Pricing mechanism applied to a Multi-Supplier Multi-Consumer Electricity Market

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The Flexines Project

Gas important in Groningen area, micro-CHP of interest for distributed generation.

- **Business case**: Estimation that in 2020 1 million μCHP units in the Netherlands, in 2030 4 million.

Naast de provincie en de gemeente Groningen, wordt dit project medegefinancierd door het Ministerie van EZ
en het Europees fonds voor regionale ontwikkeling

The Flexines Project, some history

- First discussions 5 years ago, stability of net.
- After 2 years focus on prices popped up, ECN involved.
- Shift of focus, start project 2 years ago.

The Flexines Project

Goal Develop Energy Management System (EMS) based on prices, helping user to regulate costs.

Result "Power to the people." In other words: Distributed Generation (DG).

Our role Network balance and prices.

Flexines

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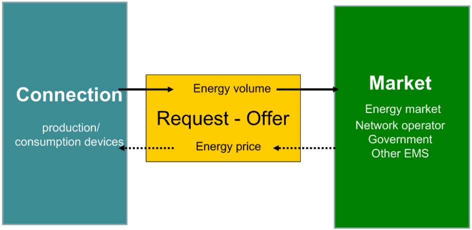


Flexines

Control network problem

Motivation:

- Want stable electricity network.
- Every house should not turn on or off devices all at the same time.
- Need coordination.

What is the control?

- When to turn on/off devices (Washing machine, μCHP etc.)

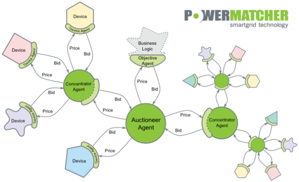
Can we use pricing to achieve the control goal?

- ?

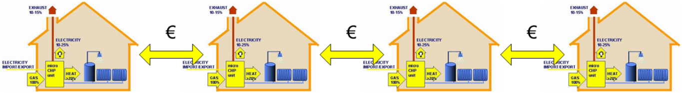
Smart grid experiment in suburb Groningen

One working pricing mechanism inside Flexines project:

- Name: Integral.
- Place: Hoogkerk.
- Field test with ECN's Power-Matcher concept.
- Multi-agent accumulating bid curves in a tree structure. Microeconomics used to determine equilibrium price.



Another alternative: Distributed control



- Interested in an alternative way of coordination.
- Centralized control $\rightarrow$ Local price communication between neighbors.
- The micro Combined Heat Power (μCHP) system is one option for local production.
  - Overall efficiency of the μCHP can be as high as 90%.
  - Electrical output is typical 1kWh.

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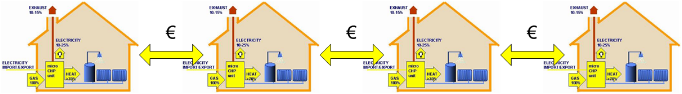

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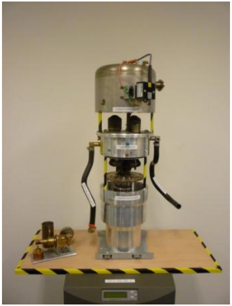


Network situation

- No longer centralized top down control
- End users also producers, prosumers
- In addition to conventional power plants, energy produced locally.
- μCHPs: relieve stress in network and increase reliability. Local balancing.
  - Local production $\rightarrow$ lower transmission losses $\rightarrow$ efficient recourse use.
- Topology changes

Recent work of Houwing/Negenborn/De Schutter, 2011, demand response with μCHP systems, but with given price patterns. Mixed-integer linear programming.

Network control goal

Goal Want imbalance to be zero.

Mean Local coordination of electrical devices. Price signals to turn on/off μCHPs.

Result Avoid peaks $\rightarrow$ may allow more connections on one transformer.

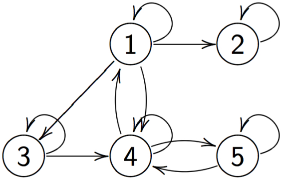
Problem formulation

$$J_u = \lim_{K \to \infty} \frac{1}{K} \sum_{k=1}^{K} E[|x(k)|_Q^2 + |u(k)|_R^2]$$

such that:

$$x(k+1) = Ax(k) + Bu(k) + w(k)$$

Where $A_{ij} \neq 0$ if and only if there is information going from user i to user j. x imbalance, w change in demand (white noise), v change in production. Information matrix A



$$A = \begin{bmatrix} * & 0 & 0 & * & 0 \\ * & * & 0 & 0 & 0 \\ * & 0 & * & 0 & 0 \\ * & 0 & * & * & * \\ 0 & 0 & 0 & * & * \end{bmatrix}$$

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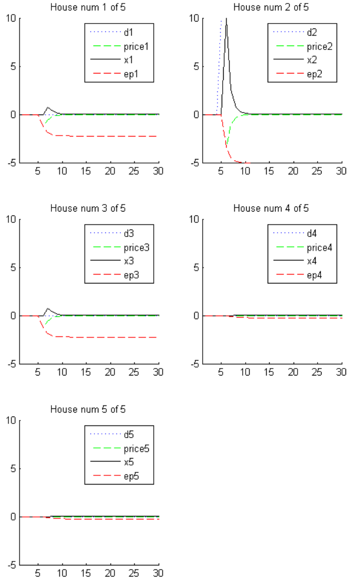
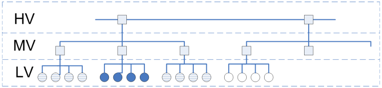
Circle connection of five households. All houses with μCHP.



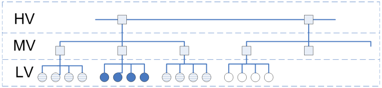
Our electricity grid



$$A_{LV} = \begin{bmatrix} \alpha & \beta & \cdots & \beta \\ \beta & \alpha & \cdots & \beta \\ \vdots & & \ddots & \vdots \\ \beta & \beta & \cdots & \alpha \end{bmatrix}$$

$$A_{LV} = \begin{bmatrix} * & * & \cdots & 0 \\ * & * & \cdots & 0 \\ \vdots & & \ddots & \vdots \\ 0 & 0 & \cdots & * \end{bmatrix}$$

Our electricity grid



$$A_{MV} = \begin{bmatrix} A_{LV}^{(1)} & \epsilon G_{LV}^{(2)} & \cdots & \epsilon^m G_{LV}^{(m)} \\ \epsilon G_{LV}^{(1)} & A_{LV}^{(2)} & \cdots & \epsilon^{m-1} G_{LV}^{(m)} \\ \vdots & & \ddots & \vdots \\ \epsilon^m G_{LV}^{(1)} & \epsilon^{m-1} G_{LV}^{(2)} & \cdots & A_{LV}^{(m)} \end{bmatrix}$$

$$A_{LV} = \begin{bmatrix} * & * & \cdots & 0 \\ * & * & \cdots & 0 \\ \vdots & & \ddots & \vdots \\ 0 & 0 & \cdots & * \end{bmatrix}$$

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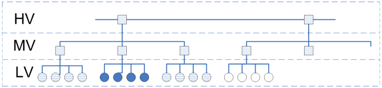
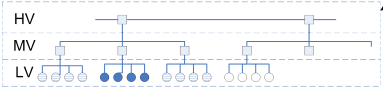


$$A_{HV} = \begin{bmatrix} A_{MV}^{(1)} & \epsilon G_{MV}^{(2)} & \cdots & \epsilon^m G_{MV}^{(m)} \\ \epsilon G_{MV}^{(1)} & A_{MV}^{(2)} & \cdots & \epsilon^{m-1} G_{MV}^{(m)} \\ \vdots & & \ddots & \vdots \\ \epsilon^m G_{MV}^{(1)} & \epsilon^{m-1} G_{MV}^{(2)} & \cdots & A_{MV}^{(m)} \end{bmatrix}$$

$$A_{LV} = \begin{bmatrix} * & * & \cdots & 0 \\ * & * & \cdots & 0 \\ \vdots & & \ddots & \vdots \\ 0 & 0 & \cdots & * \end{bmatrix}$$

Our electricity grid



$$A = \begin{bmatrix} A_{HV}^{(1)} & \epsilon G_{HV}^{(2)} & \cdots & \epsilon^m G_{HV}^{(m)} \\ \epsilon G_{HV}^{(1)} & A_{HV}^{(2)} & \cdots & \epsilon^{m-1} G_{HV}^{(m)} \\ \vdots & & \ddots & \vdots \\ \epsilon^m G_{HV}^{(1)} & \epsilon^{m-1} G_{HV}^{(2)} & \cdots & A_{HV}^{(m)} \end{bmatrix}$$

$$A_{LV} = \begin{bmatrix} * & * & \cdots & 0 \\ * & * & \cdots & 0 \\ \vdots & & \ddots & \vdots \\ 0 & 0 & \cdots & * \end{bmatrix}$$

Transportation prices

- Market in the Netherlands deregulated, separate price for network transport and energy delivery.
- In Flexines information on both is required.
- Transport can be accounted for by choices in A matrix, i.e., low weight corresponds to expensive transport.

Dual Decomposition

$$J_u = \sum_{k=1}^{\infty} E[|x(k)|_Q^2 + |u(k)|_R^2]$$

such that:

$$x(k+1) = A_D x(k) + Bu(k) + w(k) + v(k)$$
$$v(k) = A_0 x(k)$$

(Rantzer, Martensson 2009, 2010)

Recall x imbalance, w change in demand, u change in production.

Dual Variables $p(k)$: Shadow prices

$$J = \max_p \min_{u,v} \sum_i \mathrm{E}[|x_i|^2_{Q_i} + |u_i|^2_{R_i} + p_i'(v_i - \sum_{j\neq i} A_{ij}x_j)]$$

$$= \max_p \sum_i \min_{u_i,v_i} \mathrm{E}\,\underbrace{[|x_i|^2_{Q_i} + |u_i|^2_{R_i}}_{\text{own cost}} \quad \overbrace{+p_i'v_i}^{\text{expected expences}} \quad \underbrace{-(\sum_{j\neq i} p_j' A_{ji})x_i]}_{\text{revenues}}$$

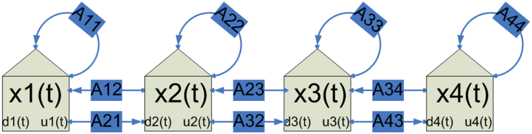
Dual decomposition allows to decompose search for optimal values as well, using gradient search. Solution corresponds to optimal solution original problem, i.e., $u(k) = -Lx(k)$ and $p(k) = -Mx(k)$.

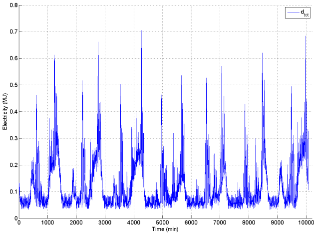
$$L = (R + B^T PB)^{-1} B^T PA$$
$$M = P(A - BL)$$
$$A^T PA - P - A^T PB(B^T PB + R)^{-1} B^T PA + Q = 0$$

Computations

- Due to gradient search, computations are feasible for large sizes.
- Implementation should be feasible, constraints on form of L for implementation can be imposed in gradient search $\rightarrow$ allowing local implementations.

Realistic electrical demand obtained from field tests

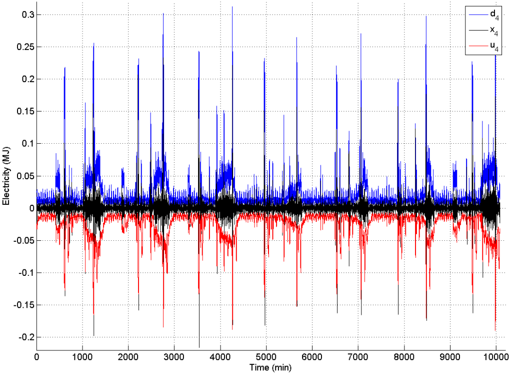




Used Information matrix A

$$A = \begin{bmatrix} 0.6 & 0.2 & 0 & 0 & 0 \\ 0.2 & 0.6 & 0.2 & 0 & 0 \\ 0 & 0.2 & 0.6 & 0.2 & 0 \\ 0 & 0 & 0.2 & 0.6 & 0.2 \\ 0 & 0 & 0 & 0.2 & 0.6 \end{bmatrix}$$

Optimization of input $u(k)$



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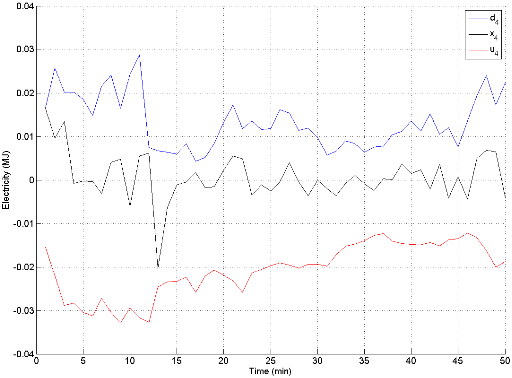

Zoom

Current work/problems

- Demand influenced by price. Include dynamic model. Demand $d(k+1) = f(d(k), p(k), noise)$. Splitting between demand that can be influenced and that cannot be influenced.
- Constraints on input, $u(k)$, (μCHP) (minimum off-time, minimum on-time).
- Not full usage of all power of μCHP $\rightarrow$ storage and/or integer regulation.
- Transient behavior machine included in constraints.
- $u(k, \tau) \in U(\tau, \text{state } \mu\text{-CHP at } k)$
- Include logic; Mixed Integer Quadratic Program.
- Extension to MPC.

Concluding remarks

- By embedding the electrical power grid in the dual decomposition framework distributed suboptimal control of decentralized power generation can be achieved.
- Method can also capture current network structure.
- Information from physical far away neighbours set to zero. This is promising with respect to computational complexity, and reduces transportation costs.
- Propose that the structure of the network in the future may change when there is a high share of controllable decentralized generation present.

Concluding remarks

- Necessary to change regulations. Political reality somewhat uncertain.......
- To solve: How to include a combination of central generation and distributed generation, while keeping balance?
- Feasible, and optimal storage topology to be incorporated in the modeling.

Based upon talks so far, not much thought on "prosumers/households", based upon current grid structure. How about local household generation for controllable devices (washing machines, etc.) and for other consumption generation by companies? Or, DG via households to balance short term market?