Embedding demand-side participation in electricity markets

[CITIES - WP4]

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Extra status info on WP4

- **CITIES WP4** has been busy over the last period...
  - *New education* with regular course (Renewable in Electricity Markets - 50 happy students) and special courses
  - Young people in the loop with *many MSc thesis projects* (10)
  - **Synergies with other projects**, e.g., '5s' - Future Electricity Markets and EnergyLab Nordhavn, as well as proposals

- A few more relevant infos:
  - Numerous Ph.D. and young researcher guests (4)
  - 2 visiting Professors in 2015, incl. **Jianhui Wang**, Argonne National Lab, and Editor-in-Chief of IEEE Transactions on Smart Grid
  - Collaborations with additional industry (e.g., Air Liquide, EDF, Danske Commodities) with Danish interests and academics (e.g., EPFL, TU Eindhoven, Tsinghua)

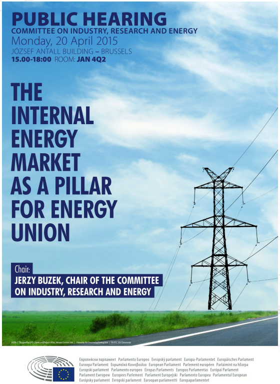
- Note that demo projects can be a bit more difficult to set up with WP4!

Outline

- **Opening thoughts**
- **Some basic characteristics of demand response actions**
- **Introducing asymmetric block offers**
- **Economic dispatch of such offers in a balancing framework**
- **Outlook**

(based on: N O'Connell, P Pinson, H Madsen, M O'Malley (2015). Economic dispatch of demand response balancing through asymmetric block offers - *under review*)

Opening thoughts



- **CITIES WP4** has its first Ph.D. project starting on 1 July 2015, on "*Market mechanisms for integrated energy systems*" (Christos Ordoudis)
- Existing synergies with other activities in ongoing and new Danish projects like *'5s' - Future Electricity Markets* and *EnergyLab Nordhavn*...

- A fundamental question: **What is the best balance between optimal and feasible ways to manage integrated energy systems in a market environment?**
  - single energy market
  - "loose" coupling of these markets (based on specific market products)
  - appropriate alignment of markets and their characteristics, for instance in terms of gate closure, time units, etc.

Basics: from response to saturation

- Consider the example case of supermarket refrigeration, though the same could be done for any **TCL (Thermostatically Controlled Loads)**...

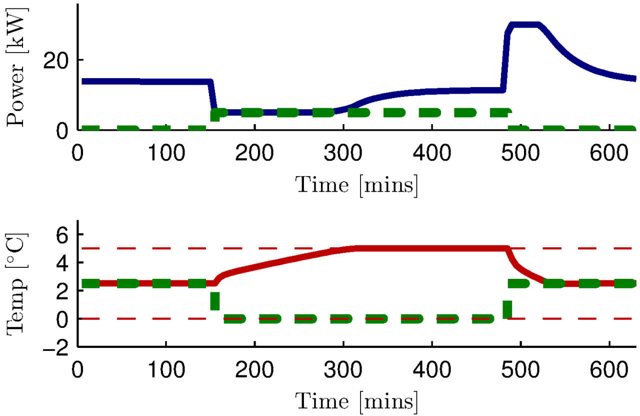


Figure : Power consumption and representative medium temperature of the refrigeration system when a reduction of power consumption to 5kW is requested. The heavy dashed lines indicate the temperature/power references to be tracked, they are active when non-zero

Resulting saturation curves

- This simple concept can be summarized by saturation curves obtained through simulations (or experiments)
- It will allow defining asymmetric balancing blocks...

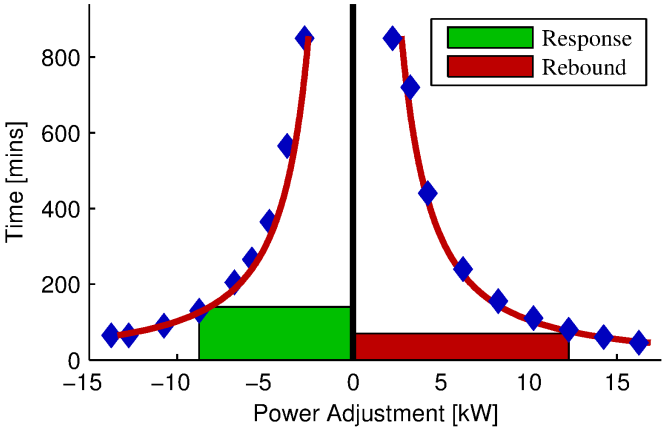


Figure : Saturation curve of a supermarket refrigeration system, with a sample response-rebound block definition

Generalized saturation curves

- One may not always want to hit the bounds...
- Saturation curves may be linearized outside of a central deadband

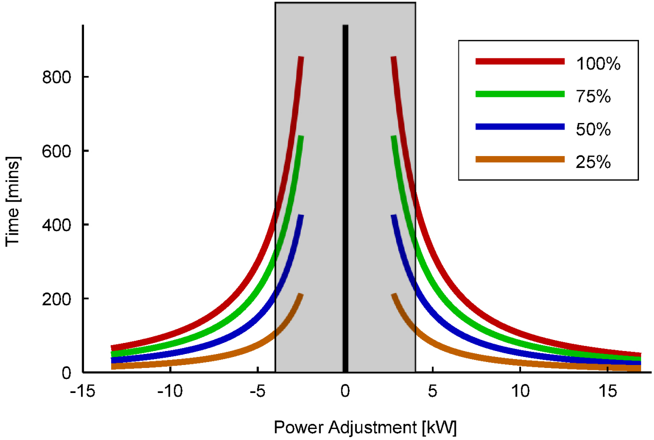


Figure : Partial saturation curves with the dead-band indicated by the shaded grey section. To ensure accuracy, partial saturation curves should not be considered for power adjustments within the shaded region

Introducing asymmetric block offers

- Demand **(response -/- rebound)** concepts can translate to asymmetric block offers in the market

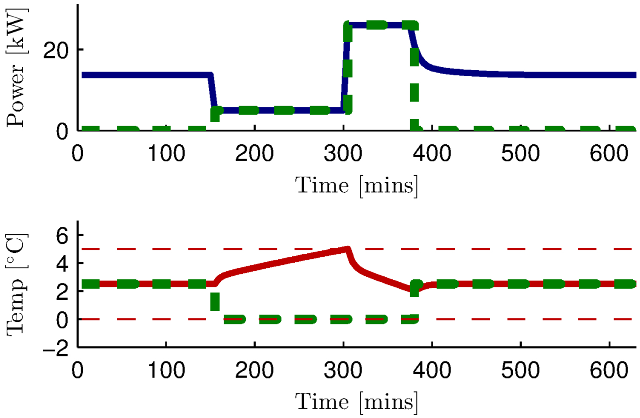


Figure : Power consumption and representative medium temperature of the supermarket refrigeration model during a controlled response and rebound event, with power and temperature references indicated by the heavy dashed lines, they are active when non-zero

Economic dispatch in balancing framework

- **The balancing market may be generalized** to consider such asymmetric block offers from the demand side
- The optimal dispatch for both of conventional and demand response units can be formulated as a coventional mixed integer linear program (MILP), i.e.,

$$\min_{\mathbf{x}} \quad \mathbf{c}^{\mathsf{T}}\mathbf{x} \tag{1a}$$

$$\text{subject to:}$$

$$\mathbf{h}(\mathbf{x}) = 0 \tag{1b}$$

$$\mathbf{g}(\mathbf{x}) \geq 0 \tag{1c}$$

where $x = \{P_{i,t}, P^{DR}_{d,c,t}, v_{d,c,t}, SU^{DR}_{d,c,t}, SD^{DR}_{d,c,t}\}$

- This is computationally expensive though!!

An illustrative case study (1)

- 6 regulating power profiles were chosen from ELIA data
- Time resolution is of 5 mins (instead of original 15 mins)

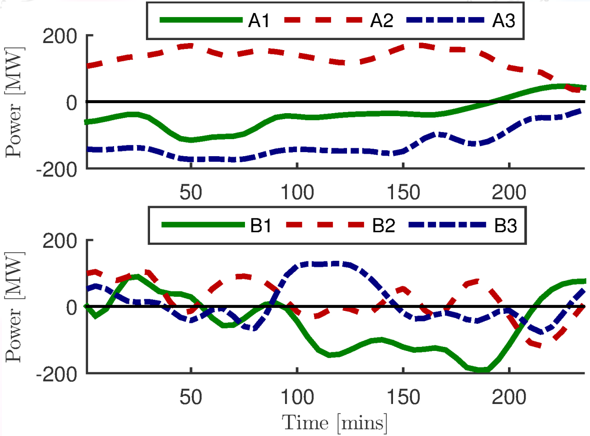


Figure : Regulating power profiles - smooth (Case A - upper) and fluctuating (Case B - lower). Source: ELIA

An illustrative case-study (2)

- Besides conventional generators, we consider that 2 demand response units may be able to provide a set of asymmetric block offers
- These are inspired by supermarket refrigeration capabilities, with 50% saturation only, though scaled to a population of 1000 supermarkets
- Regulation service from demand side have lower cost figures

Unit	Block	P^{resp} [MW]	T^{resp} [min]	P^{reb}[MW]	T^{reb} [min]
1	1	13	30	-17	20
	2	-17	30	13	30
	3	10	50	-10	50
	4	-17	20	10	50
	5	-9	40	11	45
	6	11	45	-9	40
2	1	-17	20	8	70
	2	8	70	-17	20
	3	13	30	-15	25
	4	-15	25	13	30
	5	-10	50	12	35
	6	12	35	-10	50

Results: example dispatch

- The demand side ends up supporting balancing
- Conventional generators are still those who contribute the most here...

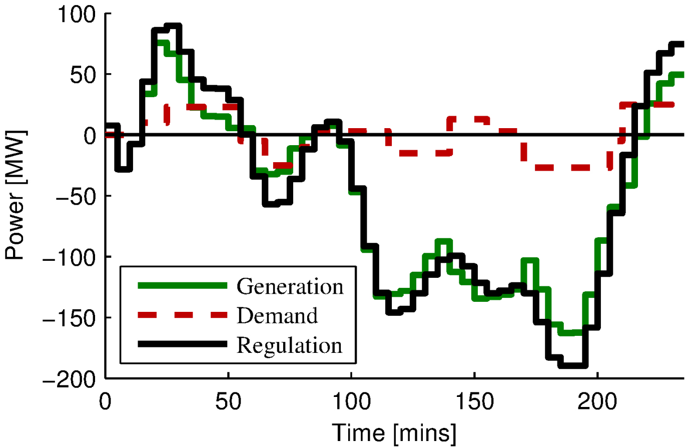


Figure : System dispatch of conventional and demand response units for the provision of regulating power - Case B1

Results: cost reduction

- Cost reduction is a function of
  - *cost differential* between generator and demand sides
  - *technical characteristics* of demand-side offers
  - *variety of asymmetric blocks*

Table : Cost Reduction with Demand Response - Case A

	A1	A2	A3
6 DR Blocks	10.53%	4.14%	0.1%
Full Model	36.63%	4.88%	11.36%

Table : Cost Reduction with Demand Response - Case B

	B1	B2	B3
2 DR Blocks	9.54%	18.10%	19.70%
3 DR Blocks	17.10%	23.42%	21.25%
4 DR Blocks	20.81%	23.42%	25.13%
5 DR Blocks	21.23%	23.43%	25.13%
6 DR Blocks	21.43%	23.63%	26.00%
Full Model	24.45%	28.72%	34.22%

- Cost reduction is less than if having "perfect" control of demand through a full model

Outlook

- There may be various alternative approaches to define demand-response products and schedule it through market mechanisms
- **Asymmetric block offers are a natural approach** to account for response-rebound effects
- **A clear issue is computational cost** since the problem becomes combinatorial...
- Other similar ideas for the loose coupling of energy markets will be explored

Thanks for your attention!