Flexible resources to facilitate the smart grid transition – challenges and opportunities

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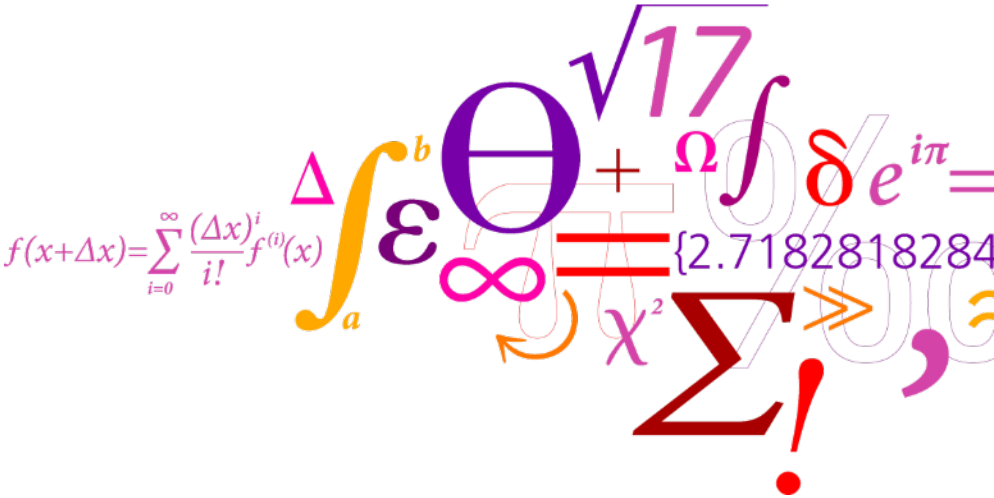


DTU Electrical Engineering
Department of Electrical Engineering

Outline

- Flexible/distributed energy resources

- Challenges in implementing DER response schemes:
  - Technical & control perspective
  - Market and societal aspects

- Opportunities: examples from various Danish research projects
  - Ecogrid 2.0
  - ACES, Parker and CAR

- DTU Risø syslab experimental facility

- Lessons learned

Distributed energy resources – overview

- **Power range 1 kW to 10 MW**

- **Generating**
  - – Photovoltaic; wind;
  - – Mini-hydro; mini-CHP (gas, biomass, waste)

- **Consuming**
  - – Electrochemical storage
    - Stationary/Mobile (EV)
  - – Thermostatically controlled loads
    - Heat pumps; Resistive loads
    - Refrigerators

Defining theoretical and practical flexibility attributes – are grid operators getting what they asked for?

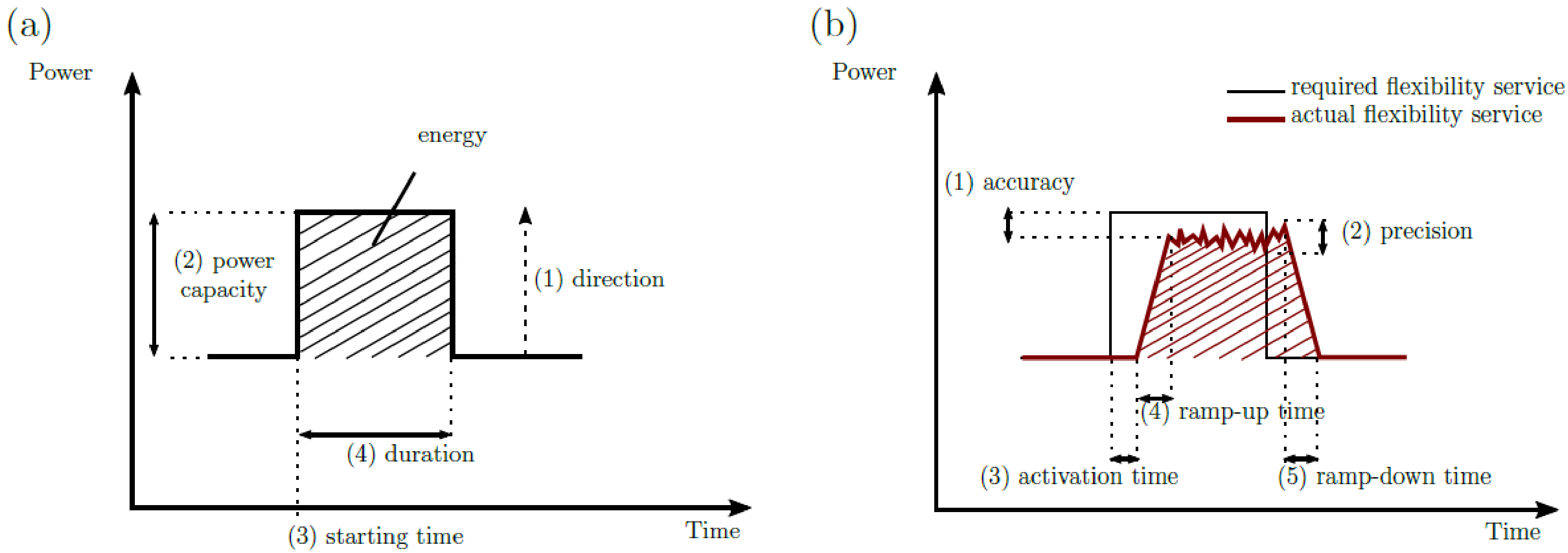


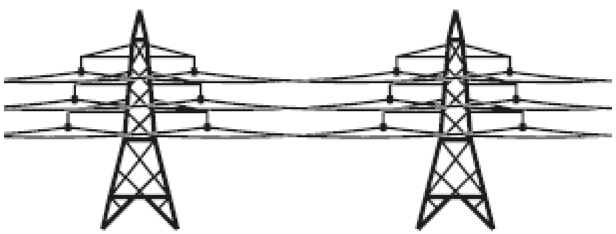
Figure 1: (a) Theoretical and (b) practical attributes of a flexibility service (excluding the location).

K. Knezović, M. Marinelli, A. Zecchino, P. B. Andersen, C. Traeholt, “Supporting involvement of electric vehicles in distribution grids: Lowering the barriers for a proactive integration,” Energy, vol 134, pp. 458-468, Sep 2017.

Grid services, energy market and the DERs - how / where to participate?

Energy market

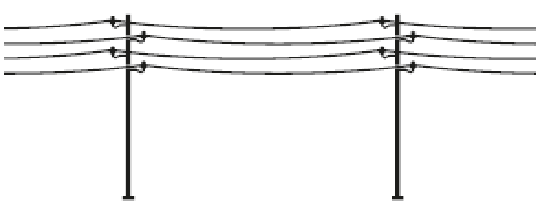
- Buy low, sell high… (bidirectionality needed)
- Charge/consume cheaply…



System services (TSO level; Energinet)

- Frequency (primary) – power based
- Frequency (secondary) – energy based
- Frequency (tertiary/manual) – energy based

→ markets are established, estimating the revenue is direct

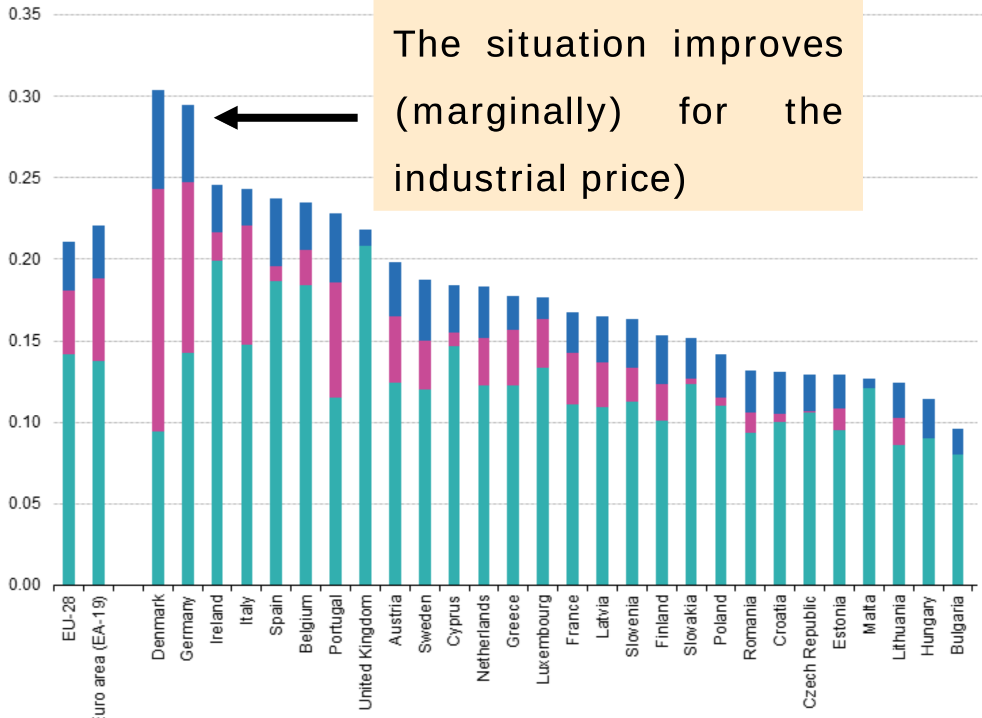


Local services (DSO level; Radius, Seas…)

- Congestion management
- Voltage control
- Phase balancing

→ No markets established, estimating the revenue is tricky…

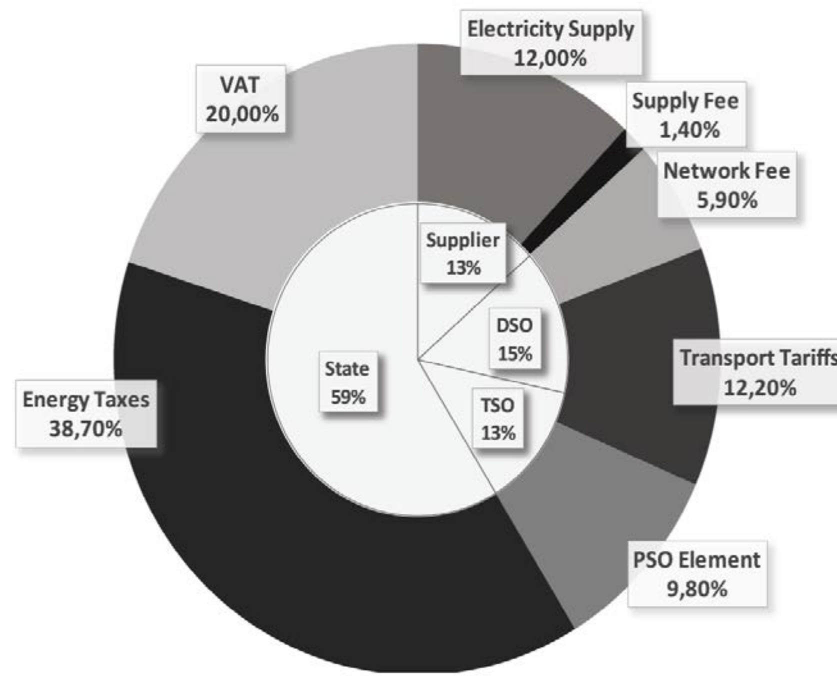
Energy cost breakdown – why energy-related services are not really convenient in Denmark (but may be elsewhere)



The situation improves (marginally) for the industrial price)

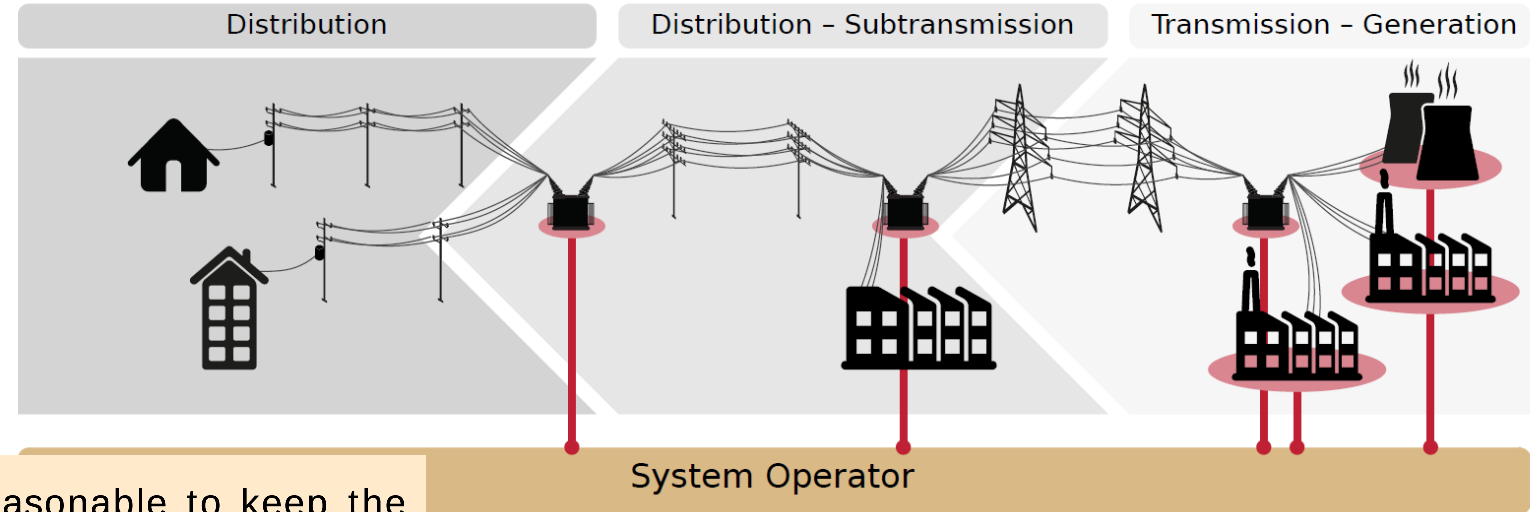
Are we able to convince the customers with such small cake?

(¹) Annual consumption: 2 500 kWh < consumption < 5 000 kWh.
(²) Taxes and levies other than VAT are slightly negative and therefore the overall price is marginally lower than that shown by the bar.

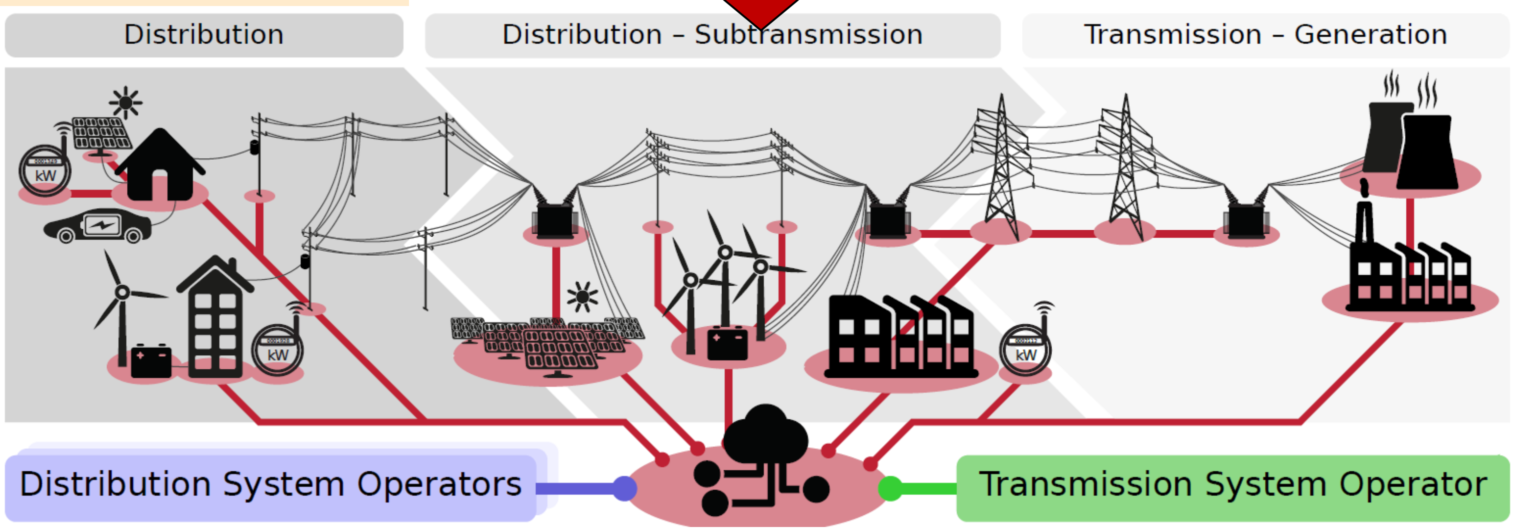


A. Gadea, M. Marinelli, A. Zecchino, "A Market Framework for Enabling Electric Vehicles Flexibility Procurement at the Distribution Level Considering Grid Constraints," 20th Power System Computation Conference (PSCC), Dublin, 11-15 Jun. 2018.

Electric Power Systems (r)evolution

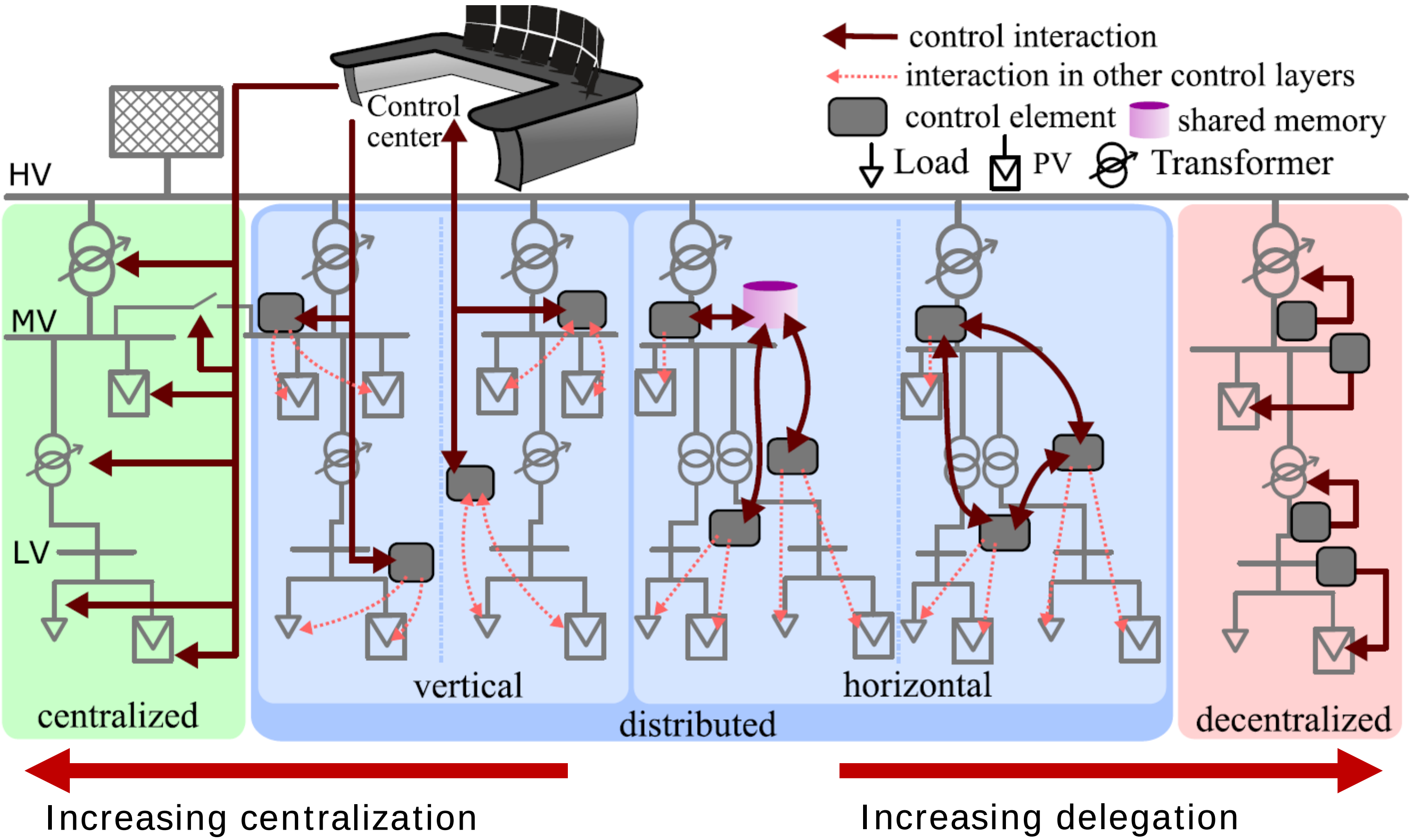


Is it reasonable to keep the same control architecture?



Diagrams courtesy of Alexander Prostejovsky

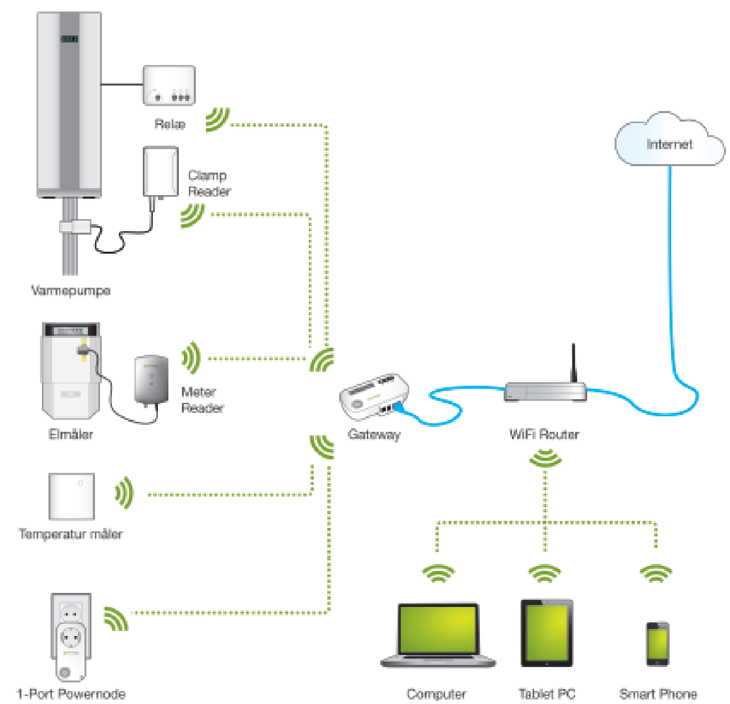
Architectural perspective (centralized, distributed, decentralized) how to leverage the flexibility?



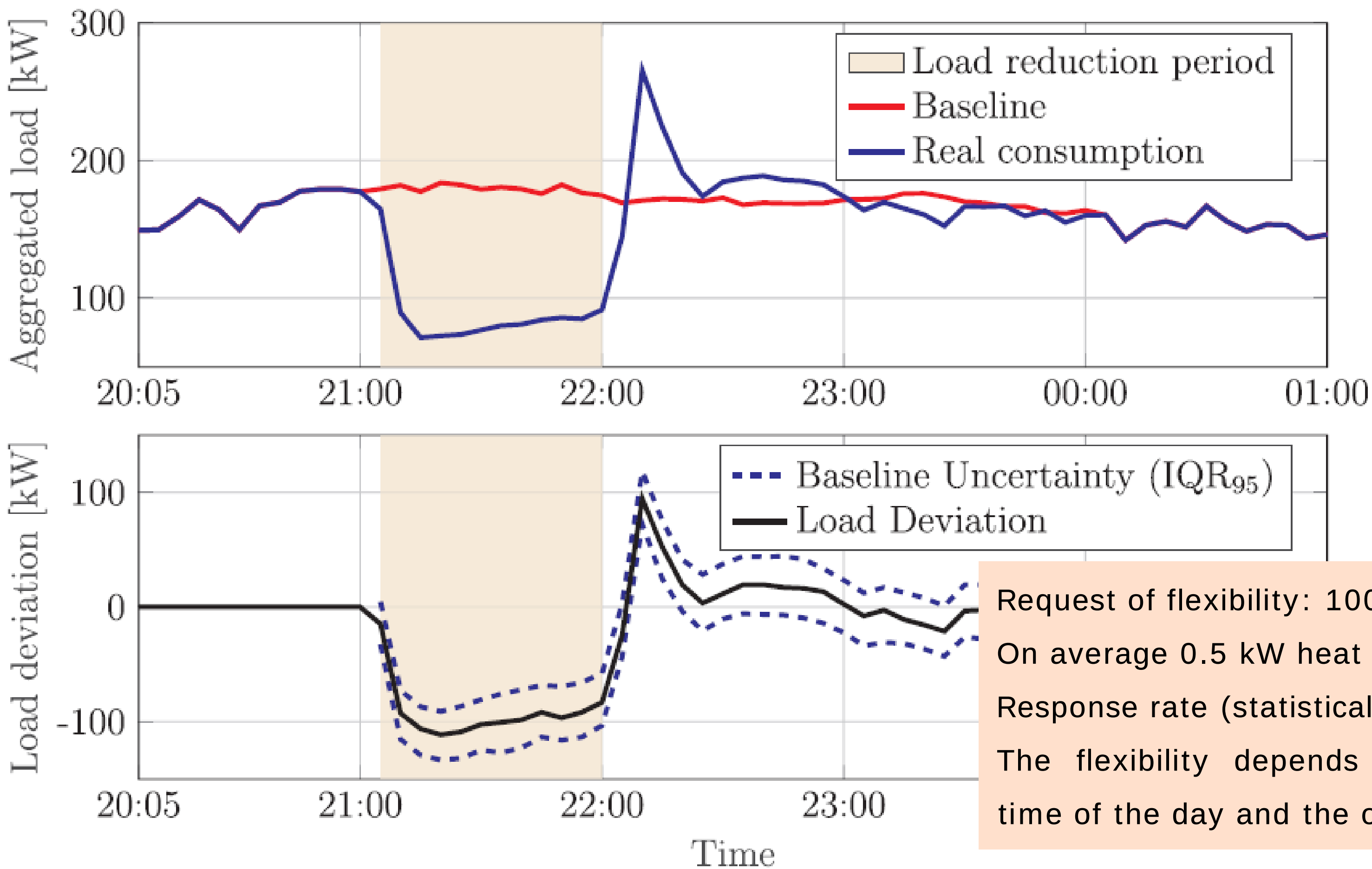
X. Han, K. Heussen, O. Gehrke, H. W. Bindner and B. Kroposki, "Taxonomy for Evaluation of Distributed Control Strategies for Distributed Energy Resources," in *IEEE Transactions on Smart Grid*, vol. 9, no. 5, pp. 5185-5195, Sept. 2018.

Ecogrid 2.0 project in numbers

- Timeframe: 42 months (Jan 2016 until June 2019)
- Budget: 98 million DKK (=13 M€)
- Founded by EUDP (Danish development fund) EcoGrid 2.0 is built on the experiences with price signals in the first project, EcoGrid EU.
- www.ecogrid.dk
- The 9 partners in the project:



Ecogrid 2.0 project results – an example of DSO service (aggregation of units)



Request of flexibility: 100 kW for 1 h;

On average 0.5 kW heat units

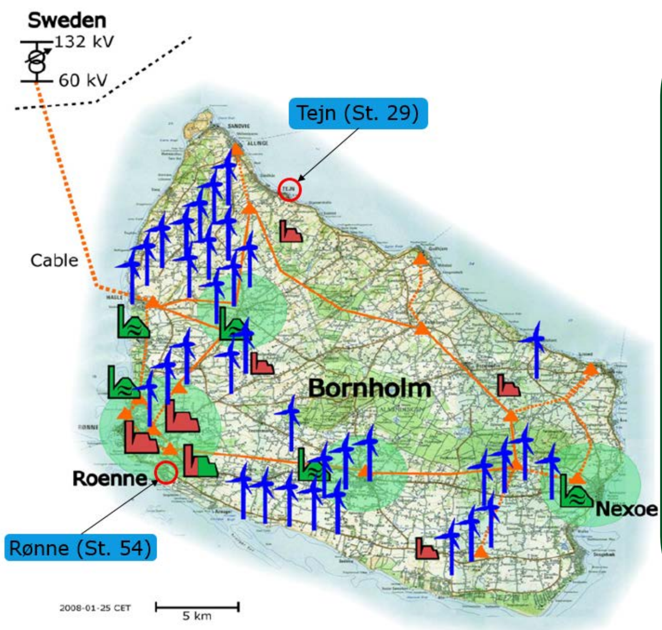
Response rate (statistically 90%)

The flexibility depends heavily n the time of the day and the outdoor temp.

C. Ziras, C. Heinrich, M. Pertl, H. Bindner, "Experimental flexibility identification of aggregated residential thermal loads using behind-the-meter data, vol. 242, 2019.

The ACES project

Across Continents Electric vehicles Services



Budget: 10 MDKK (=1.4 M€)

Public grant (EUDP): 55 %

Equivalent person-months:

130 over 3y (04/17-03/20)

Public chargers and EVs used in the demo:

20 Nissan Leaf and env-200

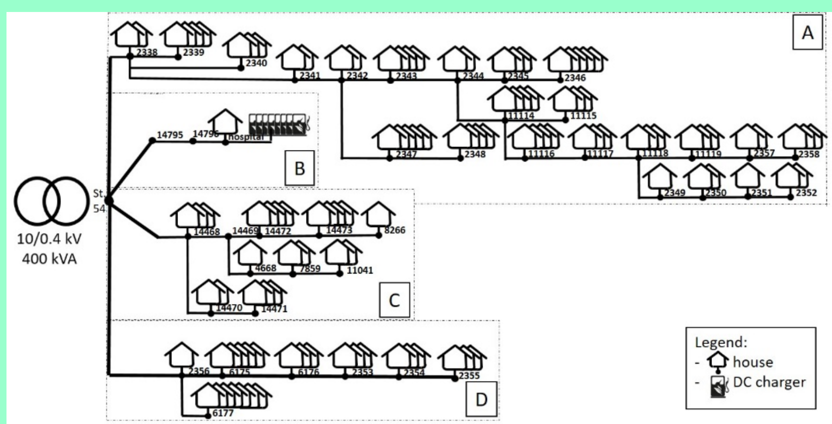
www.aces-bornholm.eu

DTU Elektro

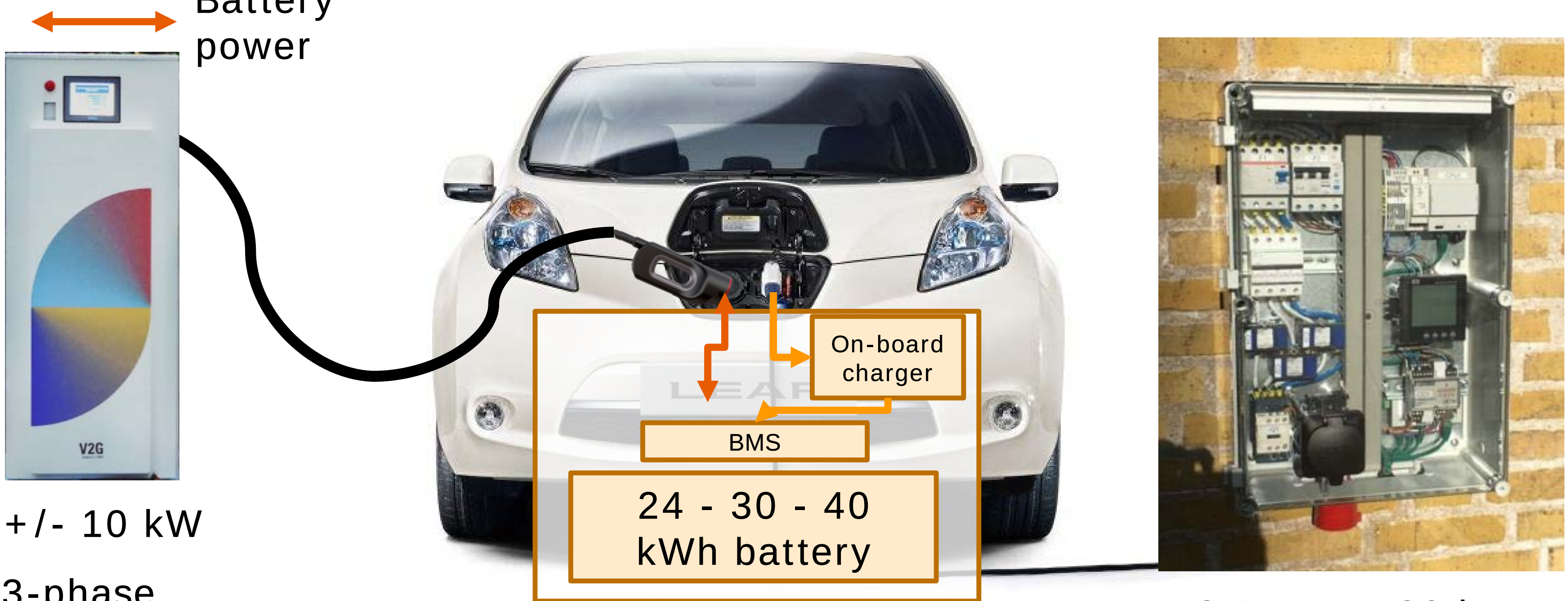
Institut for Elektroteknologi

Distribution Feeder in Rønne

- LV grid: 400 V
- 10/0.4 kV 400 kVA distribution transformer
- 4 subfeeders: 110 known load consumptions
- **8 10 kW DC chargers**
- Common district heating



Investigated AC and DC (V2G) charging / control options for EVs



+/- 10 kW

3-phase

3.7 - 11 - 22 kW

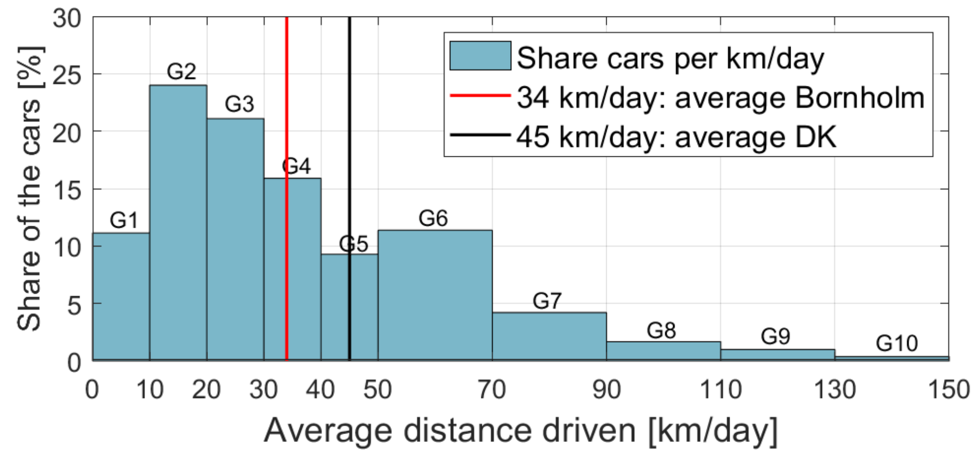
1; 3-phase

- **Charging options considered:**
  - 10 kW DC via external charger bidirectional control
  - 3.7 - 11 - 22 kW AC via internal charger unidirectional control

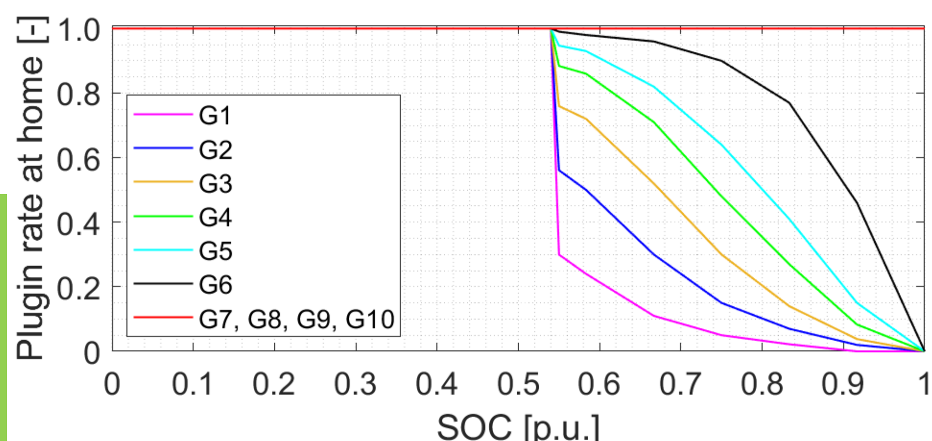
Getting to the local grid – the driving behaviour matters

- Considering realistic driving/charging behaviour, what's the expected loading impact on two representative distribution grids assuming a 100% EV scenario?
- If reinforcement is necessary, what would be a fair value for a load deferring?

- historical driving characteristics of private conventional vehicles from Denmark



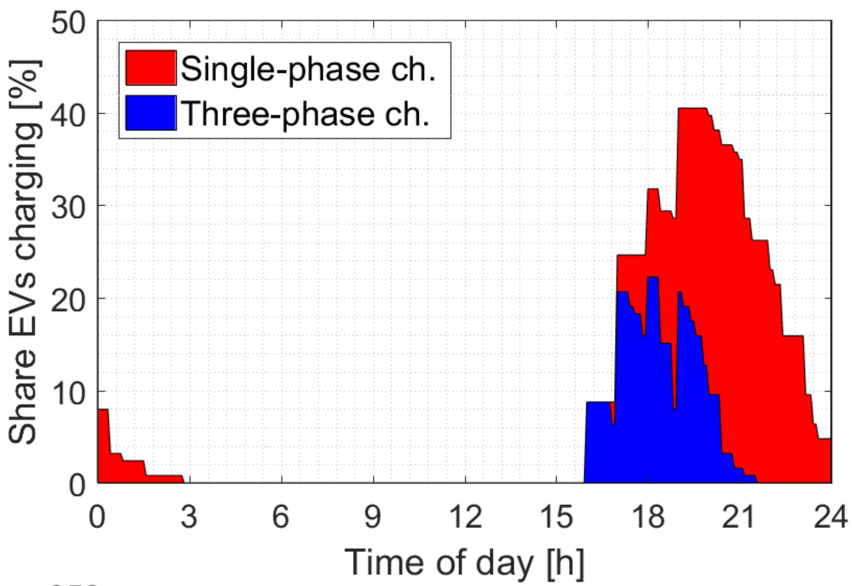
- home plug-in behavior of EVs from Japan

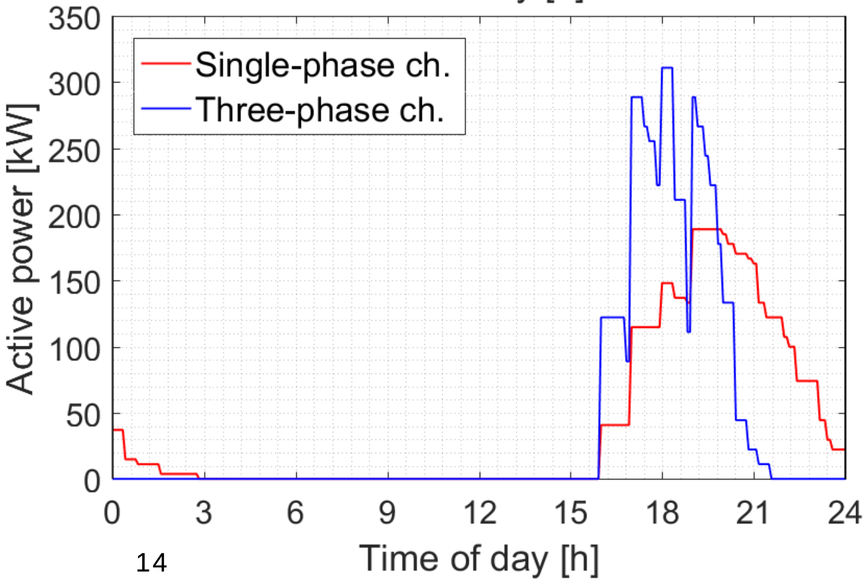


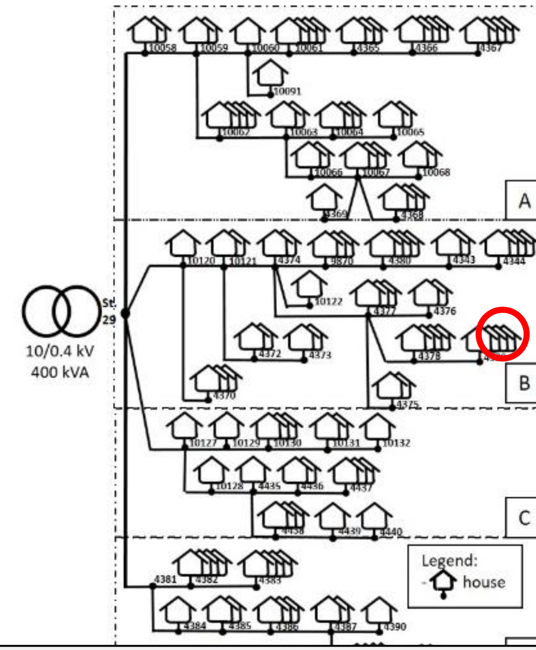
EVs: 40 kWh battery capacity

L. Calearo, A. Thingvad, K. Suzuki, M. Marinelli, "Grid Loading due to EV Charging Profiles Based on Pseudo-Real Driving Pattern and User Behaviour," *Transportation Electrification Transaction,* full paper under review

Example with 127 EVs (127 households in Tejn → 100% EV penetration



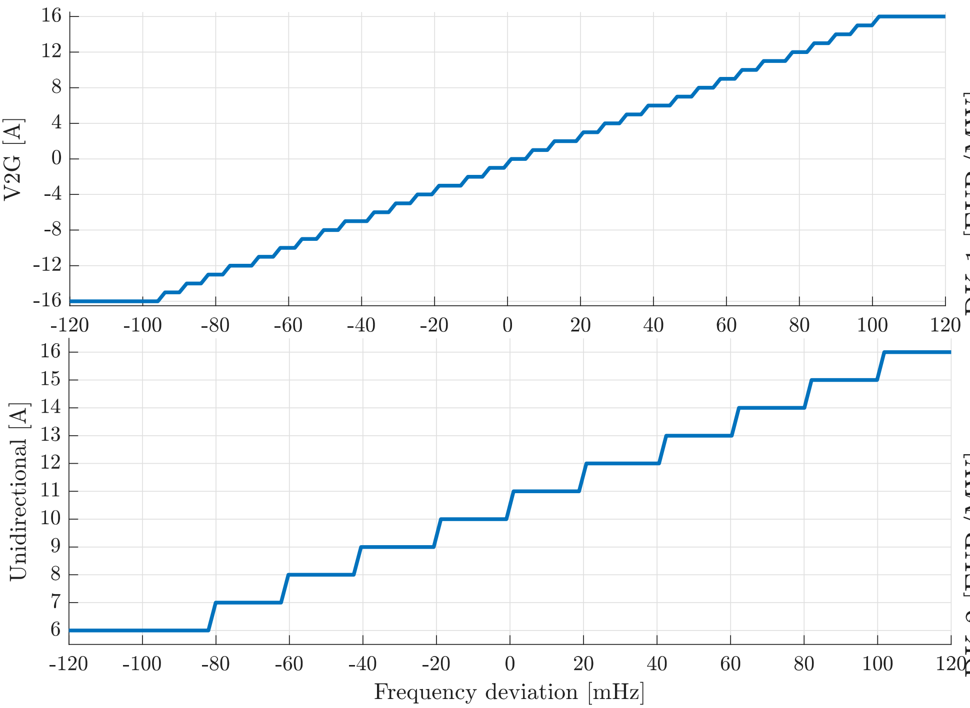


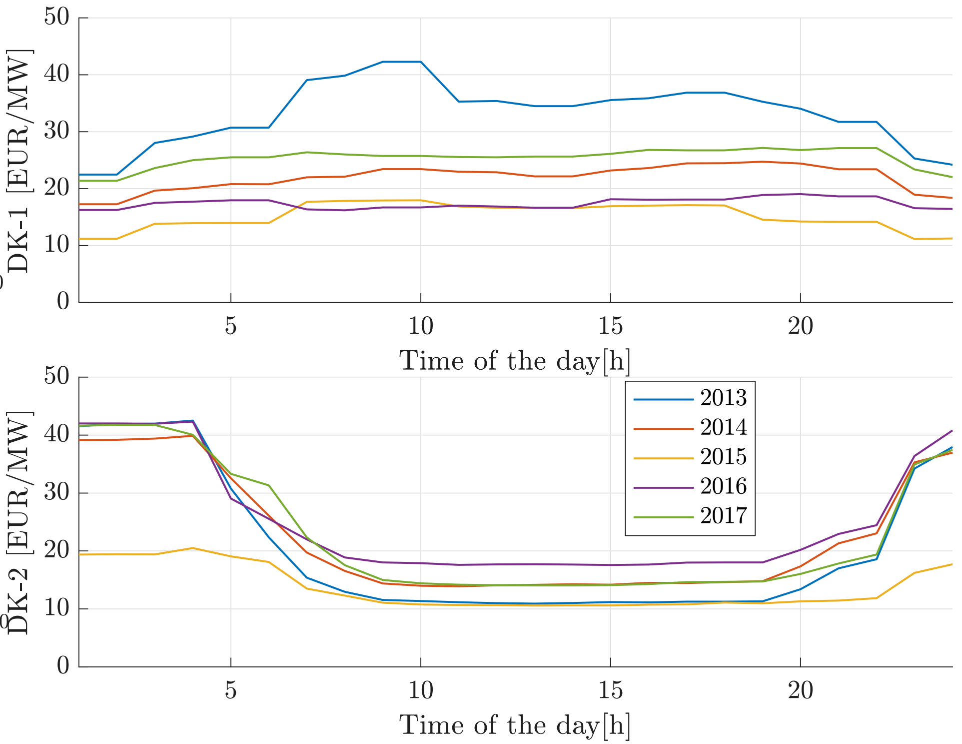


- **Single-phase chargers (3.7 kW):**
- max 40-45% EVs charging together
- **Three-phase chargers (11.1 kW):**
- max 20-25% EVs charging together
- Higher rated power of the chargers → less EVs charging at same time, but higher peak consumption.

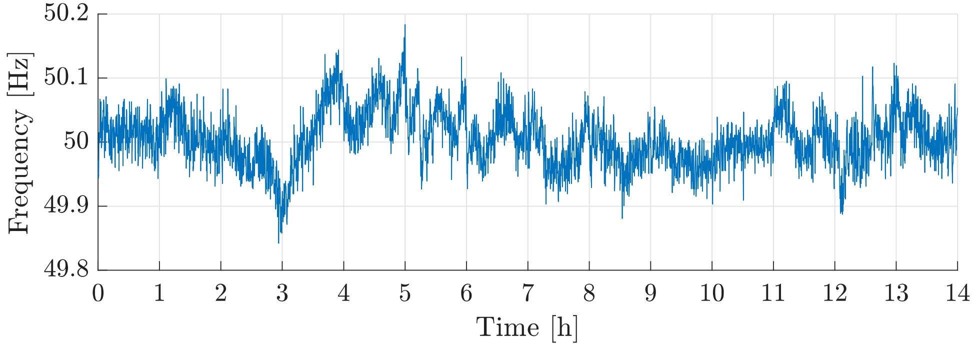
Primary Frequency Control – bidding with bidirectional (±10 kW) or unidirectional (±1.4 kW) charge

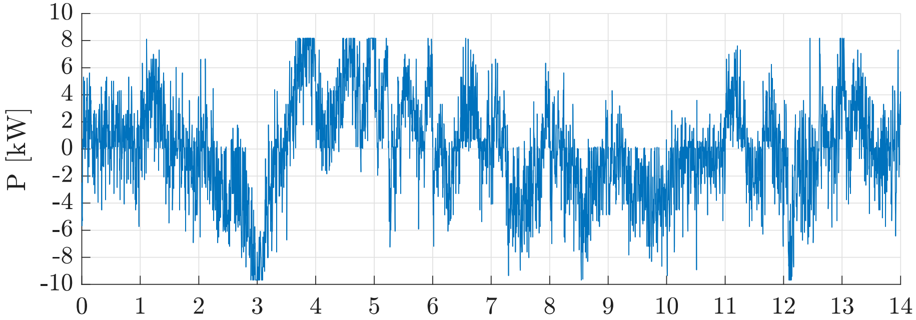
- How to reliably bid into the frequency market having a limited storage capacity?
- Considering also a “far from ideal” V2G charger with losses and unpredictable frequency patterns, do we need to spare some capacity for adjustments?

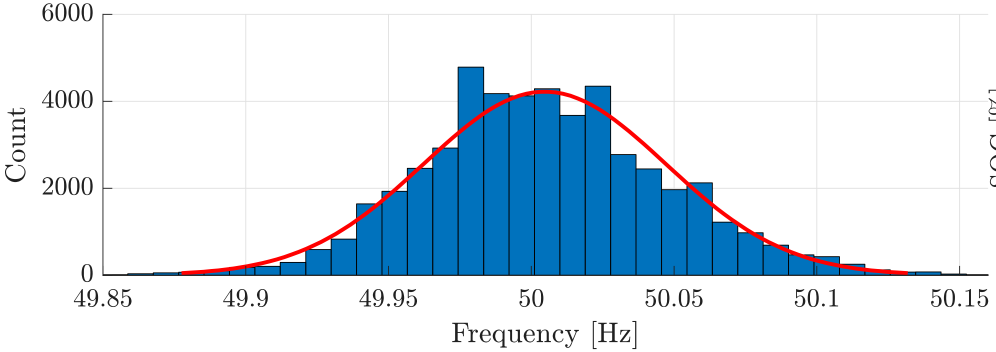


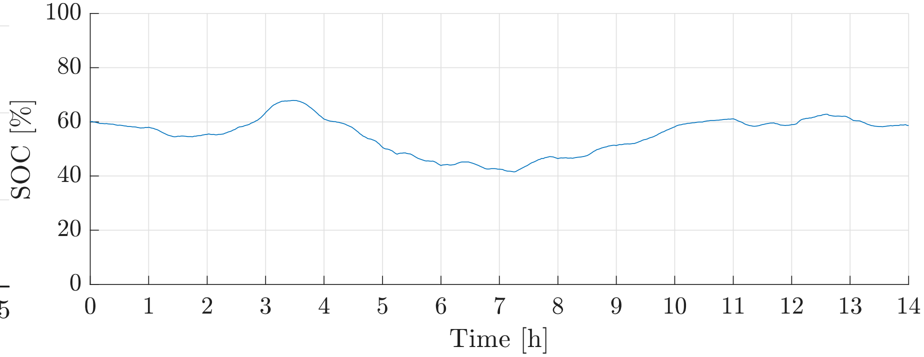


Frequency sample – 12th Sep. 17:00 to 13th Sep 07:00



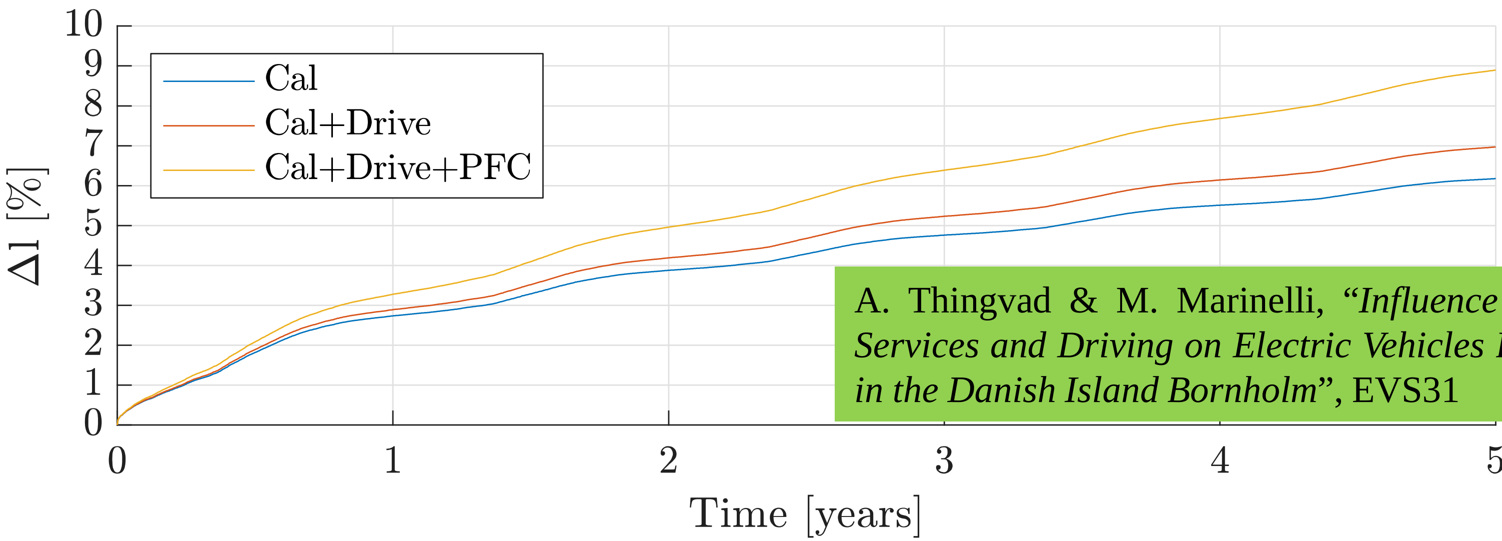






A. Thingvad, C. Ziras, M. Marinelli, "Economic Value of Electric Vehicle Reserve Provision in the Nordic Countries under Driving Requirements and Charger Losses," Journal of Energy Storage, Vol 21, 2019.

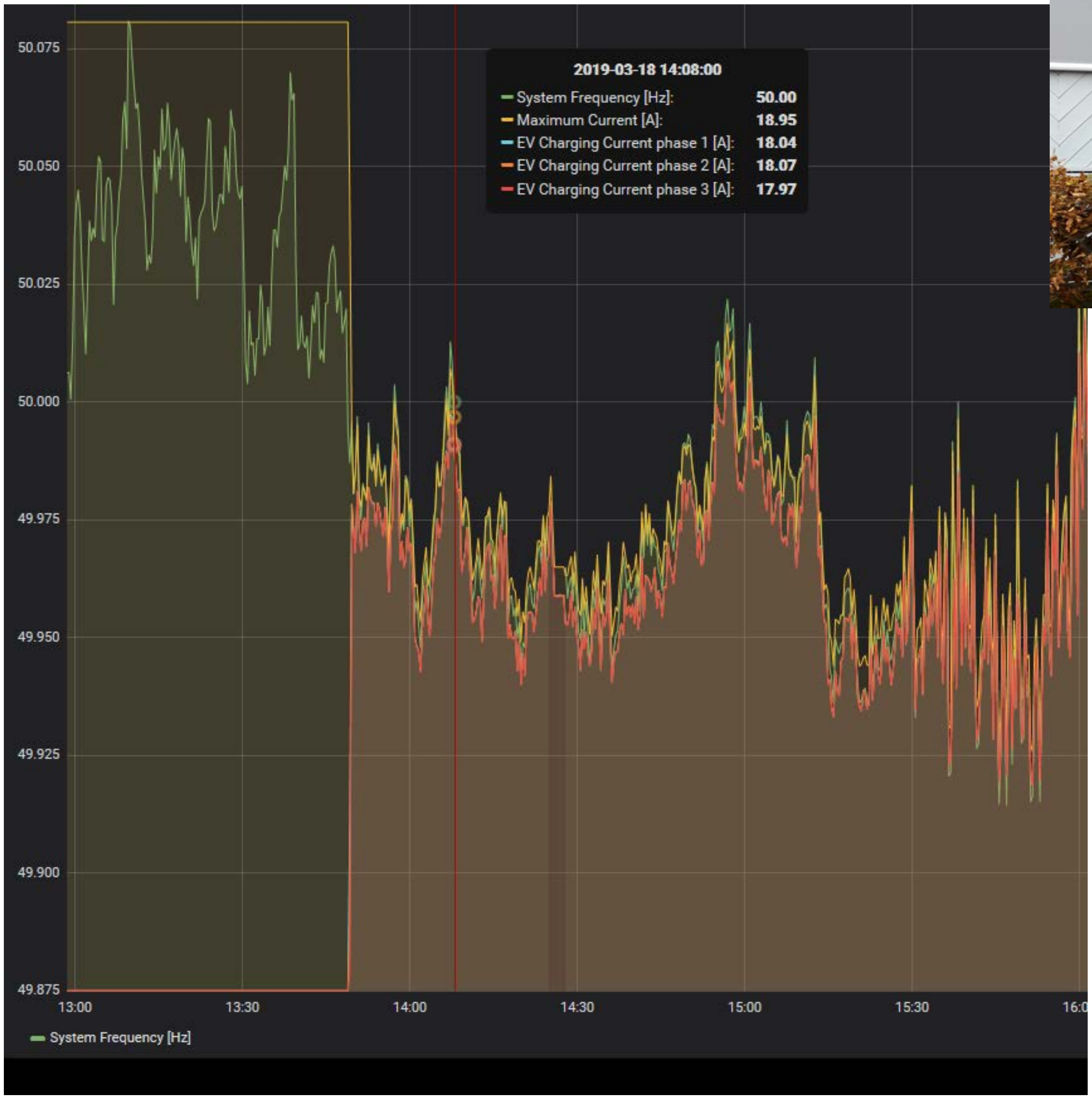
And what about EV degradation considering both grid services and driving?



A. Thingvad & M. Marinelli, "*Influence of V2G Frequency Services and Driving on Electric Vehicles Battery Degradation in the Danish Island Bornholm*", EVS31

- The largest concern seems to be the simple passing of the time, which would account for most of the capacity loss over the years.
- Simulations based on 14 h/day of frequency service and 1 h/day of driving (approx. 14000 km/y).
- Measurements on current degradation are ongoing. More results to follow soon.

Charger controller installed in Bornholm at Griffen Hotel (Rønne)



Equipment used:

EVSE: charger controller 6-32 A 3-ph

EV: Tesla model S

Controller running:

Frequency control (remote meas)

Response time around 5-6 seconds (mostly on the EV side)

https://brokergraphs.syslab.dk/d/wTY2in-mk/evbe?orgId=1&from=now-3h&to=now&refresh=5s

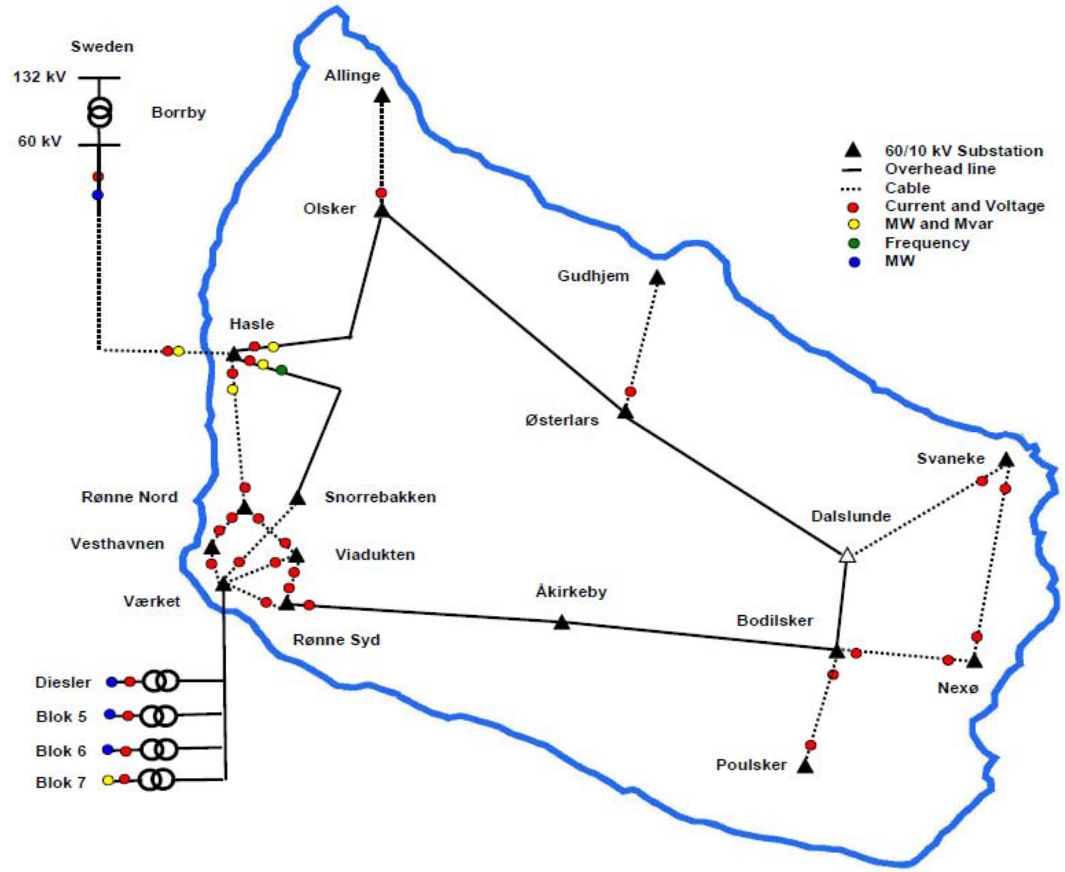
Can we use EVs on a large scale to effectively replace primary frequency control?

- Bornholm power system is normally connected to the mainland (Sweden) via a sea cable (60 kV) with a transfer capacity equal to 60 MVA (480 A on 3x240 Cu), 43.5 km offshore (+2 larger OH sections onshore).

- Consumption:
  – Peak power (winter time) 60 MW
  – Minimum load 13 MW
  – energy 268 GWh (equal to 4870 h or 55% CF)

Bornholm power system is a suitable testbed

A. Zecchino, A. M. Prostejovsky, C. Ziras, M. Marinelli, "Large-scale Provision of Frequency Control via V2G: the Bornholm Power System Case," *Electric power system research, vol. 170, pp. 25-34, May 2019.*



Investigating the response on an equivalent 1-bus system

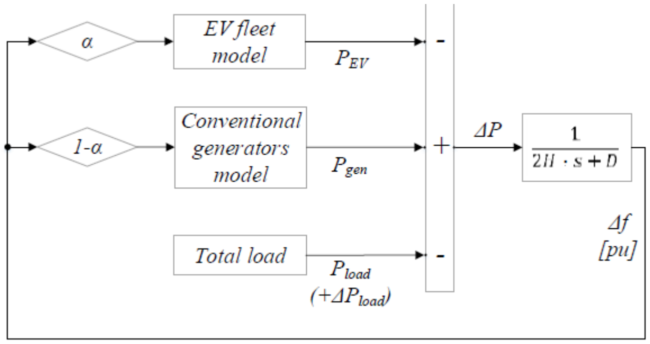
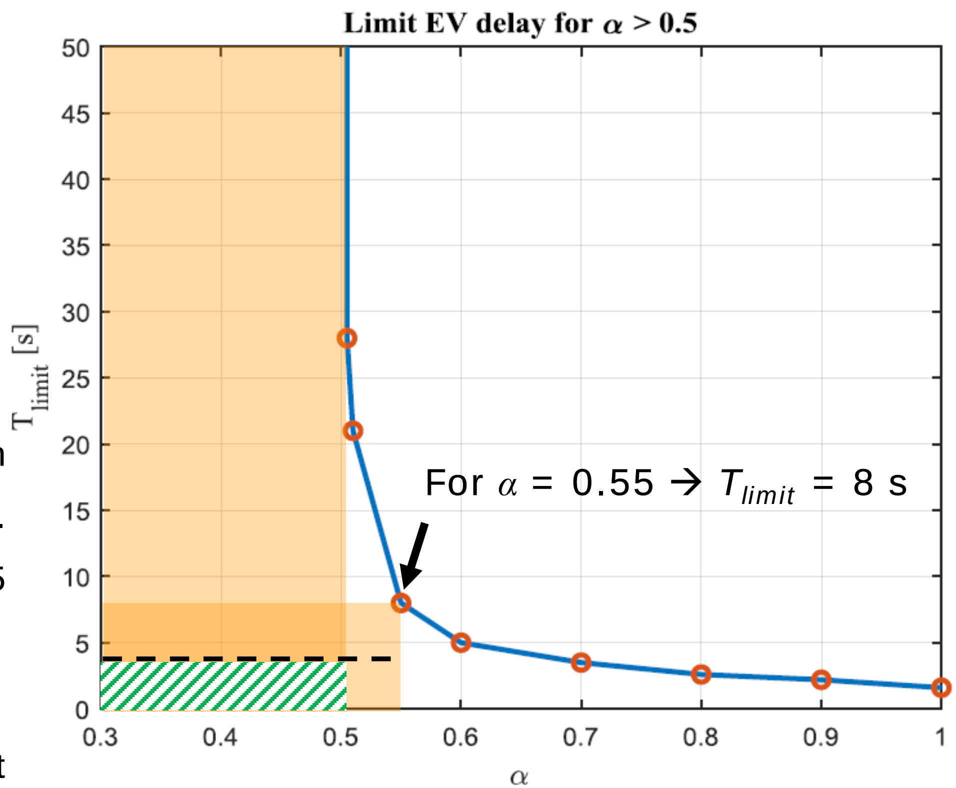


Fig. 3. Simplified power system with the classical single-bus layout.

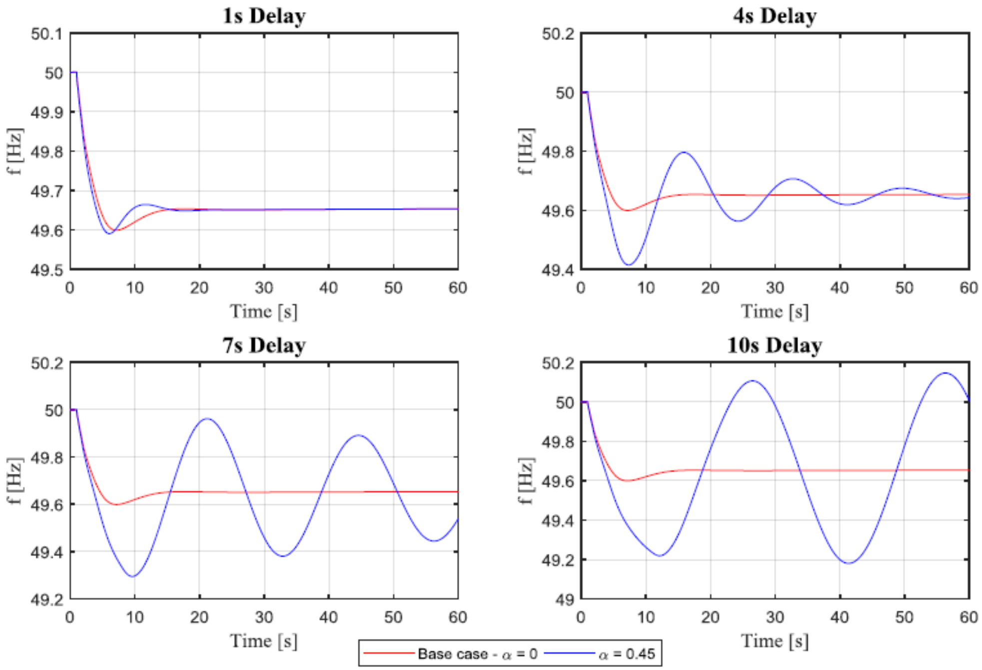
An additional recommendation is included, which sets a limit time value T_{limit} for the EV response. This is calculated for a α slightly above the 0.5 limit: α = 0.55.

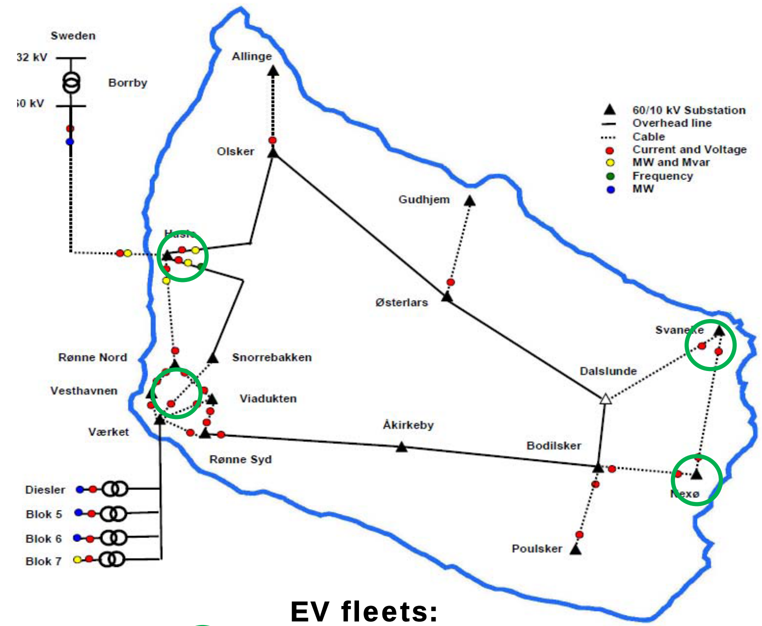
2 is a safety factor, introduced to prevent operating too close to the limit and to take into account possible imperfections in the calculation of T_{limit} for the power system under exam.



Recommendation 2:
$\tau < T_{limit} / 2$

Replacing the diesel genset for providing frequency reserve along with the steam unit – test on the whole Bornholm power system





EV fleets:

EV fleet #1: Rønne (225 EVs)
EV fleet #2: Hasle (75 EVs)
EV fleet #3: Nexø (75 EVs)
EV fleet #4: Svaneke (75 EVs)

- 60 MW load
- 30 MW wind generation
- 30 MW from CGUs

(**blok 5** and **blok 6**)

- **Loss of 2 MW wind turbine**

- 5 MW of reserve from **blok 5** over 200 mHz
- Either 4.5 MW diesel or **450 EVs** with ±10 kW V2G chargers performing frequency regulation

SYSLAB experimental facility @Risø

- SYSLAB is a **platform** for Decentralised Energy Resources research and testing
- It is a flexible experimental setup up
- It includes several production and consumption units
- It has embedded computing power and flexible communication
- It has very flexible control possibilities
- It can be extended

SYSLAB experimental facility extension @Risø

- **SYSLAB Multienergy extension**
- 2,5 km District heating transmission
  - Low temperature
  - Ultra low temperature
- 5 buildings connected
  - Smart office living lab (50 seats)
  - 2 PowerFlexHouses
- 20 heating ”DER”
  - Total 40 electric/heating ”DER”
  - Distributed controllers
- Fibre ethernet
- SYSLAB software and infrastructure

- *Fully in opration by end of 2020*

Some lessons learned

- Current market structures and framework conditions facilitate demand response/DER participation to a lesser extent: the most beneficial aspects are hardly leveraged.
- Achieving a fair price (for both customer and grid operators) for the various grid services is critical, especially for local grid services.
- Technology and social aspects are equally important: the focus on social practices will help the move away from a "technology push" approach to smart Grids.
- Uncertainty in the amount of power&energy provided by heterogeneous sets of units is crucial for large-scale applications, particularly frequency based services.
- Mimicking the response of conventional power plants when providing balancing services with heterogonous aggregation of DERs is necessary to replace conventional units.
- Wear of equipment (EVs particularly) seems to be limited, despite heavy usage.

STAY TUNED! –

CHECK RESULTS ON THE PROJECTS WEBSITES

- **ACES: www.aces-bornholm.eu**
- **CAR: www.sbcar.eu**
- **Parker: www.parker-project.com**
- **Ecogrid 2.0: www.ecogrid.dk**