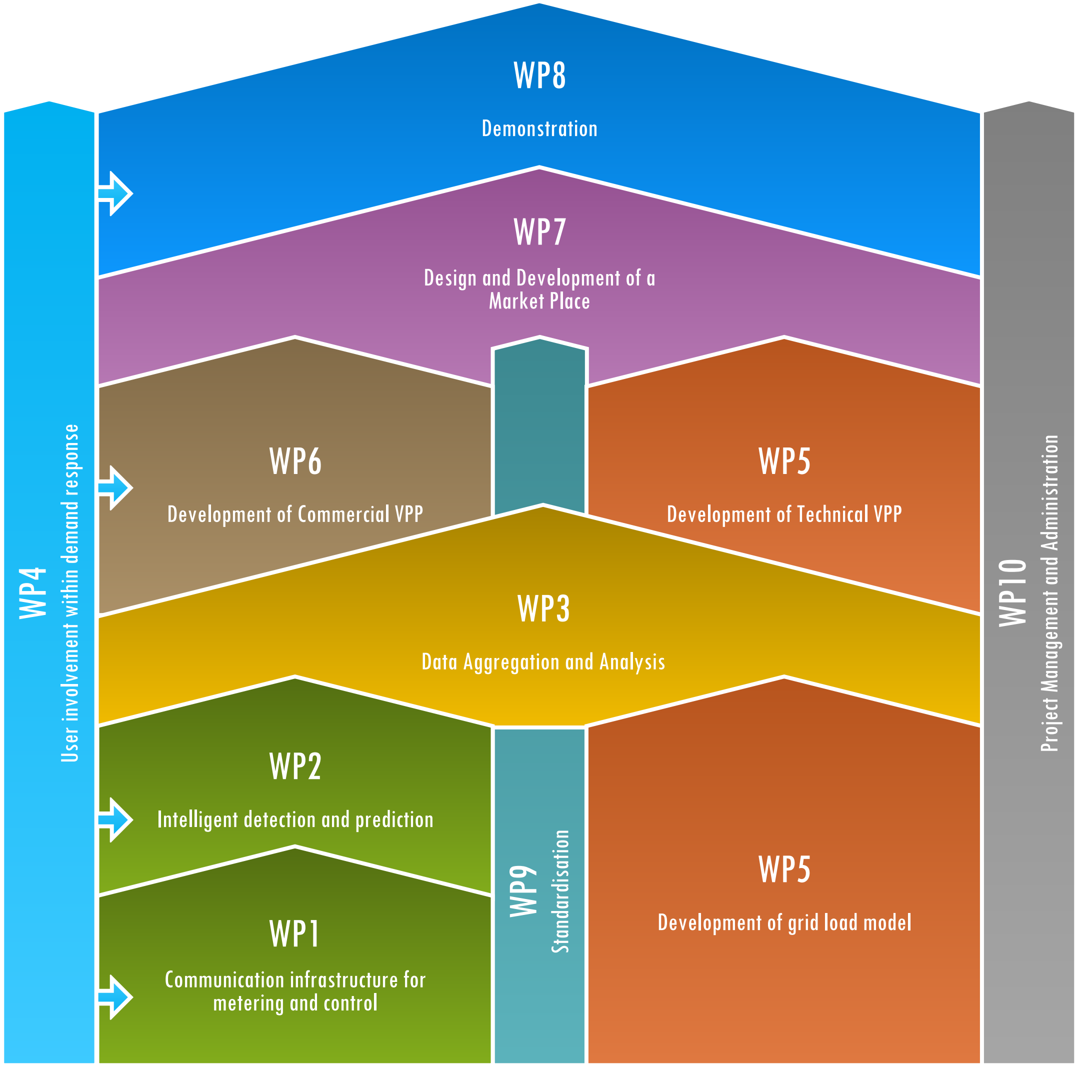
- Time Schedule: Start 2012 – End 2016
- Partners:

AALBORG UNIVERSITY · Center for Indlejrede Software Systemer · Department of ENERGY TECHNOLOGY E.T. · daisy · HCI

Copenhagen Business School HANDELSHØJSKOLEN · NYFORS · zensehome · NEAS ENERGY · conscius

- Project Management: NEOGRID TECHNOLOGIES
- Budget: 4.7 M€/41 MY

Work Packages



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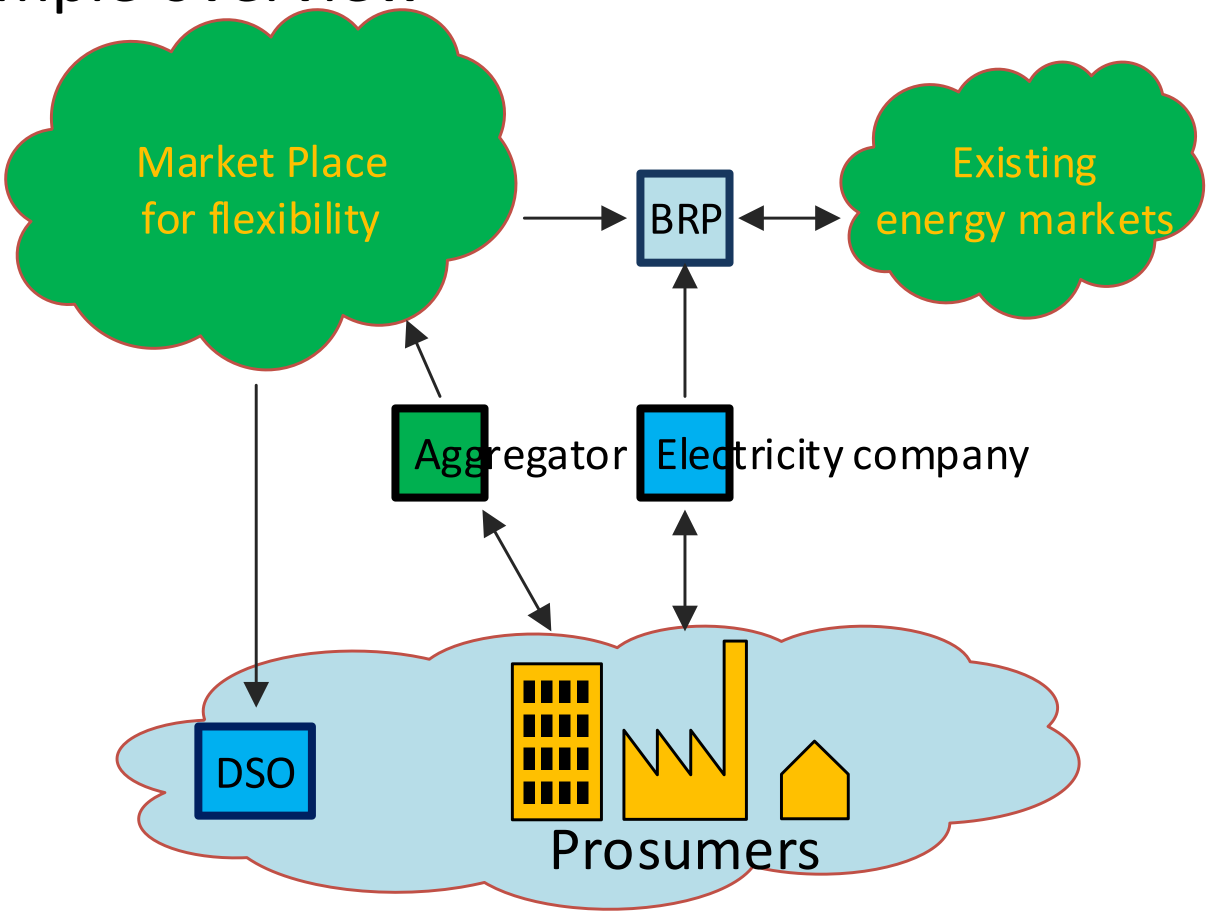
Main actors

Simple overview



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Typical prosumers

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Flexibility

- Flexibility is in processes that can be *shifted in time*
- Flexibility requires a *comfort range*
- Sources of flexibility
  - Ventilation, heating, cooling and freezing
  - Battery charging
  - Water pumping
  - Many special industry processes, i.e.
    - Aalborg Portland’s 10 MW chalk excavator
    - Artificial light in greenhouses
    - Iron foundry
- Occurs in
  - **Single family houses** and residential buildings
  - Office and administration buildings
  - Industries

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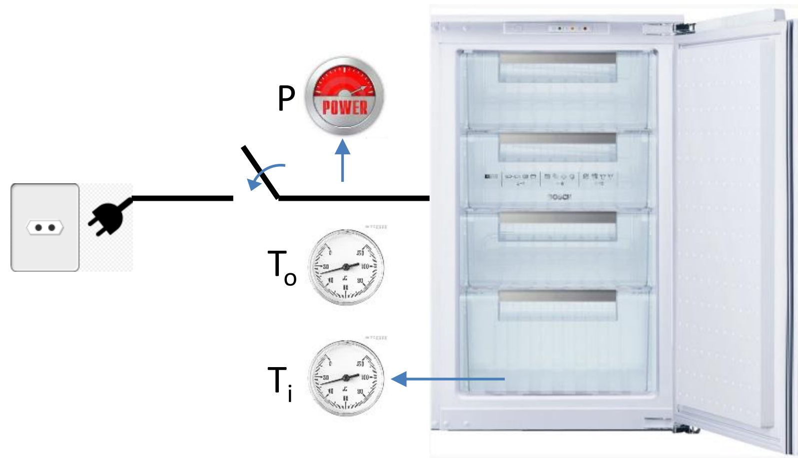
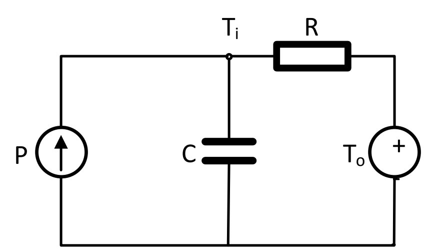
Demonstration freezer

- Key data
  - P = -100 W
  - UA = 1/R = 0.8 W/°C
  - τ = RC = 3.5 hours
  - C = 2.8 Wh/°C



- Comfort criteria
  - Temperature interval accepted by owner
- Baseline
  - Freezer operation to secure -18 °C
- Discrete time model

$$T_i(n+1) = Ti(n)[1 - \frac{dt}{RC}] + \frac{dt}{C}[P(n) + \frac{T_o}{R}]$$



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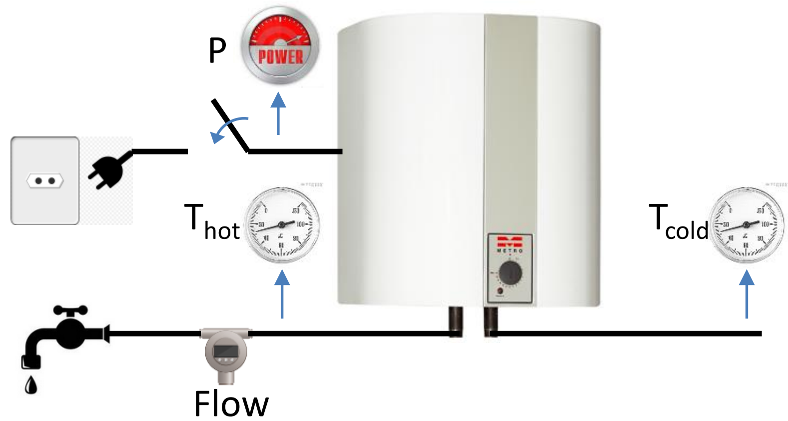
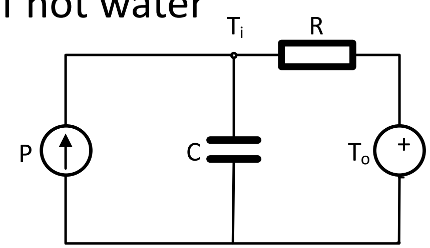
Demonstration water heater

- Key data
  - Vol = 30 l
  - UA = 1/R = 0.55 W/°C
  - P = 1150 W
  - τ = RC = 3.5 hours
  - C = 35 Wh/°C
  - T_{hot} = 60 °C, T_{cold} = 10 °C



- Comfort criteria
  - Hourly needed amount of hot water 35 °C
- Baseline
  - Operation to deliver hourly needed amount of hot water
- Discrete time model

$$T_i(n+1) = Ti(n)[1 - \frac{dt}{RC}] + \frac{dt}{C}[P(n) + \frac{T_o}{R}]$$



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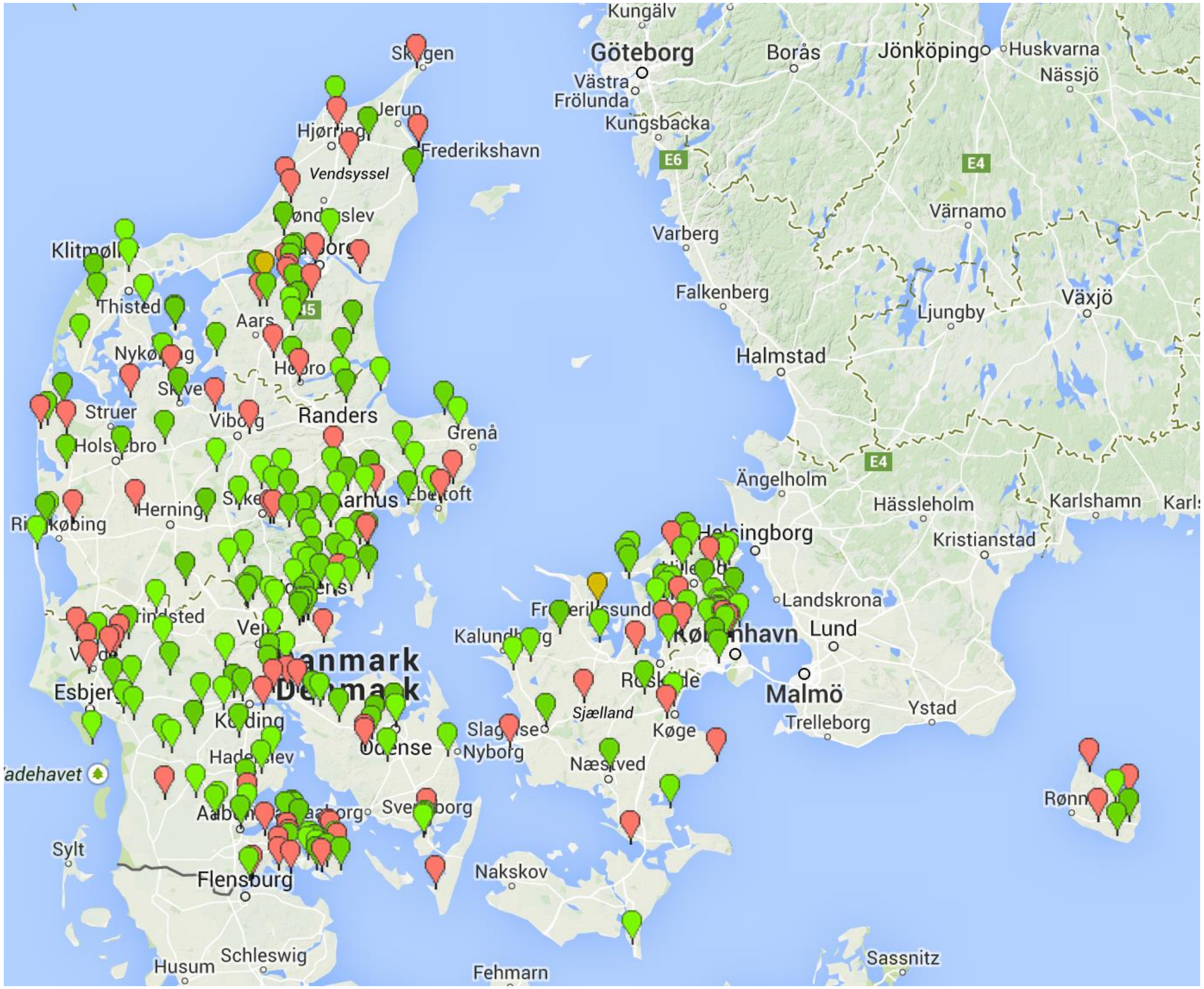
www.styrdinvarmepumpe.dk plants



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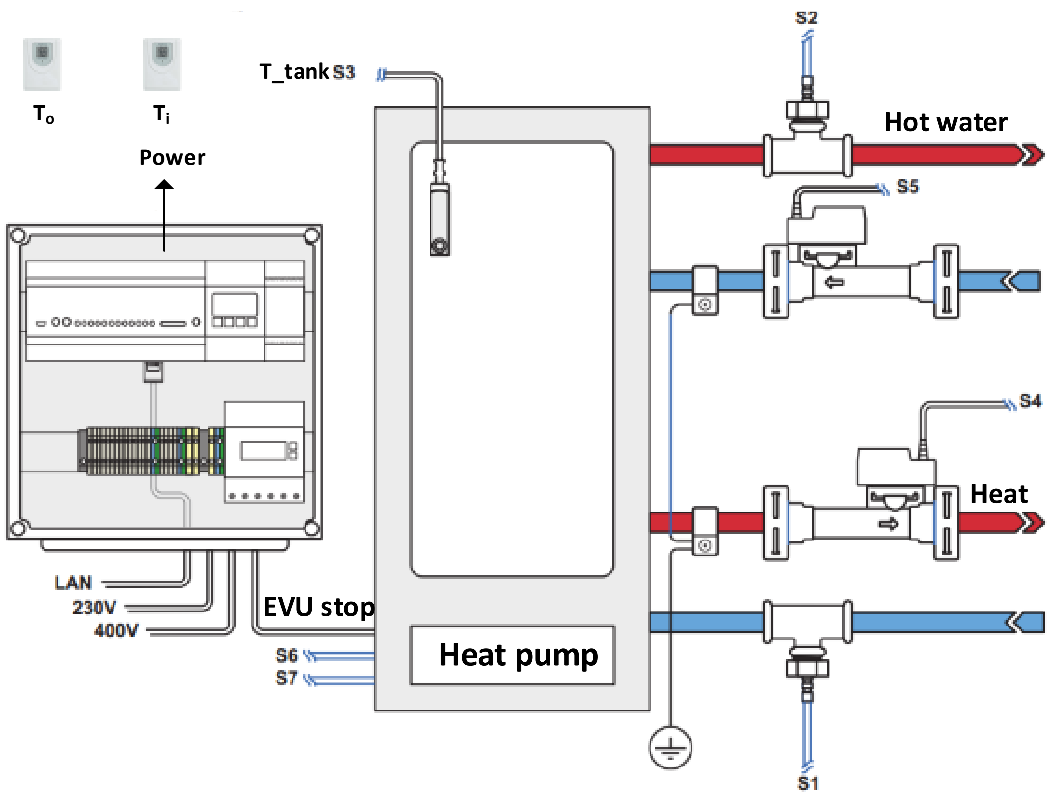
Heat pump system setup



- 300 installations
- 5 minutes resolution

- Controlled via relay input
- Can stop heat pump
- Can not force start
- But allow heat pump to run
- XMPP: online monitoring
- XMPP: online control

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Demonstration heat pump

- Two basic types of heat pump setups om TotalFlex
  - Individual modelling and control
    - Energy savings, simple hourly optimization
  - Pool modelling and control, used for
    - Smart Grid purposes
    - Imbalance control, keeping a plan
    - Energy Markets where MW quantity is needed
- Based on adaptive modelling using
  - Historical weather data (hourly outdoor temperature and sun radiation)
  - 5' indoor temperature data
  - 5' used energy for domestic hot water and heat
  - 5' electricity consumption data (to check heat pump COP)
- Adaptive model which can predict
  - Hourly energy demand for hot water and energy based on weather forecast
- Some uncertainty due to unpredictable user behavior

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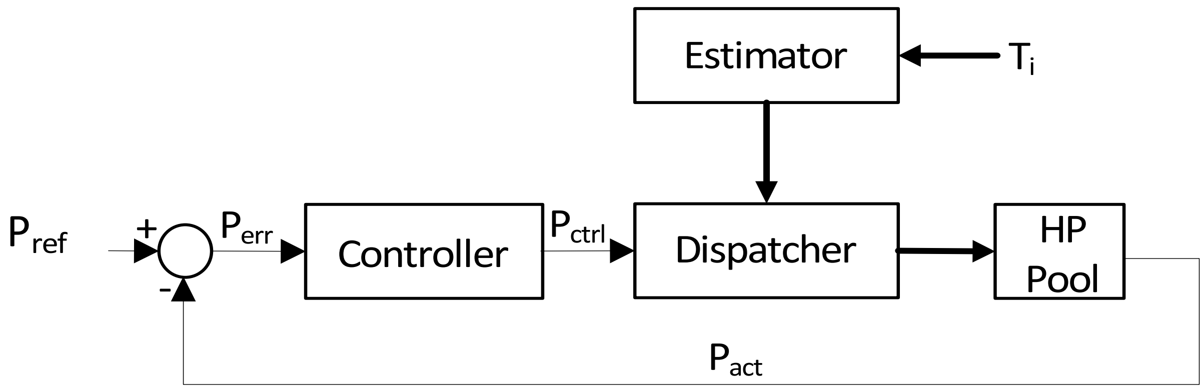
Operating pool of heat pump



- Prioritized operation with 5 minute schedule
  - Immediate start
    - T_{tank} < limit, Used hot water > limit, rest time > 3h, $T_i < T_{low}$
  - Immediate stop
    - $T_i > T_{max}$
  - Adjust to P_{ctrl} meeting run- and rest time constraints
    - Starting heat pumps with lowest nominal temperature
    - Stopping heat pumps with highest nominal temperature

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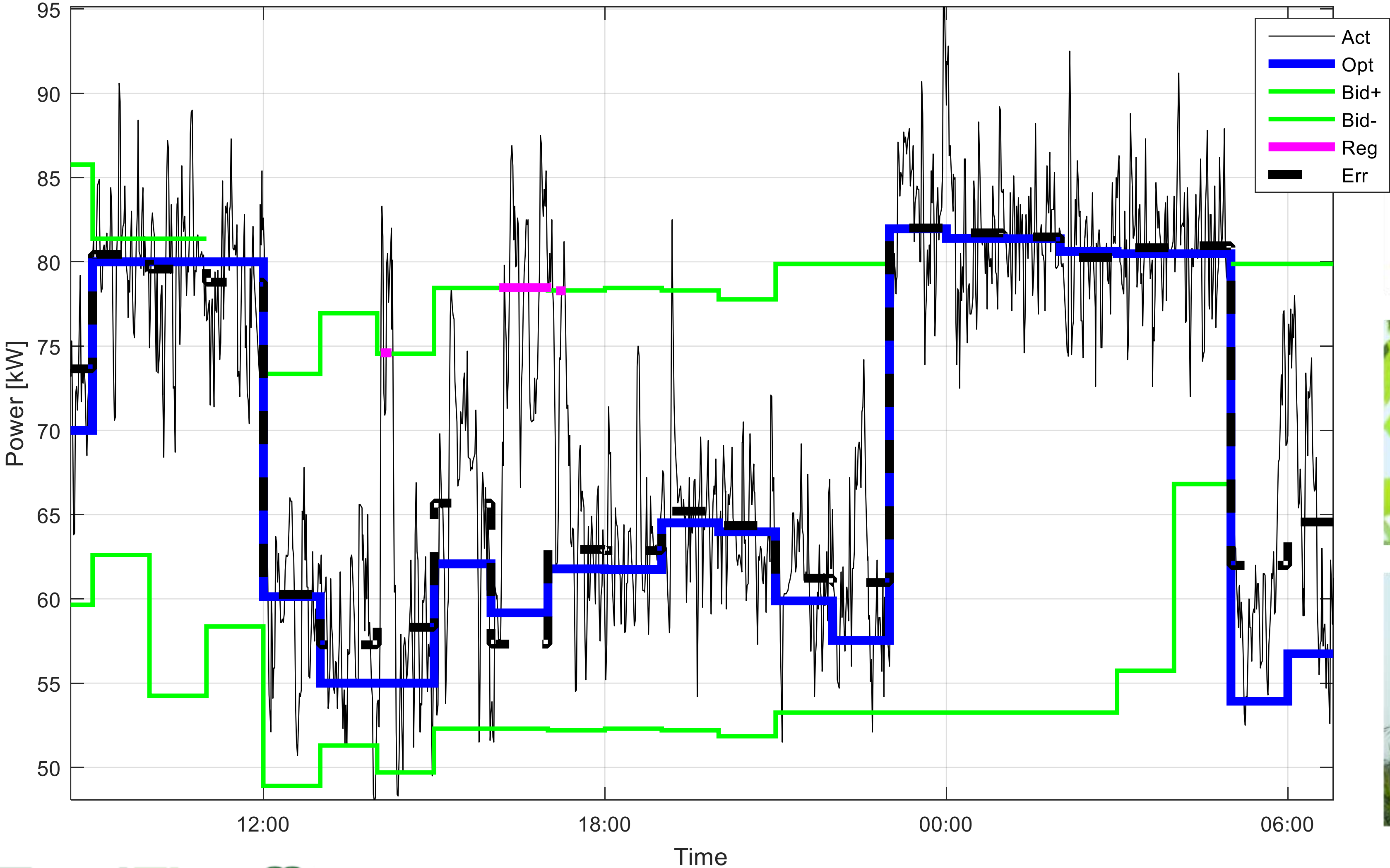
Pool performance feb 3rd 2015



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Heat pump demonstration

- Heating season not started yet
  - live demo of heat pump will start in October

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Demonstration simulated street

- Typical street with residential houses
  - Consumption with extra installed heat pumps and EV forecasted and simulated
- Flex-offers can be generated

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Flex-offer basics

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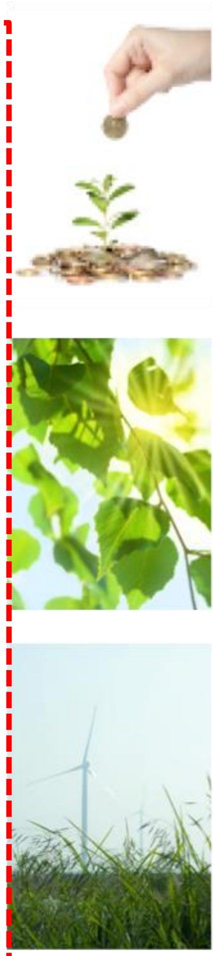
Types of DEMAND (in HOUSEHOLD)

Non-flexible

- Lamp
- TV
- Computer
- Cooking Stove

Flexible

- Refrigerator
- Air conditioner
- Dishwasher
- Electric vehicle



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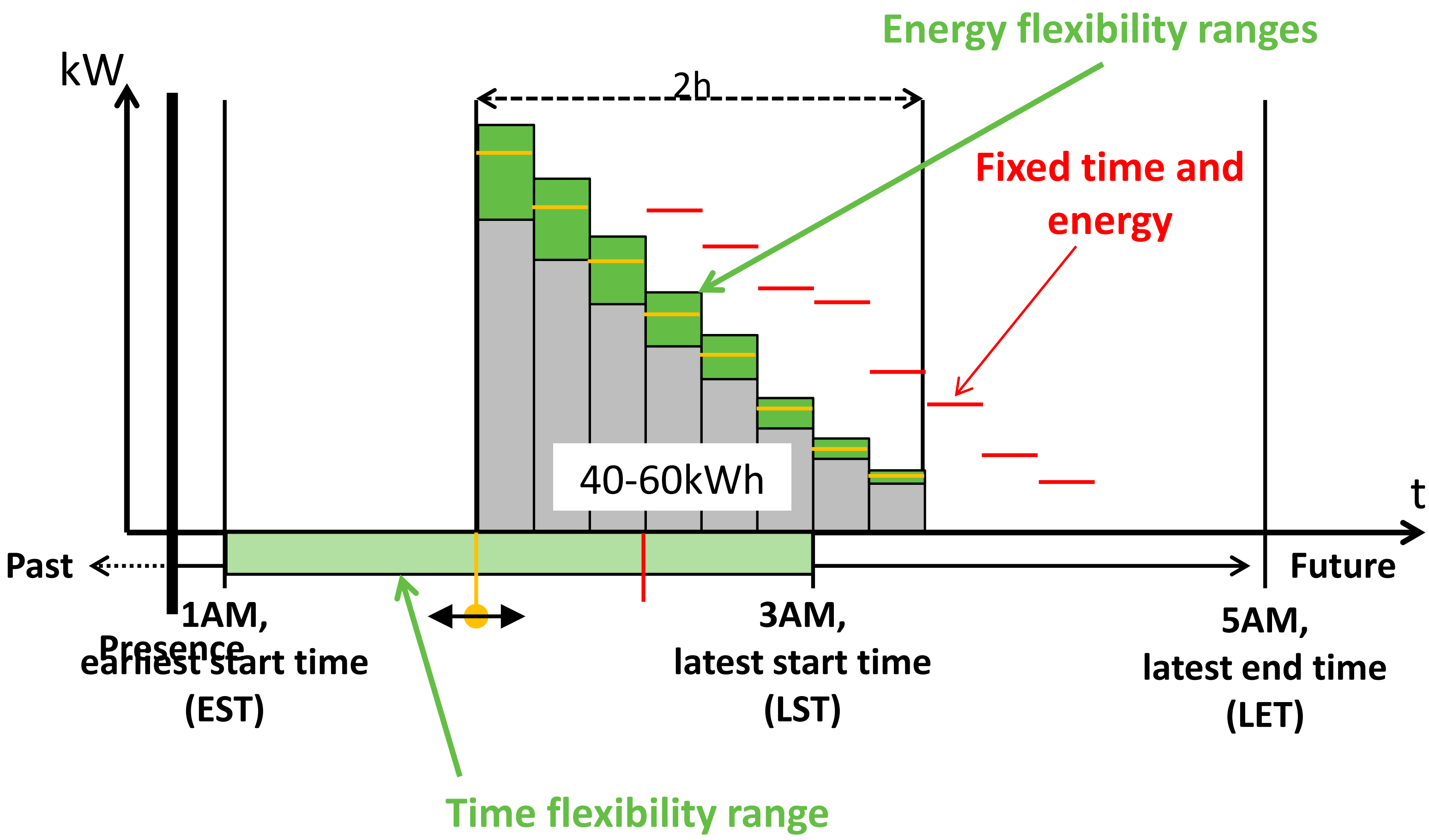
Flexible Offer (FlexOffer):

- Represent flexible demand (and supply) in the unified way



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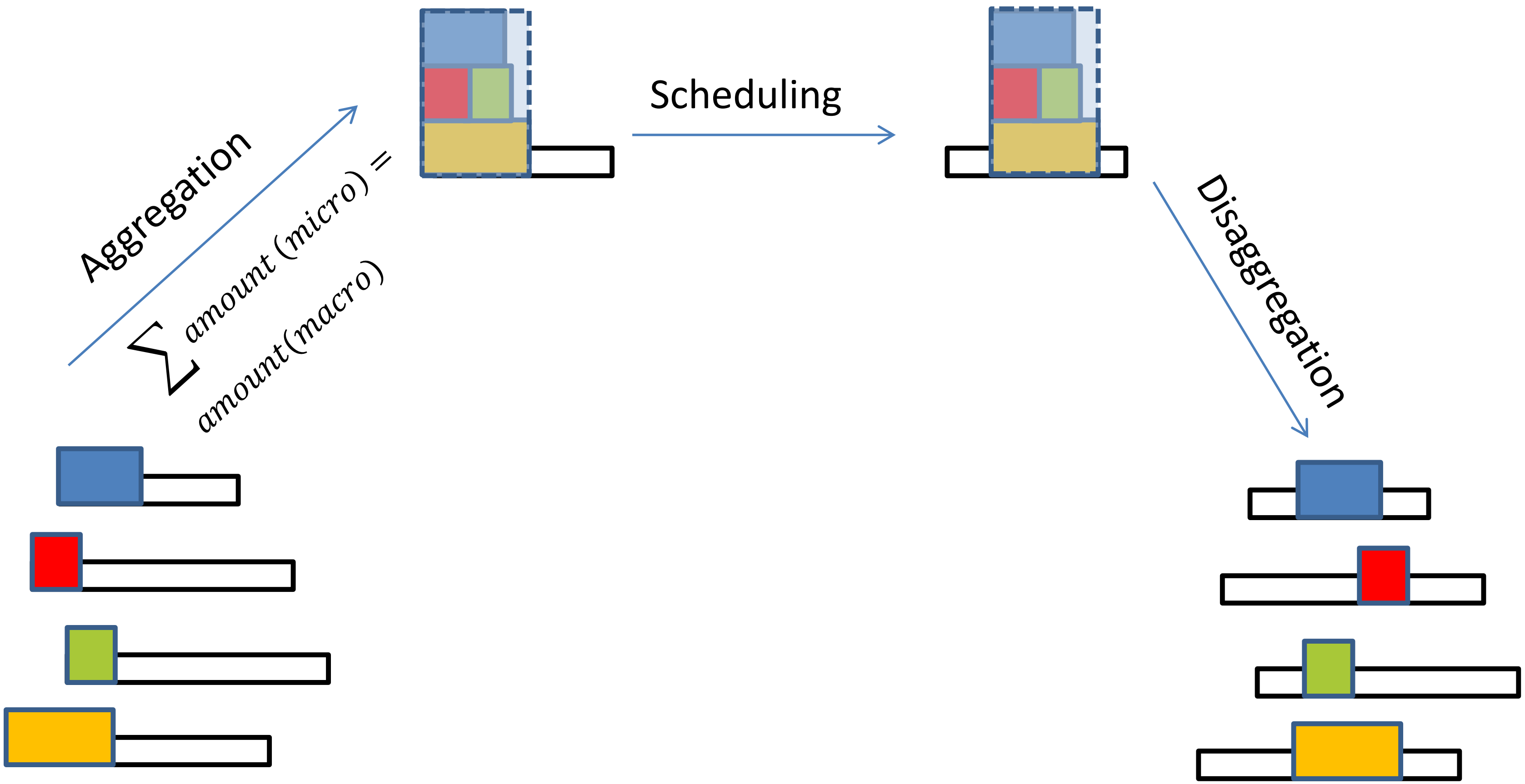
The cycle of FlexOffer Aggregation and Disaggregation



Collected from prosumers

Distributed back to prosumers

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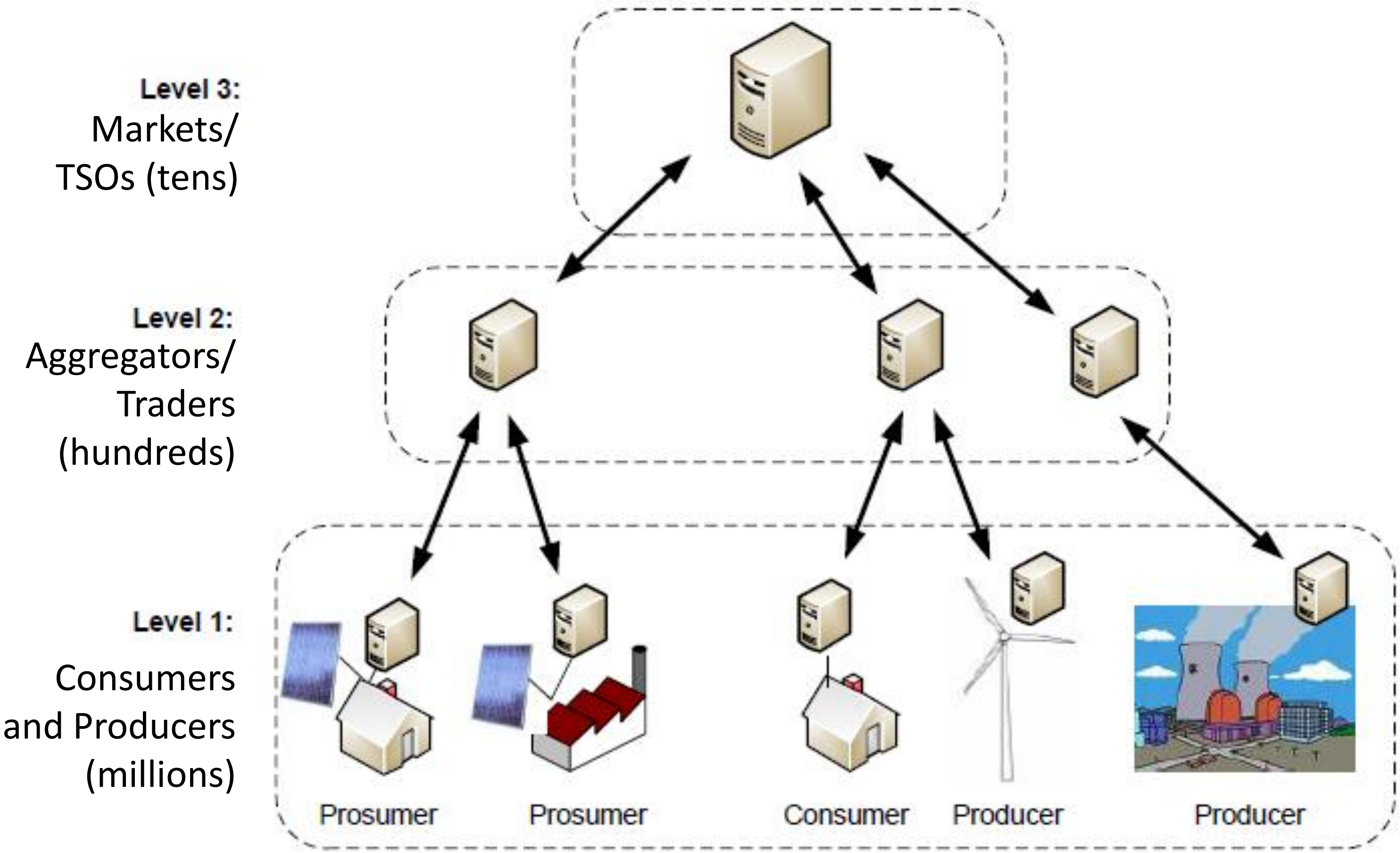
Energy Data Management System (of MIRABEL)



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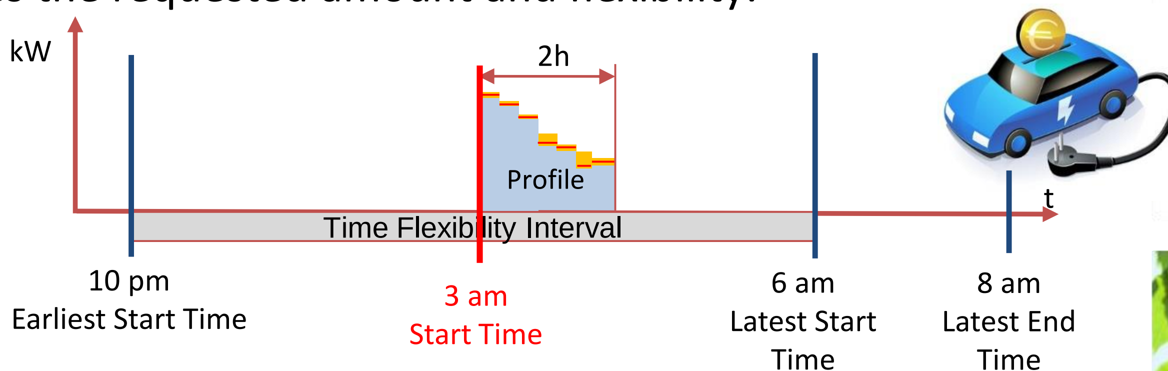
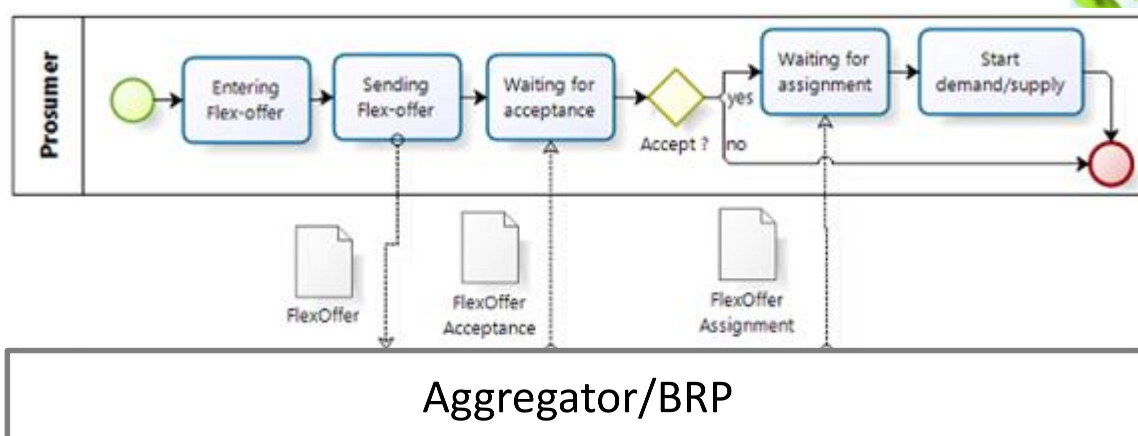
FlexOffer Use Case Example (Part 1)

1. At 10pm, a consumer arrives home and wants to recharge the electric car’s battery at lowest possible price by the next morning. Completion time is 8 am.
2. The consumer’s LEDMS generates a FO
3. The FO explicitly defines the requested amount and flexibility:



4. A negotiation with Aggregator is started until energy is consumed



5. Aggregator rewards the consumer for its flexibility

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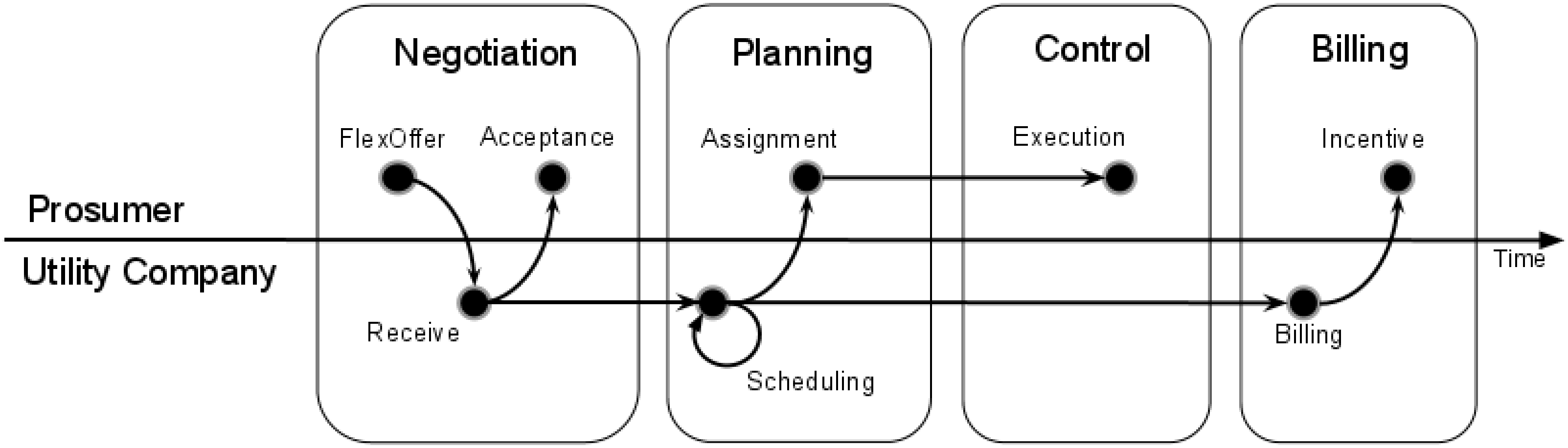
FlexOffer LifeCycle



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Aggregator role

Laurynas Šikšnys

Emmanouil Valsomatzis

Katja Hose

Torben Bach Pedersen

Per Dahlgaard Pedersen

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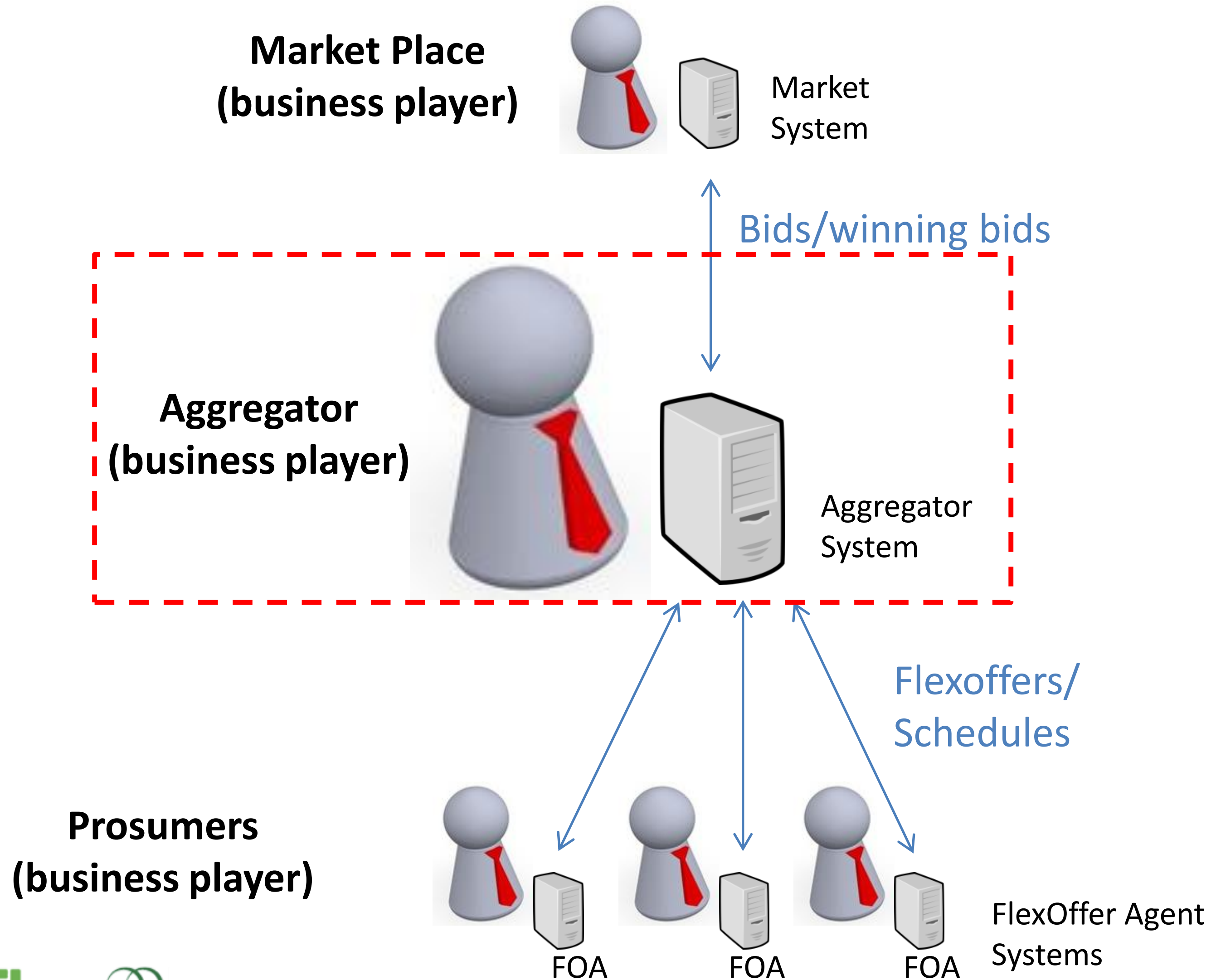
Aggregator's context



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Aggregator Overview

Aggregator is a business entity.

- Contracted with Prosumers
  - Having the right to control DERs
  - Having obligations of delivering the required *price, temperature comfort*, CO_2 *footprint*, etc.
- Acts as a Commercial Virtual Power Plant (CVPP)
  - Providing visibility and (near) real-time control of DERs.
- Makes CVPP available on the Market Place
- Utilizes:
  - Flex-offer Concept
  - Flex-offer Aggregation
  - Flex-offer Disaggregation
  - Market Bid Generation
  - Flex-offer Scheduling (optimization)

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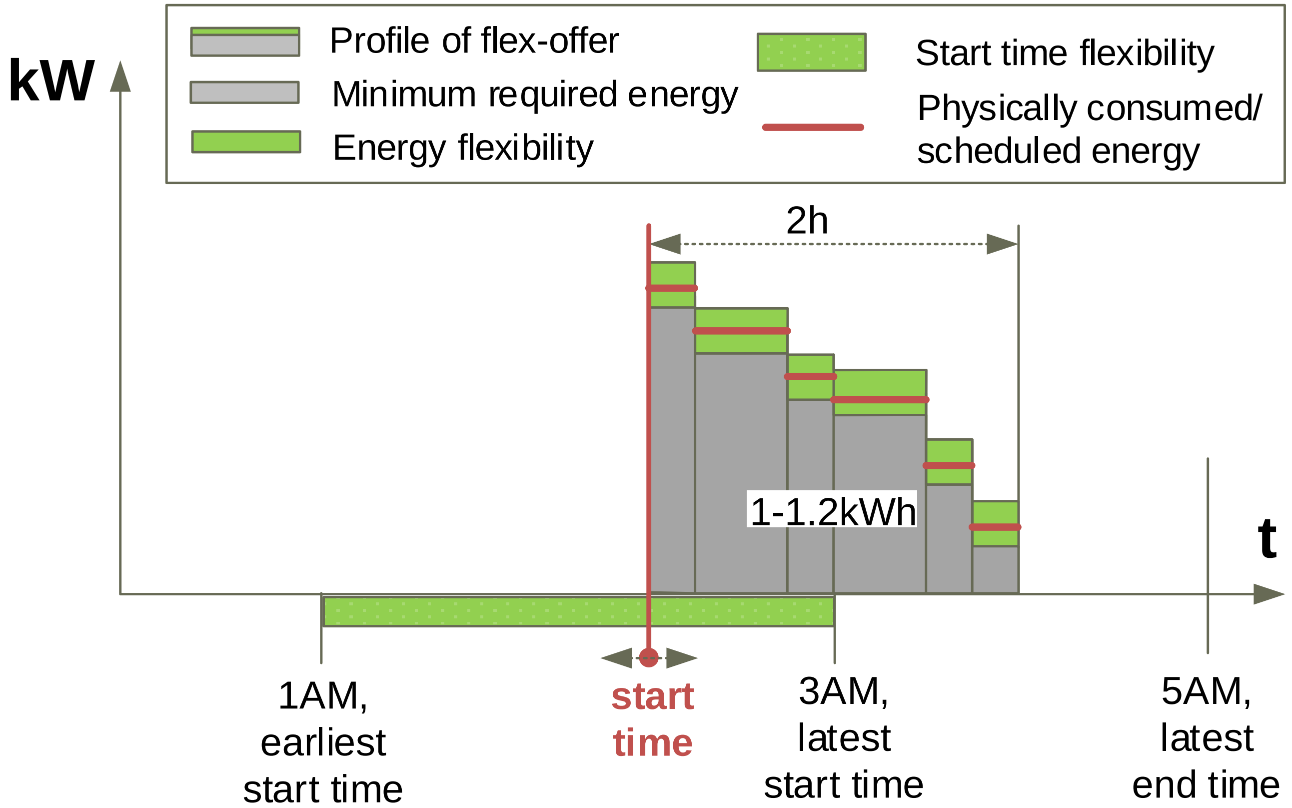
Functionality Overview

- Collection and management of flex-offers from Prosumers



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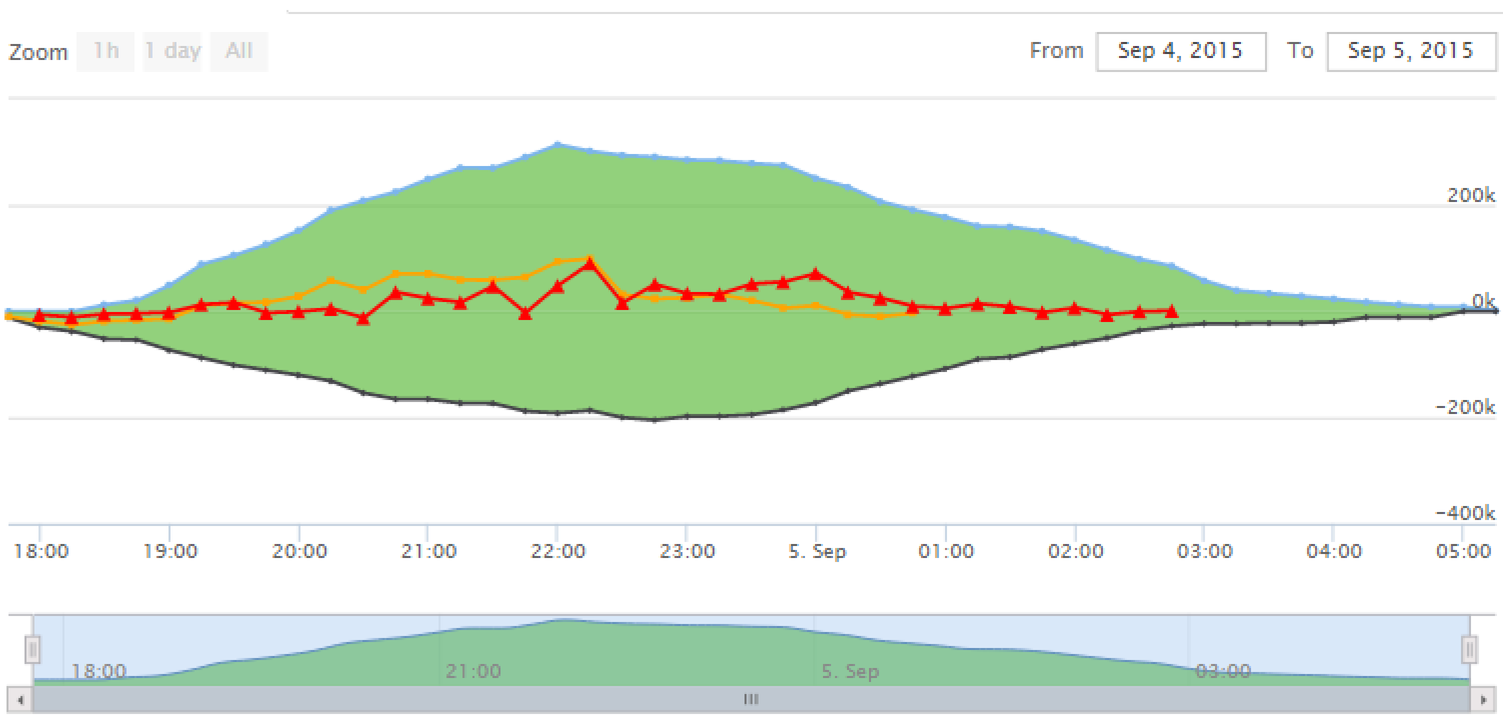
Functionality Overview

- Collection and management of flex-offers from Prosumers



The area of scheduling opportunities

Default operation (baseline)

One of many possible schedules

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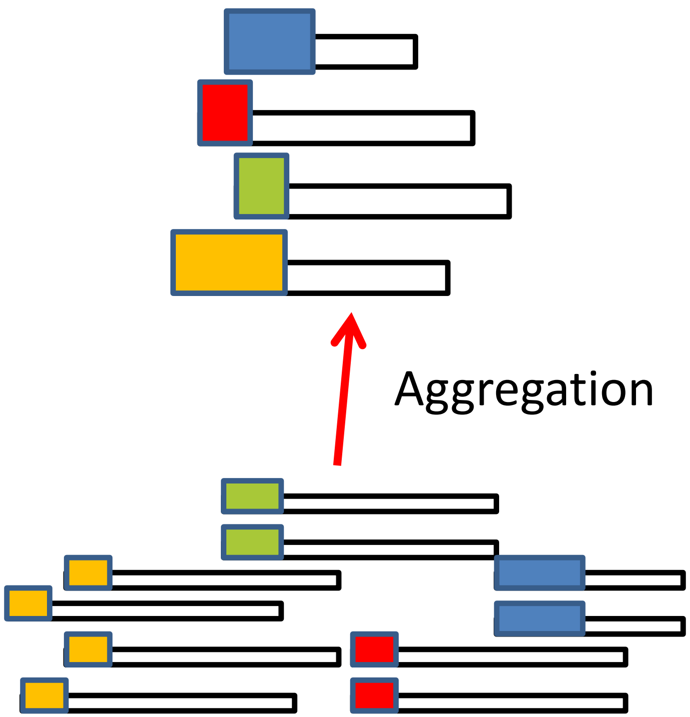
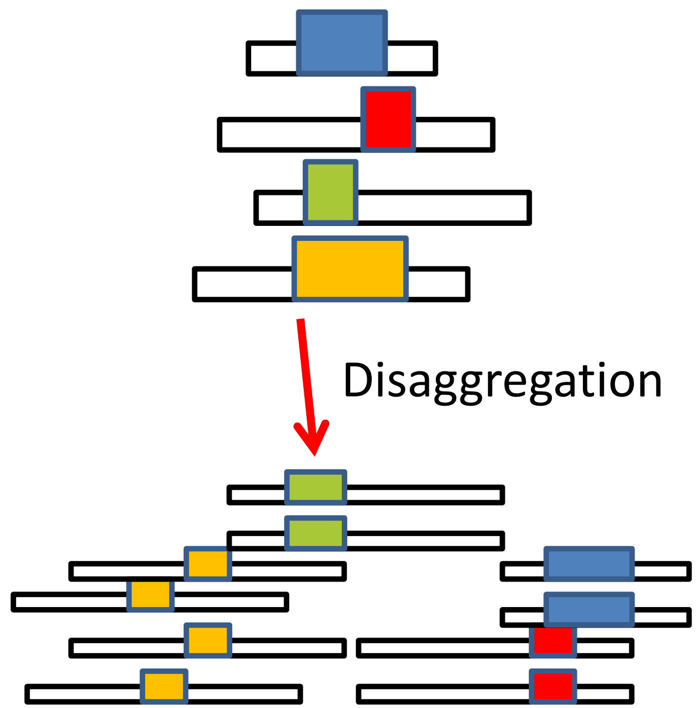
Functionality Overview

- FlexOffer Aggregation and Disaggregation





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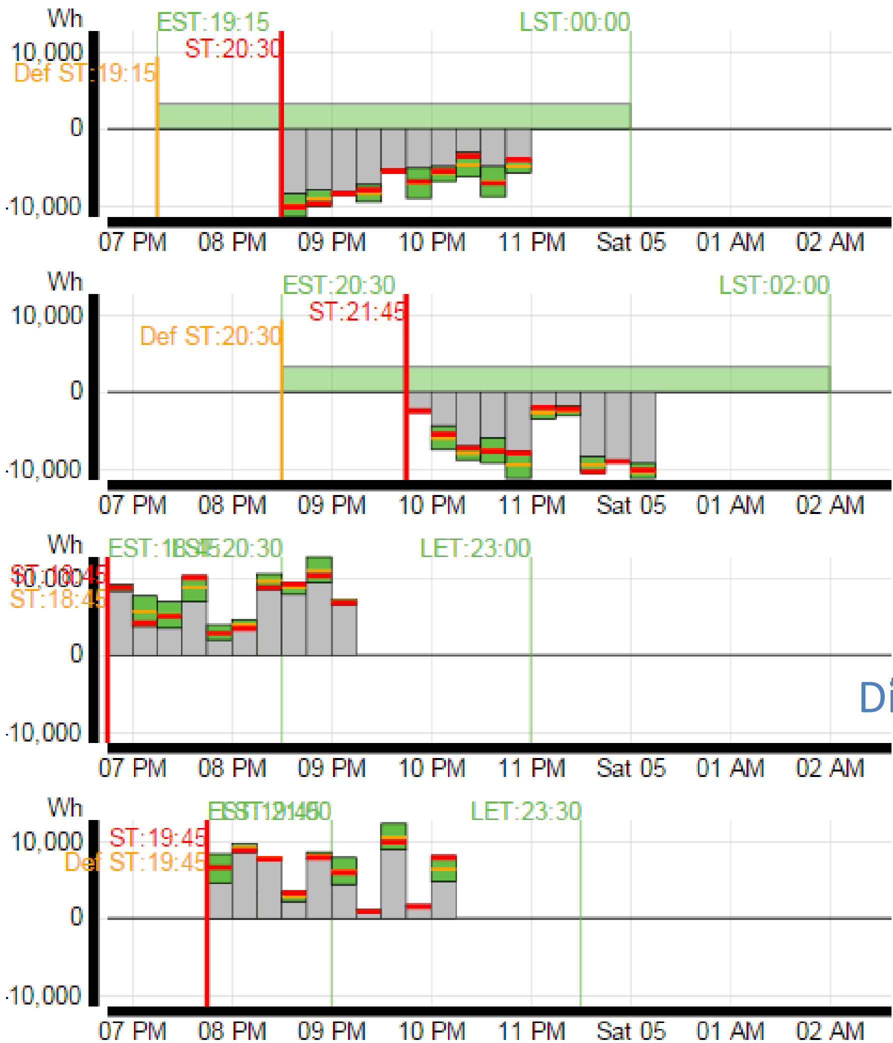
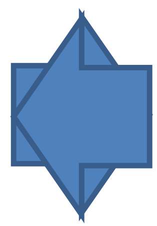
Functionality Overview

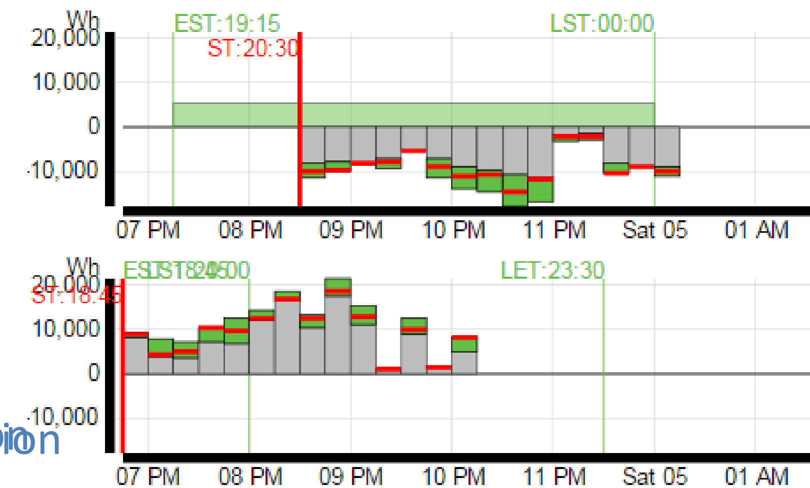
- FlexOffer Aggregation and Disaggregation





Aggregation

Disaggregation



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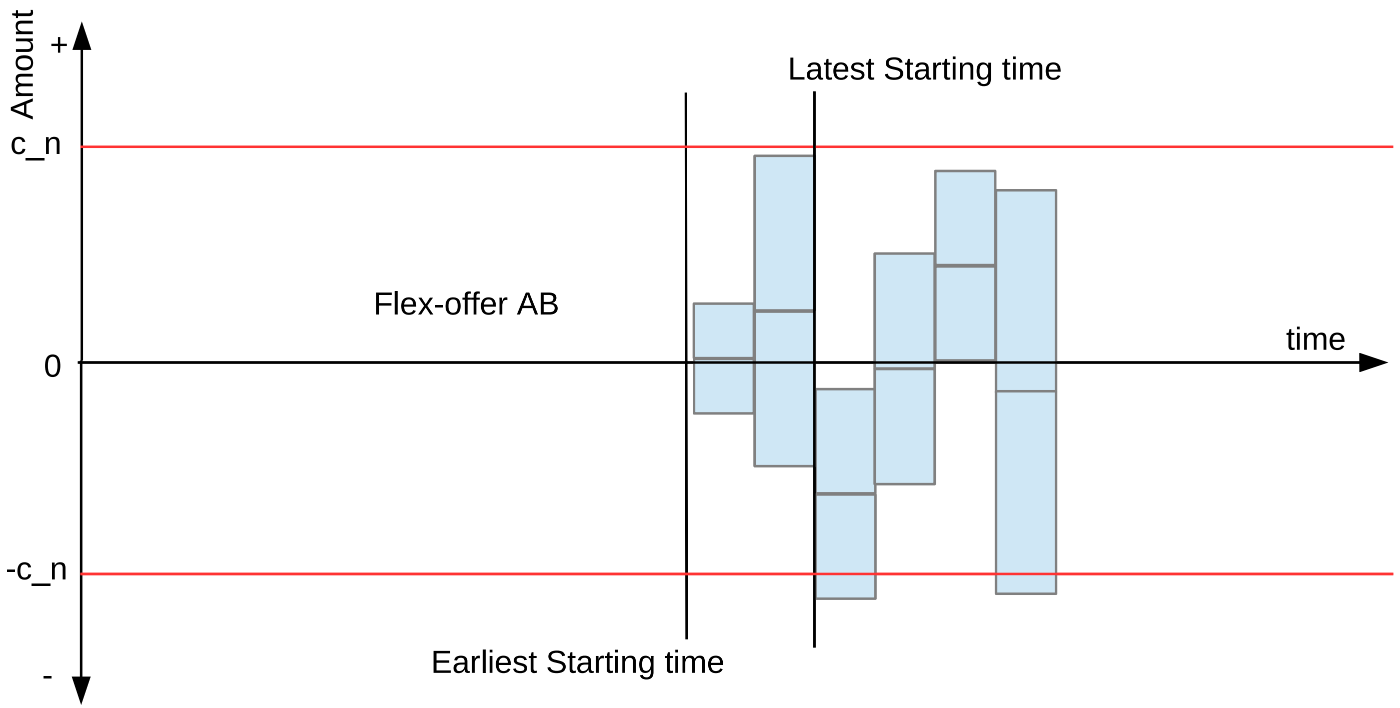
Functionality Overview

- Advanced Aggregation



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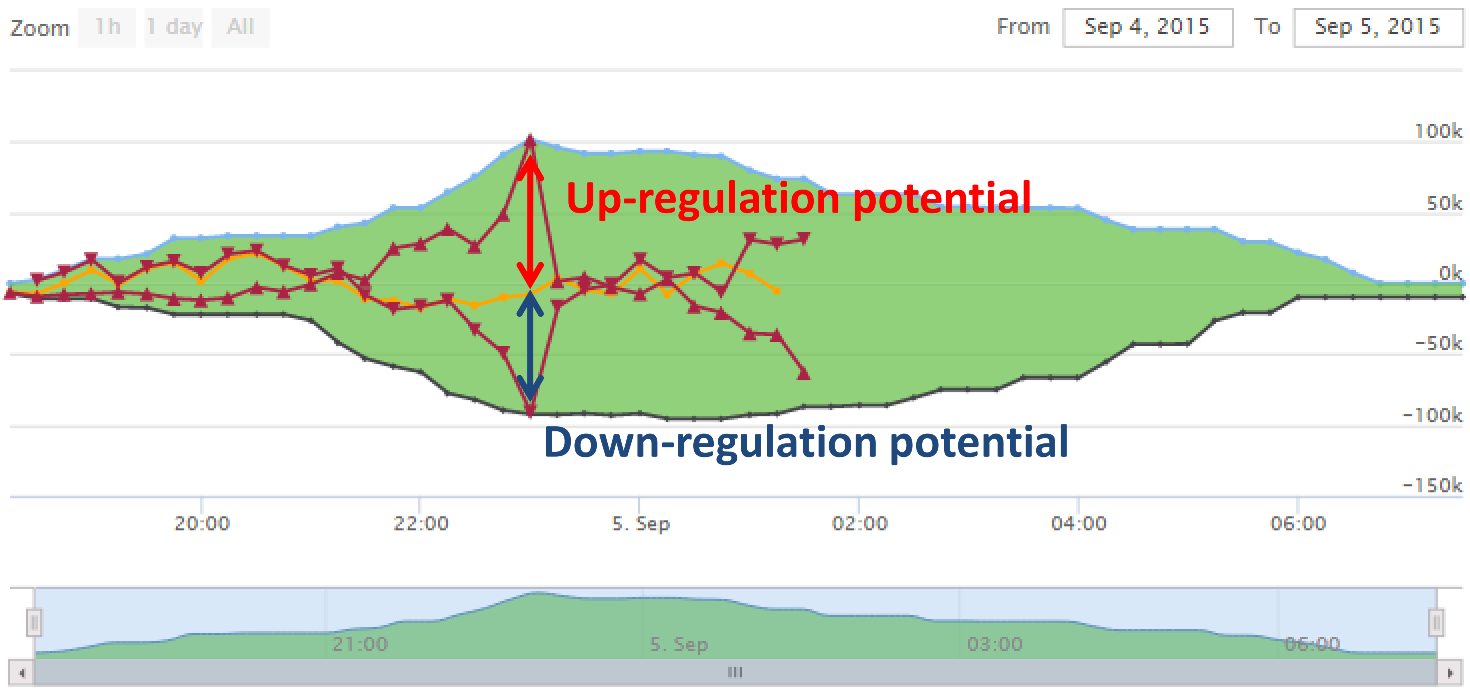
Functionality Overview

- Market Bid Generation



Select the bid start-time

23 : 00

Generate a pair of bids | Send the bid pair

Bid Id	Type	Quantity	Prices
Positive bid	Positive	109.57 kWh	186.03 DKK/MWh
Negative bid	Negative	83.11 kWh	192.37 DKK/MWh

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Functionality Overview

- Market Bid Generation
  - Bid prices estimated based on prosumer contracts / bills

Prosumer bill

Item	Value	Price
Number of flexoffers	20	
Fixed reward for all flexoffers		10.00 DKK
Total Time Flexibility	328 time units (15 min)	32.80 DKK
Total Energy Flexibility	393,018.43 Wh	39.30 DKK
Number of default schedule deviations	20	2.00 DKK
The sum of stat time scheduling deviations with respect to the default schedule	26 time units (15 min)	5.20 DKK
The sum of energy deviations with respect to the default schedule	147,075.19 Wh	29.42 DKK
Total Reward		118.72 DKK

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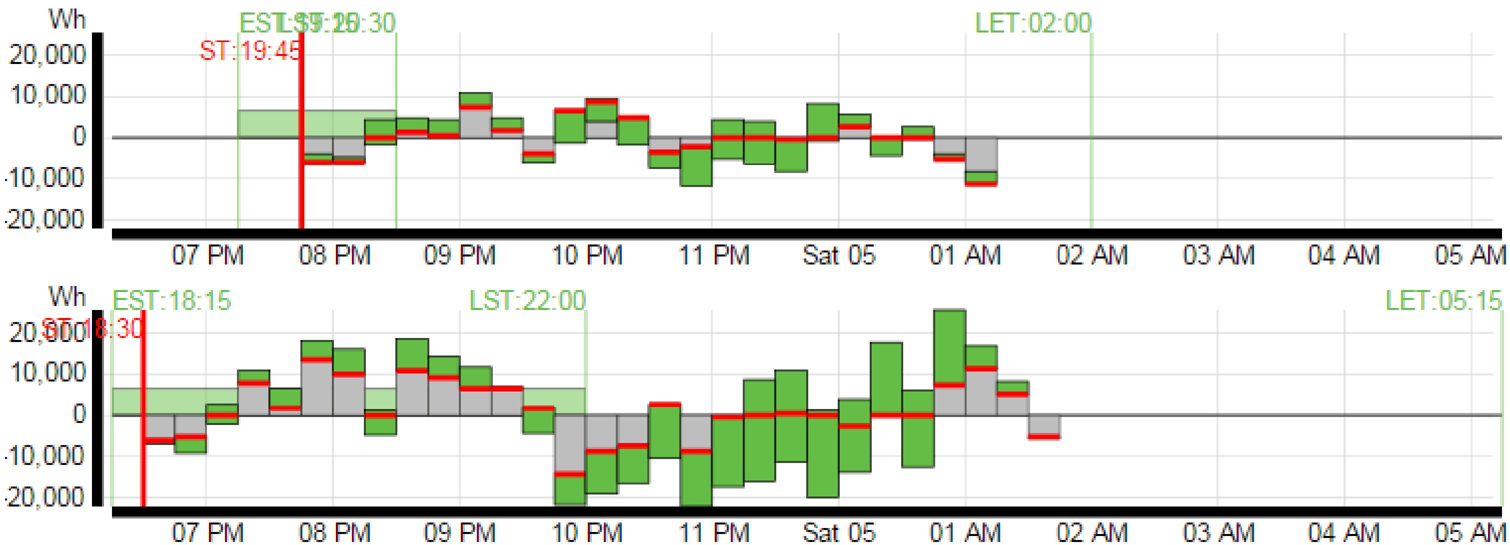
Functionality Overview

- FlexOffer Scheduling

Synchronize Time Axis ☑ Amount Axis ☑

View As: Graph ▾



Welcome to the CBC MILP Solver Version: 2.9.4 Build Date: May 19 2015 command line - SolverLP Interface -maxNodes 10 -solve -quit (default strategy 1) maxNodes was changed from 2147483647 to 10 2 SOS with 22 members processed model has 144 rows, 137 columns (22 integer (22 of which binary)) and 1498 elements SolverLP: Solved 1 partitions. The partitioning took 0.000053 secs. Solving took 0.313115 secs. Total solving time is 0.314072 secs.

Execute Query | History ▾ | Pre-defined queries ▾

SELECT execute(schedule(aggregate(fo))) FROM fo_get_simple

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DSO challenges and benefits

Research coducted by:

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Jayakrishnan R. Pillai, jrp@et.aau.dk

Iker Diaz de Cerio Mendaza, idm@et.aau.dk

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Scope…

- A DSO is responsible for the reliable supply of electricity to consumers.

- The traditional loading of the grid will change due to:

    1. Power-hungry and partially controllable loads, e.g., Heat Pumps (HP) and Electric Vehicles (EV)

    2. Intermittent dispersed generation, e.g., Photovoltaics (PV)

- These new trends will compromise the reliability of the grid.

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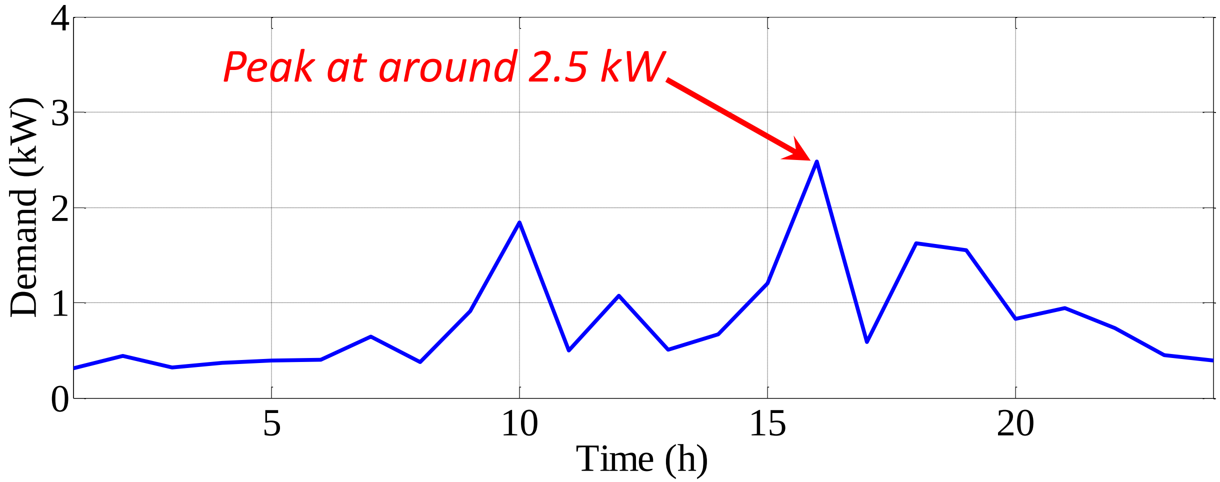
Scope...

- As an example:



- A typical residential HP rating is approximately 2kW
- A typical EV rating is around 11kW
- The coinciding peak of HP-EV-Household might add up to 15.5 kW for this example, i.e., *more than 6 times the present household peak*!

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Scope…

- For this upcoming problem the Distribution System Operator (DSO) has two options:

  1. **Reinforce the grid**, i.e., upgrade the capacity
     a) *Costly*
     b) *Simple and efficient*
  2. Proceed to control mechanisms or flexibility markets via **Smart Grid**
     a) *Complicated, unprecedented planning, several issues to be solved such as privacy, malicious attacks, standardisation etc.*
     b) *Less expensive, delays reinforcement, enhanced monitoring, facilitates control, benefits such as peak shaving, loss minimization, congestion prevention etc.*

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Problem…

- The DSO is able to control or request control of the loads due to their flexibility potential
- How does the DSO calculate the required flexibility?
- This is the task of the **Technical Virtual Power Plant** (TVPP)
- The TVPP utilises knowledge over the expected loading and total available flexibility of the grid to calculate the required load flow modifications
- These will result in solving Voltage and Current/Power flow problems

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Solution…

- To calculate the required flexibility and optimisation framework is employed:

1. According to Newton-Raphson load flow (LF)

$$\begin{pmatrix} \Delta P \\ \Delta Q \end{pmatrix} = \underbrace{\begin{pmatrix} dP/dV & dP/d\vartheta \\ dQ/dV & dQ/d\vartheta \end{pmatrix}}_{\text{J (i.e. Jacobian matrix)}} \begin{pmatrix} \Delta V \\ \Delta\vartheta \end{pmatrix}$$

Linear model, iterative solution

2. By solving the LF and inverting J:

$$\begin{pmatrix} \Delta V \\ \Delta\vartheta \end{pmatrix} = \begin{pmatrix} \quad \mathrm{J}^{-1} \quad \end{pmatrix} \begin{pmatrix} \Delta P \\ \Delta Q \end{pmatrix}$$

The first row relates flexibility (*ΔP, ΔQ*) to voltage changes (*ΔV*)

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Solution…

3. Voltage constraints:

   - ***$Vmin < V+\Delta V < Vmax$***
   - *V is the voltage as calculated by the load flow*
   - *Vmin, Vmax are set by grid codes (e.g. Vmax = 1.05 pu)*

4. Overcurrent/Overload constraints:

   - ***$|P + \Delta P| < (V + \Delta V)\ Imax\ \cos\varphi$***
   - ***$|Q + \Delta Q| < (V + \Delta V)\ Imax\ \sin\varphi$***
   - *P, Q is the power which is already flowing in the grid*
   - *Power factor is assumed to be constant (flexibility << non-flex load)*

5. Flexibility constraints:

   - ***$\Delta Pmin < \Delta P < \Delta pmax$***
   - *Δpmin, Δpmax are the flexibility limits of the consumers/devices*

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Solution…

6. Objective function:

    - ***Min(ΔPall)***
    - *Δpall refers to the total flexibility of the network (i.e. Δpall = ΔP1 + ΔP2 + ΔP3, where ΔPi refers to the flexibility offered by the ith consumer/device)*

- The *DSO* would buy as little flexibility as possible in order to alleviate his grid limit violations

- However, the objective function is flexible in incorporating costs or other, e.g., fairness, factors *Ci:*

    min(C1 * ΔP1 + C2* ΔP2 + C3* ΔP3 …)

- Other constraints might involve the power factor, the voltage unbalance etc.

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Solution…

A simulation example…

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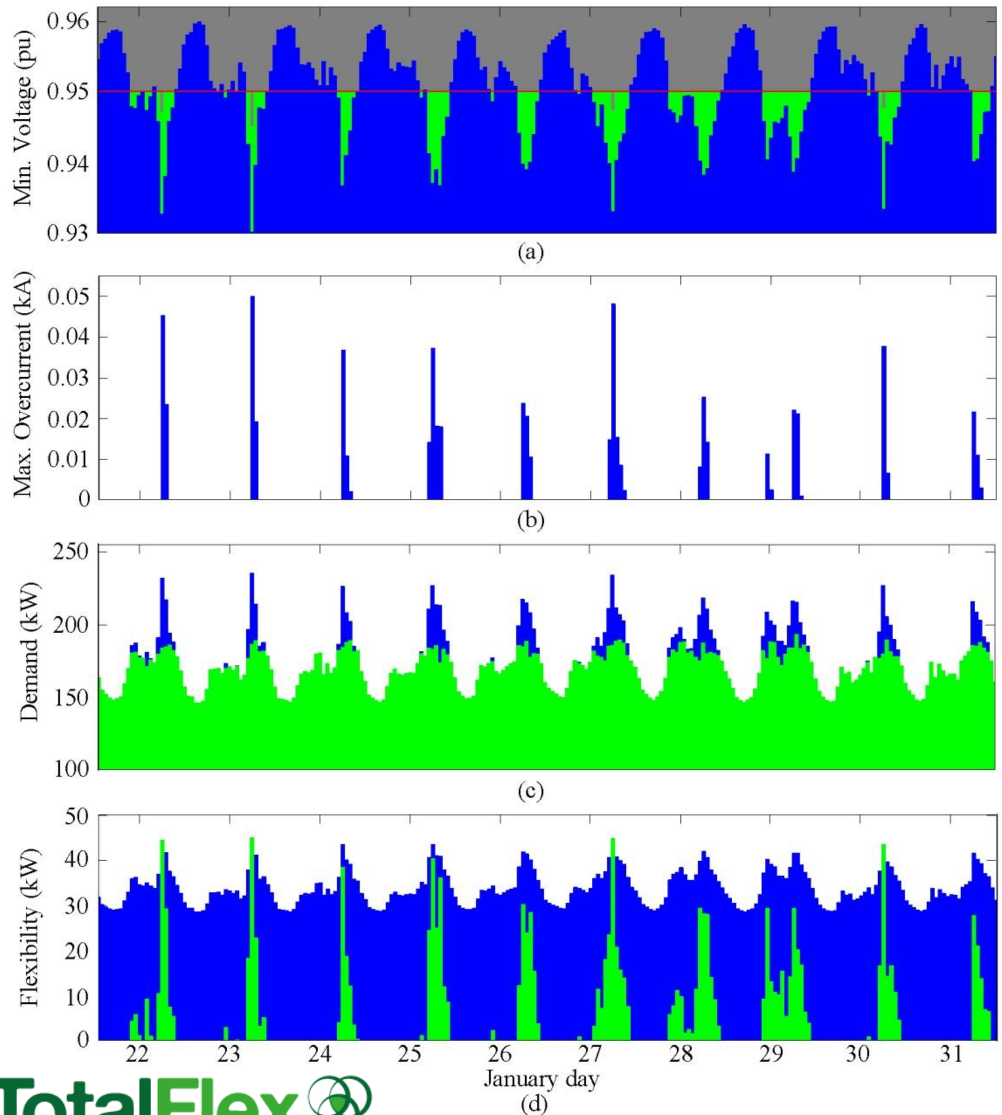
Results…

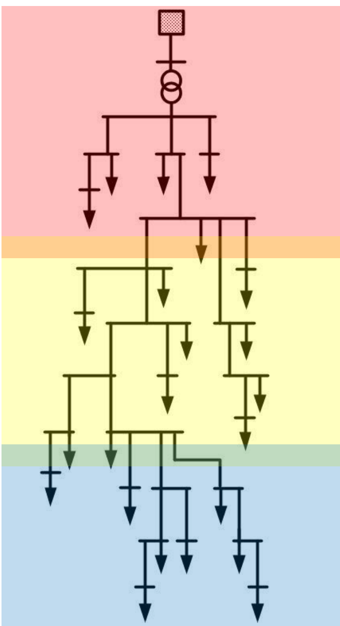
- Applying the problem to a heavily loaded grid:

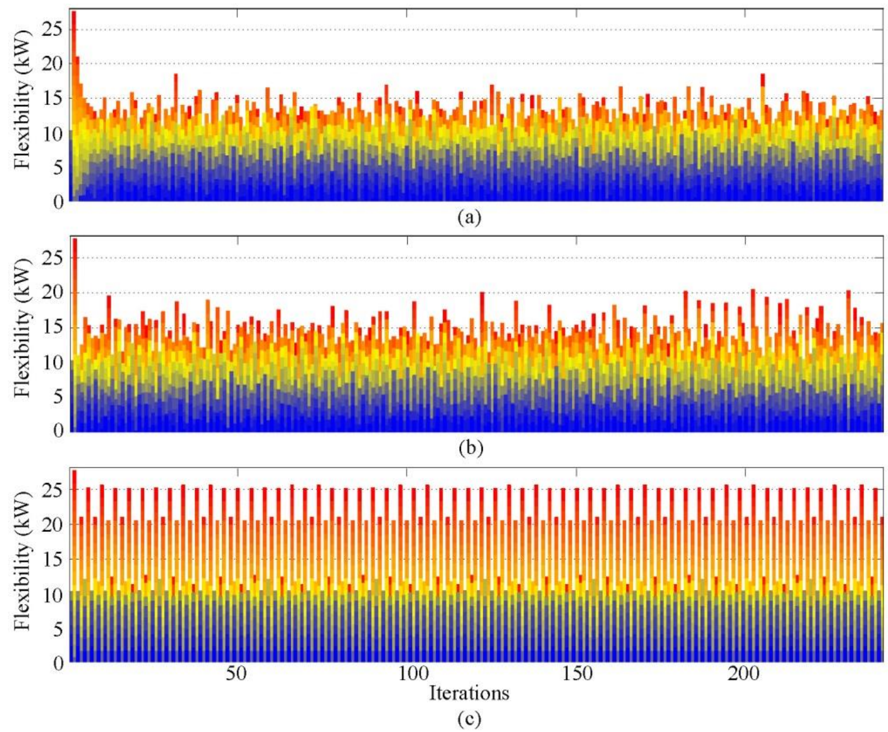


If flexibility cannot solve the problem, then the best possible solution is obtained (relaxation variables)

Results…

- Another issue which is applied is the ”fairness”, i.e., a tuning factor which enables the algorithm to produce **sub-optimal** solutions for the same problem.





- Different solutions are provided which will aid in fair activation of flexibility and a variety of bidding options

Conclusion…

More information regarding:

- ***Congestion management***
- ***Forecasting of load/flexibility***
- ***Estimation of flexibility***

…will be provided personally at the poster show area.

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TotalFlex demonstration

Market Place for flexibility

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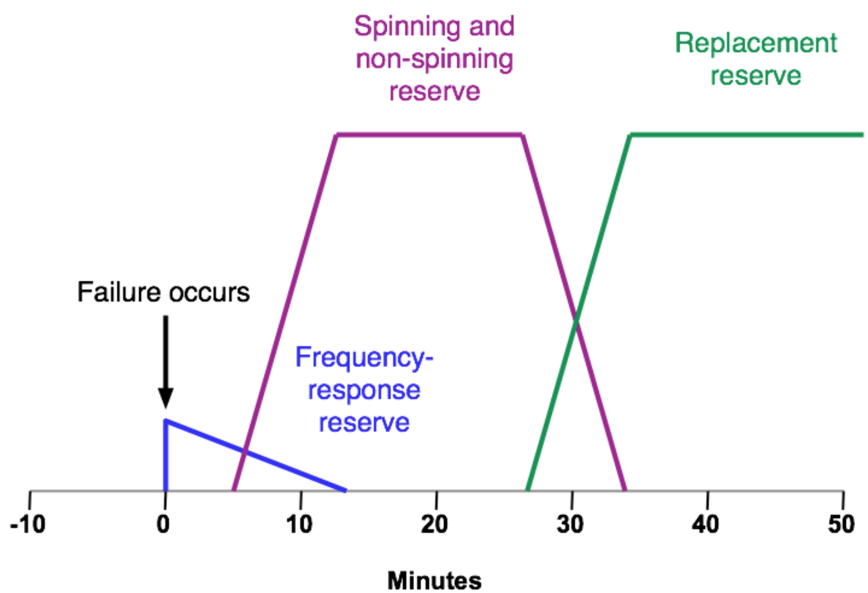
Existing energy markets

- Day ahead
  - Spot market
- Intra day
  - Elbas
- Intra hour
  - Frequency reserve
  - Regulating power
  - Manual reservers



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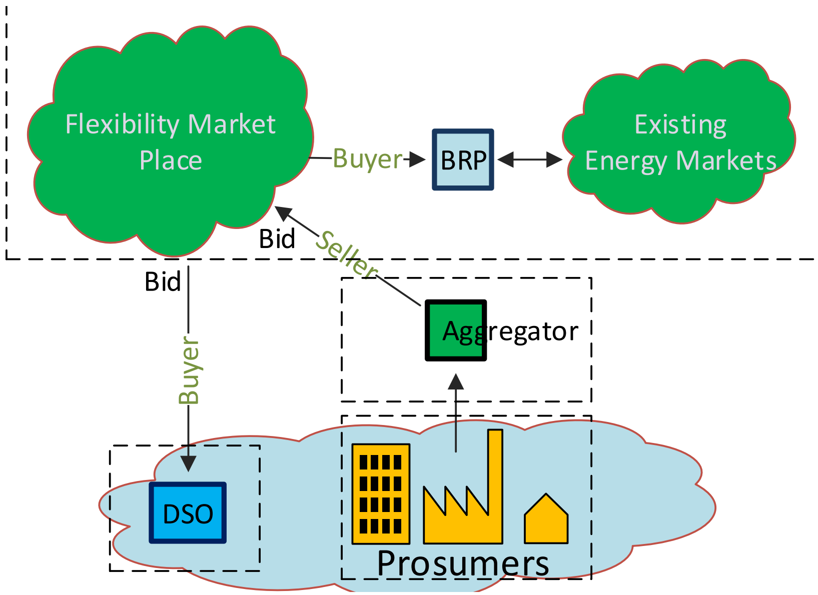
Market Place

- Type
  - Electronic market place
- What is sold?
  - Flexibility bids, right to decide when consumption or production take place



- Sellers
  - Prosumers, sometimes via aggregators
- Buyers
  - DSOs, BRPs

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Market Place

- Market Place might exist for all existing phases of energy markets
  - Long term, Day ahead, intra day, intra hour, 5 minute, online or on demand
- Many variants
  - Several time horizons maybe with dependencies like mutual exclusivity
  - Divisible or indivisible amounts
  - Multiple exclusive bids from same device
  - Parallel market clearing for overlapping geographical areas
- How is the market cleared?
  - Marginal price setting, best price for seller
- How is settlement done with prosumer?
  - Various contracts
  - Imbalance considerations

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TotalFlex demonstration

Introduction to live demo

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Demonstration - basic assumptions

- 15 min intra hour market for up/down flexibility
- Independent and simultaneous bids from buyer and sellers
- Seller
  - Water heater, freezer, simulated street
- Buyer
  - Simulated buyers

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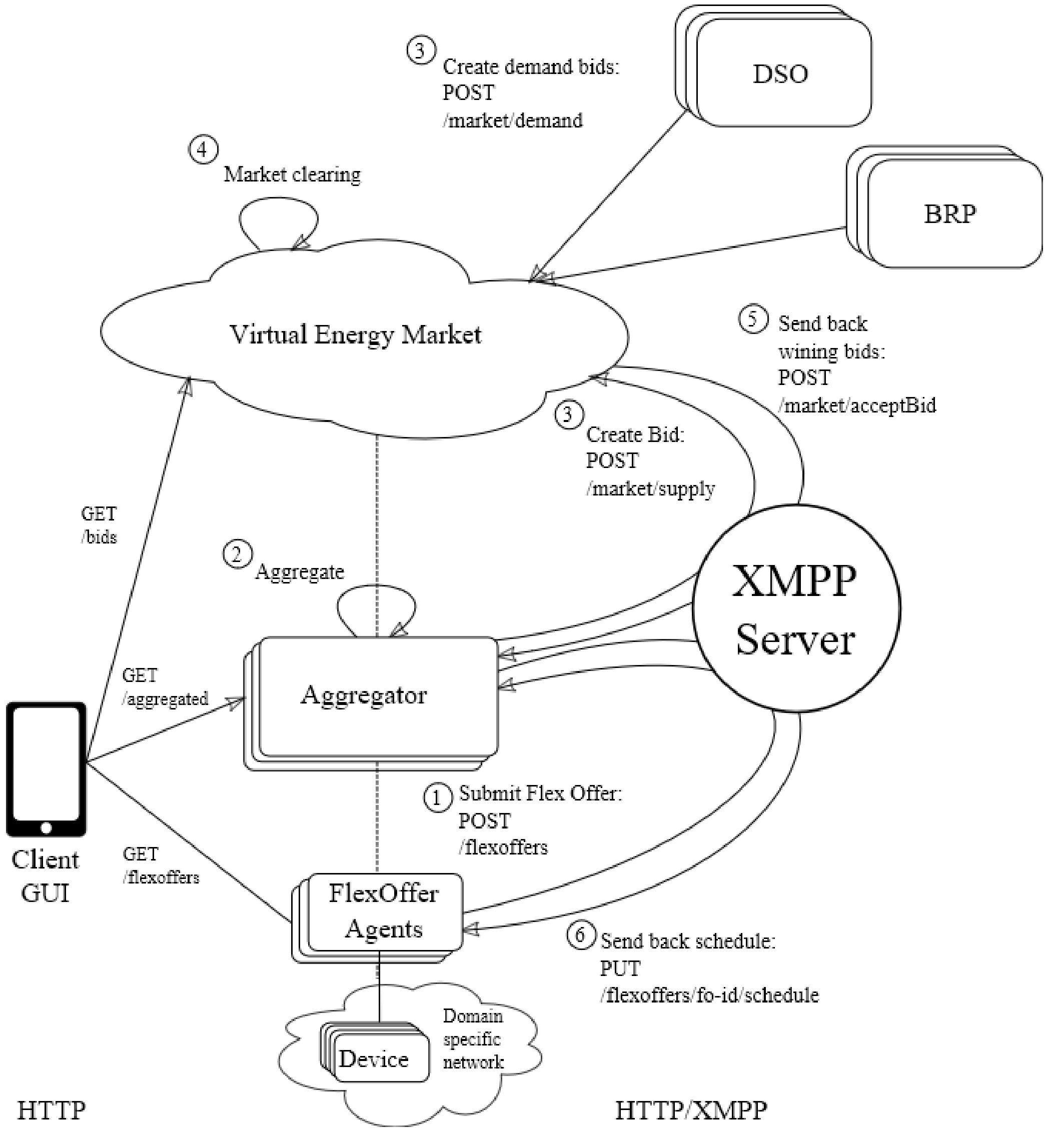
Architecture



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TotalFlex demonstration

Live demo

TotalFlex

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TotalFlex demonstration

Summary and next step

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Summary

- Simple realization of a flexibility market has been shown
- Secures the prosumer the highest payment for flexibility
- Via the flex-offer concept it utilizes all available flexibility, independent of size
- Coexists and supports existing energy markets
- Simple intra hour market clearing has been shown
  - More complex market places will demonstrated

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Questions?

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